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Managing the Decommissioning and Remediation of Damaged Nuclear Facilities

Final Report of the Collaborative Project DAROD

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International Atomic Energy Agency

MANAGING THE DECOMMISSIONING AND REMEDIATION OF DAMAGED NUCLEAR FACILITIES

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FINAL REPORT OF THE COLLABORATIVE PROJECT DAROD

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FOREWORD

In response to the accident at the Fukushima Daiichi nuclear power plant in March 2011, the IAEA developed the IAEA Action Plan on Nuclear Safety. One of the objectives of the plan was to ensure that, following a nuclear emergency, people and the environment are protected from ionizing radiation.

One of the activities undertaken to address this objective was the International Project on Managing the Decommissioning and Remediation of Damaged Nuclear Facilities (DAROD Project). The DAROD Project, led by the IAEA, was developed to provide practical guidance to meet the challenges surrounding the decommissioning and remediation of accident damaged nuclear facilities. The project achieved this through the use of case studies which brought together knowledge and experience in this area of expertise.

The DAROD Project was one of the final activities initiated under the IAEA Action Plan on Nuclear Safety. A series of consultancy meetings and technical meetings were organized in Vienna starting in January 2015, and a concluding international workshop was held in Penrith, United Kingdom, in October 2017.

This publication represents the culmination of the efforts of the DAROD Project, documents the work undertaken and presents the project's findings regarding the decommissioning and remediation of damaged nuclear facilities.

The IAEA gratefully acknowledges the assistance of the contributors to this publication. The IAEA officers responsible for this publication were J.H. Rowat and V. Ljubenov of the Division of Radiation, Transport and Waste Safety and V. Michal and P. O'Sullivan of the Division of Nuclear Fuel Cycle and Waste Technology.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

The purpose of this publication is to document the activities and outcomes of the DAROD project, i.e., the "International Project on Managing the Decommissioning and Remediation of Damaged Nuclear Facilities". This IAEA project brings together knowledge and experience gained in addressing the challenges associated with the decommissioning and remediation of damaged nuclear facilities (DNFs).

The Agency identified a lack of practical information and guidance concerning the issues and challenges encountered by facilities during the time period extending from the end of an emergency phase to the completion of decommissioning and/or remediation, and for the purposes of this publication, this period will be referred to as the post-emergency phase. The DAROD project was established in response to Action 10 of the IAEA Action Plan on Nuclear Safety[1], and to the outcomes of the following IAEA efforts:

- The International Experts Meeting on Decommissioning and Remediation after a Nuclear Accident (IEM IV, 28 January to 1 February 2013) [1]; and,
- Experiences and Lessons Learned Worldwide in the Cleanup and Decommissioning of Nuclear Facilities in the Aftermath of Accidents, IAEA Nuclear Energy Series No. NW-T-2.7 (2014) [2].

The above efforts highlighted a number of important issues concerning the decommissioning and remediation of DNFs. The efforts illustrated that the steps taken to decommission and remediate DNFs have a high degree of complexity and uncertainty with respect to many aspects of decommissioning and remediation, e.g., planning, characterization, decommissioning techniques, cost estimating, and communication.

The DAROD project was based in large measure on the substantial international guidance and experience for decommissioning available from the IAEA, OECD-NEA, and European Commission, and on information from case studies concerning DNFs provided by Member States, including experience gained at legacy sites. The DAROD project identified specific areas where guidance needs to be strengthened or expanded to provide sufficient information for dealing with DNFs. Some of these areas include the following:

- Assessing the integrity of damaged structures, and the stabilization of damaged plants;
- Planning and preparation for the removal of damaged fuel and fuel debris;
- Performing radiological characterizations in hostile environments, e.g., in areas with high levels of radiological contamination;
- Performing rapid and efficient characterization of the environmental contamination of water, soils, and biota; and,
- Identifying technologies for undertaking decommissioning and remediation of DNFs, for example, decontamination and segregation techniques, and remote handling systems.

[1] The IAEA Action Plan on Nuclear Safety (GOV/2011/59-GC(55)/14) was approved by the IAEA Board of Governors and endorsed by the IAEA General Conference in September 2011 (GC(55)/RES/9).

A primary tenet underlying the purpose of decommissioning and remediation is that the required actions need to be based on mitigating the potential risks to human health and the environment. To that end, much can be learned about the effectiveness of decommissioning and remediation initiatives from the follow-up monitoring that has been carried out at existing sites.

1.2. OBJECTIVE

The objective of this publication is to summarize the outcome of the DAROD project with the purpose to learn and benefit from the experiences derived from meeting the challenges associated with the decommissioning and remediation of actual DNFs. It is recognized that considerable guidance already exists for managing the decommissioning and remediation of sites and facilities that have not been damaged through accidents or unplanned events through, for example, the information contained in regulations, international guidance documents, and IAEA publications.

Therefore, the purpose of the DAROD project is not to duplicate existing information but rather to identify where this guidance may require expansion and clarification when applied to DNFs and for activities involving planning of the post-emergency phase. The management of legacy facilities can also provide information for the long-term care and management of accident damaged facilities once the emergency situation has been stabilized.

The approach for implementing the DAROD project took into consideration existing IAEA publications related to decommissioning and remediation. An important project objective was to ensure that established safety requirements are reflected in the development and implementation of decommissioning strategies for DNFs.

This publication is intended to be used by various interested parties – regulatory bodies, operating organizations, technical support organizations, governmental officials, and the public – involved in the decommissioning and remediation of nuclear facilities damaged after an accident or due to a legacy deterioration.

1.3. SCOPE

The types of facilities considered in the scope of this publication comprise damaged authorized facilities which may include power and research reactors, as well as other nuclear facilities (including legacy facilities), but with the exclusion of uranium mines and tailings. DNFs are therefore authorized facilities where (i) accidents, (ii) intentional acts to disrupt operations, or (iii) uncontrolled degradation of facilities have resulted in a situation where the standard decommissioning practices generally utilized at non-accident damaged sites may not be adequate.

Within this publication, the term ‘normal’ is frequently used and is intended to refer to facilities that are in normal operation [3], i.e., in one of the six major stages of the lifetime (siting, design, construction, commissioning, operation, and decommissioning) of an authorized facility, and are in a state characterized by “operation within specified operational limits and conditions”. By contrast, the term ‘accident conditions’ is intended to refer to the circumstances leading to a DNF and is considered to represent “deviations from normal operation that are less frequent and more severe than anticipated operational occurrences” [3]. In most cases, the accidents and incidents resulting in a DNF are likely to lie outside of anticipated operational occurrences and design basis accidents.

For the purposes of this publication, legacy facilities are considered as being those facilities that were either never subject to regulatory control, or that were subject to regulatory control, but not in accordance with modern standards. Legacy facilities include poorly managed facilities that may have been inappropriately operated, thereby resulting in significant damage or the spread of radioactive contamination, or may have resulted from neglect that extended over a long period of time and resulted in significantly degraded structures such that current codes and standards cannot be met. The risks associated with legacy facilities are often exemplified by the following characteristics: (i) uncontrolled spread of contamination, (ii) structural damage or degradation, and (iii) loss of information and/or records. The hazards and risks presented by DNFs and legacy facilities are similar and, therefore, were considered together in the DAROD project. In the context of this publication, the term 'damaged nuclear facilities' refers to those facilities where (i) accidents, (ii) intentional acts to disrupt operations, or (iii) uncontrolled degradation have occurred.

Regarding DNFs, the scope of the DAROD project addressed the time period from the end of the emergency phase until such time as remediation or decommissioning of the facility is completed, with a focus on the physical infrastructure and contaminated areas within a licensed site boundary. For the purposes of this project, this time period is termed the 'post-emergency phase'. Following an accident, emergency response actions are taken to respond to the situation, a period which may last from several days to many months. The actions carried out during the emergency phase are generally intended to establish a sufficiently stable facility configuration to allow proceeding with subsequent decommissioning and remediation. Once stabilization activities have been completed, the licensee or operator can then begin to take the necessary time to plan and sequence appropriate actions to further reduce hazards, and to follow the decommissioning process as described in IAEA Safety Standards Series No. GSR Part 6, Decommissioning of Facilities [4]. Activities conducted during the post-emergency decommissioning and remediation period are a 'planned exposure situation' as described in IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [5]. The reality for many DNFs is that, while the basic elements of the decommissioning process may be applicable, i.e., protection of people and the environment, regulatory responsibilities established, etc., the actions to achieve these objectives may be non-routine.

1.4. STRUCTURE

The structure of this publication reflects, to the extent possible, the structure of the DAROD project as described below. Section 2 summarizes the IAEA activities related to the decommissioning and remediation following a nuclear accident. Section 3 includes summary of discussions on regulatory issues, Section 4 on technical issues and Section 5 on institutional framework and strategic planning. Last Section 6 offers observations and conclusions.

Because of the complexities and various subjects requiring expert input to the DAROD project, three working groups were established. These working groups focused on (i) specific topics, (ii) discussed lessons learned, and (iii) described approaches that could be used to address the issues and challenges associated with of DNFs. A coordinating working group was also formed to manage the overall project and to ensure effective coordination among the working groups. Case study experts provided specific information regarding DNFs that had been included as part of the project scope.

The structure of the DAROD project is shown in Fig. 1. This project is complementary to related initiatives and publications of the IAEA as further described in Sections 2.1 and 2.2.

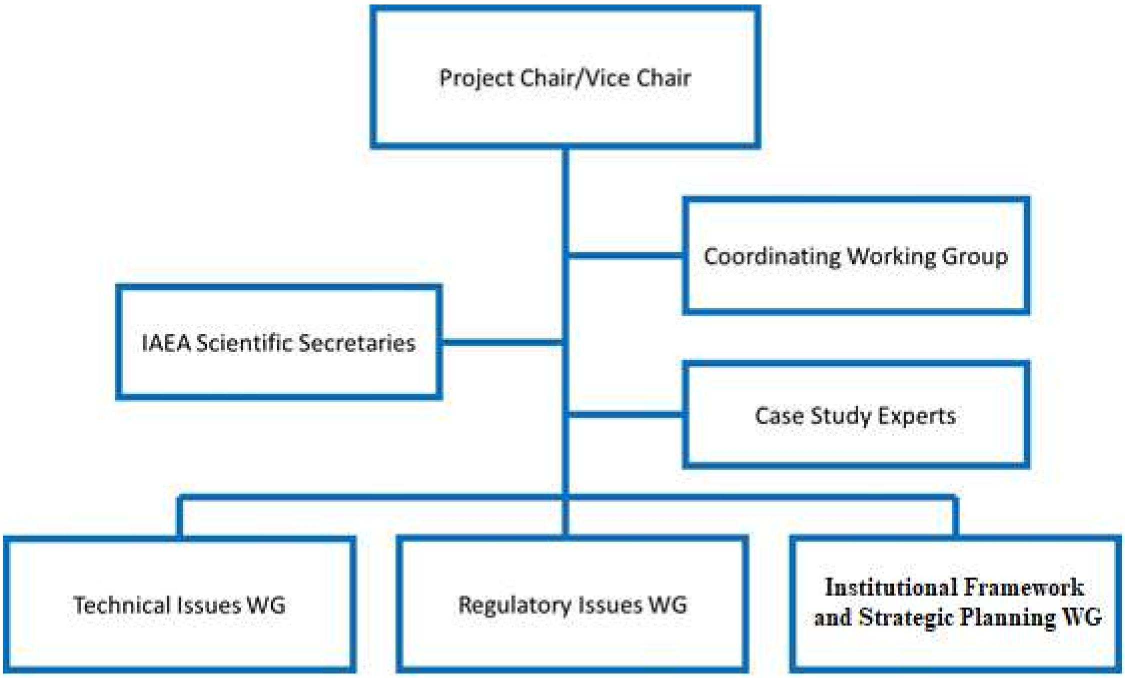

FIG. 1. DAROD project structure.

The project approach comprised (i) plenary sessions, (ii) Coordinating Working Group (CWG) and Working Group (WG) meetings, and (iii) an international workshop. The first project meeting began with a plenary session where the objective and scope of the project were agreed upon by participants. Three working groups were established as shown in Fig. 1 above. These working groups were responsible for developing and compiling the information that formed the basis of this publication.

The three working groups, composed of representatives nominated by the participating IAEA Member States, covered the following key areas: regulatory issues, technical issues, and institutional framework and strategic planning. The main activities of the working groups were to:

- Identify and define site specific and common issues regarding the key areas (regulatory issues, technical issues, institutional framework and strategic planning);
- Interact with case study experts to discuss lessons learned, knowledge, conclusions and experience;
- Gather and extract key relevant information relating to managing the decommissioning and remediation of DNFs; and,
- Draft sections of the final publication.

Once the working groups were formed, each group developed an approach and goals which further refined the subject matter for their group. These activities were coordinated with the other groups to ensure that overlap was not occurring, or that important issues were not being missed. An overall work plan was then developed that provided clear milestones for each working group and for the DAROD project as a whole. By the end of the first meeting, the working groups understood their objectives, the process for meeting their goals, and the associated work plan.

A DAROD final international workshop was held in Penrith, Cumbria, UK in October 2017. Thirty-five participants from 20 countries took part in this workshop, which was organized by the IAEA and hosted by the Nuclear Decommissioning Authority (NDA).

The purpose of the workshop was to:

— Bring together the relevant experts concerned with the decommissioning and remediation of DNFs, including decision makers and those whose responsibilities provide input into the decision making process as related to those areas of concern in the DAROD project. The experts were represented by regulators, owners, licensees, governments, and other stakeholders;
— Disseminate relevant lessons learned based on international experience gained to date in terms of the management of DNFs, as well as other such facilities and sites; and,
— Add to the general knowledge base being covered by the DAROD project.

The workshop was open to participants from IAEA Member States which have DNFs, legacy nuclear sites, and nuclear power plants in either shutdown or operational states and which present a challenge to decommissioning or remediation.

This publication is structured such that sections have been drafted based on the initiatives of each of the working groups wherein the issues, challenges, knowledge, conclusions, and experience identified in the case studies are discussed. A summary of the issues and challenges is presented below. Each of the sections also includes conclusions made by the working groups in terms of how these issues and challenges were managed or approached with respect to the facilities described in the case studies.

Regulatory issues and challenges:

— Identifying the nature and extent of changes that may be required to the regulatory approach and regulatory responsibilities in order to address the DNFs;
— Determining which nuclear and non-nuclear regulations and standards are applicable to the DNF situation at hand, and which, if any, require modification;
— Evaluating the effectiveness of the safeguards and nuclear material control practices being considered and/or applied at a DNF;
— Determining the most effective approach for applying the safety principles, requirements and guidance provided by the IAEA Safety Standards, the OECD-NEA, and the European Commission; and,
— Evaluating the applicability of the clearance concept.

Technical issues and challenges:

— Identifying the issues affecting the ability to characterize physical and radiological hazards, and developing methods by which to carry out the characterizations;
— Developing methods for the monitoring of affected facilities;
— Identifying the issues affecting the ability to perform structural assessments, and developing methods by which to perform the assessments;
— Identifying and evaluating the functionality and availability of safety systems, e.g., fire, ventilation, criticality control, shielding;
— Developing an approach for the provision or replacement of safety related systems, e.g., fire, ventilation, criticality control, shielding;
— Evaluating the requirement for environmental monitoring including groundwater;

— Implementing the required environmental monitoring programmes;
— Identifying the radioactive waste management infrastructure and technical capabilities required to manage circumstances wherein waste streams may arrive sooner than expected, and that these waste streams may be greater in volume and different in nature than previously planned for;
— Identifying the requirements for waste management treatment methods, e.g., volume reduction;
— Identifying the unique aspects of, and methods for, managing damaged fuel and fuel debris;
— Identifying new technologies that could assist in decommissioning; and,
— Identifying the methods required for providing adequate protection of workers.

Institutional framework and strategic planning issues and challenges:

— Reviewing and evaluating the assignment of responsibilities of the owner, operator, licensee, regulator, decision makers, and both national and local governments;
— Identifying and reviewing existing organizational structures, and determining the need for any required changes to existing organizations, or for the establishment of new organizations;
— Evaluating, and if necessary, developing risk management and cost estimation methodologies that are suited to dealing with non-standard inputs of information and conditions characterized by a high degree of uncertainty;
— Identifying possible financing mechanisms that might be employed for funding the decommissioning and remediation of DNFs;
— Identifying and developing an effective process for interacting and communicating with stakeholders;
— Evaluating the current decision making processes, and determining the need for possible changes to those processes;
— Determining if the original planned final end state for decommissioning remains appropriate, and providing the rationale used in the decisions concerning that determination (including considerations concerning the use of entombment and safe enclosure);
— Developing a systematic methodology that can be used in selecting an optimum strategy for managing the DNF that takes into consideration such factors as cost, time, public perception, waste volume, safety;
— Identifying those factors that could have an impact on meeting the remediation and decommissioning project objectives for the DNF, e.g., high levels of complexity and uncertainty, high levels of risk, requirements for hold points, uncertainties about public concerns, international considerations; and,
— Determining the extent of any requirements for additional infrastructure, e.g., replacing buildings, safety systems, liquid and waste treatment systems, waste management facilities.

The key observations and conclusions presented in each working group section are further highlighted and discussed in Section 6 entitled “Observations and Conclusions”, and the publication has been structured in this manner to facilitate ready access to the main conclusions arising from the DAROD project.

Following case studies were considered within the DAROD project:

- Fukushima Daiichi NPS, Japan (reactor accident): The Great East Japan Earthquake that occurred on 11 March 2011 and the subsequent tsunami off Japan's Pacific coastline caused severe damage to the Fukushima Daiichi NPS. The resulting nuclear accident was assigned to Level 7 on the International Nuclear and Radiological Event Scale (INES). Decisions to decommission the damaged Units 1 to 4 and the undamaged Units 5 and 6 at the Fukushima Daiichi NPS were taken in 2012 and in 2014, respectively;
- Chernobyl NPP, Unit 4, Ukraine (reactor accident): The world's worst nuclear accident occurred in the Union of Soviet Socialist Republics (USSR) at Chernobyl NPP Unit 4 on 26 April 1986. As a result of an explosion in the reactor core, safety systems and physical barriers were completely destroyed, and this in turn led to a complete loss of control over Unit 4. As a consequence, it became impossible to control (i) the retention and/or release of radioactive material, (ii) the nuclear fission reaction, and (iii) the removal of residual heat from the fuel. The nuclear accident was assigned to Level 7 on the INES;
- Three Mile Island NPP Unit 2 (TMI-2), USA (reactor accident): TMI-2 was damaged on 28 March 1979. The U.S. Nuclear Regulatory Commission (NRC) determined that a combination of equipment malfunctions, design related problems, and worker errors led to the partial meltdown of TMI-2 and very small off-site releases of radioactivity. The resulting nuclear accident was assigned to Level 5 on the INES;
- A1 NPP, Slovak Republic (reactor accident): A serious incident occurred during the reactor's operation on 5 January 1976 when a technical failure occurred during refuelling. The incident involved a fresh fuel assembly which, when loaded into the reactor, was subsequently ejected into the reactor hall by the pressure of coolant gas when a locking mechanism in the fuel channel failed. The resulting nuclear accident was assigned to Level 4 on the INES;
- Marcoule Nuclear Centre, France (legacy facility): Marcoule is a nuclear research centre with various radioactive legacy wastes emplaced in vaults and pits. The original mission of the centre was to supply plutonium for French defence purposes, and to produce electricity from nuclear power on an experimental basis. The mandate included (i) production of fissile materials, (ii) treatment and recycling of spent fuel, and (iii) waste conditioning. Marcoule is also the site of the Marcoule Pilot Plant (APM), a nuclear fuel reprocessing plant operated from 1962 to 1997 with the objective of developing industrial processes and equipment for the processing and vitrification of radioactive waste;
- First Generation Magnox Storage Pond (FGMSP), Sellafield, UK (legacy facility): Sellafield is a complex nuclear site which undertakes (i) spent fuel reprocessing, (ii) spent fuel storage, (iii) decommissioning, (iv) the management of nuclear materials, and (v) associated waste management activities. The site includes the so-called legacy ponds and silos which present significant hazards and risks that are similar to those found in post-emergency damaged facilities. One such facility is the FGMSP which is the subject of the case study;
- Industrial Uranium Graphite Reactors (IUGRs), Russian Federation (legacy facilities): IUGRs were the first industrial reactors employed for plutonium production, and all Russian IUGRs are now shutdown. In total, 13 IUGRs were constructed and operated in the Soviet Union: 5 units at Mayak, 5 units at Siberian Chemical Combine (SChC, Tomsk), and 3 units at Mining Chemical Combine (MCC, Krasnoyarsk region). The decommissioning of one facility (EI-2 at Tomsk) was completed in 2015, and another facility is currently being prepared for decommissioning;

— Al-Tuwaitha Nuclear Research Centre, Iraq (intentional disruption): In 1991, during the Second Gulf War, most of the nuclear facilities at the Al-Tuwaitha Nuclear Research Centre were destroyed by bombing, the consequences of which were serious contamination issues.

The case studies were not intended to be exhaustive descriptions of the facilities and their status. Instead, the case studies were developed with a focus on describing how the issues and challenges surrounding DNFs were approached.

One of the challenges in preparing this publication and the associated case study summaries was the fact that the work on the DNFs is constantly advancing, i.e., the status of the facilities is not static, but rather is changing as a result of ongoing active decommissioning and remediation work. Therefore, the observations and approaches presented in this publication may be at variance with actual future circumstances or with the status of the sites at the time this publication is issued.

2. IAEA ACTIVITIES RELATED TO DECOMMISSIONING AND REMEDIATION FOLLOWING A NUCLEAR ACCIDENT

2.1. KEY PUBLICATIONS AND MEETINGS

The IAEA has developed a body of information on decommissioning, and some of the key publications and meetings that address the topic of remediation and decommissioning following a nuclear accident are summarized below.

IEM IV: International Experts' Meeting on Decommissioning and Remediation after a Nuclear Accident [1]

IEM IV focused on the complex technical, societal, environmental, and economic issues that need to be considered in terms of the decommissioning and remediation activities that are required after a nuclear accident, specifically those activities that are necessary after the emergency exposure period of an accident has been declared ended. The objective of IEM IV was also to assist Member States in preparing for and managing the consequences resulting from a nuclear accident.

Nuclear Energy Series publication NW-T-2.7 "Experiences and Lessons Learned Worldwide in the Cleanup and Decommissioning of Nuclear Facilities in the Aftermath of Accidents" [2]

The purpose of this publication is to review IAEA Member States' experience concerning the cleanup and decommissioning of nuclear facilities in the aftermath of accidents, and to report on and disseminate these experiences and lessons learned on a worldwide basis.

Nuclear Energy Series publication NW-T-2.10 "Decommissioning after a Nuclear Accident: Approaches, Techniques, Practices and Implementation Considerations" [6]

Based on lessons learned from past events, this publication was prepared to provide an overview of the approaches, techniques, practices, and implementation considerations used in managing decommissioning activities after a nuclear accident. The publication is primarily focused on the technical aspects of on-site decommissioning which need to be addressed and managed after a nuclear accident (INES level 4–7).

The Fukushima Daiichi Accident: Report by the Director General [7]

This publication was developed through an extensive international collaborative effort, involving five working groups, and included about 180 experts from 42 Member States, both with and without nuclear power programmes, as well as several international bodies. The publication provides a description of the accident and its causes, and includes a discussion of how the accident evolved, and the resulting consequences. The descriptions and discussions contained in the publication are derived from the evaluation of data and information available from a large number of sources at the time of writing.

Contents: Report by the Director General; Technical Volume 1/5, Description and Context of the Accident; Technical Volume 2/5, Safety Assessment; Technical Volume 3/5, Emergency Preparedness and Response; Technical Volume 4/5, Radiological Consequences; Technical Volume 5/5, Post-accident Recovery; Annexes.

2.2. APPLICABILITY OF IAEA SAFETY STANDARDS

The two IAEA safety standards reviewed in detail in terms of their applicability to DNFs were GSR Part 6 [4] and GSR Part 3 [5]. A generic analysis was performed to examine the applicability of IAEA Safety Standards such as GSR Part 6, taking into account the unique safety related aspects that may be found with DNFs and legacy sites.

Generally, most of the requirements from GSR Part 6 are applicable to the planning, performance, and completion of activities being carried out at DNFs and legacy sites. However, it may not be possible to immediately or fully implement some of the requirements. For example, the preparation of a decommissioning plan of the type discussed in GSR Part 6 [4] wherein, for example, the plan includes explicit details about facility end states.

As discussed in more detail in Section 5, the plan for the decommissioning and remediation of a DNF may need to include interim end states until enough is understood about the DNF that a full decommissioning plan can be prepared. However, the safety requirements contained in GSR Part 3 [5] are fully applicable to a DNF to ensure that decommissioning and remediation actions are conducted safely.

A new IAEA Safety Standards Series No. GSG-15 (DS468) "Remediation Strategy and Process for Areas Affected by Past Activities or Events", contains case studies on the application of the remediation process for areas affected by, respectively, the Chernobyl accident and the Fukushima Daiichi accident. The Guide is expected to be published by the end of 2021.

3. REGULATORY ISSUES

3.1. INTRODUCTION

As an introduction to the material presented in this section, it is useful to consider the following quotation taken from the IAEA Safety Glossary (2018 Edition) [3]:

"The terms siting, design, construction, commissioning, operation, and decommissioning are normally used to delineate the six major stages of the lifetime of an authorized facility and of the associated licensing process. In the special case of disposal facilities for radioactive waste, the decommissioning is replaced in this sequence by closure."

Regulatory requirements applicable to the six major stages in the lifetime of an authorized facility, e.g., reactors or nuclear materials processing facilities, are largely based on internationally recognized practices and are both well understood and accepted. However, these practices and requirements primarily focus on the safe use of nuclear materials and nuclear power under non-accident or non-post-emergency conditions, i.e., when the facility is still in an authorized state and operating within approved operating limits and conditions. By contrast, the case studies contained in this publication represent circumstances and unique conditions encountered with DNFs that may challenge the appropriateness and relevance of regulatory systems, standards, and laws that are intended for the routine and normal stages of a facility lifetime.

In addition to the regulations governing the six normal stages of an authorized nuclear facility, other regulatory requirements covering, e.g., radioactive discharges, clearance levels, waste management practices, radiation protection, safeguards, or fissile material controls, may be challenging to apply in the case of DNFs. Furthermore, following the decommissioning and remediation of a DNF, previous plans and expectations concerning the site end states for contaminated land, vegetation, and groundwater may no longer be practically achievable.

In many cases, these challenges to established regulatory practices and standards in the case of DNFs may also apply to the hazard and risk reduction activities performed on degraded legacy facilities.

The challenges associated with DNFs, and the impacts of these challenges on regulatory matters, are discussed in the following sections using the knowledge and experience provided in the case studies. The topics covered in the discussions include:

- Changes to regulatory approaches;
- Applicability and modification of nuclear and non-nuclear regulations and standards;
- Safeguards and nuclear materials control practices; and,
- Applicability of the clearance concept for materials.

3.2. CHANGES TO REGULATORY APPROACHES

3.2.1. Introduction

In the case of DNFs or degraded legacy facilities, the regulatory permitting or licensing process may need to be adapted and changed in a manner that will make the regulatory approach more flexible to accommodate the unique challenges and atypical conditions found with DNFs. In some cases, an action plan may be required of the licensee to facilitate a staged (step-by-step) approach to the licensing and approval process. Under some circumstances, a staged licensing approach may present a regulatory challenge because the remediation and decommissioning activities for DNFs may need to begin prior to a clear understanding of how the activities will be carried out, and what the final facility end state may be. For example, risk reduction through decommissioning and remediation may need to start without final decisions in place concerning plans for waste characterization, waste treatment, facility end states, and disposal facilities. A regulatory approach for a decommissioning and remediation project that does not include details and justifications for all aspects of the project is not usually a standard approach and, consequently, the normal regulatory approaches may need to be changed to facilitate flexibility. In some cases, the state of a DNF might be such that it does not qualify for any of the types of licenses that are routinely issued by a regulatory body, and a unique type of regulatory 'license' may be required for that particular facility. The use of special regulatory vehicles for DNFs is evidenced in several case studies.

There may also be issues in terms of waste management plans and waste acceptance criteria. For example, it may be necessary to build facilities for the retrieval and packaging of waste arising from a DNF prior to the final specifications for waste storage and disposal facilities and their associated waste acceptance criteria. This situation may be at variance with normal regulatory expectations and practices wherein wastes are (i) expected to be fully characterized, and (ii) waste forms are based on compliance with the waste acceptance criteria for waste storage and disposal facilities.

In some of the case studies involving DNFs, there was a period of time during the accident when there were uncontrolled releases of radiological contamination to the environment. While it is reasonable to expect that these releases can be reduced and brought under some degree of control, various previously approved parameters such as discharge limits, intervention levels, monitoring requirements, and remedial actions that were in place prior to the accident may no longer be applicable, and therefore may need to be reviewed and changed based on agreements with the regulator. In the case of a DNF, regulatory challenges may arise if (i) there is an ongoing inability to fully control radioactive releases to the environment, (ii) previous control levels can no longer be met, and (iii) future releases from the DNF do not meet current international standards. Therefore, it is important that the regulatory body recognizes that the accident has compromised the ability to manage releases and understands the potential for future uncontrolled releases. Given the realities of the post-emergency conditions, including the levels of radioactive releases relative to pre-accident conditions, the regulatory body may need to review and revise expectations in terms of discharge limits, intervention levels, monitoring arrangements, and required remediation actions. The case study examples include discussions about changes in regulatory expectations for groundwater monitoring at Chernobyl and TMI-2, and aerial discharges from the open air FGMSP at Sellafield.

External pressures, such as those arising from stakeholder and public opinion (solicited or otherwise), may influence the nature of the regulatory approach applied to DNFs. For example, the regulatory approach may become reactive, and may be influenced by the requirement to provide assurance to the public regarding the safety status of the facility. This will not be true in all cases and may depend on the political and economic environment. This pressure may lead to regulatory issues, for example, in cases where stakeholder or public engagement forces changes in the project objectives for remediation and decommissioning, e.g., changes to project completion schedules, final end states, etc. Notwithstanding this possible issue, there are often long-term benefits to open engagement with stakeholders and the public.

Another potential regulatory issue related to the above discussion is that it might be expected to see regulatory bodies substantially shift their focus and efforts to the damaged facility and to addressing the concerns of the public and other stakeholders. This shift in focus could impact regulatory priorities in terms of planning and resource allocation and require actions to ensure that other regulatory responsibilities receive the required attention.

3.2.2. Case studies on changes to regulatory approaches

Fukushima Daiichi NPS, Japan

The Fukushima Daiichi Nuclear Regulatory Authority (NRA) Regional Office has offices both on-site and near the site to monitor the operational safety activities of TEPCO. These monitoring activities include (i) conducting interviews with TEPCO officials, (ii) on-site inspections of the work being carried out, and (iii) a daily patrol of the power plant.

Under normal circumstances, nuclear safety inspectors and other personnel stationed at or near a site only perform monitoring activities during daytime operations. By contrast, the Fukushima Daiichi NRA Regional Office monitors the site around the clock. In addition, and in response to the accident, the number of stationed inspectors and other personnel was increased from 8 to 12.

The NRA approves the implementation plans that are prepared for the actions being proposed for the DNF. In addition, it approves any new actions that will revise the implementation plans as a result of, for example, research and development (R&D) or characterization results. The overall aim of the NRA is to continuously improve safety, security and safeguards.

The primary changes to the regulatory approach as a consequence of the Fukushima Daiichi accident were as follows:

- Establishment of a new regulatory body, i.e., the NRA;
- A recognition of the need for a more flexible regulatory approach;
- The extent to which public opinion had an impact on the decision making process related to the discharge of radioactivity, or on the types of material requiring NRA approval prior to release from regulatory control.

Three Mile Island NPP Unit 2 (TMI-2), USA

At TMI-2, a dedicated NRC site team was established and remained on-site for a significant period after the accident. Following this, a special TMI Program Office (TMIPO) was formed within the NRC which provided overall direction for the TMI-2 cleanup operations and inspections. This office was staffed by approximately 30 employees during the first few years, with some of the staff located near the plant in Middletown, PA. The TMIPO utilized a new and unique regulatory approach to implement the NRC's approval processes during the cleanup of the TMI-2 accident. The specifics of this approach involved delegating certain decision making authorities related to cleanup to the TMIPO on the basis of the NRC's approval of a Programmatic Environmental Impact Statement (PEIS), in which cleanup activities and their associated impacts had been systematically assessed. In a supplement to the PEIS, the NRC stated that staff were allowed to undertake major cleanup activities provided that those activities had been assessed as part of the scope of the PEIS. As such, the PEIS became a crucial document in the regulatory approval process wherein all cleanup methodologies proposed by the licensee had to be evaluated against the assessments included in the PEIS. This approach provided a clear framework by which the TMIPO could approve procedures and methodologies proposed by the licensee without further NRC approval. Notwithstanding this regulatory framework, it is important to note that, although the TMIPO was afforded this decision making authority, there was still accountability to and frequent communication with the NRC.

The PEIS was developed after the City of Lancaster, PA, undertook legal action concerning the potential disposal of processed accident generated water into local waterways, and a directive issued by the Commission on November 21, 1979 instructed NRC staff to develop the PEIS. A draft of the document was released for public comment on August 14, 1980, and the Commission issued a policy statement endorsing the final PEIS on April 27, 1981.

During the development and approval of the PEIS, NRC staff held 31 meetings with the public, media, and local officials, and the final PEIS included NRC staff responses to nearly 1000 comments received concerning the draft PEIS (following a 90-day comment period). Stakeholder engagement also influenced the regulatory process for other environmental assessments and NRC processes through the requirements for public input and the solicitation of comments. For example, the TMI-2 recovery technical specifications included prohibitions against the purging or other treatment of the reactor building atmosphere as well as the discharge or other disposal of the high level radioactively contaminated water in the reactor building in spite of the fact that activities such as these would have been allowed prior to the accident and could have been conducted in full compliance with the effluent limitations or Commission regulations in affect and applicable to TMI-2. Furthermore, while it is possible that these activities could have been permitted under the effluent limitations applicable to normally operating facilities, the Commission determined that the public interest warranted prohibiting such undertakings pending completion of an environmental review.

Unit 4 Chernobyl NPP (ChNPP), Ukraine

The Chernobyl accident occurred in 1986 when Ukraine was part of the Soviet Union, and therefore the issues related to the mitigation of accident consequences were addressed at the highest governmental level of the Soviet Union. The Soviet regulatory body Gosatomenergonadzor was established in 1983 as a State Committee but was not yet an independent organization when the Chernobyl accident took place. At the time of the accident, all activities related to the design, construction, and operation of nuclear power reactors were under centralized governmental control, and information about "nuclear issues" including research and investigations was classified or secret.

Following the collapse of the Soviet Union in 1991, an independent Ukrainian national authority for the regulation of nuclear and radiation safety was established in February 1992 (Gosatomnadzor).

The State Committee for Nuclear and Radiation Safety faced a number of challenges with respect to Unit 4 of the Chernobyl NPP, one of them was finding a term to define the DNF, e.g., "storage facility for unorganized radioactive waste", and then:

- To define (classify) those activities that could potentially be implemented to deal with the damage to this facility, e.g., maintain DNF safety, DNF decommissioning, DNF remediation, DNF conversion or transformation;
- To identify the safety requirements and the scope of the safety case for the licensing of this facility; and,
- To review the safety case prepared by the Chernobyl NPP and issue the license.

The Ministry of Health of Ukraine is responsible for establishing the discharge limits from the shelter structure. The discharge limits for the shelter structure had to be specifically defined and apply to (i) vented discharges through the ventilation stack and (ii) fugitive discharges through openings in the shelter structure, as calculated by mathematical methods.

In the case of Chernobyl, there was a lack of waste management infrastructure (storage and disposal facilities) to manage the large amount of radioactive waste arising from site activities. To date, the waste management approaches used for the wastes resulting from the Chernobyl accident mitigation activities have been the same as those used for the management of normal operational waste from the Chernobyl NPP. Assessments of the potential options for disposing of the accident waste, including the licensing of near surface repositories in the exclusion zone, has shown that the management of these wastes cannot be easily resolved.

A1 NPP, Slovak Republic (previously Czechoslovakia)

As part of the process surrounding the formation of the Slovak Republic, the approach used in the decommissioning and remediation of the A1 NPP was adjusted to include stakeholder engagement. As a consequence, public opinion is now considered in the regulatory licensing process (including decommissioning).

Social and political changes in 1989 resulted in, among other things, significant changes in the policies towards the protection of the environment, and in the approval of the Act on Environmental Impact Assessment (EIA) issued in 1994. The new EIA Act requires more details in evaluating possible environmental impacts, and it formally established the EIA processes for the specific activities and undertakings that are defined in the EIA Act. The principal change for activities involving nuclear processes was that the new EIA Act established the requirement for public involvement in the approval process for a proposed facility or activity and included public involvement in the decision making process.

The project for "putting the A1 NPP into radiation safe status" (without spent fuel and without uncontrollable releases of radioactivity) was completed in 1999 in accordance with the EIA Act and a 1993 Government resolution. In spite of the fact that the EIA process for this activity was characterized by overall uncertainty regarding both the project timing and project scope, it was the first opportunity for the public to become involved in addressing the problems connected with the A1 NPP decommissioning.

First Generation Magnox Storage Pond (FGMSP), Sellafield, UK

The FGMSP at Sellafield had been left in a state of limited care and maintenance. In 2000, the Nuclear Installations Inspectorate (NII, now the Office for Nuclear Regulation, ONR) had significant concerns and decided that regulatory intervention was necessary to secure improvements, and issued a number of specifications. In 2011, ONR recognized the inherent inflexibility associated with the use of specifications to control complex, novel, and long duration decommissioning projects.

Using the nuclear site license, a new approach was identified as a tool which would provide the appropriate flexibility for monitoring hazard and risk reduction progress. The new arrangements made by Sellafield Limited, the site operator and licensee, calls for the identification and governance (including change control procedures and interface with the regulators) of key decommissioning milestones. Sellafield Limited must provide tangible risk and hazard reduction milestones. These arrangements provide a robust, unambiguous, and flexible tool to monitor progress.

As part of this shift in regulatory approach, the UK Government, Sellafield, and regulators put in place a set of ‘special arrangements’ for FGMSP. This was in recognition that FGMSP was considered to present an ‘intolerable’ level of risk that must be addressed, and acknowledged that best value would be achieved by accelerating the hazard and risk reduction programme so as to end the period of ‘intolerable’ risk.

‘Special arrangements’ were seen as the vehicle by which to promote the transition from a care and maintenance approach to a decommissioning mind-set approach. This mind-set may be best described as the methodical identification of barriers to accelerated risk reduction together with the use of risk-informed decisions as to how to deal with them. As part of this process is the need to appropriately balance execution risk with total risk over time. The result of this approach is that the overall accelerated risk reduction becomes the primary driver in guiding decisions and options rather than undertaking risk targets that might be expected or reasonable for new nuclear facilities, but which would delay decommissioning or even be unachievable. Under this approach, fit for purpose engineering and safety case solutions are developed as needed.

In 2014, ONR developed a new regulatory strategy for the Sellafield site with a focus on stimulating, facilitating, and expediting hazard and risk reduction and thereby building confidence that hazards can be reduced. The aim of the new strategy for regulating Sellafield is to achieve the following outcomes:

- Accelerated hazard and risk reduction across the Sellafield site;
- Evidence based confidence that the licensee is complying with its statutory obligations, and that workers and the public are protected from the hazards of the site; and,
- Building stakeholder confidence that ONR’s regulatory approach is appropriately targeted, risk based, proportionate, and effective.

An important element of this strategy is for ONR to communicate its objectives to all stakeholders. Therefore, ONR has a policy of openness and transparency and makes information available to the public via its web site and at the local site stakeholder meetings.

Recognizing that there are several stakeholders with an interest in accelerating hazard and risk reduction on the Sellafield site, a new working group has been established. The group has a mandate to facilitate a coordinated approach to complex issues, particularly in those cases where input may be required from a broad range of decision makers. The group incorporates six key organizations (known as the G6), i.e., (i) Sellafield Limited, (ii) Nuclear Decommissioning Authority (NDA), (iii) Department for Energy and Climate Change, (iv) UK Government Investments, (v) Environment Agency, and (vi) ONR. All members work through a collaborative approach towards the common objective of facilitating hazard reduction, for example, by enhancing opportunities or removing barriers to progress.

Eight strategic improvement themes have been identified and agreed to with key delivery stakeholders and are considered to be the key enablers to the successful realization of the above outcomes. The eight strategic improvement themes are as follows:

- Effective prioritization: historically, Sellafield Limited was simultaneously undertaking over 500 interlinked projects relating to safety and security. The number of projects was radically reduced under the new strategy, and a prioritized list of hazard and risk reduction projects was produced;
- Effective use of resources, linked to prioritization;

— Removal of blockers and barriers: one contributing barrier to the achievement of the above outcomes appears to have been the result of enforcement actions taken by the regulators in the past, actions which diverted focus away from the priority hazards. The new strategy aims to remove unnecessary bureaucracy while still maintaining adequate and proportionate regulatory oversight. It also requires Sellafield Limited to address the remaining 'blockers', some of which may require changes to existing practices and processes;
— Removal of distractions and diversions: Sellafield was operated as a number of individual facilities, each of which was pushed to improve compliance arrangements, and reduce risks such that they are as low as reasonably practicable (ALARP). Under the new strategy, the site is regulated as a whole with nuclear safety, security, transport, safeguards, and conventional safety being fully integrated within ONR who in turn work closely with the Environment Agency to ensure that there is no conflict between different regulatory expectations;
— Incentivization programmes to drive the hazard and risk reduction programme as fast as reasonably practicable;
— 'Fit-for-purpose' solutions that are intended to avoid complex or disproportionate design standards that may be lengthening the design process such that there are delays in delivering hazard and risk reductions;
— Balance of risk: the application of a balanced and proportionate regulatory approach which recognizes and accepts increases in the short-term risk profile as a necessary consequence of reducing long-term risks and hazards. The balance of risk approach is shown diagrammatically in Fig. 2 below, and demonstrates that if a facility is allowed to deteriorate to an unacceptable level, then intervention becomes nonviable;
— Communications: a coordinated and systematic approach to communications and stakeholder interactions with the aim of establishing a 'no surprises' culture.

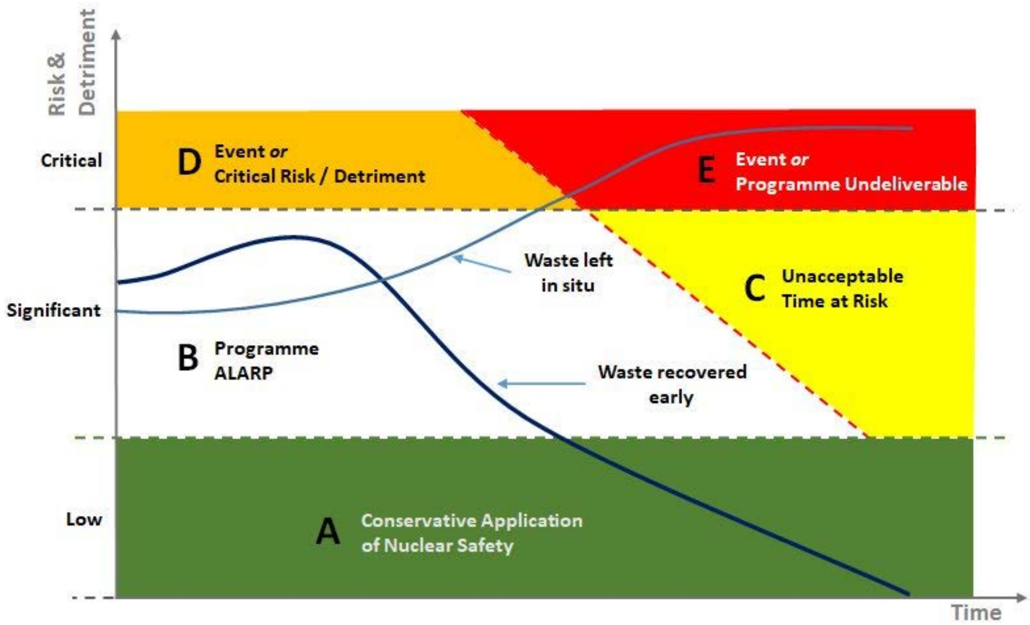

FIG. 2. Risk framework and approach at Sellafield.

The key desired outcome for the application of the eight strategic improvement themes is to secure risk and hazard reduction as quickly as possible at Sellafield. However, if ONR is not satisfied with the progress being made by Sellafield Limited, they still have extensive powers under the nuclear site license, including a range of enforcement actions.

For the FGMSP at Sellafield, retrievals had commenced with the pond inventory being transferred to interim storage. However, in many cases, this work was proceeding without a well-defined plan in place as to how this material would be ultimately managed and disposed of. Recent initiatives such as those described above are intended to enhance planning processes.

To enable the risk and hazard reduction activities to continue without unnecessary barriers, Sellafield Limited has documented arrangements in place that allow hold points to be established within the programme. These hold points provide ONR with an opportunity to decide whether a planned activity requires explicit permission to proceed, and ONR has the ability to lift hold points without unnecessary delay at various stages in a project. This process allows hold points to be moved or re-defined quickly on an as needed basis to ensure that projects can proceed without nuclear safety risk. This process is commonly known as 'flexible permissioning'.

Marcoule Nuclear Centre, France

The regulatory authority dedicates considerable attention to the implementation of decommissioning activities and to the initiation of actions focused on reducing the radiological risks associated with legacy facilities. However, the general regulatory approach used in overseeing the remediation and decommissioning of DNFs has not been changed relative to the approach used for facilities that are not considered to be DNFs.

Industrial Uranium Graphite Reactors (IUGRs), Russian Federation

Historically, all IUGRs in the USSR operated as a part of the nuclear weapons complex for the production of weapons-grade plutonium under the supervision of Minsredmash. Later, the IUGRs came under the Ministry of Atomic Energy, and today are under the supervision of the Rosatom State Corporation. Licensing of IUGR operations by the Russian nuclear regulator Gosatomnadzor (now part of Rostechnadzor) started in the early 1990s based on the fact that several IUGRs were being operated in a dual-purpose mode, i.e., producing plutonium and also supplying heat and electricity for local populations. Currently, 11 IUGRs are under decommissioning licenses, with the exception of the shutdown ADE-2 reactor which is still under an operational license. A decommissioning license authorizes an operator to start the decontamination and partial dismantlement of non-safety related systems and equipment.

After being shut down in 1991, the EI-2 reactor was regulated under an operational license issued to the Siberian Chemical Combine (SChC), a license which included license conditions which permitted the operation and maintenance of the necessary safety systems (e.g., ventilation, electricity and heat supply, radiation monitoring), and the removal of uranium fuel for reprocessing. The decommissioning strategy for the reactor core was long-term storage for a period of 100 years, a strategy primarily dictated by the lack of decommissioning funding.

In 2008, a project for decommissioning IUGRs was included in a federal programme entitled "Insurance of Nuclear and Radiation Safety of the Russian Federation for the year 2008 and for the period until 2015". To facilitate the implementation of the project, a new organizational entity called the "Pilot and Demonstration Centre for Decommissioning of Uranium-Graphite Reactors" (PDC-UGR) was established in September 2010 with a mandate to develop and implement innovative decommissioning technologies. Shortly after the establishment of PDC-UGR, there was a transfer of all reactor plant property and personnel to PDC-UGR.

Following intensive R&D which demonstrated that it was possible to provide effective isolation of the underground graphite reactor core through the use of additional engineered safety barriers, the IUGR decommissioning strategy was changed to one involving the safe entombment of the reactor core together with the dismantlement of auxiliary systems and the demolition of the reactor building. However, a decommissioning license was not issued until the new operator (PDC-UGR) could demonstrate the viability of filling the reactor space in a void-free manner using clay based material and provided the corresponding safety justification cases. An analysis of the lessons learned during the EI-2 decommissioning project led to the conclusion that the licensing process used by the regulatory body would be better served through the use of a combined license, which covers both the decommissioning process and the implementation of a disposal facility for use with the special or unique wastes produced during the decommissioning of IUGRs.

Although it is recognized that GSR Part 6 [4] does not include the entombment option as a recommended end state for the decommissioning of a nuclear facility, other safety requirements established in GSR Part 6 were nonetheless found to be applicable to the project.

Al-Tuwaitha Nuclear Research Centre, Iraq

The Radiation Protection Centre (RPC) was established in 1971 as the sole regulatory body in Iraq for nuclear activities. In 2006, the RPC was designated as the national regulatory body with responsibility for all decommissioning activities in Iraq. Originally, the RPC functioned in accordance with laws passed during the 1970s and 1980s whereby all nuclear facilities at Al-Tuwaitha were maintained and operated based on the standards of international suppliers. Later, these laws and standards were found to be inadequate for the new responsibilities of the RPC, and a new legal framework was developed in accordance with IAEA Safety Standards. Significant efforts have been directed at meeting the goals of the national regulatory requirements, efforts which included instituting numerous changes and modifications to the detailed articles of the law, as well as preparing new regulations to cover decommissioning and waste management activities.

3.3. APPLICABILITY AND MODIFICATION OF NUCLEAR AND NON-NUCLEAR REGULATIONS AND STANDARDS

3.3.1. Introduction

Existing regulations and standards developed for use during the six major stages in the lifetime of an authorized facility may not be applicable to a DNF, or may need to be changed based on information concerning (i) the nature of the event leading to the DNF, and (ii) the condition of the DNF following the emergency, including any operational constraints such as the unavailability of key safety systems. The regulatory challenge is therefore determining how existing standards, guidance, and regulations should be applied, and whether new standards, guidance, and regulations need to be produced which take into account the circumstances surrounding the DNF. This in turn presents an additional challenge given the timescales and resources that are often generally required to produce or revise regulations and standards.

In most cases, legislation is generally in place for nuclear facilities that are operating normally (including being in a safe shutdown state), but specific regulations and a revised regulatory approach may be required to address the unique requirements of a DNF. The ease with which the required changes can be achieved may depend upon the nature of the regulatory system that is in place. For example, a regulatory system that is highly prescriptive may find it more difficult to make the changes in comparison to a regulatory system based on goal setting principles.

Events resulting in DNFs have, in some cases, necessitated the establishment of new regulations and standards. For example, it may be necessary to create a new type of license to accommodate a DNF. This issue can arise if existing decommissioning standards, regulations, or requirements, e.g., stipulations concerning end states, are no longer appropriate or are not achievable for a DNF. Under these circumstances, the regulatory framework may need to undergo substantive changes to accommodate the realities surrounding a DNF through, for example, the development of special decommissioning standards or regulations.

3.3.2. Case studies on applicability and modification of nuclear and non-nuclear regulations and standards

Fukushima Daiichi NPS, Japan

The Fukushima Daiichi NRA undertook a full revision of regulatory requirements based on (i) lessons learned from the Fukushima Daiichi accident, and (ii) a consideration of international safety requirements such as those of the IAEA Safety Standards. The revision process took place in July 2013 for commercial nuclear power plants, and in December 2013 for nuclear fuel cycle facilities. The revisions included (i) strengthening measures for the prevention of severe accidents, (ii) adoption of the latest technical knowledge, and (iii) adding systems which currently authorized nuclear facilities will also be required to adopt.

In situations requiring special regulatory attention, the NRA issues a public notice to indicate that a facility has been designated as a so-called 'Specified Nuclear Power Facility'. The NRA immediately notifies the operator of the designated facility of "matters for which measures should be undertaken" and specifies the deadline for the implementation of the required measures. The operator is then responsible for obtaining NRA approval of the implementation plan, and takes the necessary steps to ensure operational safety, or the physical protection of specified nuclear materials. The operator is subject to NRA inspections to confirm compliance with the implementation plan.

In the case of Fukushima Daiichi NPS, special measures not normally part of the Reactor Regulation Act were applied as specified by a Cabinet Order. Once these special measures are implemented, and the plant either (i) returns to a state where it can once more comply with normal regulations in the Reactor Regulation Act, or (ii) undertakes approved decommissioning measures, the facility can be returned to a more normal regulatory oversight process.

Three Mile Island NPP Unit 2 (TMI-2), USA

In the case of TMI-2, a new and unique regulatory approach was utilized for use during the accident remediation phase rather than introducing new regulations. The implementation of a TMI Action Plan, which was an NRC approved consolidation of recommendations based on numerous investigations, did result in several new or modified regulations, but these new regulations were primarily related to emergency planning and the safety of operational nuclear facilities. The role of the NRC in the implementation of the actions identified in the TMI Action Plan was primarily to review new licensee applications, and to impose confirmatory orders and specific license conditions.

While not a change to the regulations themselves, there was one noteworthy adjustment in the implementation of the applicable regulations as a consequence of the fact that the NRC PEIS required TMI-2 to utilize more restrictive design objective effluent criteria as mandatory limits. The PEIS noted that "throughout the cleanup, any anticipated releases to the environment must be controlled by the licensee in accordance with the staff's proposed effluent criteria to conform to the individual dose design objectives listed in 10 CFR Part 50, Appendix I, as mandatory limits", and on June 26, 1981, NRC staff amended the licensee's environmental technical specifications to define the criteria in Appendix R of the final PEIS as limiting conditions for the cleanup operations.

Unit 4 Chernobyl NPP (ChNPP), Ukraine

An example of a prescriptive regulatory environment that required changes to manage a DNF involved the Chernobyl shelter structure wherein it was essentially impossible to establish specific safety standards due to the lack of accurate data. In response to this situation, the regulator established general safety objectives, principles, and criteria, and the responsibility was left to the licensee to determine and demonstrate the optimum method by which to meet those general requirements.

The accident in Unit 4 occurred at a time (1986) when Ukraine was a part of the Soviet Union, and issues related to the mitigation of the consequences of the accident were addressed at the highest governmental level. At that time there was no independent regulatory body with responsibility for the oversight of nuclear power plants. All activities related to the design, construction, and operation of nuclear power reactors fell under centralized governmental control, and information about 'nuclear issues' (including research and investigations) were classified or secret. Concurrent with the role of the centralized government control, there was a separate department in the Ministry of Medium Machine Building with responsibility for overseeing nuclear safety, and this department worked in the nuclear industry performing inspections based on the regulatory document "General Safety Provisions for Nuclear Power Plants" published in 1982 (Russian abbreviation "OPB-82").

After the initial consequences of the accident at Chernobyl NPP Unit 4 had been mitigated, and the construction of the shelter structure was completed, a decision was made to create a separate Inspectorate for Nuclear Safety in Kiev, Ukraine, with a mandate to provide supervisory oversight for nuclear power plants. This Inspectorate performed inspections at nuclear power plant sites as well as at research reactor sites, and issued specific authorizations related to the operation of nuclear facilities (other radiation facilities and radiation sources were under the control of the Ministry of Health). During this same period, the regulation "General Safety Provisions for Nuclear Power Plants (OPB-82)" was significantly revised and updated taking into account the lessons learned from the Chernobyl accident. OPB-82 was amended to introduce additional requirements for nuclear power plants, i.e., to (i) perform analyses of hypothetical accidents, and to use the results of the analyses as a basis for emergency planning, (ii) create training centres and training plans, (iii) develop measures to prevent the buildup of dangerous concentrations of explosive gases, and (iv) develop methods for radiation monitoring following an accident. It is also noteworthy that a sentence about the acceptability of positive high intensity reactivity was deleted from the regulation as this condition was one of the factors that led to the accident in 1986.

The updating and revision of OPB-82 resulted in the development and promulgation of OPB-88, i.e., a new version of "General Safety Provisions for Nuclear Power Plants". As part of the development of OPB-88, the section entitled "Terms and Definitions" was substantially expanded to include new terms such as (i) management of beyond design basis accidents, (ii) pre-commissioning operations, (iii) first criticality and operational criticality, (iv) safety functions, (v) components, (vi) common cause failure, (vii) safety culture, (viii) commissioning, and (ix) special regulations and rules. These new terms substantially expanded definitions and facilitated interactions and communications in the design and operation of NPPs. OPB-88 clearly states that NPP safety should be ensured through the consistent implementation and application of the defence in depth concept which relies on protective barriers to prevent the spread of ionizing radiation and radioactive substances, and on measures to protect these barriers.

General requirements for physical protection, fire safety, communication and notification systems, as well as other requirements were developed based in large measure on the results of the Chernobyl accident analysis. OPB-88 also contains classification schemes based on the importance of systems and components (the definition of 'component' was introduced for the first time) to safety. The purpose of these classification schemes is to provide a means for defining quality assurance requirements. Strict requirements on operating organizations to secure a license or authorization granted by the regulatory authority to perform specific activities were also established.

After the Soviet Union collapsed and Ukraine gained independence in 1991, Ukraine was required to make decisions and to implement activities and practices for the (i) development of national nuclear legislation, (ii) mitigation of accident impacts, and (iii) the future management of the Chernobyl NPP and the shelter structure. Therefore, an important issue for Ukraine was the creation of a system of state control and an associated regulatory system for ensuring the safe use of nuclear energy and radiation.

In response to this issue, an independent national authority for the regulation of nuclear and radiation safety – the State Committee for Nuclear and Radiation Safety (Gosatomnadzor) – was established in February 1992. The primary responsibilities of Gosatomnadzor were to (i) develop rules and regulations for nuclear and radiation safety, (ii) provide licensing and supervision for nuclear and radioactive waste management facilities, and (iii) establish rules and regulations for the use of radiation sources, uranium mining and milling, physical protection, and safeguards.

The underlying laws addressing the use of nuclear energy, radiation, and radioactive waste management were adopted in 1995. Over the course of the next several years, the regulatory authority developed and approved regulations, and implemented licensing processes as required by laws and regulations.

In 2000, "General Safety Provisions for Nuclear Power Plants (OPB-2000)" were developed and put into force. OPB-2000 did not require significant changes relative to OPB-88, i.e., only small corrections were made with respect to the management system and nuclear regulations in the state. In the eight years following the approval of OPB-2000, a new version of the "General Safety Provisions for Nuclear Power Plants" (OPBU-2008) was prepared and promulgated. OPBU-2008 made changes to the NPP safety requirements, and the structure of the document was changed to reflect the key safety principles and criteria established in INSAG-12, Basic Safety Principles for Nuclear Power Plants [8]. As discussed above, one of the fundamental lessons learned as a result of the Chernobyl accident was the need to revise and improve nuclear and radiation safety requirements for NPPs. In considering the evolution of regulatory requirements for NPP safety since 1986, the regulatory regime and NPP licensing has become stricter, more comprehensive, and more aligned with international practices, including those of the IAEA.

The licensing of the Chernobyl shelter structure proved somewhat difficult due to its unique and complex nature, and in developing the basic nuclear laws and regulations discussed above, the shelter structure was not included.

In dealing with the shelter structure, the regulatory authority faced a number of challenges with respect to Unit 4 of the Chernobyl NPP, principle among which was finding a term by which to define the damaged facility, e.g., damaged nuclear facility (DNF), storage facility for unorganized radioactive waste, etc., and then:

- To define (classify) those activities that could potentially be implemented to deal with the DNF, e.g., maintain safety, decommission, remediate, or reconstruct;
- To identify the safety requirements and the scope of the safety case to support the licensing of this facility; and,
- To review the safety case prepared by the Chernobyl NPP and issue a license.

At the same time, the regulatory authority had to (i) resolve issues related to the development of special regulations or specific safety requirements for the shelter structure, (ii) develop approaches to inspect the safety of this facility, and (iii) issue an appropriate type of license.

The first post-emergency license was issued in March 1997 with the licensed activity being defined as ‘shelter operation’. The license included a detailed description of the permitted activities that comprised “shelter operation”, namely (i) activities required for maintaining shelter structure safety through the use of systems and components specified in the license, and (ii) activities related to transforming the shelter structure into an ecologically safe system, the scope of which had been defined in an approved document entitled “Shelter Transformation Strategy”.

The license also established a number of general and specific conditions governing current and future activities at the Shelter, and various separate authorizations for different projects related to “shelter transformation into an ecologically safe system” were also included. The importance was also the fact that the license clearly assigned full responsibility to the operator (ChNPP) for ensuring the safe operation of the Shelter, a responsibility that applied regardless of the actions of other organizations involved in the Shelter activities. During the period that the license was in effect, a number of changes and modifications were introduced.

The regulatory authority and ChNPP put into practice a programme for the development of licensing plans of both a general and detailed (for specific projects) nature, with the intention of providing a means of improving the efficiency and effectiveness of the licensing process. The licensing plans are subject to review and approval by not only the nuclear regulatory authority, but also by other regulatory authorities in accordance with procedures provided under law. Based on the licensing plans, a set of more detailed plans can be developed for projects such as shelter stabilization, New Safe Confinement (NSC), Integrated Automated Monitoring System, and others.

A1 NPP, Slovak Republic (previously Czechoslovakia)

No regulatory changes resulted as a specific consequence of the A1 NPP accident; however, the regulatory framework has evolved in a manner consistent with international practice.

First Generation Magnox Storage Pond (FGMSP), Sellafield, UK

The UK has a goal setting regulatory regime that can adapt existing laws and principles to accommodate a damaged nuclear facility (DNF) of the type that is described in the Sellafield case study. For example, the nuclear site license conditions and environmental permit do not specify how the licensee is required to meet regulatory requirements, but does include overarching requirements to reduce risks to as low as reasonably practicable (ALARP), and to employ the environmental principle of using best available techniques.

ONR applies existing regulations, safety requirements, standards, and relevant good practices to its regulation of FGMSP, and Sellafield is expected to comply with these to an extent that is as far as reasonably practicable. No new regulations, principles, criteria, or standards have been defined for the regulation of FGMSP. The ONR "Safety Assessment Principles for Nuclear Facilities" are fully in line with IAEA safety standards. IAEA publications are explicitly identified as relevant good practice within regulatory Technical Assessment Guides.

Regulators expect licensees to apply relevant good practice in proportion to the nature and characteristics of the facilities being regulated, i.e., balanced with the risks present, using the overriding legal requirements of risks being ALARP, and using best available techniques. What constitutes "relevant good practice" for a legacy facility, where the risks are considered to be intolerable, can be different from the practices required for new facilities. The fundamental principle embodied in the above approach is that of a graded approach, whereby the degree to which the standards are applied is based on the risk presented by the facility.

Marcoule Nuclear Centre, France

No changes to regulations, standards, or guidance were required as a result of the circumstances present at the Marcoule Nuclear Centre.

Industrial Uranium Graphite Reactors (IUGRs), Russian Federation

For the decommissioning of IUGRs, an option entitled "long-term storage within the shaft of the reactor for the term of not less than 100 years" has been recommended. This option is meant to be an intermediate approach, and reflects a postponement of the final decision, a decision which could be either (i) the subsequent removal of the facility, or (ii) continuation of storage up to a final in situ strategy. This approach, whereby the final decision is postponed, corresponds to stage 2 in the IAEA classification of 'restricted use'. The final decision as to what strategy is to be used in the decommissioning of the IUGRs will be made near the end of the 100-year storage period, and depend on the radiological characteristics of the facility, the state of engineered barriers, the level and nature of available technologies, and on other factors, including social or economic considerations.

The option discussed above is based on Federal law No. 190-FZ "On radioactive waste management and amendments to certain legislative acts of the Russian Federation" (2011). Federal law 190-FZ introduces the concept and option of a "special radioactive waste" for which (i) the risks arising from radiological exposures, (ii) other safety related and environmental risks, and (iii) the expenses resulting from the removal of the radioactive waste from current storage and its subsequent treatment and storage would exceed the risks and expenses resulting from leaving the waste in its current location. Based on Federal law 190-FZ, the cores of the IUGRs can be classified as special radioactive waste, and therefore remain in place (in situ disposal).

The technology used in the decommissioning of the IUGRs involves creating reliable geotechnical barriers to prevent the release of radionuclides from the facility to the environment over a period of thousands of years, i.e., over the hazardous lifetime of the radioactive waste. "The concept of the decommissioning of industrial uranium graphite reactors by option of radiation and safe storage in place" was approved on December 28, 2009. In the case of the IUGRs, the graphite core, the supporting metal structures, and the biological shielding are considered to be special radioactive waste and are therefore not subject to dismantling and removal. The ability to utilize the special considerations for special radioactive waste found in Federal law 190-FZ is only permitted if suitable barriers can be created that will provide reliable isolation of the radionuclides contained in the materials and components of the reactor facilities.

The decommissioning strategy used for the IUGR special radioactive waste comprises a set of natural and geological features and structures, e.g., containment and covers, for the reactor shaft, and for the reactor premises. The primary source of radioactivity at the IUGRs is the irradiated graphite.

Al-Tuwaitha Nuclear Research Centre, Iraq

In the case of Al-Tuwaitha, there was no legal or regulatory framework in place for decommissioning at the time of its destruction. Since then, decommissioning standards, based largely on international practice, have been adopted to cover all remediation and decommissioning activities. Five regulations related to decommissioning have been developed. Four have been passed and approved by the legislative consultancy of the State, i.e., regulations for decommissioning, the safe transport of radioactive material, radiation protection, and dose limits (including clearance and exemption), and one remains under review, i.e., radioactive waste management and disposal. These regulations were developed in coordination and cooperation with the IAEA and the U.S. Nuclear Regulatory Commission. The introduction of the new regulations primarily came about as a result of the Iraq Decommissioning Project (IDP), an effort starting in 2006, coordinated by the IAEA, and undertaken by various ministries of the Government of Iraq as well as by international contributors from many countries. The establishment of the IDP served as a means for clearly defining the responsibilities of the licensee, regulators, and other stakeholders. The current regulatory framework is based on securing approvals for specific decommissioning plans for individual facilities.

3.4. SAFEGUARDS AND NUCLEAR MATERIALS CONTROL PRACTICES

3.4.1. Introduction

In the case of DNFs, it is reasonable to expect that the nuclear material located at the facility had been subjected to accurate material control accounting practices before the damage took place.

Ensuring safeguards compliance and adequate material control can be a challenging process following a serious accident due to the inability to inspect and determine the quantity, form, or location of the inventory. Additionally, it may not be possible to quantitatively determine the amounts and locations of materials that were lost into the ground or air, or in the case of legacy fuel ponds, fuel that has corroded into sludge. Furthermore, it may be very difficult to remove or recover the remaining inventory following a serious accident, e.g., in the case of molten fuel, relocation of the nuclear materials may not be possible.

Realistic and practical requirements for the accountancy of nuclear material after an accident are needed, and these requirements will need to be agreed to with the safeguards authority.

3.4.2. Case studies on safeguards and nuclear materials control practices

Fukushima Daiichi NPS, Japan

In October 2011, the IAEA, the Japan Safeguards Office, and the Nuclear Material Control Centre inspection team entered the site for the first time following the earthquake. Although the IAEA was able to verify safeguard seals at the Cask Custody Building and the inventory in the core of Unit 6, the same was not possible for (i) Unit 5, (ii) the spent fuel pools (SFPs) at Units 5 and 6, and (iii) the Common Spent Fuel Storage (CSFS) because of a malfunction of surveillance cameras resulting from the blackout. Although surveillance was subsequently re-established at the spent fuel pools at Units 5 and 6, and at the CSFS using battery operated cameras, re-verification at these locations and in the core of Unit 5 was not possible due to inoperable bridge cranes.

While all the nuclear material stored at Units 4 to 6, CSFS, and Cask Custody Building at the time of the accident has been successfully re-verified, nuclear material in Units 1 to 3 remains inaccessible due to high radiation fields and damage to the buildings. The decommissioning actions being carried out in these units include the removal of damaged structural material and rubble, and the ongoing decontamination of Unit 3. A similar process is planned for Unit 1. The radiation levels in Unit 3 are still very high as confirmed by IAEA independent measurements conducted in conjunction with measurements made by the operator.

Fuel assemblies in the SFPs of Units 1 to 3 will be removed and re-verified following the removal of rubble, decontamination, and restoration, and will include the installation of functional fuel handling systems, and the removal of core fuel debris.

Three Mile Island NPP Unit 2 (TMI-2), USA

Special nuclear material[2] (SNM) accountability is required in all NRC licensed facilities containing reactor fuel and other SNM. However, following the accident at TMI-2, damaged fuel debris was dispersed throughout the plant, and therefore tracing the origins to specific fuel assemblies was not possible. As a result of this situation, the NRC and the U.S. Department of Energy (DOE), who was prepared to receive the fuel debris, allowed the final SNM accountability for TMI-2 to be performed after defueling was completed. The NRC also granted the licensee exemptions from regulatory requirements for record keeping, inventorying, and reporting of special nuclear, source, and by-product materials. As an alternative, the licensee developed a plan that identified the methods and the details of the accountability programme, and the accountability of SNM was based on a thorough post-defueling survey of areas, systems, and components.

On 1 February 1993, the licensee notified the NRC in its last post-defueling survey report that the best estimate of the residual fuel remaining in the reactor vessel was (925 ± 370) kilograms (one standard deviation). The estimate of fuel remaining within the reactor vessel was accomplished via underwater video inspections and passive neutron measurements. Earlier licensee estimates based on measurements, sample analyses, and visual observations indicated that no more than 174.6 kilograms of residual fuel remained outside the reactor vessel, and in the remainder of the facility.

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[2] Special nuclear material is defined by the Atomic Energy Act of 1954 as plutonium, uranium-233, or uranium enriched in the isotopes uranium-233 or uranium-235, but does not include source material.

Unit 4 Chernobyl NPP (ChNPP), Ukraine

In order to control and provide for the accounting of nuclear materials at the shelter structure, the following material balance areas were specified:

- Nuclear materials located within the shelter structure;
- Storage area containing nuclear materials removed from the shelter structure following the accident. The various forms of fuel containing material (FCM) were classified as follows:
  - Spent nuclear fuel;
  - Fresh fuel, broken fuel assemblies, and individual fuel elements;
  - Reactor core fragments;
  - Finely dispersed fuel (dust);
  - Uranium and plutonium compounds in aqueous solutions; and,
  - Hardened lava-like FCM.

The implementation of safeguard provisions at the shelter structure had to take into consideration the nature of shelter structure operations, the physical and chemical state of the FCM, and the location of the FCM. For example, radiation levels where some of the FCM is located is 2520 mSv/h, and therefore special and reasonable approaches had to be taken for carrying out safeguard tasks.

The reality of the situation is that strict nuclear material accounting and control in the shelter structure is essentially impossible given the nature, location, and form of inventory items. There is currently no scientifically proven procedure by which to determine the amount of nuclear materials in the shelter structure, although different approaches were used during the post-emergency period to estimate the amount of nuclear materials. These approaches included indirect calculations and experimental estimates using different theories about the types of nuclear fuel reaction processes that might have occurred during the accident, theories based on information about the nuclear fuel that was present in Unit 4 at the time of the accident.

In July 2004, IAEA specialists measured gamma and neutron levels through an opening in the shelter structure as a means of selecting the appropriate types of equipment for further measurements, and in October 2004, a video recording was made through the same opening. During the period of January 2005 to August 2006, IAEA specialists developed, installed, and tested a combined monitoring system, and in 2007, IAEA staff used a borehole in the shelter structure to test a monitoring system prototype. Images of damaged fresh fuel assemblies were also obtained.

The experience gained during the installation of the shelter structure monitoring system has shown that in addition to addressing issues about technical factors, e.g., the selection of appropriate types of video systems and detection systems, it will be equally important to take into account the radiation levels and exposures in the areas where the installation and maintenance of surveillance equipment is planned. Similarly, it will be important to assess the long-term effect of such factors as temperature, humidity, and radiation on the IAEA surveillance equipment.

A1 NPP, Slovak Republic (previously Czechoslovakia)

A national system for the accountancy and control of nuclear materials was developed by the Czechoslovak Atomic Energy Commission (CSKAE). This system was based on requirements contained in the safeguards agreement between the government of Czechoslovakia and the IAEA (INFCIRC/173 [9]) and conformed with INFCIRC/153 [10], i.e., it reflected the requirements of the Treaty on the Non-Proliferation of Nuclear Weapons (hereinafter referred to as Non-Proliferation Treaty), which was signed by the government of Czechoslovakia in 1968. The legal framework of the agreement was supplemented in 1974 when a Ministry of Foreign Affairs regulation on the Non-Proliferation Treaty came into force and became part of the national legal framework. In 1977, a CSKAE regulation came into effect, which established the details of a regulatory framework for the accountancy and control of nuclear materials.

After the breakup of Czechoslovakia into the Czech Republic and the Slovak Republic in 1993, UJD SR assumed responsibility for managing the national system for the control and accountancy of nuclear materials in compliance with (i) provisions of the atomic act, (ii) regulations on accountancy and control of nuclear materials, and (iii) requirements concerning the notification process for selected activities. As part of the process whereby the Slovak Republic joined the European Union in May 2004, EURATOM safeguards provisions were implemented in the Slovak Republic based on EURATOM, and on the Commission Regulation (EURATOM) No 302/2005 of 8 February 2005 on the application of EURATOM safeguards. Since December 2005, a trilateral safeguards agreement with its additional protocols has been in force (INFCIRC/193/Add.9 [11]) between the IAEA, EURATOM, and the Slovak Republic, an agreement which replaced the bilateral safeguards agreement (INFCIRC/173 [9]).

The accidents at A1 NPP did not have any consequences in terms of the accountancy and control regime for nuclear materials. The inspection programme of UJD SR was designed and performed to meet the requirements of the agreement between the government of Czechoslovakia (later the Slovak Republic) and the IAEA for the application of safeguards in support of the Non-Proliferation Treaty. Inspection of spent fuel assemblies was based on an indirect method of verification, i.e., inspections performed through the use of IAEA surveillance equipment. Accountancy and control of nuclear materials at A1 NPP was performed in cooperation with the IAEA until 1999 at which point the damaged and unused A1 NPP fuel was transferred to the Russian Federation. After 1999, there was a safeguards system established for decommissioning activities. Design information is verified to ensure that safeguards measures are appropriate and able to detect the misuse of a facility or of nuclear material.

First Generation Magnox Storage Pond (FGMSP), Sellafield, UK

One of the challenges found with legacy facilities, such as FGMSP, is the ability to provide an accurate inventory of the safeguarded nuclear materials due to the degraded conditions of the materials, and the accuracy of the inventory records.

At FGMSP, a significant fraction of the fuel is severely corroded and as a result the nuclear materials are partly located within the sludge layer in the pond. This provides significant challenges in providing an inventory for safeguards purposes and nuclear materials control. Due to the nature of the material in FGMSP, it is not possible to verify the inventory, and it is also not possible for the inventory to be removed. Sellafield works with EURATOM to comply with the European Commission Directive to fulfil its safeguards requirements.

Industrial Uranium Graphite Reactors (IUGRs), Russian Federation

Very little information regarding safeguards is discussed in the case study. Nuclear fuel has been completely retrieved from the IUGR facilities, although the reactor graphite is contaminated by transuranic radionuclides. In some instances, the weight of the fuel materials that have been absorbed into the reactor graphite could be as high as hundreds of grams. To address the issue of nuclear material accounting and control, estimates of the weight and composition of the transuranic radionuclides contained in the graphite were made through the use of detailed engineering and radiation surveys.

Al-Tuwaitha Nuclear Research Centre, Iraq

Nuclear fuel from the destroyed IRT-5000 and Tammuz-2 research reactors was removed from Al-Tuwaitha in 1993/1994 and shipped to Russia under the supervision of the IAEA. Some remaining equipment, such as damaged lead glass and manipulators from the hot cells on the site, are subject to Iraqi safeguards inspections that are consistent with the IAEA requirements.

3.5. APPLICABILITY OF THE CLEARANCE CONCEPT FOR MATERIALS

3.5.1. Introduction

For the purposes of this publication, the term 'clearance' is defined as follows (from the IAEA Safety Glossary (2018 Edition) [3]: "Removal of regulatory control by the regulatory body from radioactive material or radioactive objects within the notified or authorized facilities and activities." Furthermore, for the purposes of this publication, (i) removal from regulatory control refers to regulatory control applied for radiation protection purposes, and (ii) the terms 'clearance', 'free release', 'unconditional release' and 'unrestricted release' are considered synonymous.

The clearance concept as applied to DNFs raises a number of issues, not the least of which is that different jurisdictions have different policies in terms of clearance levels. For DNFs, an added complication can arise as a result of political and public opinion regarding waste materials, a complication that may prevent the use of approved standard clearance levels that are already in place. This complication arose in the cases of both Chernobyl and Fukushima Daiichi.

3.5.2. Case studies on applicability of the clearance concept for materials

Fukushima Daiichi NPS, Japan

Procedures and regulations for the clearance of materials from operational nuclear sites are currently in place; however, public and political opinions may affect future decisions concerning the extent to which the processes for material clearance can be used for the Fukushima Daiichi NPS. Therefore, the concerns raised by public opinion are taken into account in any decisions concerning the discharge of radioactivity or the release of materials from regulatory control, and this is the case even if NRA approval has been received for the discharges or releases.

Three Mile Island NPP Unit 2 (TMI-2)

The NRC Final Programmatic Environmental Impact Statement (PEIS) was developed based on allowed surface contamination levels published in NRC Regulatory Guide 1.86, "Termination of Operating Licenses for Nuclear Reactors (published in June 1974, and withdrawn in August 2016)", on the basis that these levels were considered suitable for unrestricted access or unrestricted release of decontaminated equipment or facilities at the time of the NUREG publication (March 1981). However, the NRC Regulatory Guide 1.86 limits were based on the capabilities of handheld survey instrumentation at the time of writing, and the NRC later clarified policies on the release of materials and equipment by reactor licensees to note that there should be no materials released with detectable radioactivity levels that are above background. NRC guidance has since been provided on the acceptable detection limits that reactor licensees can use for surveys to release materials and equipment. Acceptable survey practices are described in NRC Inspection and Enforcement Circular No. 81-07, "Control of Radioactively Contaminated Material", and Information Notice No. 85-92, "Surveys of Wastes before Disposal from Nuclear Reactor Facilities" (both guidance documents were not established as a result of the TMI-2 accident, but rather as a result of ongoing communications with all reactor licensees). As the NRC does not have established clearance levels, the policy on no detectable radioactivity would currently apply for any future release of materials and equipment from TMI-2.

Unit 4 Chernobyl NPP (ChNPP), Ukraine

With respect to the possibility of a clearance process for materials from the shelter structure, the issue of releasing material from regulatory control has not been considered due to the contamination levels at the site, and significant concerns (actually, strong opposition) by stakeholders involved in the clearance process at the Chernobyl NPP. Chernobyl NPP Units 1 to 3 are being decommissioning, and the amount of dismantled equipment increases each year. In 2010, the regulatory authority developed and approved a special regulation to govern activities related to the release of materials from regulatory control. Implementation of this regulatory document by the licensee envisaged the development of a "clearance methodology" for specific materials (currently only metal). In the interim, documentation demonstrating compliance with the currently established criteria for release from regulatory control must be submitted to the regulatory authority for approval for each batch of materials being proposed for release, and the regulatory authority has the right to carry out inspections related to this activity. The "unconditional clearance" option is currently only allowed in the decommissioning license for Chernobyl NPP Units 1 to 3.

The existing strategy for managing the damaged NPP Unit 4 (i.e., strategy of transforming the Shelter Object into an ecologically safe system, in accordance with an approved document entitled "Shelter Transformation Strategy") for the site provides very generic statements on the nature of decommissioning activities. For example, the strategy states that Stage 3 activities involving the removal of radioactive waste and FCM will include decommissioning the old "shelter". Statements of this type contained in the existing decommissioning strategy make the nature of future decommissioning activities unclear. Ultimately, the decommissioning strategy that is selected will very much depend on the effectiveness of the work to excavate and remove the radioactive waste and FCM.

A1 NPP, Slovak Republic (previously Czechoslovakia)

In accordance with the Public Health Act, authorization by the Public Health Authority of the Slovak Republic is required for the clearance of radioactive material and radioactively contaminated items. GSR Part 3 [5] states that radioactively contaminated material can be released into the environment if the effective dose to the individual in the critical group of the population affected by all reasonably foreseeable circumstances related to the clearance of material is of the order of 10 μSv per year or lower. Slovak legislation follows the above principle and recommends a collective dose value of 1 man Sv as a means for the optimization of radiation protection.

The dose criterion for clearance is considered as having been met if the specific activity of radionuclides contained in the released material is lower than the related clearance levels (sum of quotients approach is applied in case of a mixture of radionuclides). The criteria for the clearance of material from regulatory control are based on basic safety requirements for protecting the health of workers and the public against ionizing radiation. A government resolution was issued in 2006, specifying generic clearance levels for the unconditional or unrestricted clearance of individual radionuclides, e.g., 300 Bq/kg for Cs-137 and Co-60.

Conditional release considerations: The legal framework in the Slovak Republic allows the reuse of materials which do not meet the requirements for unrestricted release. In order to invoke the use of conditional release for the reuse of materials, it is required that a case be prepared that demonstrates that the reuse scenario applies to predictable situations for which it can be proven that the impact to critical groups, i.e., workers and the general population, does not exceed the constraints for individual and collective effective doses. The existing dose constraint in the Slovak Republic for conditional release, i.e., under special circumstances, is 50 μSv per year, and the individual effective dose needs to be documented for each individual exposure case involving the conditionally released materials. To date, the conditional release of materials has not been applied in practice in the Slovak Republic. Therefore, the various aspects of the approval process have not been clearly identified, and discussions between the regulatory body and operators are needed to address the potential issues, and to establish guidance. Processes for the conditional release of materials with radioactivity that is only slightly above the unconditional release levels are also under consideration.

The methods by which conditional release criteria were derived were based on international recommendations in combination with inputs based on Slovak environmental parameters. Similarly, methods for the assessment of material flow and economic impacts were also developed. Actual inventory data from nuclear facilities in the Slovak Republic were taken in developing the databases used in modelling studies and assessments. These studies and assessments enabled cost/benefit analyses to be carried out for various conditional clearance scenarios. The results of these scenarios then allowed estimates to be made of the potential quantities of clearable material, and from these estimates approximations were made as to possible reductions in the volumes of required disposal capacity. It is anticipated that the results of these assessments may prove useful in the optimization of waste management systems in the Slovak Republic.

First Generation Magnox Storage Pond (FGMSP), Sellafield, UK

Sellafield applies existing limits for the re-use and disposal of wastes. These limits follow regulatory levels set by the Environment Agency and have not been changed for the decommissioning of legacy facilities.

One area of policy change is an allowance for the use of interim storage states to be considered. This change allows decommissioning to be progressed quickly without the need for defining a final disposal route for all wastes and represents a departure from previous policy which required licensees to create waste products that fully met waste acceptance criteria (WAC) for future geological disposal facilities.

Marcoule Nuclear Centre, France

The clearance concept is not directly applicable in France where the regulatory framework uses the so-called ‘zoning concept’. The zoning process divides facilities into zones that generate either nuclear (or radioactive) waste, or conventional waste. The zoning process takes into account the nature and the history of the operations within a facility, and it is confirmed by radiological monitoring. Using this concept, clearable waste would be, by definition, waste arising from within a conventional waste zone.

Industrial Uranium Graphite Reactors (IUGRs), Russian Federation

The clearance concept is applicable to materials resulting from decommissioning activities but is not applicable to the IUGR sites.

Al-Tuwaitha Nuclear Research Centre, Iraq

Clearance procedures used at Al-Tuwaitha follow the IAEA standards, and are identified in the decommissioning plans approved by the regulatory body. For example, clearance levels and exemptions for certain waste streams were established based on IAEA standards, such as (i) Derivation of Activity Concentration Values for Exclusion, Exemption and Clearance, IAEA Safety Reports Series No. 44 [12]; (ii) Application of the Concepts of Exclusion, Exemption and Clearance, IAEA Safety Standards Series No. RS-G-1.7 [13]; and (iii) Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, IAEA Safety Standards Series No. GSR Part 3 [5].

3.6. CONCLUSIONS AND OBSERVATIONS

Serious accidents may drive changes to regulatory organizations and frameworks, changes which can include revisions to and the development of new regulations. A risk based regulatory approach balancing current risks against long-term risks may potentially provide more rapid hazard and risk reduction. A risk based approach can allow the licensee to prioritize and focus on the highest risks by using a fit-for-purpose approach.

The uncertainties associated with a DNF may require changes to the decommissioning and remediation plans as information is gained on the condition of the DNF. A pragmatic and flexible regulatory strategy can allow a licensee to progressively make changes to the decommissioning plan based on the results of the decommission process. The regulator needs to be responsive and receptive to changes, and balance the need for progress with the need to remove uncertainty, e.g., through further analysis and assessments. This responsiveness can often be attained by reducing or changing formal regulatory stages, i.e., through the use of hold points, or by increasing regulatory oversight of the licensee thereby providing assurance that work is being performed in a compliant and safe manner. A rigid, prescriptive regulatory regime can be counterproductive, and may slow progress in the reduction of hazards and risks.

Safeguards compliance can be challenging following a serious accident due to the uncertainties surrounding the quantity, form, or location of the nuclear material inventory. Realistic requirements for practical accountancy and control of nuclear material are needed, e.g., for dealing with inventory of fuel in a melted core, or corroded fuel sludge in the base of a pond.

If a facility end state cannot be clearly defined as the result of an accident, final decommissioning plans may be difficult to develop. Many case studies have described the use of interim states, which often represent the achievement of a step change (i.e., reduction) in risk levels, to enable realizable decommissioning plans to be defined. However, it also merits noting that the case studies highlight the fact that Member States have avoided specifying a final end state that is less restrictive than that expected for undamaged facilities. Lofty or unrealistic end state targets can delay decommissioning and can be economically unviable.

The topic of waste clearance raises a number of issues. Different regulatory jurisdictions have different policies for the clearance of materials. In the case of DNFs, there is an added complication that arises from the political and public opinion regarding waste materials, which may prevent clearance even in a case where the wastes formally meet regulatory clearance levels.

4. TECHNICAL ISSUES

4.1. INTRODUCTION

There are significant technical challenges associated with decommissioning and remediation activities for a DNF, for example:

- The physical structures may be severely damaged and create hazards that will not allow entry into some areas in order to perform proper characterization studies. Waste streams may be quite different from those that existed during prior to an accident;
- The amounts of waste generated during DNF decommissioning activities may be greater than those anticipated for the decommissioning of the undamaged facility, and as a result exceed the capacities of existing waste management systems;
- Innovative techniques and the use of existing or new equipment and systems may be needed to respond to unique conditions found at the DNF site; and,
- The loss of operational information, records, and documentation as a result of damage or inaccessibility can be particularly problematic, and has often proven to be an issue in the case of legacy sites.

Based on case studies, the objective of this section is to identify technical challenges that can arise with DNFs, and to communicate how some of these challenges were met. The situations discussed in the case studies can also provide insight into how, as part of normal planning processes, these challenges might be mitigated through, for example, emergency planning.

The topics covered in this section, as they relate to significant technical challenges associated with decommissioning and remediation activities for a DNF, include the following:

- Physical, radiological and hazards characterization;
- Monitoring, sampling, and measurement;
- Structural assessments;
- Methodology used to specify, provide or replace safety systems;
- Safety system availability and functionality;
- Management and monitoring of environmental contamination;
- Waste infrastructure and technical capabilities;
- Waste management;
- Damaged fuel and fuel debris management;
- Relevant technologies for remediation and decommissioning – remote technology;
- Decontamination technology; and,
- Protection of workers.

4.2. PHYSICAL, RADIOLOGICAL AND HAZARDS CHARACTERIZATION

4.2.1. Introduction

As part of determining the conditions at a DNF, characterization is critical to the overall success of the decommissioning and remediation of DNFs. Characterization needs to address, to the extent possible, the physical, radiological, toxicological, and other hazards that are present at the start of the post-emergency phase.

Considerations and challenges associated with characterization activities at a DNF include the following:

- Uncertainty about structural integrity;
- Difficulty gaining access to all or part of the DNF to perform characterization activities due to, e.g., constraints arising from physical and/or radiological conditions;
- Unique physical and/or radiological characteristics and properties of objects and materials requiring evaluation and characterization, e.g., molten fuel at Chernobyl, unknown by-products from the reaction of various materials in the facility, sludges in ponds, etc.;
- Monitoring or measurement devices may not be adequate for capturing the extent of the hazards, for example, radiation monitors may have insufficient capacity to measure very high radiation fields, or instruments may have electronic components that are subject to damage by high radiation fields. This challenge may be particularly relevant during initial characterization activities where remote monitoring capability does not exist; and,
- Unique techniques and methods may be needed to address special characterization requirements. In some cases, the techniques and methods may lie outside the scope of "typical" characterization approaches, for example, the measurement of cosmic muons was employed at Fukushima Daiichi as a means of determining the location of fuel and fuel debris.

The following discussion provides a summary of the key points, challenges, observations, and conclusions identified in the case studies as they relate to performing physical, radiological, and hazard characterization studies in the post-emergency phase.

4.2.2. Summary of key points

Although the principles and general approaches to the physical and radiological characterization of DNFs are the same as those for shutdown conditions following normal operation, the application and use of these data may significantly differ.

Experience gained from major accidents indicates that available characterization technologies may not be capable of undertaking the required analyses because the levels of radioactivity are significantly higher than those encountered during normal situations. Therefore, the deployment and/or development of advanced or non-standard characterization techniques may need to be considered. Similarly, the hazards at a DNF are likely to be different and greater in magnitude than those typically found at a facility in a planned shutdown state. These different, and often greater, hazard levels can also be expected to affect the nature and type of characterization techniques that can be used.

In the case of assessing the physical damage to a nuclear facility, a wide variety of physical characterization techniques may be required to obtain required and important information about the status of the facility. In some instances, the ability to access critical areas may not be possible or impractical. Under these circumstances, the use of advanced remote handling techniques may need to be employed.

4.2.3. Case studies on physical, radiological and hazards characterization

Fukushima Daiichi NPS, Japan

At the Fukushima Daiichi NPS, an end to the emergency phase was declared when each of the affected units was determined to be in a stable condition. At this point, additional information was needed to understand the state of the reactor buildings, and to identify physical and radiological hazards. However, the details of the damage could not be determined through direct observation due to restrictions such as high radiation dose rates, and the highly contaminated water in the reactor buildings.

As a consequence of the restrictions, suitable technologies needed to be developed to determine the condition of the facility. Examples of the technologies that were subsequently employed included determining the state of the spent fuel by analysing water samples and by visual observations to determine if leaking fuel was present. Identifying the condition of the fuel debris in the reactor pressure vessels (RPVs) and the primary containment vessels (PCVs) was accomplished through the use of remote robotic systems.

The following techniques were used to assist in examining each unit:

- A remotely operated robot equipped with a gamma-ray detection camera and a dosimeter to investigate highly radioactive areas, and to measure radiation dose rates in buildings;
- Remotely controlled robotic equipment capable of taking samples for use in investigating contamination levels; and,
- A small, remotely operated robot capable of passing through existing equipment penetrations in the PCV to observe the interior of vessels and to detect damage.

A visual inspection of the PCVs was a challenge due to the high radiation dose rates; therefore, remote examination equipment needed to be developed and deployed in order to understand the distribution of fuel debris, and the conditions inside the PCVs. The efforts to investigate the PCV at Unit 2 using a robot were unsuccessful when sediments obstructed the path of the robot. As an alternative strategy, the inside of the PCV was investigated by inserting a closed circuit digital (CCD) camera, a dosimeter, and a thermometer through a penetration. Camera images were able to capture structural information from inside the pedestal including, for example, the displacement of gratings, the accumulation of sediments, and a possible access route using an existing pedestal opening.

In addition to the above initiatives, engineering studies of fuel debris retrieval methods had to be performed including R&D initiatives which took into account the actual features of each unit, and then carried out the work required to design functional equipment that could operate in the units. A technique utilizing muon tomography was also applied to obtain information about the distribution of fuel debris in the RPVs.

Three Mile Island NPP Unit 2 (TMI-2), USA

Radiological contamination at the TMI-2 site following the accident involved a number of physical forms including (i) contaminated coolant water, (ii) noble gases within the reactor building, and (iii) contamination on many of the building and equipment surfaces. Krypton-85 was the major gaseous radionuclide of concern, and this contaminant was managed through controlled releases (purging) from the building. Liquid and surface radiological contaminants primarily included the radioactive isotopes of Caesium and Strontium. A number of remote handling technologies including long handled tools, robotics, and video cameras had to be used during characterization activities due to the challenges presented by high dose rates. In addition, some of the material and equipment that was damaged during the accident, or contaminated during decommissioning, was subjected to further analysis and characterization at research laboratories.

An international programme, entitled TMI-2 Vessel Investigation Project and sponsored by the OECD-NEA, was carried out to evaluate the potential failure modes of the vessel, and to assess the margin for failure of the TMI-2 reactor vessel during the accident.

Unit 4 Chernobyl NPP (ChNPP), Ukraine

Following the end of the emergency phase, extensive research was initiated to determine where nuclear fuel had accumulated within the destroyed unit, and to determine the quantity, state, and composition of that fuel.

The process of determining the radiological status of the destroyed unit constituted a very major challenge with the primary issue being the lack of tools and equipment capable of being operated in high radiation fields. In order to limit dose exposures to workers making measurements in these high radiation fields, special attention was paid to keeping measurement times low, and keeping both the measurement equipment and measurement procedures simple.

As a result of the level of heat generated during the accident, the fuel melted and interacted with structural materials, e.g., zirconium, metal, backfill for the biological shielding, sand, concrete, etc. The accident conditions also generated lava-like FCM which spread along the lower levels of Unit 4 making characterization that much more difficult. The radiological characteristics of these materials were later determined by analysing samples from different areas within the shelter structure.

A1 NPP, Slovak Republic (previously Czechoslovakia)

Several characterization campaigns were performed at the A1 NPP site following the incident to determine, e.g., nuclide compositions, levels of contamination, etc., and by means of these campaigns, the consequences of the accident were systematically assessed. Data from existing sensors and measurement equipment served as the primary means for gathering the data used in evaluating the condition of the facility. More detailed data related to the level of contamination and the dose rates found within systems and rooms was collected through focused characterization campaigns. The extent of fuel damage was evaluated at a later date during its removal from the A1 NPP reactor hot cell.

In some instances, radiological conditions prevented entry into specific areas. However, most of the equipment installed in these areas did not require repair or maintenance, or if repair was necessary, it could be performed remotely. Remotely operated tools and equipment, ranging from simple telescoping mechanical tools to the use of remotely controlled vehicles equipped with analysis and sampling tools, were also employed.

Abnormal amounts of rainfall and insufficient flood protection measures led to the infiltration of surface water into buildings, underground tanks, and shafts at the A1 NPP site in June 1979. As a consequence, a large amount of contaminated water was generated, and subsequent leaks of this water resulted in the contamination of groundwater. In response, a special project for the characterization and remediation of groundwater and water discharges was developed and launched.

First Generation Magnox Storage Pond (FGMSP), Sellafield, UK

FGMSP at Sellafield is uncovered and open to the atmosphere and the elements. As such, it has deteriorated over the decades and now requires significant improvements and major modifications to allow the facility to be safely decommissioned, e.g., repair and shielding of cracks in the concrete containment system.

As a consequence of the lack of detailed historic knowledge about the inventory in the pond, significant uncertainty exists in terms of waste characteristics. In response to the lack of knowledge about waste properties, retrieval work has been planned on a “lead and learn” basis, with provisions being made for quarantining the waste following retrieval, pending characterization and waste route identification.

Marcoule Nuclear Centre, France

The decontamination and decommissioning activities were required to deal with various waste materials, including:

- Leaking and corroding drummed waste in pits, vaults, or trenches;
- Vessels containing thick deposits of solids and sludge; and,
- Untreated waste, e.g., magnesium, graphite, water treatment products.

There was a high degree of uncertainty concerning the characteristics of the waste at the Marcoule site, and even when data were available, the type of information required for planning future decontamination and waste conditioning operations was often not available. In order to improve waste characterization data, and to minimize the need for sampling, new in situ technologies were developed. Examples of these technologies included:

- Gamma imaging technologies: Gamma cameras were used to identify areas containing high levels of gamma emitting radionuclides, and to provide radiological mapping in inaccessible areas. Prototypes such as the Aladin camera, and the compact industrial instrument, Cartogam, were developed and used;
- Real-time in situ radiological mapping software based on geo-statistical methods: For soil characterization, dedicated software tools were developed, including KARTOTRAK, a comprehensive software application for data collection, geo-statistical processing, and mapping; and,
- Laser induced breakdown spectroscopy: This technology enables the chemical composition of a material to be remotely analysed through the use of optical emission spectrometry from laser-generated plasma.

Industrial Uranium Graphite Reactors (IUGRs), Russian Federation

The primary objective in characterizing the IUGRs prior to decommissioning was to determine the levels of contamination in the graphite core. A radiation survey of the graphite core was performed to determine the distribution of transuranic elements and fission products in the graphite. In addition, an assessment of nuclear safety was required due to the presence of particles in the core, resulting from the swelling of damaged fuel.

Al-Tuwaitha Nuclear Research Centre, Iraq

Very shortly after the destruction of the Al-Tuwaitha site, it was recognized that the radiological information that was available about the site would not be sufficient for planning a decommissioning programme. Furthermore, it was discovered that operational records and documentation had been largely destroyed or lost, and that the radiological characteristics of the site had changed significantly in comparison to the operational period of the facilities. As a consequence, it was decided that a complete detailed characterization initiative would be required to obtain the necessary data. In response, the Iraqi Ministry of Science and Technology (MoST) undertook a comprehensive characterization plan that had been developed in consideration of the principles contained in IAEA Safety Standards Series No. SF-1, Fundamental Safety Principles [14].

4.3. MONITORING, SAMPLING, AND MEASUREMENT

4.3.1. Introduction

Monitoring initiatives involve not only facilities, but also air, water, land, and both human and non-human biota. Events leading to a DNF can be particularly problematic with respect to monitoring as there is an increased probability that there will be, for example:

- New contaminant release points, some of which may not be detected, thereby leading to a flawed and incomplete monitoring system;
- New radionuclides and gases that were not present prior to the accident, and which may require unique monitoring instrumentation;
- New areas of contamination that may cover large areas outside the licensed site, and which could require an increase in the magnitude and scope of the monitoring programme; and,
- New contamination source terms that arise as a result of decommissioning activities, for example, dust from excavations and concrete removal, and contaminated liquids released during the removal of old tanks.

The following discussion provides a summary of the key points, challenges, observations, and conclusions identified in the case studies as they relate to the monitoring of air, land, water, and human biota.

4.3.2. Summary of key points

The following points may be particularly useful in preparing emergency plans, and could play an important role in the design of a facility whereby the consequences of an accident can be minimized or avoided. Further to this discussion, the key points below could also provide insight into how monitoring systems might by designed and configured to provide effective monitoring of key parameters during and after an accident:

- Normal operations at a nuclear facility require routine monitoring of the facilities, environment, and workers. As part of the post-emergency phase, a means for assessing the functionality of those monitoring systems is important in determining what systems may need to be re-established. Furthermore, there may be value as part of emergency planning in establishing a contingency plan for alternative means of monitoring should pre-accident monitoring systems not be available;
- A means for monitoring facility conditions is of key importance in determining the levels of risks and hazards following an accident. Establishing this type of monitoring capacity may require unique approaches as access to a facility may be limited;
- Following an accident, it is important to establish a monitoring programme as soon as practicable to determine the level of radiological hazards as it applies to workers, the facility, and the environment. This programme might include portable monitoring equipment capable of detecting (i) low or high levels of contamination, (ii) airborne contamination including both radionuclides and harmful gaseous by-products, and (iii) radionuclide uptakes by both human and non-human biota;

— It is important to ensure that systems are in place for the analysis of monitoring data including software that can predict the potential movement of released contamination through, for example, 3-dimensional modelling; and,
— Monitoring needs to be accompanied by a management plan that sets out the actions to be taken if measured levels exceed stipulated limits as mentioned in the case studies.

4.3.3. Case studies on monitoring, sampling, and measurement

Fukushima Daiichi NPS, Japan

At the Fukushima Daiichi NPS site, parameters such as water temperature, water level, and on-site radiation dose rates are monitored continuously. Gaseous emissions are also continuously monitored, and the monitoring demonstrates that these emissions do not exceed established concentration limits.

The PCV gas control system reduces radioactive emissions to a level that is less than 1% of the total radioactive inventory in the three reactors, and is capable of analysing radiological releases, and measuring hydrogen concentrations. In addition, continuous measurements are made of airborne radioactivity concentrations and radiation dose rates at 11 on-site locations. These locations consist of monitoring stations at the site boundaries as well as temporary monitoring stations that were installed after the accident.

Multiple preventive measures have been taken to manage the large volumes of contaminated water used in the circulating cooling systems. The preventive measures are based on three principles: (i) removing the sources of contamination, (ii) preventing the contamination from entering groundwater, and (iii) preventing the uncontrolled release of contaminated water. As a means of achieving the third measure, groundwater levels are continuously monitored and managed to prevent contaminated water from flowing out of the reactor building into the surrounding ground. This control measure is accomplished by maintaining the water in the basements of the reactor buildings at levels lower than the surrounding groundwater levels. Monitoring is also performed to ensure that the relative water levels are not changing in a way that would enable contaminated water to flow from the reactor building basements into the surrounding groundwater, particularly when the ground is frozen and forms a barrier of frozen soil.

Secondary wastes, e.g., used ion exchange media, are generated by facilities used in the treatment of contaminated water, and a temporary storage area has been developed to hold the high integrity containers used to store the waste material generated by these facilities. These temporary storage areas are monitored for leakage from the storage containers.

Post-emergency monitoring at Fukushima Daiichi included monitoring the release of radioactivity from each reactor building by measuring the levels of Cs-137, total beta-emitting nuclides, and tritium in both groundwater and the sea water in the port. Radiation survey maps were generated for the building and the site. Monitoring of the sea was accomplished by sampling seawater and seabed soil within a 15 km radius in front of the power station using an unmanned survey boat, and a detailed implementation plan for the monitoring of restricted areas and evacuation areas was also developed. Based on the results obtained by the general monitoring of large areas around the site, a programme for the detailed monitoring of houses, roads, and school grounds was implemented to collect basic data for the development of implementation plans designed to improve the environment in these areas.

Three Mile Island NPP Unit 2 (TMI-2), USA

The environmental monitoring activities for TMI-2 were approved as part of the post-defueling monitored storage (PDMS) technical specifications. These activities were specifically included in the TMI site radiological environmental monitoring plan to ensure that adequate environmental surveillance and control remain in place until the site is eventually decommissioned.

The principle safety concern during PDMS is the inadvertent release of radioactive material into the environment. For this reason, structures, systems and components (SSCs) were explicitly stipulated as the means by which to provide reasonable assurance that the facility could be maintained in a defueled condition without undue risk to the health and safety of the public. These systems were called 'PDMS environmental protection systems', and included the following:

- Reactor vessel, to maintain residual debris geometry and thereby removing the possibility of an inadvertent criticality event;
- Containment structure, to ensure the containment of the remaining radioactive contamination during the PDMS period;
- Purge, breather, ventilation, and filtration systems, to control the release of radioactive effluents from the reactor building and from the auxiliary and fuel handling building;
- Fire protection system, to detect and mitigate any effects of a fire within the facility;
- Flood protection system, to minimize the intrusion of water into the facility and thereby any resulting release of radioactive contamination into the environment; and,
- Support and monitoring systems, to ensure the PDMS is managed in a fashion such that the required activities can be performed.

Air monitoring is routinely performed around the TMI-2 facility, and enhanced air monitoring was employed as part of the controlled purge release period during which time the vented radiological activity of Kr-85 was estimated to range from 1417 to 1859 TBq, with a median value of 1632 TBq. Environmental monitoring was performed utilizing both fixed monitors in the ventilation system and mobile sampling systems located around the plant. During purging activities, off-site radiation monitoring was also conducted by various oversight organizations and stakeholders.

As a consequence of the flooding that occurred in the TMI-2 basement during the accident, immediate and near-term recovery actions included groundwater monitoring to detect any uncontrolled radioactivity releases to the ground around the reactor building and the auxiliary building. A Reactor Building Integrity Assessment Program was also established to monitor potential leakage paths from the TMI-2 reactor building sump. The leakage monitoring points, which were based on engineering evaluations, were established at (i) groundwater monitoring wells, (ii) storm drainage areas, (iii) cork seals in structures surrounding the reactor building, and (iv) the tendon access gallery, i.e., a passageway surrounding the reactor building below the basement, approximately 20 feet below the water surface in the reactor building.

The off-site release of radiological material was very minimal; however, ongoing environmental monitoring was performed as a condition of the license, and during decommissioning, typical monitoring methods will be employed.

Unit 4 Chernobyl NPP (ChNPP), Ukraine

To address concerns about criticality events in those areas with the largest accumulations of fuel containing material, monitoring activities for the destroyed reactor included the installation of devices to provide continuous monitoring of the FCM. Upgraded systems were put into routine operation in July 2000, but these systems did not fully meet the requirements for monitoring and were replaced by a modern integrated automated monitoring system, which monitors parameters related to nuclear safety, radiation levels, the state of building structures, and seismic events.

During the accident, radiation monitoring was performed in three ways: (i) real time measurements, (ii) routine measurements, and (iii) special surveys. The special surveys were primarily performed by research organizations. Later, during the post-emergency phase, the development and use of modernized instrumentation gradually introduced new methods for radioactive waste characterization, methods which are now widely used around the world.

Performing dose assessments for personnel during the first days of the accident proved to be difficult. However, during the next few weeks the situation improved, and more equipment and measurement devices became available. Furthermore, as monitoring and measuring deficiencies were identified, armoured engineering vehicles (AEV, see Figure 3) could be upgraded to address these deficiencies in just a few days. For example, by the end of May 1986, vehicle AEV2D, which was equipped with significant safety related improvements, was manufactured and delivered to ChNPP. The improvements in the AEV2D vehicle included enhanced radiation protection, the ability to monitor the movement of the vehicle, and to manipulate handling devices through the use of TV cameras.

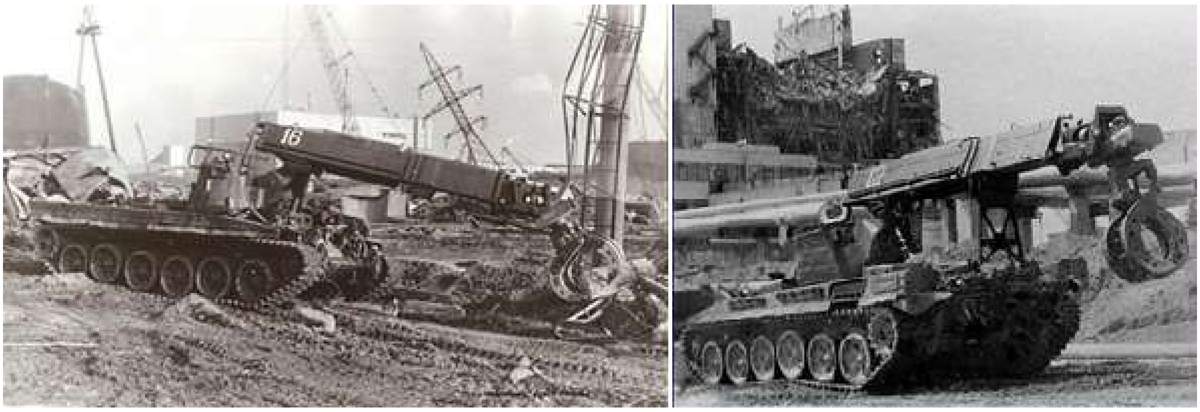

FIG. 3. Armoured engineering vehicles (courtesy of ChNPP).

A1 NPP, Slovak Republic (previously Czechoslovakia)

Radiation monitoring of the A1 NPP site and surrounding areas was initiated after the accident in 1977, and continues as part of ongoing decommissioning activities. Based on the monitoring results, measures were taken to prevent the release of contamination outside of the A1 NPP site boundary through, for example, groundwater movement. The results of measurements have confirmed that the release of radiological contamination has been stabilized since 2000.

Independent on-site measurements of air, soil, and groundwater in the area of Jaslovské Bohunice are periodically performed. Summary reports of monthly results of the monitoring programmes are published on a website established by the A1 NPP operator.

Detailed monitoring and measurement of dose rates, smearable contamination, and contamination of the A1 NPP primary circuit and reactor was completed in 2004. Additional monitoring of the reactor vessel, primary circuit pipes, turbo-compressors, steam generators, main valves, gas tanks, and heavy water systems containing collectors, coolers, distilling and purification stations, pumps, and valves was also performed. The results obtained through this monitoring and measurement programme will provide important inputs into the future planning of decommissioning activities. A 3-dimensional model of the reactor was developed as part of this project, and has proven to be invaluable for orientation, visualization, planning, and the analysis of results.

The radioactivity levels measured in the airborne and gaseous effluents from the A1 NPP stack were two to three times the allowable limits during the first two days after the accident, but the radioactivity in the effluent water exceeded the allowed limits by a factor 5000 during the first week. Radioactive material settled out on the bottom and banks of the wastewater channel of the A1 NPP (the Manivier Channel), and also eventually made its way into the Dudváh River. A permanent system for pumping groundwater from a borehole is now in operation to prevent the spread of contamination beyond the border of the A1 NPP site.

First Generation Magnox Storage Pond (FGMSP), Sellafield, UK

The monitoring of facilities at FGMSP was problematic due to the fact that open pond releases to air are significant from the site and are not amenable to abatement. The monitoring requirements for the facilities are defined in an environmental management plan which sets out actions to be taken in the event that estimated discharges exceed certain predetermined threshold levels. A numerical model capable of predicting the impact of retrieval operations on aerial discharges has been developed and validated against actual air sampling data.

As noted above, open pond releases occur directly to the atmosphere with no engineered controlled or filtered discharge. The level of release is dependent on the operation of the pond, i.e., pond water activity concentrations, level control, the extent and nature of operations, and weather conditions. Gaseous releases are estimated using a system of five continuous high volume air samplers located around the site.

Overall, the releases from the FGMSP open pond surface are the most significant source terms within the facility and represent one of the single most significant sources of emissions to air for the site as a whole. It is expected that gaseous releases will increase during the preparation for and execution of retrieval activities.

To ensure that such increases are monitored, and to allow suitable management interventions in the event of excessive elevations in the levels of releases, FGMSP has installed an additional network of high volume air samplers to support estimates of aerial releases from the pond surface. These air samplers are monitored routinely and also during specific retrieval operations.

Pond water from FGMSP was originally discharged via a redundant effluent tank, which was employed as a means of settling out sludge prior to discharge of the effluent directly to the sea. In 1985, the Site Ion Exchange Effluent Plant (SIXEP) became operational, and FGMSP discharges were thereafter routed to this facility. SIXEP provides sand-bed filtration for alpha-bearing particulate matter, and ion exchange, principally for the removal of Cs-137 and Sr-90.

Marcoule Nuclear Centre, France

Following the shutdown of the Marcoule facility, the methods for monitoring remained the same as those employed prior to shutdown, and the monitoring systems are required to remain in place until the associated radiological source terms are removed. However, additional monitoring methods were introduced during some decommissioning activities with possible risk of contamination releases. For example, additional monitoring systems at gas discharge points were installed to monitor gas releases during sedimentation operations, e.g., for ruthenium isotopes. Nuclear operators routinely conduct monitoring campaigns to evaluate the overall impact of the Marcoule site on the environment, and these campaigns enable measurements to be made on aquatic and terrestrial ecosystems to determine if there has been any accumulation of radioactive material as a result of, for example, winds or currents.

Industrial Uranium Graphite Reactors (IUGRs), Russian Federation

The operational incidents which led to increased levels of contamination within the IUGR cores complicated subsequent decommissioning operations but did not affect any of the installed monitoring systems. The installed monitoring systems included (i) equivalent dose rate instruments, (ii) stationary dosimeters, (iii) equipment for measuring airborne radioactivity, and (iv) groundwater monitoring wells and soil sampling stations.

The EI-2 reactor was decommissioned using in situ isolation of the graphite core, a technique which involved the installation of new engineering barriers in addition to those provided by the core structure. Calculations were made in support of this decommissioning strategy based on (i) actual on-site conditions, (ii) the properties and characteristics of existing safety barriers, and (iii) the safety barriers provided by the use of void-free filling technology. These calculations identified the following potential radiation impacts on the public and the environment:

- The combined specific activity concentration of the radionuclides migrating beyond the engineered barriers into the underground aquifer that discharges into the Tom River would be significantly less than 10^{-3} Bq/kg over the entire forecast period (10 000 years), a concentration which is at least two orders of magnitude below authorized levels;
- Over the entire forecast period, radiation exposures to the critical population group would not exceed 0.3 mSv/a; and,
- Levels of C-14 and Cl-36 are not expected to exceed authorized levels for any of the scenarios that were studied involving the use of the in situ methodology.

Al-Tuwaitha Nuclear Research Centre, Iraq

Prior to the destruction of the Al-Tuwaitha facilities, monitoring programmes were in place for air, soil, and vegetation, as well as for surface and ground water. For the groundwater monitoring programme, 6 boreholes had been installed at the site prior to the damage to the facilities, and additional monitoring was added as an outcome of an EIA required by the regulatory body. The EIA also required routine monitoring programmes for on-site and off-site soil, water, air, and vegetation. In addition, the groundwater monitoring programme was improved, and currently there are 14 boreholes for monitoring groundwater. Additional monitoring now takes place for air, water, soil, and vegetation with the frequency of monitoring being based on (i) the type of radioactivity being encountered, (ii) the nature of decommissioning activities, and (iii) the potential for the release of contamination.

In concert with the above activities, a decision was made that a radio-analytical laboratory was needed to support both environmental monitoring, and the characterization efforts required for future decommissioning activities. Through assistance from donor countries and organizations, a new laboratory was established with appropriate equipment and trained personnel to support decommissioning activities.

Immediately following the damage to the nuclear facilities, there was loss of operational control, and while most of the nuclear fuel had been removed from the reactors and relocated prior to the destruction, some areas did exhibit high radiation exposure rates. The damage to the facility also resulted in the loss of the radiation protection programme, but once the situation at the site was stabilized, a radiation protection programme was re-established and routine monitoring was resumed. As part of re-establishing the radiation protection programme, new equipment was procured, and additional training was provided to the workers.

The Radiation Protection Department (RPD) was established within the Ministry of Science and Technology in 2004. The role of the RPD organization was to provide operational radiation protection for activities being carried out as part of the Iraqi Decommissioning Project and thereby ensure protection for workers, the public, and the environment. The RPD was also given responsibility for performing a characterization survey of the facilities at the Al-Tuwaitha site.

4.4. STRUCTURAL ASSESSMENTS

4.4.1. Introduction

An assessment of the structural integrity of the structures comprising a DNF is critical to ensuring that activities in the post-emergency period can be carried out in a manner that will protect workers, the public, and the environment. The following challenges were identified as being problematic to the assessment of the structural integrity of damaged facilities:

- Structural damage that is not detectable or visible;
- Accessibility problems that limit the ability of personnel to take samples or make measurements; and,
- Limitations to software in terms of being able to adequately model the structural conditions that exist after an accident.

The following discussion provides a summary of the key points identified in the case studies as they relate to structural assessments. Also included in the discussions are examples of the challenges that have been encountered in the post-emergency phase.

4.4.2. Summary of key points

Following a severe accident, it becomes extremely important to assess the structural integrity of a DNF in order to thoroughly understand (i) the potential risks associated with subsequent activities in the damaged structures, (ii) the ability of the remaining structures to prevent, for example, uncontrolled releases, and (iii) the initiatives that may be required to establish the levels of structural integrity required for future actions.

Further to the above points, it is worth noting that, in the absence of structural data, the costs and schedules for mitigation, remediation, and decommissioning projects may need to be based on extreme worst case assumptions, and this in turn could make these projects prohibitively expensive and lengthy.

To achieve the required degree of understanding about the structural conditions of a DNF, a plan is generally required as to how the structural assessment can be performed, e.g., through the use of personnel, remotely controlled equipment, or analytical modelling.

4.4.3. Case studies on structural assessments

Fukushima Daiichi NPS, Japan

The major structures at the Fukushima Daiichi NPS, i.e., the reactor building, PCV, and RPV for each unit, have been evaluated, and they continue to be evaluated. The three methods considered for fuel debris retrieval were: (i) underwater top access, (ii) partial underwater top access, and (iii) partial underwater side access. The evaluation process employed in selecting the optimal approach to fuel debris retrieval took into account the damage caused by the accident, the anticipated degradation of structures over a 40-year period, and the increased loading of the any new facilities and cooling water that would likely be required for fuel debris retrieval from the inner PCV.

A seismic structural safety assessment using detailed analytical models is underway and is being applied to the suppression chamber supports which have seismic safety margins that are relatively small. The seismic assessment is taking into account any effects that the repair of the lower PCV may have had.

The PCV pedestal structure was also evaluated to determine to what extent its strength and stiffness may have been affected as a result of exposure to the high temperature and the subsequent injection of coolant that occurred during the accident.

Three Mile Island NPP Unit 2 (TMI-2), USA

Several post-emergency evaluations were performed to assess, for example, the structural integrity of the facility, the extent of core damage, the potential for radiological exposure, and the potential for environmental contamination.

In order to prepare for re-entry and decontamination of the TMI-2 containment facilities, the licensee developed a “Planning Study for Containment Entry and Decontamination”, published on July 2, 1979. This study included a structural assessment of the containment structures, and considered physical effects from the following:

- Elevated containment pressure and temperature;
- Hydrogen detonation;
- Containment spray actuation;
- High radiation levels and cumulative doses;
- Reactor coolant system thermal-hydraulic transients;
- Flooding of the containment structure; and,
- Extended operation at negative containment pressure.

Prior to TMI-2 being placed into PDMS, the NRC identified SSCs that provided reasonable assurance that the facility could be maintained in a defueled condition without undue risk to the health and safety of the public. These SSCs are known as the PDMS environmental protection systems, and the containment structure represents one of the systems. Several steps were taken to place the containment structure into an acceptable condition for PDMS. Additionally, the PDMS technical specifications required routine surveillance inspections of the isolations used for various containment penetrations.

Unit 4 Chernobyl NPP (ChNPP), Ukraine

Gaining an understanding of the structural characteristics and capabilities of the shelter structure was challenging for the following reasons:

— The load-bearing framework of the support structure for the shelter structure, which comprised the remaining support structures from Unit 4 and their coupling points, were significantly damaged and overloaded with both the weight of collapsed building material and the equipment and material used during the emergency phase. Furthermore, reinforced concrete structures and steel frameworks were affected by corrosion; and,
— The reliability and durability of the load-bearing framework could not be determined because high radiation levels and debris limited access to many of the components and units. Similarly, debris and radiation hindered both the visual inspection of steel structural nodes, and the application of corrosion resistant coatings.

As a consequence of the inability to perform structural assessments, there was a high risk of structural failures which could lead to significant radioactive contamination of workers, the public, and the environment. As a result of the above concerns, efforts began immediately after the construction of the shelter structure to survey structural conditions, and to implement measures to strengthen the structural components. Structural components of the shelter structure represent the key barriers to preventing the release of radioactivity to the environment. Given the importance of the integrity of the shelter structure in retaining radiological contamination, and to mitigate the risks of a collapse of critical structural components in the shelter structure, a set of six stabilization measures were developed and implemented to enhance the durability and reliability of building structures. The six actions taken were: (i) strengthening of the western support leg for the “Mammoth” beam[3], (ii) strengthening the eastern bearing support for the “Mammoth” beam, (iii) strengthening of the upper portion of the deaerator stack frame, (iv) attaching “hockey stick panels” to the northern buttress wall with foundation bolts, (v) waterproofing (repair) of a light roof, and (vi) removal of non-critical structures from within the shelter structure.

A1 NPP, Slovak Republic (previously Czechoslovakia)

As a consequence of the incident at the A1 NPP, there was no physical damage to the reactor building structures, reactor vessel, or primary and secondary cooling circuits. The damage to the core components of the reactor was localized, i.e., involving only the tank for the heavy water moderator in the core of the reactor, and one channel in the reactor core where the fuel assembly with the limited flow of cooling gas had been located. All of the main systems such as cooling, fire suppression, ventilation, criticality control, and shielding, were operable after the accident.

Measures were taken to prevent the leakage of radiological contamination from the main reactor building where the reactor, components of the primary cooling circuit, and spent fuel (together with its cooling media) were located or stored. As part of the initiatives following the incident, the tightness of the civil structure was improved, and a special drainage collection system was reconstructed to capture any leakage from the main reactor building, and to transfer the liquids to certified retention tanks.

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[3] The “Mammoth” beam is a massive 70-m long steel beam (weighing 127 tons), placed on top of the deaerator gallery to cover the southern side of ChNPP Unit 4.

First Generation Magnox Storage Pond (FGMSP), Sellafield, UK

Due to the degraded condition of the Redundant Effluent & Sludge Pipework System, Sellafield needed to isolate this system using 'hot tap' and 'cold tap' processes before undertaking further decommissioning work. A layer of a hard-drying resin compound was sprayed over the lines to provide the required structural stability, and the pipes were then drilled and injected with expanding foam to provide a permanent pipe seal.

The integrity of the concrete pond structure has been subject to degradation over its years of service. Cracks have occurred in certain areas, and in one area there has been leakage of contaminated water in the past, leading to significant dose rates on the external face of the pond wall. This situation has prompted the imposition of worker access restrictions to this area, and the installation of a protective shield wall. The leakage in the concrete pond structure was stopped by sealing the crack with a resin based compound that was applied using remote access and manipulation techniques.

There is an on-going system of monitoring and inspection of the pond wall integrity which relies on a range of techniques, including (i) pond liquor balance calculations, (ii) visual inspections, (iii) crack monitoring equipment, and (iv) the monitoring of water accumulated in an under-pond system of drains and channels serving the newer "pond 3 extension" area of FGMSP.

Marcoule Nuclear Centre, France

Structural assessments were performed to provide information about the integrity of concrete barriers, particularly for facilities that relied on this form of passive confinement. For example, periodic surveys of concrete vault structures containing drums of bitumen were performed using video systems suspended on cables. These assessments provided data for subsequent engineering studies that were employed in determining when new or additional facilities or equipment might be needed for decommissioning activities, e.g., a new crane, waste treatment cells, or glove boxes. The assessments also played an important role in the development of 3-dimensional mock-ups of facilities which could then be used for the simulation of dismantling scenarios.

Industrial Uranium Graphite Reactors (IUGRs), Russian Federation

There was no structural damage to the IUGR reactor buildings as a result of the incidents. In the cases involving fuel swelling, only the associated fuel channels and those graphite blocks in closest proximity to the affected channels were damaged. The routine response to a fuel swelling incident was the removal of the damaged fuel, fuel channel, and graphite blocks or graphite bushings followed by a repair of the core. At the end of the IUGR design life (20 years), the building structures and reactor core support structures routinely went through inspections to confirm their stability and reliability.

Al-Tuwaitha Nuclear Research Centre, Iraq

One of the goals of the First Gulf War in 1991 was to ensure that the nuclear facilities at Al-Tuwaitha could not be used to further develop and support the Iraq nuclear programme. Consequently, many of the facilities were significantly damaged (see Fig. 4), and this damage created significant safety issues in terms of subsequent characterization surveys and decommissioning activities. Initially, many of the buildings and areas could not be accessed due to the potential for structural collapse, or blockages due to rubble. Therefore, the buildings required civil engineering assessments and extensive planning to remove potential hazards prior to performing the radiological characterization surveys.

FIG. 4. Destroyed IRT-5000 research reactor (courtesy of Iraqi Ministry of Science and Technology).

4.5. METHODOLOGY USED TO SPECIFY, PROVIDE OR REPLACE SAFETY SYSTEMS

4.5.1. Introduction

For the purposes of this publication, it may be useful to consider the term ‘safety system’ as being analogous to the concept of structures, systems and components (SSCs) [3], i.e., “a general term encompassing all of the elements (items) of a facility or activity that contribute to protection and safety, except human factors.” Other terms such as ‘safety related systems’, ‘safety related item’, ‘protection systems’, are considered synonymous to ‘safety system’ in the context of this publication.

The methodology employed to determine what safety systems are required in a DNF generally includes the use of safety assessments. Safety assessments can, in some cases, take a significant amount of time and resources to both prepare and to obtain approvals. By contrast, if the safety assessment is focused on a very specific activity, it may be possible to complete the preparation and approval process with less time and effort. For this reason, it may be useful to phase the safety assessment process whereby a focused safety assessment is employed for the that portion of the post-emergency phase where information is being gathered about the condition of the DNF, and then to complete a more general and comprehensive safety assessment in support of a decommissioning phase when the DNF has been sufficiently characterized that a final end state can be defined as part of the decommissioning plan. Challenges associated with specifying the safety systems required during the post-emergency phase include the following:

- Lack of characterization data by which to perform the safety assessments required to specify the necessary safety systems;
- Inability to effectively assess the condition of a DNF may force an overly conservative approach to specifying the need for safety systems, and this in turn may unnecessarily elevate costs and lead to delays;

- Results of the safety assessments may identify safety system requirements that cannot be implemented due to the actual condition of the DNF. For example, it may not be possible to provide confinement given the nature and extent of facility damage;
- Regulatory requirements may demand a significant amount of time for the preparation, review, and approval of the proposed requirements for safety systems with the result that the implementation of hazard mitigation steps may be delayed; and,
- Lack of or limited guidance or precedence for defining the safety assessment strategy or methodology that should be used in defining the required safety systems for a DNF. For example, whether a risk based or deterministic approach should be used.

4.5.2. Summary of key points

As a consequence of accidents leading to a DNF, safety systems may be unavailable, fail, or be damaged. Under these circumstances, the initial step would generally involve identifying the critical systems that are needed to ensure safe conditions, e.g., cooling systems, followed by the establishment of new or modified safety systems that provide the required controls. These safety systems may also include remote monitoring if access is limited. The safety systems in a DNF are generally concerned with four main areas: (i) control of criticality, (ii) monitoring of temperatures and heat flows including the means of providing reliable heat dissipation, (iii) safety and environmental monitoring, e.g., the measurement of dose rates and airborne releases to the environment, and (iv) maintaining the structural integrity of the facility through, for example, the provision of a new confinement structure.

4.5.3. Case studies on methodology used to specify, provide or replace safety systems

Fukushima Daiichi NPS, Japan

As a means of ensuring criticality safety, a new radiation monitor was installed in the PCV gas control system of each unit to continuously monitor Xe-135 concentrations, and a boric acid injection system was installed as a measure to ensure subcriticality of the core material. In addition, because a small amount of hydrogen continues to be released from the accumulated water in the suppression chamber, nitrogen gas is injected to reduce the risks of hydrogen accumulation. To improve the maintainability and reliability of the safety systems employed for sustaining the stable condition of fuel debris, permanent monitoring devices provide continuous monitoring of the temperatures in the RPV and the PCV.

Three Mile Island NPP Unit 2 (TMI-2), USA

There were a number of safety systems that were destroyed or damaged as a result of the incident. For example, much of the reactor monitoring instrumentation was damaged, or was assumed to be inaccurate after the accident. As one means of compensating for the loss of reactor monitoring instrumentation, remote cameras were used to assess damage, and could generally be inserted through existing building penetrations.

The system most impacted by the accident was the polar crane, a particularly important piece of equipment required for various remediation tasks. The crane was severely damaged as a result of the accident, i.e., it became highly contaminated, its electrical components were damaged by hydrogen burns and exposure to excessive moisture in the containment building atmosphere.

Unit 4 Chernobyl NPP (ChNPP), Ukraine

Following the accident and the subsequent construction of the shelter structure, a New Safe Confinement (NSC) structure was installed to provide protection of the accident site. The NSC structure includes complex equipment for the removal of FCM from Unit 4 of the Chernobyl NPP. Radioactive waste management and other systems were also designed and installed to protect workers, the public, and the environment, and to ensure nuclear, radiological, and industrial safety for the NSC facility. In addition, an integrated management system was established to help ensure effective operations. It includes systems, structures, and controls for:

- Radiation monitoring;
- Seismic monitoring;
- Structural monitoring;
- Operational support infrastructure including ventilation, water supply, power supply; and,
- Management of radioactive solid and liquid waste and FCM.

A1 NPP, Slovak Republic (previously Czechoslovakia)

There was no damage to any safety systems as a consequence of the incident at the A1 NPP.

First Generation Magnox Storage Pond (FGMSP), Sellafield, UK

At the time of the final fuel receipts in 1992, a number of systems related to safety were degraded and inoperable. For example, the gantry system of the FGMSP Skip Handling Machine had suffered from a lack of regular maintenance and the constant exposure to the harsh Cumbrian coastal, salt-laden environment. Similarly, the Redundant Effluent & Sludge Pipework System was so corroded that it had to be stabilized and sealed off permanently, and similarly a number of other systems and structures were so severely corroded that replacement was the only option. In addition to the challenging radiological conditions that existed above the pond, a number of conventional safety issues had to be managed such as the requirement to work at heights.

In preparation for retrievals, the radiation level in the pond needed to be reduced to ensure that worker dose uptake levels would be acceptable. Previously, the pond had been purged with contaminated water taken from another fuel storage pond on-site, and this made dose control in the FGMSP area difficult to achieve. To address this problem, an independent pond purge system was designed and installed to purge the pond using a carefully controlled mixture of clean demineralized water and caustic soda. This purge system continuously replaces contaminated pond water with clean water, and also reduces airborne discharges from the pond (see Fig. 5).

FIG. 5. The First Generation Magnox Storage Pond gantry refurbishment system has successfully completed a key risk reduction enabler for recovery of the pond inventory (courtesy of Sellafield Ltd).

A series of complex sludge retrieval systems have been developed to enable the removal of sludge from FGMSP, and to transfer it to the Sludge Packing Plant 1 (SPP1). The systems include fixed and floating platforms, pumps, hoses, and various umbilical connections.

Marcoule Nuclear Centre, France

Legacy wastes that arose during the 1960s were stored outdoors in vaults or trenches, and as a consequence, additional containment and confinement structures were required in support of retrieval initiatives. To this end, an outside confinement system was employed that was equipped with specific ventilation systems including the capability to provide filtered airflow from areas with lower levels of contamination to areas with the potential for higher levels of contamination

Industrial Uranium Graphite Reactors (IUGRs), Russian Federation

Incidents involving the swelling of uranium fuel have not generally affected the safety systems in the IUGRs. In some cases, when a damaged fuel channel could not be repaired, it was closed, but with no further means of control in place. Nevertheless, all reactor core monitoring systems are in place to provide the information necessary for the continued safe management of the reactors. Methods for the identification and measurement of transuranic radionuclides were developed during preparations for decommissioning, methods which are required for determining the location and characteristics of graphite blocks contaminated with nuclear material.

Al-Tuwaitha Nuclear Research Centre, Iraq

As a result of the bombing of the Al-Tuwaitha Nuclear Research Centre, most of the safety systems were severely damaged, and it was judged that gaining access to repair or replace many of the systems would be too dangerous or difficult due to the extent of the damage. It was therefore decided that any required systems would have to be provided as part of the decommissioning project.

As a safety measure, fencing was installed around the site, and additional monitoring capability was provided for radiation protection, e.g., more handheld radiation detection instrumentation and mobile air monitoring equipment. As a means for evaluating the impact of decommissioning activities on workers, the environment, and the public, the preparation and approval of a safety assessment plan and report is required by RPC prior to undertaking decommissioning activities. RPC has been given the responsibility for the development of safety assessments and safety cases for all radiological activities associated with decommissioning.

4.6. AVAILABILITY AND FUNCTIONALITY OF SAFETY SYSTEMS

4.6.1. Introduction

The methodology used to determine what safety systems are required for a DNF during the post-emergency phase generally includes the use of safety assessments, and once the required safety systems are identified in this manner, it is necessary to determine the availability and functionality of those systems that are found within the DNF. Some of the challenges associated with assessing the availability and functionality of safety systems are as follows:

- Gaining access to the safety systems for testing and evaluation purposes;
- Designing, procuring, installing, and testing a replacement system or a temporary modification to an existing system; and,
- The ability to undertake temporary measures that may not have been subjected to a full regulatory review and quality assurance process for design and construction. This topic relates to previous discussions about the extent to which accidents may require regulatory flexibility in order to accommodate the need for urgent and immediate action.

4.6.2. Summary of key points

Given the uncertainties that may surround the availability and reliability of safety systems within a DNF following an accident or emergency, it may be necessary to quickly establish temporary controls that protect workers, the public, and the environment until the pre-accident safety systems can be evaluated and if necessary, replaced with approved systems. The ability to readily establish temporary safety systems may require a flexible regulatory system that supports a rapid but effective approval process.

4.6.3. Case studies on availability and functionality of safety systems

Fukushima Daiichi NPS, Japan

Stable cooling of the fuel in the SFPs of Units 1 to 4 was established using part of the original cooling system together with newly installed heat exchangers. A reliable cooling system is required for the removal of all spent fuel from the SFPs, and potentially for the removal of fuel debris. To help ensure the availability of this safety system, the following measures have been undertaken:

- Replacement of the secondary pressure hoses with polyethylene pipes and the installation of sunscreens on the outdoor pressure hoses;
- Replacement of backup components for the active and main components of the pumps, heat exchangers, and the cooling tower;
- Installation of electrical switching equipment to provide the means for supplying power to the cooling systems from multiple sources;
- Installation of a temporary emergency diesel generator; and,
- Installation of an additional source of water that will feed directly into the pools via an external water injection line.

For fuel debris cooling within the RPVs and primary containment, a water injection line has been installed which recirculates water leaking into the turbine building.

The installation of new external walls and a cover over the reactor building of Unit 4 was deemed as necessary to support fuel removal activities being carried out in the SFP. The walls and cover were designed to minimize the weight being applied to the damaged building.

Three Mile Island NPP Unit 2 (TMI-2), USA

Additional systems, structures, and components were developed for use during the remediation activities at TMI-2. Examples of new or modified systems include:

- Alternate plant and reactor core instrumentation;
- Decay heat removal systems;
- A reactor coolant pressure control system;
- An alternate condensate pumping system;
- Improvements to the balance-of-plant electrical distribution systems;
- An additional hydrogen re-combiner;
- A portable disposable demineralizer system;
- A liquid waste sampling system;
- Auxiliary and fuel building supplementary air filtration systems;
- A main condenser air extractor filtration system;
- A fuel pool waste storage system,
- A temporary auxiliary boiler system; and,
- Various wastewater cleanup systems.

In order to reduce radiation doses to workers, new or modified radiation protection structures were established. These included additional shielding in several locations throughout the facility, as well as the development of a shielded defueling work platform (DWP). The DWP was designed specifically for work at TMI-2 and located approximately 3 meters above the reactor vessel flange. The platform had a rotating 5.2 meter diameter surface with six-inch thick steel shielding plates and was designed to provide shielded access to the reactor vessel for defueling tools and equipment. The DWP was used by defueling operators, and for specially designed long-handled tools, remote viewing equipment, and two jib cranes that were employed for manipulating the tools.

Unit 4 Chernobyl NPP (ChNPP), Ukraine

During the post-emergency phase, subcriticality was ensured by maintaining three systems: (i) a gadolinium nitrate solution feed system, (ii) a neutron-absorber feed system, and (iii) the modernized dust suppression system.

As a result of the accident, the reactor core, most of the process equipment, and the building structures of Unit 4 were destroyed. The containment barriers and safety systems were destroyed completely, and it was these barriers and systems which were designed to protect the environment from the radionuclides contained in the irradiated nuclear fuel. Therefore, improvements had to be made to address the stability, durability, reliability, and effectiveness of both the existing and the added SSCs used in maintaining and enhancing safety.

These SSCs included structural systems, control systems, dust suppression capabilities, and emergency alarm and response equipment. The goal of the stabilization initiatives was to reduce the risks of a collapse of the shelter structure, although ultimately, the risks associated with an unstable shelter structure are expected to be resolved through the dismantlement or reinforcement of the unstable shelter structure within the confines of the New Safe Containment.

A1 NPP Slovak Republic (previously Czechoslovakia)

There was no damage to any safety systems as a consequence of the incident.

First Generation Magnox Storage Pond (FGMSP), Sellafield, UK

At FGMSP, attention has been given to those areas where the decommissioning programme is potentially vulnerable to the failure of key components or systems that have no backup. Where this type situation has been identified, arrangements have been or are being developed to ensure that contingency plans are in place in the event of failure. Examples include:

- The skip handler machine is a critical component in ensuring that fuel and other material can be retrieved, but it is an aged system and in the past has suffered from poor availability. A focus on asset management, plus the development of both a remote operated vehicle (ROV), and skip and fuel manipulation capabilities, has provided additional confidence in the ability to provide skip handling capabilities;
- Effluent discharge is currently routed through an aged distribution tank system to the SIXEP. A major capital investment decision has been taken to provide a contingency plan to address the possible unavailability of SIXEP. However, the contingency plan will not be available until approximately 2023, and therefore backup arrangements are being developed at the FGMSP plant level should the route to SIXEP become unavailable;
- Contingency options for the management of fuel and intermediate level waste (ILW). The development of (i) self-shielded boxes, (ii) an interim storage facility for the self-shielded boxes, and (iii) the opening of existing encapsulation plants on-site for the processing of FGMSP ILW have been undertaken to provide contingency options for practices that are currently used for these waste types.

Marcoule Nuclear Centre, France

At the end of the operational life of the Marcoule Nuclear Centre, the existing safety systems within the facility did not meet new regulatory requirements governing decommissioning and remediation. Therefore, while there had been no deterioration of system operability, there was a requirement to install new systems that would be compliant with the new regulations. Those new systems, structures, and components included, e.g., containment, compressed air, power, fire detection and prevention, flood prevention, in situ characterization, sampling and analysis.

Industrial Uranium Graphite Reactors (IUGRs), Russian Federation

In preparation for the decommissioning of the IUGRs, work was carried out to establish long-term stability for three of the SChC IUGRs, work which included:

- Dismantling uncontaminated equipment and systems that were no longer required;
- Filling the sub-reactor space with concrete; and,
- Preparing the reactor core and adjacent spaces for void-free filling of the reactor space with clay based material.

In parallel with these decommissioning activities, all equipment located in the turbine (machine) halls of the NPPs (see Figs 6 and 7) were dismantled.

FIG. 6. Machine hall of Siberian NPP before decommissioning of IUGRs (courtesy of Siberian Chemical Combine).

FIG. 7. Machine hall of Siberian NPP after cleanout (courtesy of Siberian Chemical Combine, RF).

Al-Tuwaitha Nuclear Centre, Iraq

As previously noted in the discussions concerning the methods used to provide or replace safety systems, most of the safety systems in the Al-Tuwaitha facility were severely damaged during the bombing, and it was considered too dangerous or difficult to repair or replace them. The condition of the site was such that even basic systems such as an electrical supply and containment structures were not available. As a consequence of the severe damage, essentially all of the entire site infrastructure required replacement.

4.7. MANAGEMENT AND MONITORING OF ENVIRONMENTAL CONTAMINATION

4.7.1. Introduction

Environmental contamination includes radiological and non-radiological hazardous material affecting surface water, groundwater, soil, vegetation, etc., and the management of this contamination can present unique challenges in the case of a DNF. The nature of the challenges is likely to depend on site specifics, and be dictated by such factors as the source, type, form, and quantity of the contamination, as well as by the environmental pathways by which the contamination can enter the environment. Environmental contamination can have major impacts both on-site and off-site, and often requires significant measures to mitigate those impacts.

An overview of considerations and circumstances that can lead to challenges related to the management of environmental contamination includes:

- Fundamental uncertainties about the nature and quantity of radionuclides that have been released to the environment which in turn leads to difficulties in making knowledge based decisions about an effective management strategy. It is important to realize that the issues and impacts surrounding environmental contamination apply not only to DNFs, but also to legacy facilities that may have unconditioned or poorly contained radiological contamination;
- The nature and type of uncertainty that can often be found in the case of DNFs and legacy facilities may necessitate a more comprehensive and detailed understanding of groundwater and groundwater flow patterns compared to a situation where the source term is better understood, e.g., with facilities unaffected by accidents. Advanced characterization techniques to collect the necessary input data may need to be used in conjunction with sophisticated modelling and analysis tools. Such tools could include regularly updated 3-dimensional models of the site with the capability to provide, for example, simulations of groundwater flows;
- Unique conditions found with DNFs or legacy sites may require the use of monitoring techniques not typically required at nuclear facilities unaffected by an accident or incident. For example, an accident may have resulted in the release of non-radiological hazardous materials which may not have required monitoring and modelling prior to the accident;
- The level of contamination at a DNF may be sufficiently significant as to warrant the prompt use of standard techniques, but in a manner that is broader or different than usual;
- The importance of ensuring that undertaking actions aimed at achieving short-term mitigation does not cause additional problems in the long term. Contamination control methods used to urgently address accident conditions could lead to continuing negative

impacts. For example, placing a concrete cover over soil contamination may present a larger challenge from the long-standing perspective as opposed to an alternate approach such as the immediate removal and storage of the contaminated soil; and,
- Special, non-standard methods may be needed to protect the environment from the uncontrolled release of radioactive material from a DNF or legacy facility.

4.7.2. Summary of key points

It may be beneficial to establish an exclusion zone and access control measures around a DNF through the use of detection, safety analysis, and monitoring methods to determine appropriate boundaries for the zones.

Safety assessments can be particularly important in developing an understanding of what radionuclides, fission products, and hazardous materials could or are being released from the DNF or legacy facility, and the potential impacts of these releases. Based on the results of safety assessments that take into account dispersion models and monitoring results, it should be possible to establish an exclusion zone with a sufficient safety margin. Also flood protection methods for use both inside and outside of a DNF merit consideration.

4.7.3. Case studies on management and monitoring of environmental contamination

Fukushima Daiichi NPS, Japan

Several options have been implemented or are being considered to prevent the ingress of groundwater into the site and to avoid or mitigate the release of contaminated water into the harbour or sea. These options also include provisions for the removal of radioactive nuclides.

The options being considered for preventing the ingress of ground water include the following:

- Installation of a groundwater bypass system to divert groundwater away from the reactor buildings;
- Pumping out groundwater that is located close to the reactor buildings;
- Establishment of frozen barrier walls to prevent the ingress of ground water;
- Installation of impervious barriers, e.g., paving material, over soil surfaces to prevent the migration of rainwater into the soil and groundwater;
- Solidification of soil through the use of sodium silicate (water glass);
- Installation of an impermeable wall along the boundary between the site and the harbour;
- Removal of radionuclide contamination from water using commercially available technologies;
- Removal of highly contaminated water located in the underground tunnels (trenches); and,
- Covering the reactor buildings to prevent the release of radioactive dusts to the environment.

Three Mile Island NPP Unit 2 (TMI-2), USA

Current plans call for the ground water monitoring systems and equipment used during the post-emergency phase to be used to support decommissioning planning. This monitoring would be in addition to that required in the license for TMI Unit 1.

Unit 4 Chernobyl NPP (ChNPP), Ukraine

A key measure that was undertaken to provide protection of the environment during the early stages of the accident involved the construction of the shelter structure over the damaged Unit 4. The shelter structure was commissioned in November 1986 to ensure the long-term preservation and protection of the damaged unit, and to control the release of radioactive contamination to the environment. In addition, permanent measures were instituted at the ChNPP site as well as in the surrounding area to provide dose control, and to monitor land, vegetation, surface water bodies, and groundwater.

Construction of the New Safe Confinement (NSC) and its subsequent commissioning was carried out in the period of 2008 to 2017. The NSC is intended to ensure protection of workers, the general public, and the environment from nuclear and radiation hazards associated with the shelter structure over the next 100 years.

A1 NPP, Slovak Republic (previously Czechoslovakia)

Abnormally high amounts of rainfall at the A1 NPP site combined with inadequate flood protection measures led to the flooding of buildings, underground tanks, and shafts in the controlled areas of the plant. As a consequence, large quantities of water became contaminated, and this in turn led to the contamination of groundwater. The area where groundwater became contaminated with Co-60 and other radionuclides extended to approximately 1 km from the site. The area contaminated by Cs-137 and alpha radionuclides extended to hundreds of meters, and tritium contamination was spread over a distance of up to 5 km from the site. A special project for the characterization and remediation of groundwater and water discharges has been developed and launched.

First Generation Magnox Storage Pond (FGMSP), Sellafield, UK

Liquid and airborne releases that migrate beyond the site boundary are managed via the existing effluent treatment infrastructure at Sellafield. Overall, releases from the FGMSP open pond surface represent the most significant source term within the facility, and moreover represent one of the single most significant sources of releases to the air for the site as a whole. It is expected that gaseous discharges will increase during the preparation for and execution of retrieval activities.

To ensure that any increases in gaseous discharges are detected and monitored, and to provide assurance that suitable management interventions are implemented in the event of excessive elevations in discharge levels, FGMSP has installed an additional network of high volume air samplers to analyse and assess the aerial discharges from the pond surface. These air samplers are monitored both routinely, and also during specific retrieval operations.

Monitoring of contamination beyond the site boundary is conducted in accordance with an environmental surveillance programme specified in the environmental permit for the site.

Marcoule Nuclear Centre, France

The current environmental and health impacts of site activities are extremely low (less than 10 μSv per year for the reference population) as determined by performing over 30 000 measurements each year. Information is available to the public concerning the environmental and health impacts associated with the site, and this information is frequently updated. The provision of environmental and health information has been found to be an important factor in terms of how the public perceives the site. Examples of the types of activities that are carried out as part of the site monitoring programme include the following:

- Air monitoring at several regulatory stations;
- Monitoring of the terrestrial environment through the analysis of vegetation and agricultural products;
- Measurement of the water table at the Marcoule site; and,
- Measurement of radioactivity levels in the aquatic environment, e.g., water in the Rhône River, aquatic fauna and flora, and sediment.

Industrial Uranium Graphite Reactors (IUGRs), Russian Federation

The use of both existing and additional physical barriers has prevented unauthorized access to the site and has limited the transport of radionuclides to the environment from the EI-2 graphite reactor. These actions redefined the classification of the reactor site changing it from an operating site to a site for the "conservation of exceptional waste". To prevent the ingress of groundwater into the reactor shaft, and to avoid the release of contaminated water, additional barriers utilizing natural clay were also installed.

Al-Tuwaitha Nuclear Research Centre, Iraq

As a result of the extensive damage to the Al-Tuwaitha facility, many of the controls employed for protecting the environment, e.g., containment, were lost, and as a consequence radioactive material was not properly contained. Some environmental monitoring systems for surface water, groundwater, soil, vegetation, and air were in use prior to the damage; however, a more extensive environmental management programme, which includes the routine monitoring of both on-site and off-site soil, water, air, and vegetation, was established as a requirement of an EIA. The details of the new environmental monitoring programmes are provided in the previous discussions on sampling and monitoring.

4.8. WASTE INFRASTRUCTURE AND TECHNICAL CAPABILITIES

4.8.1. Introduction

It is important to establish adequate resources, facilities, and processes to carry out the handling, treatment, segregation, and minimization required for the waste that is generated as part of the decommissioning and remediation of a DNF. Utilization and consideration of various technical approaches is also important as part of establishing a successful waste management programme. Some of the challenges, conditions, and circumstances associated with waste management infrastructure and technical capabilities are:

- The inability to accurately estimate, characterize, and categorize the on-site and off-site wastes that may result from the remediation and decommissioning of DNFs;
- The constraints associated with regulatory frameworks established for the management of normal operational waste may not have the flexibility required for the efficient and timely handling and disposal of DNF waste; and,
- The requirements to manage the risks from wastes that may have been placed in inappropriate locations during the emergency phase.

4.8.2. Summary of key points

Understanding the characteristics, type, and quantity of waste generated from the remediation and decommissioning of DNFs is critical to the successful management, treatment, storage, and disposal of the waste material. The waste generated from a DNF may vary greatly from the types of waste expected from a decommissioning project involving a normal facility where there have been no major accidents or unplanned events. The volumes, radiological content, and physical properties of radioactive waste originating from a DNF need to be determined in order to develop a systematic suite of technologies for effective treatment and conditioning. Key points relating to this topic include the following:

- A detailed analysis of the various waste streams that are or could be generated as part of the decommissioning and remediation of a DNF needs to be performed;
- DNF waste may be of a type that is not addressed under existing regulatory requirements and frameworks;
- The location and form of DNF waste may lead to difficulties in the removal, treatment, and packaging of the wastes; consequently, modifications to existing methods and techniques may be required; and,
- The existing waste management infrastructure in a Member State may not be capable of handling the waste originating from a DNF.

4.8.3. Case studies on waste infrastructure and technical capabilities

Fukushima Daiichi NPS, Japan

The following general points are important in terms of radioactive waste management, and were considered in developing the waste management infrastructure and technical capabilities for use at Fukushima Daiichi NPS. A specific radioactive waste management strategy is needed to guide on-site radioactive waste management, and that waste management strategy should include not only long-term storage and disposal, but also to the extent possible, the reuse and recycling of materials. Early estimates of future waste arisings, based on waste quantity and category, are important for long-term planning, and need to be updated periodically. Close coordination is required between those responsible for on-site waste management planning and activities, and those who manage storage and disposal facilities. This coordination is crucial for identifying and addressing technical constraints or issues that could affect the waste conditioning and subsequent disposal of the wastes arising from accident sites. The waste management challenges following the Fukushima Daiichi accident involved the need to:

- Reduce the amount of waste generated during the remediation and decommissioning activities. This challenge is being mitigated by minimizing the quantities of packaging materials and equipment brought on to site, and through the reuse and recycle of these materials;
- Construct additional storage for solid radioactive waste;
- Characterize the various types of rubble, determine the properties of the secondary waste generated by the water treatment system, and develop analytical techniques for radioactive material that is difficult to analyse. The analysis of solid radioactive waste (melted fuel) is required to effectively plan for the retrieval of the fuel debris. The evaluation of waste processing, storage, and disposal capability and requirements is in progress to ensure the safety and rationality of the entire waste management process, i.e., from waste generation, through storage and processing, up to disposal; and,

— Establish ways to systematically manage and prioritize a large and diverse range of wastes for processing and disposal, a range not typically encountered with facilities unaffected by major unplanned events.

Three Mile Island NPP Unit 2 (TMI-2), USA

The forms and types of waste generated or encountered as a result of the accident at TMI-2 included (i) contaminated coolant water requiring treatment and disposal, (ii) fuel material requiring disposal through the utilization of specialized underwater processing, (iii) reactor core material, and (iv) highly contaminated resins.

The packaging of fuel material started with the removal of fuel debris from the reactor. Operators removed damaged fuel and structural debris from the reactor vessel by a "pick and place" method for the defueling of the loose TMI-2 core debris using the DWP. Numerous manually and hydraulically powered long-handled tools were used to perform a variety of functions such as pulling, grappling, cutting, scooping, and the breaking up of core debris. These activities were followed by the loading of debris into defueling canisters which had been positioned underwater in the reactor vessel. The heavy duty fuel handling tools were only marginally successful in performing these tasks, and a drilling machine that had been originally designed to take core bore samples was reinstalled and was the main mechanism employed to break up core debris. Unique shipping casks were also designed to transport fuel debris from the facility to the Idaho National Engineering Laboratory (now Idaho National Laboratory) for storage pending proposal.

Unit 4 Chernobyl NPP (ChNPP), Ukraine

Two long-term storage facilities for the radioactive waste arising from the accident were established in June 1986 (Buryakovka and Podlesny), and a third which is referred to as the Complex. Currently, only Buryakovka is in operation.

A well-developed infrastructure exists for managing the wastes being generated at the Chernobyl site, including wastes from the decommissioning of Units 1 to 3, as well as from the work being carried out within the shelter structure.

The Industrial Complex for Solid Radioactive Waste Management (ICSRM) includes three facilities for solid radioactive waste management. The facility is designed for the acceptance, treatment, and disposal of solid radioactive wastes generated during both the operational and decommissioning phases of the ChNPP, including operational waste from the shelter structure. The radioactive waste from the site is categorized in terms how it will be further managed, i.e., temporary storage of high level waste (HLW) and low level waste (LLW) or final disposal of low and intermediate level waste (LILW).

A1 NPP, Slovak Republic (previously Czechoslovakia)

Technologies and methods for use in the decontamination, dismantling, and management of radioactive waste, including a final waste repository, were not available at the time of the accident. The first extensive radiological characterization of the reactor, the primary and auxiliary systems, and the spent fuel systems was performed in the period from 1986 to 1990, during which time the volumes, radiological content, and physical and chemical properties were determined. Based on the types of waste streams and their radiological properties, a systematic development of technologies for the treatment and conditioning of the wastes was undertaken, and methods including bituminization, cementation, incineration, and vitrification were examined. A direct outcome of the radiological characterizations and assessments that were performed on the various radiological inventories was the development of a national repository for low and intermediate level waste (LLW/ILW).

First Generation Magnox Storage Pond (FGMSP), Sellafield, UK

The SPP1 is being built to hydraulically receive over 1350 m^3 of sludge from FGMSP. The SPP1 represented a key risk reduction project comprising three stainless steel buffer storage vessels to contain the sludge, allow it to settle, and then to decant the separate liquid. However, the real challenge arose when the two facilities were physically connected, i.e., the FGMSP and the SPP1. In one of the most technically challenging crane lifts ever performed on the Sellafield site, a 31 meter long, 50-ton pipe bridge, for use in the transfer of radioactive sludge, was lifted into position. Space was extremely tight, the load was heavy, and the pipe bridge had to be lifted over operating nuclear facilities.

Decommissioning of FGMSP relies on the use of many existing facilities at the Sellafield site. For example, fuel will be stored in the Fuel Handling Plant, and some ILW will be treated in the Waste Encapsulation Plant. A number of new construction projects are underway to ensure that Sellafield has the necessary facilities to process and provide interim storage for ILW.

Marcoule Nuclear Centre, France

The Marcoule Nuclear Centre includes approximately 15 facilities for the treatment and interim storage of fuel containing material, effluents, and solid waste generated by cleanup and decommissioning programmes. Treatment facilities and processes are installed, upgraded, or replaced in response to factors including (i) technological developments, (ii) new regulations, (iii) the aging and obsolescence of existing systems, or (iv) incidents. Although no major nuclear incidents occurred at the Marcoule site, the site infrastructure was deemed as no longer being adequate to ensure the optimum and safe management of waste arising from decommissioning or legacy waste retrievals; therefore, it was decided that new facilities would need to be put in place. As a result, site support facilities, some of which were more than 50 years old, had to be renovated or in some cases replaced to ensure continued safe operations and the ability to meet programme objectives. Some of these support facilities included the following:

- A multipurpose interim storage facility for bituminized sludge waste and cemented waste packages;
- A new facility and associated infrastructure for irradiated waste coming predominantly from the dismantling operations of the Phénix reactor, most of which comprises activated scrap metal;
- Waste cementation systems, including sorting and characterization, were established in various facilities. For example, alpha waste generated during operational and maintenance activities carried out in the plutonium polishing area of the plant was cemented; and,
- Facilities will have to be constructed to provide processes needed to manage new wastes for which there are currently no treatment processes. These new processes may include, e.g., (i) in-can melting for various sludge materials containing long lived radionuclides that are contained in process vessels and which remain undissolved after chemical rinsing, and (ii) encapsulation using new cementation matrices or geopolymers for legacy waste.

Industrial Uranium Graphite Reactors (IUGRs), Russian Federation

The decommissioning of the EI-2 reactor demonstrated the feasibility of using in situ isolation (entombment) for large amounts of contaminated graphite waste, thereby minimizing both doses to workers as well as overall project costs. The acceptability of using entombment as a method for decommissioning a large graphite reactor core will still need to be confirmed by monitoring.

Al-Tuwaitha Nuclear Research Centre, Iraq

The French-built Radioactive Waste Treatment Station at the Al-Tuwaitha site was partially damaged during the bombing but was able to be repaired. However, the waste treatment equipment contained in the facility was old and required either extensive renovation or replacement and, consequently, the existing radioactive waste management system did not have the capacity to keep pace with the decommissioning activities. This shortfall in capacity led to an accumulation of containers containing both untreated and uncharacterized waste, and the importance of establishing the necessary waste management capabilities prior to undertaking the decommissioning process is now recognized.

The recognition that many of the existing waste storage and disposal facilities would not be sufficient to handle the increased amounts of waste generated from decommissioning and remediation activities led to a decision that an interim storage facility and a final disposal facility for low level and intermediate level waste was needed. An immediate issue that became apparent as part of the decommissioning process was the need to secure high level radioactive sources located throughout the facility. To address this issue, the nuclear shelter that had been designed for use as an operations centre during a reactor accident was converted into a secure national storage facility for disused radioactive sources collected from throughout Iraq.

4.9. WASTE MANAGEMENT

4.9.1. Introduction

A waste management programme with the capability for, e.g., volume reduction, decontamination, waste sorting, and solidification, is a critical component for effectively managing the waste resulting from an accident as well as from post-emergency and decommissioning efforts. The primary considerations associated with waste management in the case of a DNF include the following:

- Large amounts of waste that may have been generated in a relatively short period of time, i.e., during the emergency phase. This challenge applies equally to both liquid and solid waste, and was found to be the case in both the Chernobyl and Fukushima Daiichi accidents;
- Special organizational and technical measures have to be taken to safely manage large volume waste streams, and this can be even more challenging to achieve at the beginning of the post-emergency phase;
- An accident may result in the extensive contamination of soil and water which, in turn, can have a particularly significant impact on waste volume estimates, and on the selection of treatment, storage, characterization, and disposal techniques. Treatment methods for new or non-standard types of waste may not be readily available, and previous waste volume estimates that may have dictated a national waste management strategy will most likely need to be significantly updated as a result of the accident;

— Determining the nature and capacity of the required waste processing facilities and systems is usually very dependent on the results of volume estimates, classification methods, and the categorization of the various types and forms of waste material. Obtaining accurate results can be challenging under post-emergency circumstances; and,
— Decisions concerning the waste management strategy for a DNF, particularly those involving final disposal strategies, need to be made and clearly communicated to all stakeholders.

IAEA-TECDOC-1826, Management of Large Volumes of Waste Arising in a Nuclear or Radiological Emergency [15], provides practical guidance to States for the management of large amounts of waste generated from recovery efforts following an emergency.

4.9.2. Summary of key points

A primary consideration in waste management for DNFs is that large amounts of liquid and solid waste containing a wide variety of radionuclides with potentially high levels of radioactivity can be generated in a relatively short period of time during an accident.

The ability to effectively determine the required nature and capacity of any waste management system or facility can largely depend upon the extent to which accurate estimates can be made of the volume and characteristics of both existing and future wastes. Decisions concerning waste management, particularly those involving waste disposal, need to be made as early as possible, and be clearly communicated to all stakeholders.

The required waste processing technologies are often not available on a DNF site, and to help ensure that the decisions concerning the selection of the technologies are as effective as possible, all aspects of waste management need to be considered, including sorting, decontamination, mechanical or chemical processing, storage, transportation, and disposal as well as the interdependencies between the stages. As part of the decision making process, a thorough review of the potential technical options and their associated economics is often needed that takes into account facilities already on-site, as well as any regulatory constraints such as authorized release levels, permitted doses to workers and the public, free release criteria, waste volume limits, and transportation limitations.

4.9.3. Case studies on waste management

Fukushima Daiichi NPS, Japan

The management of radioactive waste at Fukushima Daiichi requires a broad range of technical capabilities, including storage, treatment, volume reduction, immobilization, minimization at source, disposal, etc. Of particular importance is the on-going requirement to minimize the amount of radioactive waste that is generated during the activities at a DNF including a post-emergency phase. The reduction and minimization of generated waste can be achieved by (i) limiting the amount of potentially waste generating material that is brought onto site, e.g., by avoiding the use of disposable protective clothing and instead employing clothing that can be cleaned, (ii) minimizing the generation of secondary solid radioactive waste by limiting the spread of contamination to, for example, soil, (iii) reusing material and equipment, and (iv) recycling material. In those cases where an incinerator is employed for volume reduction, off-gas filters and various consumables will become secondary waste as part of incinerator operations. The issue of secondary waste is an important consideration in the selection of waste processing technologies, particularly in those circumstances where the volume of the secondary waste could nullify the advantages provided by the primary volume reduction methodologies. Similarly, the secondary waste might contain organic material or hazardous material that could impact the performance of subsequent waste management processes such as disposal.

Secondary wastes, e.g., used ion exchange media, are generated at the facilities used in treating contaminated liquids. The secondary wastes resulting from the treatment methods, including highly contaminated liquids generated by the desalination process, are placed in a temporary storage area that has been specifically developed to hold the high integrity containers used to store this type of waste material. Equipment has been installed at these areas to monitor for leakages. The volume and processing of all secondary waste generated is also taken into consideration.

Three Mile Island NPP Unit 2 (TMI-2), USA

Waste generated during the TMI-2 accident included radiologically contaminated water which required processing and disposal as low level waste. A residual quantity of approximately 8 million litres of slightly contaminated radioactive water was generated during the accident and during subsequent cleanup operations. The volume reduction method selected for the contaminated water involved the evaporation of the water at the TMI site over a 2.5-year period. The residue from this operation, which contained small amounts of the radioactive isotopes Cs-137 and Sr-90, and large volumes of boric acid and sodium hydroxide, required solidification and disposal as low level waste.

Unit 4 Chernobyl NPP (ChNPP), Ukraine

After the accident, radioactive waste processing was not immediately carried out. The top layer of soil containing accident debris was moved to the sides of the reactor compartment building using bulldozers and other machinery. Some of the contaminated areas were covered with precast reinforced concrete slabs, and other areas where slab installation was not possible were covered with concrete. Scattered fuel element debris and reactor graphite from the destroyed Unit 4 building were collected in metal containers.

As a means of reducing the time that personnel spent in contact with high level radioactive waste, a decision was taken that leaving the contaminated material in place, including the remains of damaged Unit 4, represented the best approach. Containers with high level radioactive waste destined for disposal were placed in storage areas located along the walls of the damaged Unit 4. The damaged reactor and the collection of high level waste were subsequently shielded by creating primary shielding walls along the perimeter of the emergency storage area. These walls, together with the radioactive waste contained within them, were called ‘pioneer walls’.

All of the generated material was classified as radioactive waste, including non-standard waste such as (i) combustibles, e.g., used industrial oil, thermal and waterproofing insulation from the roof, (ii) vegetation, e.g., shrubs, grass, trees, (iii) construction material, e.g., fragments of concrete, crushed stone, asphalt, and (iv) equipment, e.g., vehicles, helicopters, tires. The waste management principles and processes employed in response to the ChNPP accident involved sorting the wastes by type and level of radioactive dose rates.

A1 NPP, Slovak Republic (previously Czechoslovakia)

Technologies, techniques, and facilities for decontamination, dismantling, and radioactive waste processing and management, including radioactive waste repositories, were not available at the time of the accident. In response, a complete infrastructure was developed and implemented for radioactive waste treatment including, e.g., sorting, size reduction of metal waste, chemical decontamination, and both electrochemical and mechanical (abrasive blasting) decontamination of metals. The capability for volume reduction and immobilization were also developed and included, for example, evaporation, cementation, bituminization of concentrates and spent resins, super-compaction, incineration, and vitrification of the Chrompik coolant (3% solution of potassium chromate, K_2CrO_4).

First Generation Magnox Storage Pond (FGMSP), Sellafield, UK

Significant quantities of solid intermediate and low level waste need to be retrieved from the FGMSP, both to reduce the hazardous inventory in the pond, and to facilitate access to other material and waste, including fuel and sludge. However, the FGMSP plant area is very space-constrained, and any requirements to carry out pond-side waste manipulations such as decontamination, monitoring, size reduction, has a direct impact on the programme schedule by limiting the ability to carry out parallel operations.

In preparation for retrieval of the radioactive material, the radiation level in the pond needed to be reduced to ensure dose uptake levels were acceptable for the workforce. To ensure this, a pond purge unit was designed and installed to purge the pond using a tightly controlled mixture of clean demineralized water and caustic soda. This purge process continuously replaces contaminated pond water with clean water, a process which has also reduced airborne discharges from the pond.

Sellafield Limited has been able to secure areas in other facilities and buildings for the short to medium term storage of ILW and some LLW retrieved from the pond. Of particular importance is establishing an effective programme for creating and maintaining working relationships with different programmes and facilities at Sellafield to ensure that there are common objectives concerning hazard and risk reduction.

In the case of FGMSP, the experience has very much been that designing and implementing waste processing capabilities, given the uncertainties in FGMSP inventories, has not been compatible with the urgent need to remove the waste from the facility. Consequently, the emphasis over recent years has been to develop interim storage capabilities to allow the waste to be safely stored in a largely untreated form for potentially 50 to 100 years, pending the provision of future waste conditioning and packaging processes.

Marcoule Nuclear Centre, France

Radiological contamination, especially that comprising high activity fission products and long lived alpha-emitting nuclides such as plutonium, were found in the facilities. This contamination, which was primarily located in or on concrete, and both inside and outside of process equipment, had its origins in process liquid leaks, and as a result of the lack of process ventilation systems in some hot cells.

Soil contamination under buildings also presented a challenge, particularly under the UP1 plant where either an incident or trenches filled with legacy waste had led to the spread of contamination. The nature of the contamination varied considerably from one area to another, and it was necessary to evaluate the levels and types of wastes for each facility at the Marcoule site. The evaluations and assessments were performed using geostatistical methods in some parts of the site, e.g., around legacy waste trenches and vaults, and through the use of gamma cameras and various other methods for determining the depth of contamination.

The actual techniques employed for the processing and treatment of the various forms of radioactive waste were dictated by (i) the nature of the wastes, (ii) the availability of liquid treatment facilities on-site, e.g., evaporation, cementation, vitrification, and (iii) on authorized release levels. The types of waste processing methodologies employed at the site included:

- Incineration and metal melting for LLW in the CENTRACO facility near Marcoule;
- Lead decontamination and recycling;
- Mechanical compaction followed by cementation;
- Destruction of highly radioactive and corrosive organic liquids using hydrothermal and supercritical water (H_2O) methods at the Atalante facility; and,
- Plasma incineration for use in air and underwater (under development).

Industrial Uranium Graphite Reactors (IUGRs), Russian Federation

The decommissioning of IUGRs and the rehabilitation of the sites depend on resolving issues concerning the manner by which the resulting radioactive wastes are managed.

The methods and facilities employed for storing the radioactive wastes generated during IUGR operations were designed and constructed in the late 1950s and early 1960s, and these storage facilities are not suitable for the disposal of waste arising from decommissioning. As a consequence, the relocation of this “historic” waste needs to be addressed as part of the overall decommissioning project.

There is a possibility that the principles of reuse can be employed for both contaminated and non-contaminated metallic decommissioning waste, such as stainless steel, steel, and non-ferrous metals, provided that the re-use is carried out under strict controls. The reuse of construction materials from decommissioning such as concrete, while not prohibited in Russia, is of limited practicality due to lack of opportunities that could utilize the material.

Al-Tuwaitha Nuclear Research Centre, Iraq

The majority of the waste handling, treatment, and volume reduction equipment at the Al-Tuwaitha site was either damaged during the destruction of the site, or is too old to be of practical value, although a solid waste drum compactor was rehabilitated and used for processing waste during decommissioning activities. New decontamination equipment has been installed that can be used to decontaminate equipment and components destined for reuse. The original liquid waste evaporator equipment was damaged, and a decision was made to replace it with a mobile chemical precipitation unit.

As part of the regulatory approval process for the decommissioning activities, a comprehensive radioactive waste management plan is required by the RPC, a plan which needs to specify the waste management approaches that will be used at the site during decommissioning. The radioactive waste management processes employed on-site include waste segregation, minimization, and pretreatment. These processes, which were used in both completed and on-going projects, have produced different types of wastes that are classified as both radioactive and hazardous wastes. These wastes are packaged in accordance with specified WAC, and are then transferred to the Iraqi Radioactive Waste Management and Treatment Directorate. Treatment strategies and equipment used by the Directorate include:

— Solid waste drum compactor;
— Mobile chemical precipitation unit;
— Cementation;
— Chemical decontamination; and,
— Abrasive blasting.

4.10. MANAGEMENT OF DAMAGED FUEL AND FUEL DEBRIS

4.10.1. Introduction

The management of damaged fuel and fuel debris is essential for the mitigation of hazards, and for minimizing impacts to workers, the public, and the environment. The management of damaged fuel and fuel debris presents some of the most challenging issues encountered during post-emergency decommissioning, and some of these issues have been discussed above under the subject of physical, radiological, and hazard characterization, e.g., characterization methods, physical limitations, shielding requirements, packaging. Other issues include the fact that the fuel retrieval methods used during normal operations may not be available, suitable or accessible in the post-emergency phase.

A particularly problematic issue is the fact that because the physical form and radiological constituents of damaged fuel and fuel debris may be unknown or unique, efforts to model, retrieve, or understand how the fuel and fuel debris may be changing or interacting with other materials may be prove difficult. It is reasonable to expect that new and non-standard types of waste may be generated during accident conditions, and while the quantities of these types of waste may not necessarily be large, special approaches and techniques are likely to be required in safely managing them.

4.10.2. Summary of key points

The management of damaged fuel and fuel debris is essential for the mitigation of hazards, and for minimizing impacts to workers, the public, and the environment. Knowledge of the physical form, chemical properties, and radiological components of the damaged fuel and fuel debris is crucially important in developing special approaches and techniques for use in the safe removal, transfer, and processing, e.g., vitrification of damaged fuel materials.

For the management of fuel and fuel debris, special R&D initiatives may be required that take into consideration the unique features of each facility, as well as any recent developments in remotely controlled devices and simulation tools.

4.10.3. Case studies on management of damaged fuel and fuel debris

Fukushima Daiichi NPS, Japan

The design of the fuel assemblies used in the Fukushima Daiichi NPS is such that the fuel pellets are contained within tubes, and the tubes are assembled together using a zirconium alloy as a fuel cladding material. The fuel assemblies in the storage pools were not damaged by the accident and, therefore, the fragments did not come into direct contact with the fuel pellets.

Fuel debris and damaged internal reactor structures require retrieval and removal from the cores of Units 1 to 3. However, (i) the location and properties of the fuel debris, (ii) the locations of the damaged parts of the PCVs and RPVs, and (iii) other important internal details are not precisely known. Therefore, based on the experience gained during the accident recovery process employed at Unit 2 of Three Mile Island, it was decided that the safest approach for removing the fuel debris would be to perform the work under water since this would minimize radiation exposure to workers. In order to carry out underwater fuel debris removal, it is first necessary to stop water leakage from the PCV, a task which is in itself a challenge due to the high radiation fields and the limited space inside the water-filled PCVs. Given the difficulties associated with using the underwater method for fuel debris removal, alternatives were examined as part of studies that were conducted following the accident, and a method utilizing partial submersion is currently viewed as the one that will probably be used.

In order to assess the location and quantity of fuel debris that may have accumulated around the reactor core region, a muon detector technology was developed and tested at Unit 1. This technology detects fuel debris inside the reactor by measuring cosmic ray muons passing through the reactor, and the results revealed that there is no accumulation of fuel debris greater than 1 meter in thickness around the reactor core region. The results from Unit 1 proved the effectiveness of the muon detector method, and it was subsequently applied to Units 2 and 3.

Three Mile Island NPP Unit 2 (TMI-2), USA

Damaged fuel and fuel debris generated during the accident were handled as radioactive waste, and specially designed rail transport casks holding 7 fuel canisters each were fabricated to transport the fuel debris. A special Memorandum of Understanding (MoU) with the DOE, signed in 1981, allowed the fuel waste to be transferred to the Idaho National Engineering Laboratory (now Idaho National Laboratory) for storage pending disposal.

Unit 4 Chernobyl NPP (ChNPP), Ukraine

As a consequence of the accident, there was a potential risk that a sufficiently large quantity of nuclear fuel could melt, and that the high temperature molten material could burn through both the floor under the reactor compartment and the foundation slab, and result in contamination of the ground water with radionuclides. To eliminate this potential hazard, an additional 'cooled barrier' was created using a reinforced concrete sub-foundation slab cooled with water. Reactor core and nuclear fuel fragments, which had been scattered on the roofs of nearby buildings and into adjacent areas, were collected and buried near the walls of Unit 4.

During the post-emergency phase, intensive surveys were conducted to determine the location, quantity, condition, and composition of accumulated nuclear fuel in the destroyed Unit 4 of the Chernobyl NPP. As of today, about 40% of the shelter structure remains unsurveyed; however, based on research and studies, it has been estimated that about 95% of the nuclear fuel in the reactor at the time of the accident is currently contained within the shelter structure.

The accumulations of FCM are monitored and maintained in a subcritical state. Active management of nuclear fuel and FCM is planned as part of the strategy for dealing with the shelter structure, and in the event that the long-term containment of the DNF in the shelter structure does not prove to be a viable option, then complete retrieval and subsequent interim storage or final disposal may be required.

A1 NPP, Slovak Republic (previously Czechoslovakia)

The first step in the management of fuel and fuel debris at the A1 NPP was to retrieve, repackage, and transport fuel assemblies to the Soviet Union in the 1980s. The second step was the development and licensing of a system for the retrieval of those damaged fuel assemblies which could not be retrieved from spent fuel storage tubes (PDS) as a result of heavy corrosion and/or deformations. The first such system used compressed air for draining the Chrompik coolant (3–5% aqueous solution of potassium bichromate, $K_2Cr_2O_7$) which was used to prevent the corrosion of fuel element cladding during the storage of the spent fuel. However, because some of the stored fuel assemblies had experienced cladding damage, the Chrompik coolant had become contaminated with alpha emitting radionuclides.

New equipment and systems were later developed and licensed which allowed (i) the handling of damaged fuel and the removal of Chrompik from the PDS, (ii) the cutting of the PDS into two sections, (iii) the loading of sections containing fuel assemblies into redesigned sealed tubes, and (iv) the loading of the sealed tubes into redesigned transport containers.

Several systems were established for storing the damaged spent fuel in either their original containers or after loading into new storage tubes. For example, the PDS were returned to safe storage in the long-term SFP, and one of the short-term spent fuel tanks was prepared for storing PDS.

First Generation Magnox Storage Pond (FGMSP), Sellafield, UK

Significant quantities of fuel and fuel-bearing waste are present in the pond and in its associated bays. A substantial proportion of this fuel and fuel-bearing waste is believed to have corroded into smaller pieces of fuel residue and sludge.

A series of complex sludge retrieval systems and equipment have been developed to enable the removal of sludge from FGMSP and to transfer it to SPP1. This equipment comprises fixed and floating platforms, pumps, hoses, and umbilical connections.

For the management of fuel, the approach involves a number of different activities:

— Identification and consolidation of self-draining, intact fuel. These fuel bars and substantial fuel pieces will be collected by remotely operated vehicles in the pond, and placed in clean fuel skips;
— Washing of the consolidated fuel pieces using a “deluge skip wash box”;
— Transfer of the washed, consolidated fuel skips out of the facility and into storage in a newer fuel storage pond at Sellafield. The transfer will involve moving the skip from the pond into an internal transport flask using a refurbished import/export cell in FGMSP, and then transferring this flask by road to the Fuel Handling Plant (FHP) pond for interim storage; and,
— Development of a Bulk Uranics Final Treatment Facility to process the fuel into a form suitable for its final disposal. According to the current plan, this facility will not begin operations until around 2029.

For more degraded or heterogeneous fuel forms, for example, where fuel pieces have previously been cemented into containers, an approach is being developed to place this material and waste directly into self-shielded boxes, and then to export these boxes to a new interim storage facility where it will remain pending future decisions about processing and final disposability. This approach is also being considered as an alternative to, or contingency for, the interim storage of the washed FGMSP fuel in other ponds at Sellafield.

Marcoule Nuclear Centre, France

Unique wastes that arose during the operation of the Marcoule Nuclear Centre, and which require disposal as part of the decommissioning process include:

- Fuel rods requiring conditioning (e.g., water removal) and packaging prior to being sent to intermediate storage or to La Hague for reprocessing; and,
- Fuel debris that had been dissolved and sent to Marcoule for vitrification.

Industrial Uranium Graphite Reactors (IUGRs), Russian Federation

IUGRs were routinely defueled shortly after the end of the operational phase, and the discharged fuel was sent for reprocessing. Damaged fuel removed from the reactor after swelling incidents was also normally shipped for reprocessing. The process for securing a decommissioning license requires the operator to provide the regulatory body with safety assessments and conclusions concerning IUGRs' nuclear safety, and as part of the preparatory work for decommissioning, the target is to remove fissile material until there is less than 300 grams remaining in the core.

Al-Tuwaitha Nuclear Research Centre, Iraq

Prior to Al-Tuwaitha being severely damaged, most of the nuclear fuel had been removed from the IRT-5000 and Tammuz-2 research reactors and relocated. Following the destruction of the facilities, all nuclear fuel was removed from Iraq, and was transferred to Russia in the period of 1993 to 1994.

4.11. REMOTE TECHNOLOGY FOR REMEDIATION AND DECOMMISSIONING

4.11.1. Introduction

Post-emergency decommissioning generally requires much more in the way of extensive development and deployment of remote handling technologies compared to the case with the decommissioning of facilities where there have been no major incidents, and which underwent a normal planned shutdown. The general development of highly automated remote handling technology was in its early stages at the time of the accidents at A1 NPP, TMI-2, and Chernobyl, where semi-remote approaches and techniques were used to manage difficult tasks, e.g., retrieval and characterization of damaged fuel. Subsequent to these accidents, there has been significant progress in the development of remote technology, and today there are many applications utilizing remote handling technologies within the nuclear industry that support operations, maintenance, and decommissioning.

To help ensure the effectiveness of remote handling applications, e.g., retrieval, cutting, scanning, monitoring, and measurement, at a specific site or facility, it can be very important to carry out developmental work that explicitly takes into consideration the unique and challenging aspects that will be encountered at the actual site. As part of the development process, lessons learned from similar and relevant applications at other DNFs can be particularly useful. It is also important to note that, in addition to the development of the technological equipment, properly trained operators are required to effectively use advanced remote technologies.

4.11.2. Summary of key points

The use of remote handling technology can be an essential tool in conditions that are too hazardous for people, or where access is difficult. Robotics have made considerable advancements in recent years and interventions that were not possible in the past (e.g., Chernobyl experience) might be now well achievable (e.g., Fukushima Daiichi and Sellafield).

In considering the subject of remote handling in the case studies, it becomes apparent that the tools needed for the specific conditions found in DNFs are not likely to be an off-the-shelf item, and therefore not be immediately or readily available. In addition, there may be a lack of proven technology for the required applications. Furthermore, the case studies reveal that it is necessary to train the operators of remote handling equipment in the actual facilities where such equipment is to be used in order to achieve the highest possible levels of system performance, reliability, productivity, and safety. On-site training has the added benefit that it can be more easily tailored to address site specific difficulties arising from, for example, access to damaged structures, and it allows time for the implementation of special tooling.

4.11.3. Case studies on remote technology for remediation and decommissioning

Fukushima Daiichi NPS, Japan

Following the accident, robotic equipment was introduced into the reactors to investigate the conditions and contamination in the reactor, and to acquire data for use in the development of retrieval devices. The insertion of robots into the damaged PCV represents an unprecedented undertaking for the nuclear industry, and data from the first floor grating inside the PCV was collected. During the course of this investigation, the planned access route had to be changed due to fallen material, but the investigation was able to continue with an adjusted plan. Additionally, in March 2017, a study was carried out using a self-propelled robotic device which was inserted through the PCV X-100B penetration. This device was used in conjunction with a CCD camera and a dosimeter that had been suspended from the first floor grating outside the pedestal.

In January and February of 2017, an investigation of the inside of the Unit 2 PCV was conducted by first inserting a guide pipe equipped with a CCD camera through the X-6 penetration, and then by inserting a self-propelled robotic device through the X-6 penetration. From the X-6 penetration, the robotic device was able to move to the pedestal via the control rod drive mechanism exchange rail.

In the case of Unit 3, a device was inserted into the PCV which provided a means for (i) measuring dose rate, (ii) investigating the condition of both the internals and the bottom of the PCV using a pan-tilt camera and a CCD camera, and (ii) the sampling of accumulated water. In addition, an investigation of the pedestal internals was conducted using a self-propelled underwater ROV equipped with a CCD camera which had been inserted through the X-53 penetration.

Three Mile Island NPP Unit 2 (TMI-2), USA

Remotely controlled robotic vehicles were used extensively at TMI-2 to perform cleanup work in (i) the basement of the reactor building, (ii) the makeup demineralizer room in the auxiliary building, (iii) the reactor coolant pump seal injection valve room in the fuel handling building, and (iv) the reactor vessel. The types of robots and remote handling equipment employed at TMI-2 are summarized below, and more information can be found in the NRC publication

“Three Mile Island Accident of 1979 Knowledge Management Digest” (NUREG/KM-0001) [16]:

- The ROVER or remote reconnaissance vehicle was used in the basement of the reactor building to (i) perform video and radiation surveys, (ii) collect sludge samples from the floor, (iii) collect core samples from the wall surface, (iv) flush walls with high pressure water, (v) remove the surface of the walls using an ultra-high pressure scarification system, and (vi) remove sludge;
- The LOUIE I remote vehicle was used to measure the radiation profiles of the two makeup demineralizer vessels, and to remove loose pre-accident debris and salt deposits on the floor inside the seal injection valve room;
- The LOUIE II remote vehicle was used to perform remote floor scabbling in the seal injection valve room;
- The WORKHORSE or remote work vehicle was a large, heavy-duty robot built for decontamination and demolition work in the basement of the reactor building. WORKHORSE was a tether-controlled, six-wheeled work platform that was 10 times heavier than the ROVER, and was equipped with a boom that was capable of a seven-meter vertical reach;
- The Mini-Rover was a commercial submarine vehicle modified to remove larger fuel debris from inside the pressurizer; and,
- A remote manipulator was used to perform defueling operations in areas of the reactor vessel that were not directly below the working slots of the defueling work platform.

Unit 4 Chernobyl NPP (ChNPP), Ukraine

As part of the investigation process that followed the accident at Unit 4, significant effort went into the development of remote handling capabilities, including the creation of various institutions and organizations to support this effort. As an outcome of these efforts, remotely controlled devices, methods for the remote collection of radioactive waste, hydro jet cleaning equipment, and remote use hand tools were developed and employed. It is worth noting that, in the course of performing actual work with these tools and devices, some of the remotely operated devices and almost all of the manual tools required modifications and upgrades.

A method of “glue grabs” which utilized adhesive coated cloth and cotton rope-like material was developed for material removal. This approach was used in conjunction with special remote-controlled methods for the cutting of rubberized bituminous coating.

There was only a limited use of gripping or grappling tools mounted on cranes because these types of tools were prone to frequent failure, and the cranes were generally required for other tasks. Similarly, robotics and remotely operated devices were only used to a limited extent because the level of the technology at the time of the accident was not sufficiently advanced to support or provide widespread use. In general, it was found that robotic mechanisms were subject to a high failure rate in high radiation fields, and remote controls were easily damaged and had a limited operating range.

As a consequence of the shortcomings found with robotic devices and remotely operated systems for use in waste collection, conditioning, and disposal, extensive use of manual labour was required which resulted in increased levels of radiation dose to personnel. For example, more than 5000 workers were utilized in collecting waste on the roofs adjacent to Unit 4. However, despite the limitations found with remote handling systems, robotic devices were able to clear a large amount of contaminated areas.

A1 NPP, Slovak Republic (previously Czechoslovakia)

Various remote handling technologies were developed, tested, and used for tasks such as the retrieval of radioactive sludge from difficult to access areas, or for the decontamination of internal surfaces. Mobile robotic manipulators were used for the dismantling and size reduction of some pieces of equipment and for removing the piping of the heavy water system. Manipulators were developed, designed, and constructed as general purpose decommissioning equipment, and special tooling was developed for use with the manipulators, e.g., hydraulic shears, a circular saw, a reciprocating saw, and a system for quickly changing tools that did not require direct intervention by the operators. The manipulators are remotely controlled through the use of four cameras, their use provides a means of reducing radiation exposures to operators.

First Generation Magnox Storage Pond (FGMSP), Sellafield, UK

A significant development in the decommissioning activities that has been realized over recent years has been the development and implementation of ROV technology in the pond (see Fig. 8). The improvements that have resulted from these developments include reduced levels of worker exposure (time at the active workface), enhanced manipulation capabilities, and the avoidance of certain significant capital spending requirements, e.g., the need for a second skip handler machine.

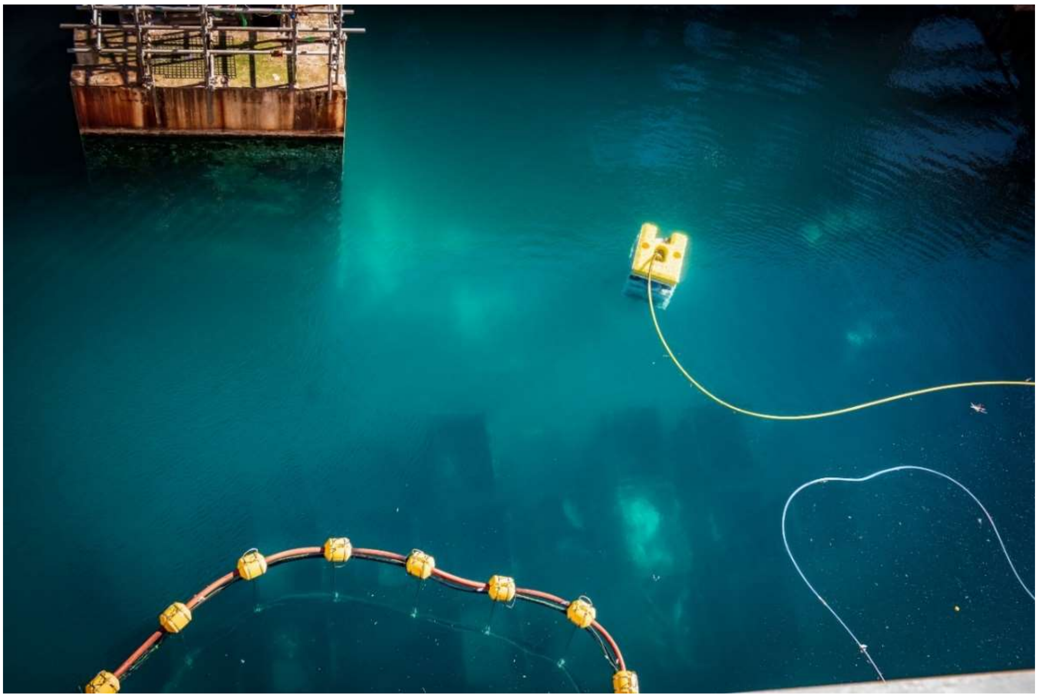

FIG. 8. Remote operated vehicle at the First Generation Magnox Storage Pond (courtesy of Sellafield Limited).

The use of robotics and remote handling technology is essential in areas that are too radioactive for personnel to enter, or where access is difficult, and consequently a series of ROVs have been developed to assist in decommissioning FGMSP. The use of remote handling equipment has rapidly become an integral part of Sellafield’s plan to clean up FGMSP and provides the added benefit that this equipment can access areas that cannot be reached by the crane.

An example of how the remote handling equipment has been utilized is the specially made Powered Remote Manipulator Arm. The arm was designed for the high radiation environment in the pond and was able to first isolate and remove redundant pipework, and then clean and apply a special coating to seal a contaminated wall. ROVs are also being used to survey, segregate and consolidate the pond contents.

Marcoule Nuclear Centre, France

The first efforts to use remote handling technologies in high radiation environments at Marcoule were not very successful, and those activities that did use expensive and complex systems took much longer to perform in comparison to those activities which used less sophisticated tools. The initial strategy for using remote technologies was to employ, to the extent possible, off-the-shelf systems. However, feedback received from personnel working in areas of high radiological contamination and high radiation fields was that the remote handling equipment that was readily available from suppliers was not well suited for use in a nuclear environment. Attempts to adapt off-the-shelf systems for use in nuclear applications led to the following findings:

- Savings resulting from the use of remote handling equipment did not offset the delays that resulted from the requirements to develop and modify the equipment for use in nuclear environments;
- Using the same system at different facilities with different operators proved difficult;
- Concerns arose about radiation doses to the staff performing maintenance on the equipment; and,
- It is important to train the operators using remote handling equipment in the actual facilities where the equipment is to be used in order to achieve the best levels of system performance, reliability, productivity, and safety.

Cutting operations, which were primarily carried out during the dismantling phase, utilized industrial techniques, e.g., mechanical and thermal methods modified as necessary for working in a nuclear environment. These industrial cutting activities were used for both metal and concrete structures. The actual choice of tools depended on a variety of factors, including (i) the material being cut, (ii) accessibility, (iii) the radiological content of the items being cut, (iv) the size and shape of the space surrounding the items requiring cutting, (v) the feasibility of use, (vi) containment requirements for the cutting site, (vii) the potential for airborne releases, and (viii) the amount of secondary waste production. For tasks involving the cutting of steel, the tools used included, e.g., saws, circular saws, disk grinders, oxy-fuel cutting torches, high pressure abrasive jets. For tasks involving the cutting of concrete, thermal lances, demolition hammers, diamond wire saws, high pressure abrasive jets, expanding cements, etc. were employed.

In some circumstances, it was necessary to develop specialized tools. One such example involved the use of Uranus, a laser based cutting system which can be used both in air and underwater (see Fig. 9). This particular tool improved the speed and efficiency of cutting while at the same time limiting aerosols and the quantities of waste generated. Air-cooled heads were developed for this system to prevent contaminated water from leaking during the cutting process.

FIG. 9. Marcoule remote controlled laser cutting system (courtesy of CEA).

Industrial Uranium Graphite Reactors (IUGRs), Russian Federation

Remote technology was developed for the inspection and analysis of all the reactor fuel channels as a means of identifying which fuel channels were contaminated with nuclear material. In the process of developing a strategy for the decommissioning of the IUGRs, it was recognized that the removal of the graphite blocks contaminated with high levels of nuclear material represented a significant technological challenge. To address this challenge, entombment technologies were identified as being an effective strategy for containing the graphite reactor core. The entombment methodology involved:

- The preparation of clay blends for use in establishing protective barriers within and around the reactor core; and,
- The use of technologies to create void-free clay barriers in and around the reactor core.

Al-Tuwaitha Nuclear Research Centre, Iraq

Remote technology was not used for remediation or decommissioning activities at Al-Tuwaitha. Instead, most of the work was performed using manual labour in combination with simple tools and standard machines and equipment. Worker dose was controlled by employing the principles of time, distance, and shielding.

4.12. DECONTAMINATION TECHNOLOGY

4.12.1. Introduction

The challenges associated with undertaking decontamination work in a post-emergency environment may be similar to those encountered during the decommissioning of facilities that have undergone a normal planned final shutdown, especially in terms of those areas that are highly contaminated and for which there are access issues. In both cases, high levels of radiation and contamination may necessitate decontamination techniques not normally used during an operational phase, and the development of these decontamination techniques may require R&D initiatives. Similarly, the decontamination processes may produce by-products and wastes not previously generated during normal operation, e.g., secondary waste with a radionuclide content not typically found in operational waste.

Decontamination procedures may require robust shielding and special containment methods, e.g., the use of isolation structures to minimize worker exposure and/or the release of contamination. Requirements for the incorporation of shielding and containment may substantially influence the design of decontamination equipment as well as the selection of decontamination methods.

4.12.2. Case studies on decontamination technology

Fukushima Daiichi NPS, Japan

Many issues at the Fukushima Daiichi NPS, including decontamination, need to be addressed through the use of robotics and remotely operated devices due to high radiation fields and high levels of radiological contamination. As such, robotics or remote handling is used in the following operations:

- Radiation dose monitoring of the site and buildings; and,
- Reduction of radiation levels resulting from contaminated material on the first floor of Unit 2 by means of decontamination procedures and the removal of contaminated rubble.

Figure 10 shows a robotic device being used to decontaminate the first floor of Unit 2. Remotely controlled equipment was also used to:

- Remove fuel assemblies from the SFPs;
- Investigate the inside of the PCVs to assess their condition, and to locate debris and broken components;
- Investigate the conditions inside of the RPVs; and,
- Retrieve fuel debris.

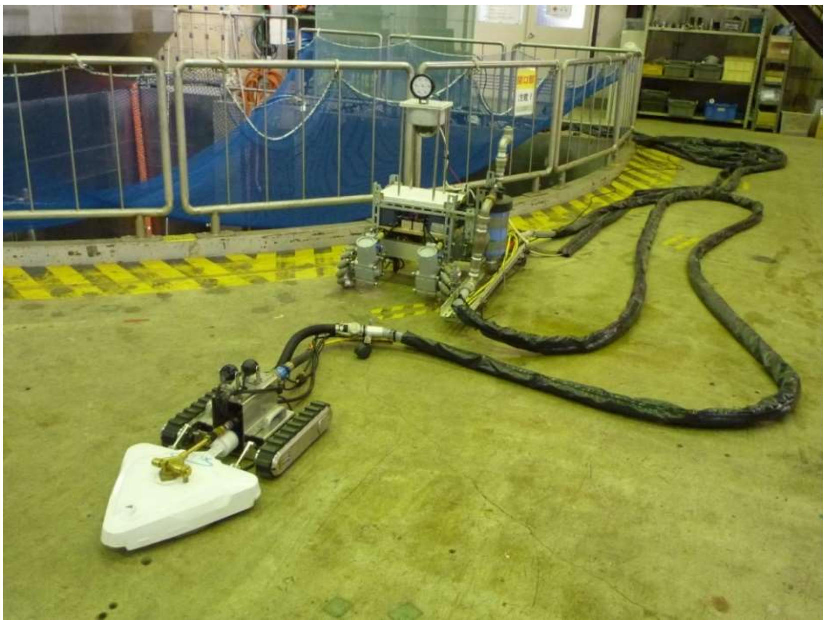

FIG. 10. Decontamination robot used in Unit 2 of the Fukushima Daiichi NPS (courtesy of TEPCO).

Tests were conducted to evaluate and improve the effectiveness of the devices used to remotely decontaminate the first floor of Unit 1, devices that used both suction and abrasive blasting techniques for the decontamination process. In the testing of the abrasive blasting methodology, the effectiveness was evaluated by (i) monitoring reductions in dose levels as a result of the decontamination process, and (ii) the speed at which the device was able to effectively operate.

Three Mile Island NPP Unit 2 (TMI-2), USA

Many different decontamination methods were used at TMI-2. The decontamination of building and equipment surfaces in the auxiliary and fuel handling buildings utilized equipment and techniques such as (i) abrasive blasting, (ii) chemical decontamination, (iii) dry and wet vacuuming, (iv) low-, high-, and ultra-high-pressure water flushing, (v) scabbling, (vi) strippable coatings, and (vii) scrubbing.

Unique methods for waste treatment and conditioning were also developed to deal with contaminated water. The EPICOR II system was used to treat intermediate level contaminated water and consisted of three process vessels equipped with various ion exchange media. The submerged demineralizer system was used to treat highly contaminated water. The system operated underwater in one of the SFPs of TMI Unit 2, and consisted of three subsystems for liquid waste treatment, gaseous waste treatment and solid waste handling.

Unit 4 Chernobyl NPP (ChNPP), Ukraine

The decontamination of building structures and the cleaning of roofs was carried out using the following methods and equipment:

- Removal of debris and contaminated material using manual tools, e.g., scrapers, shovels, and grappling devices;
- Use of adhesive pads made up of a metal mesh to which cloth and cotton ropes had been attached. These pads, after being delivered to the Chernobyl NPP site, were dipped into a bath containing adhesive materials, delivered to roofs by crane or Mi-8 helicopters, and then adhered to the roof coverings;
- Water jets;
- Crane grapples; and,
- Remote-controlled equipment, e.g., CTP-I, a specially reconstructed tractor, an MF-2 robot, and other robotic devices.

A1 NPP, Slovak Republic (previously Czechoslovakia)

Partial decontamination of selected components in the primary circuit and in the radioactive waste storage areas was carried out following the A1 NPP accident. The dry decontamination of the primary circuit was performed shortly after the spent fuel was removed from the reactor and involved placing filter cartridges into reactor channels followed by the circulation of cooling gas. However, only very low decontamination efficiency was achieved using this method. Chemical decontamination was used for two steam generators having the highest levels of contamination, and in this application, decontamination factors in the range of 2.7 to 4.5 were achieved.

First Generation Magnox Storage Pond (FGMSP), Sellafield, UK

Decontamination of solid material retrieved from the pond to minimize the volume of waste generated, is an important element of applying the waste management process hierarchy. The decontamination process can facilitate accelerated progress on retrieval activities by enabling established waste disposal routes for LLW and exempt wastes to be employed. Decontamination techniques being employed in FGMSP generally entail simple water jet washing, swabbing, and in appropriate cases, the cutting and removal of higher activity 'hot spots' from the retrieved waste, e.g., larger metal items. However, due to space constraints, these activities can interfere with other work being carried out, and prolonged efforts to decontaminate items can also lead to elevated worker doses. Consequently, there is an important balance that needs to be maintained between (i) using decontamination to achieve the levels defined for LLW or free release, and (ii) causing adverse wider impacts on programme progress due to, for example, worker rotations required for dose management. The provision of new solid waste 'lay-down' areas located away from the FGMSP work-face has helped to alleviate some of these potential problems.

Sellafield Limited has an established Centre of Expertise for decontamination. It comprises a group of specialists in the area of decontamination who provide advice on the application of decontamination techniques and sponsor the development of new approaches and techniques.

Marcoule Nuclear Centre, France

At the Marcoule facility, decontamination processes needed to be developed that could be used on a wide variety of shapes and surfaces as well as for a wide range of materials and types of contamination. Decontamination processes were selected based on various factors and criteria, including (i) radiation levels, (ii) accessibility of the contaminated surface(s), (iii) quantity and nature of the secondary waste generated, (iv) feasibility of implementation, (v) availability of resources and facilities for the management of liquid or solid wastes, and (vi) cost and time constraints. Some examples of the decontamination methods that were available include those employing (i) acids, (ii) bases, (iii) oxidizing agents applied in the form of liquids, gels, or foams, (iv) self-drying sprayable gels suitable for vacuum recovery and which produce solid waste that meet the WAC of the French National Radioactive Waste Management Agency (ANDRA), (v) laser ablation, (vi) viscous foams, (vii) complexing agents, (viii) flotation foams, (ix) supercritical fluids for use on soils contaminated with Caesium or Strontium, and (x) coating gels.

Decontamination processes for use with radioactive aqueous effluents were developed and implemented which employed physical-chemical techniques that reduced downtime in the treatment facilities, and improved the performance of the treatment facilities, i.e., a reduction in radiological and chemical releases. The decontamination systems that were developed required the design and development of specialized equipment, and the customized preparation of reagents. Development and support for the processes also included experimental studies and research. Several of the processes that were developed for the treatment of solid or liquid organic radioactive waste included incineration, mineralization of organic liquids by hydrothermal oxidation, plasma incineration, etc.

The ability to effectively and efficiently apply decontamination processes to complex radioactive wastes required a correspondingly broad range of complex activities, including (i) the formulation and qualification of conditioning matrices, (ii) the development of the conditioning process, and (iii) the validation of all steps including taking the process from the bench scale to the industrial scale.

Industrial Uranium Graphite Reactors (IUGRs), Russian Federation

Standard decontamination techniques were used as a means of minimizing doses to the staff involved in decommissioning and remediation activities.

Al-Tuwaitha Nuclear Research Centre, Iraq

In support of remediation and decommissioning activities, a variety of decontamination techniques were utilized across the site. Examples of the decontamination methods that were employed include the following:

- Ground scraping;
- Surface chipping using a hammer with a vacuum system for debris removal;
- Chemical decontamination using, e.g., nitric acid;
- Scabbling using a vacuum system for debris removal; and,
- Mechanical grinding using a vacuum system for debris removal.

4.13. PROTECTION OF WORKERS

4.13.1. Introduction

Protection of workers is of fundamental importance for areas and activities involving high levels of radiological contamination and high radiation fields. IAEA Safety Standards Series No. GSG-7, Occupational Radiation Protection [17], provides guidance on fulfilling the requirements of GSR Part 3 [5] for the protection of workers exposed to sources of ionizing radiation. In cases involving accidents, unplanned events, or legacy facilities, major challenges can exist in providing adequate protection of workers during remediation, cleanup, and decommissioning. Meeting the challenges presented by DNFs containing a wide variety of types and quantities of radiological contamination may require unique personal protective equipment (PPE), worker protection programmes, detailed work procedures, and strategies not typically required in facilities where there have been no accidents or operational upsets. Figure 11 shows examples of methods used for protection of workers.

FIG. 11. Protection of workers (courtesy of Iraqi Ministry of Science and Technology).

4.13.2. Summary of key points

The decommissioning and site remediation activities performed in a post-emergency phase often require working in an environment characterized by high radiation fields and areas containing a wide and sometimes unique variety of radiological contamination. Therefore, these environments necessitate the use of PPE, shielding, and carefully developed work procedures.

The selection of PPE and the development of work procedures that protect workers in hazardous environments is often accomplished as part of work hazard control evaluations. Ensuring that sufficient PPE will be available during an accident or in upset conditions is generally an important component of an emergency planning process that has been carried out prior to an accident or emergency.

4.13.3. Case studies on protection of workers

Fukushima Daiichi NPS, Japan

A wide range of the decommissioning and remediation activities conducted at the Fukushima Daiichi site require workers to wear protective clothing that includes gloves and shoe covers to avoid contamination. In addition, a full-face respirator is used to prevent an intake of radionuclides. The decision as to whether there is a requirement for a respirator is generally based on the overall protection factor needed for the conditions in the working area, and therefore depends on radiation levels, the presence of any loose contamination or radioactive gases or vapours, and the type of work being performed in the area.

In 2017, the working environment was greatly improved, and this allowed the Green Zone, i.e., the area where workers are allowed to work in ordinary clothing, to be expanded to more than 95% of the entire site.

Three Mile Island NPP Unit 2 (TMI-2), USA

Due to the conditions following the accident at TMI-2, and the unique nature of the contamination, new and enhanced approaches were needed to provide protection of workers and dose reduction. These approaches included new, enhanced, and updated (i) protective clothing, (ii) respiratory protection, (iii) dosimetry, (iv) methods for measuring radiation fields and contamination levels, (v) exposure tracking systems, (vi) dose reduction planning, (vii) work procedures, (viii) training, and (ix) utilization of robotics. An additional challenge arose from the fact that summer temperatures in the reactor building can approach 33°C (90°F), and in response to this issue, an ice vest was also often employed by workers to control heat stress and to extend work periods. In addition, several types of breathing apparatus for respiratory protection were developed or adapted to extend stay times in the reactor building. Examples of the respiratory equipment that was developed included a power air purifying respirator, and a power air purifying hood.

A number of radiological protection programmes and activities at TMI-2 were updated and are summarized below. Additional details about these updates can be found in the NRC's "Three Mile Island Accident of 1979 Knowledge Management Digest" (NUREG/KM-0001) [16].

New programmes are as follows:

- Increased in-plant radiation protection oversight by the licensee and by the NRC;
- An NRC special panel of experts to independently review the TMI-2 radiation protection programme;
- A dose reduction programme initiated by the NRC and the licensee; and,
- An NRC PEIS supplement on occupational radiation dose.

Radiation detection instruments and systems:

- Thermo-luminescent dosimeter (TLD) to take beta radiation measurements at the building floors;
- Wall and floor sampler to mill the concrete surfaces and collect samples in a filter for off-site analyses;
- Modified handheld ion chamber detector to provide an omnidirectional detection range for gamma measurements, and a detection range of over 180 degrees for beta measurements;
- Modified handheld tungsten-shielded, Geiger-Mueller detector with a conical lead collimator on the face of the probe to reduce the field of view from 140 degrees to 80−90 degrees;
- Mobile radiochemistry laboratory to perform transuranic and radionuclide analyses of high activity (less than 50 mSv per hour) liquid and solid samples;
- Radiation mapping and ALARA planning system to (i) provide 3-dimensional maps of radiation exposure levels in plant areas and components, (ii) train and plan for missions in contaminated areas, and (iii) track the radiation exposure results; and,
- Improved personnel dosimetry system to approximate in-containment beta source conditions. The system included a modified 4-element dosimeter and an automated system used at TMI-2 each month to process the data from approximately 6000 dosimeters.

Unit 4 Chernobyl NPP (ChNPP), Ukraine

PPE is used for (i) activities involving the impacts of the accident, and (ii) the on-going operations associated with the shelter structure. The PPE comprises a basic set of protective equipment and clothing for general use in contamination control areas together with the use of additional protective equipment as required by specific conditions and work plans, e.g., for activities in high radiation fields or where there are high levels of loose contamination.

Decisions concerning the type of PPE required for activities involving hazardous radiological conditions are made by individuals responsible for radiation safety, and take into account (i) radiological conditions, (ii) contamination levels, (iii) working conditions, and (iv) industrial workplace hazards.

For those activities involving the unique conditions found in the shelter structure, special attention is given to respiratory protection equipment (RPE), which can be of two types, i.e., systems which rely on filtration, and systems where air is supplied externally. Filtering RPE systems include respirators and gas masks where inhaled ambient air is purified through the use of filters and sorbent materials. Air supplied RPE systems generally include a supply hose attached to either a compressor or a tank of compressed air, and a breathing apparatus equipped with some form of pressure regulator. The advantage to the air supplied RPE is that breathing air comes from a clean source, i.e., a compressor in a clean area, or from a self-contained breathing apparatus which usually includes a cylinder of compressed air. Airborne contamination can occur in a variety of forms, e.g., dust, smoke, liquid droplets, vapours, and gases, and therefore RPE needs to be selected accordingly.

A1 NPP, Slovak Republic (previously Czechoslovakia)

The management of worker dose, which can include both the control of dose as well as radiation protection planning, is performed in accordance with the Public Health Act and the internal guidelines of JAVYS. Radiation protection practices and procedures are subject to the requirements of national legislation and to the internal quality management system of JAVYS to ensure that they are adequate and have been optimized. Furthermore, work programmes and work procedures are regularly assessed at meetings of the ALARA (As Low As Reasonably Achievable) committee which is part of an approval process to ensure that best practices are being employed in terms of worker protection. Software tools (e.g., VISIPLAN) have been applied to several ALARA studies as part of the development and analysis of various work programmes for A1 NPP decommissioning tasks.

Prescriptive requirements for the use of PPE during decommissioning activities are included as part of work programmes and procedures and are based on the task and the work environment in which the activities are being performed. Typical protective equipment consists of three parts, a base layer, a general layer, and a special layer that is based on any specific safety requirements or concerns. For example, a typical configuration includes cotton overalls, a TYVEK coverall, canvas and rubber gloves, sandals, plastic shoe covers, and for work in the reactor hall, a respirator or self-contained breathing apparatus mask.

The radiological conditions of the work environments are systematically monitored in accordance with applicable operating and work procedures. The presence of a diverse range of radioactive waste types, e.g., sludge, Chrompik, Dowtherm (an eutectic mixture of two organic liquids: biphenyl and diphenyl oxide), in areas containing complex equipment and systems, structures, and structural elements, e.g., the long-term spent fuel storage pool, or the reactor hall, increases the requirement for ensuring that workers are adequately protected against radiation and industrial hazards. Areas with higher dose rates may also require additional shielding.

Protection of workers, in addition to that provided by PPE and work plans, may also be achieved through the use of mock-ups, or using similar existing facilities where complicated activities may be rehearsed or practiced in safer conditions. In a similar fashion, the use of special purpose, remotely controlled handling equipment can be simulated using 3-dimensional computer models and virtual replicas of the workspace.

To address challenges and issues concerning conventional safety, all work is required to comply with the safety principles and regulations applicable to JAVYS, and specific activities are authorized through a special order issued by the equipment administrator before they can be implemented. All contractor and subcontractor employees are informed of the safety requirements that apply to the performance of specific activities in accordance with (i) the Act on Labour Inspection and the applicable regulations, and (ii) JAVYS internal guidelines concerning conventional work safety. Based on a risk assessment of proposed work activities, decisions are made as to measures that could be taken to eliminate or minimize those risks. As a regular part of ensuring worker safety, workers are familiarized with job risks and risk elimination measures through the use of pre-job briefings, walk-throughs, etc.

First Generation Magnox Storage Pond (FGMSP), Sellafield, UK

Radiation dose exposures for personnel working in and around the facility remain a major consideration in the decommissioning of FGMSP; however, this issue is being effectively managed without the use of special radiation protection equipment or protective clothing. Where or when it is necessary to reduce dose rates, permanent or temporary shielding is provided, or remote operations, e.g., ROV or long reach tools are used.

Marcoule Nuclear Centre, France

For the purposes of worker protection during the decommissioning activities carried out at Marcoule, special air-cooled suits were designed to prevent alpha contamination. These suits, the so-called 'MURUROA garment', were designed so that layers of lead could be added to reduce exposures resulting from gamma radiation.

Industrial Uranium Graphite Reactors (IUGRs), Russian Federation

The decommissioning of IUGRs requires PPE of the type commonly found in decommissioning operations. Workers wear a protective suit with gloves and overshoes to avoid contamination, and a full-face mask/respirator to prevent internal uptakes of radiological contamination. Prior to undertaking any activity of a hazardous nature, regardless of whether the risks are of a radiological or industrial safety nature, a work permit is required which stipulates a work plan, PPE, and dose control measures.

Al-Tuwaitha Nuclear Research Centre, Iraq

Workers tasked with mitigating the radiological and safety hazards found at the Al-Tuwaitha site following its destruction required basic radiation protection equipment and training in the handling of radioactive material. However, there was very little radiation monitoring equipment available, and therefore new equipment was required, including everything from dosimeters and hand-held equipment to portal and equipment monitors.

Decommissioning of the former nuclear facilities in Iraq began in 2009, but since that time only two projects have been initiated due to limited resources. The workers undertaking these projects were provided with the basic measures required for radiation protection, and during the course of the work, several training programmes were established utilizing the assistance of international donors and the IAEA. In addition, modern radiation protection equipment was made available through support from the European Union, as well as through contracts with local companies. The Central Laboratories at the Al-Tuwaitha site carry out semi-annual blood tests to monitor for radiological exposures, and the Radiation Safety Directorate monitors site activities on a daily basis to ensure that workers are being adequately protected from radiological exposures, e.g., through the use of dosimeters, and that the work is conducted in accordance with safety requirements. The measures to ensure adequate worker radiation protection are based on the Iraqi radiation protection regulations, and these in turn are based on the IAEA Safety Standards, e.g., in particular SF-1 [14] and GSR Part 3 [5]. A radiation protection plan is also required by RPC for work being conducted at the site, and the plan is reviewed to ensure consistency with radiation safety requirements.

5. INSTITUTIONAL FRAMEWORK AND STRATEGIC PLANNING

5.1. INTRODUCTION

As evidenced by the information contained in the case studies provided in this publication, the impacts resulting from nuclear accidents, incidents, and legacy facilities include not only physical and environmental consequences, but may also fundamentally affect and challenge (i) existing institutional frameworks, (ii) the relationships between the Government, the operator, and the nuclear regulator, and (iii) the ability of local communities, organizations, communication frameworks, plans, and stakeholders to deal with and manage the challenges and impacts associated with DNFs. What may have been a well-established framework that provided for effective communications, operations, and interactions between organizations and institutions during normal circumstances, may prove to be inadequate in dealing with in the aftermath of an accident or legacy facility.

In this section, five main areas are examined with respect to institutional frameworks and strategic planning as they relate to DNFs and legacy facilities. These areas include:

- Organizational and institutional structures and responsibilities;
- Strategic planning for decommissioning;
- Decision making;
- Financial issues;
- Stakeholder and socio-economic issues.

5.2. ORGANIZATIONAL AND INSTITUTIONAL STRUCTURES AND RESPONSIBILITIES

5.2.1. Introduction

The topics that will be addressed in Section 5.2 include:

- Pre-accident organizational structures and responsibilities;
- Post-emergency changes to organizational structures and responsibilities; and,
- Impacts to:
  - Government,
  - Owner, licensee,
  - Regulator(s),
  - Radioactive waste management organization (RWMO),
  - Local government and stakeholders,
  - Public–private sector contractual arrangements.

This section considers the changes to organizational frameworks and institutional structures and responsibilities that may be required to manage the abnormal situations that arise at DNFs or legacy nuclear facilities. The extent of the liabilities resulting from accidents and incidents at a nuclear facility, or with legacy facilities, are often of a magnitude that exceed those found with nuclear facilities that (i) have undergone a normal planned shutdown, (ii) have not been affected by a major accident or incident, and (iii) have not degraded in an uncontrolled fashion. This increased level of liability will often require a higher level of government oversight and involvement in the development and implementation of remediation and decommissioning work compared to that required for normal planned decommissioning and remediation. This requirement for heightened government involvement is often driven by (i) elevated public and political concern at the local, national, and international levels, and (ii) the fact that direct financial support from the national budget and (possibly) multi-national sources may be necessary. In addition, the government may have a direct interest in establishing funding and contractual approaches that are seen as ensuring the optimal use of taxpayer money, including the appropriate use of private sector expertise for post-emergency phase strategy implementation.

5.2.2. Pre-emergency organizational structures and responsibilities

The organizational responsibilities in a pre-accident phase are typically as follows:

- Government is in charge for the main policy statements considering international obligations (treaties, agreement and conventions) and national specific circumstances (energy policy, resources, waste inventory);
- Ministries are in charge for the policy implementation in line with the national legislative system, national infrastructure and funding system for radioactive waste management;
- RWMO and radioactive waste producers should elaborate a detailed strategy based on technology infrastructure, available resources, time constraints, and implement this strategy considering various technical options.

5.2.3. Post-emergency organizational structures and responsibilities

As noted in the International Experts Meeting on Decommissioning and Remediation after a Nuclear Accident (IEM IV), held in January 2013 [1], an analysis and discussion of past events involving DNFs have revealed that the pre-accident responsibilities and frameworks that define cooperative relationships may lack the clarity required for effectively managing an accident or incident at a nuclear site, and that this lack of clarity may lead to poor and counter-productive decision making. Therefore, changes to organizational structures and responsibilities both during and after an accident or incident often focus on clarifying, establishing, or changing responsibilities.

Government

In the case of nuclear facilities, governments are normally responsible for (i) establishing the overall legal and regulatory framework, (ii) setting energy, decommissioning, and waste management policies, and (iii) establishing the framework for the funding of decommissioning and waste management activities. Furthermore, in the case of an accident or incident involving a nuclear facility, it can be reasonably assumed that governmental involvement will be required in terms of international responsibilities for notifying neighbouring countries, and the IAEA.

In the case of emergency and post-emergency phases, governments may have additional responsibilities for proactively establishing governmental arrangements for receiving international support from:

- Neighbouring countries;
- Countries with required specialized resources;
- The IAEA; and,
- Organizations which may provide financial support for post-emergency activities.

The government may also take a lead in reviewing organizational responsibilities and the decision making processes, roles which ordinarily would have been left to the operator (with regulatory approval). As a means of effectively taking on these additional tasks in the post-emergency phase, a special organization may be created to act on behalf of the government to oversee all aspects of the remediation and decommissioning work, including strategy development and the coordination of implementation projects. Furthermore, given the likelihood that the accident or incident may require new and special funding arrangements, it may also be beneficial to specifically assign financial responsibilities to the newly formed special organization, or even to create a separate organization to manage financial strategies. Examples of such an approach can be found with Japan in the establishment of the Nuclear Damage Compensation and Decommissioning Facilitation Corporation (NDF), and in the UK with the creation of the NDA (to deal with the UK legacy situation, some of which include DNFs). In the case of DNFs and legacy facilities, it is also likely that an additional governmental task will include finding additional funds to finance post-emergency activities.

Owner / Licensee

Under usual circumstances, the operator of a nuclear facility is responsible for the safe operation of the facility, and for the development, implementation, and funding of a decommissioning strategy. However, an accident may lead to conclusions by the government, regulatory body, or other decision makers that the operator is no longer capable of fulfilling its operational and decommissioning responsibilities. In addition, the operator or owner/licensee may face financial losses and/or changes to contractual agreements as a consequence of the accident.

Regulator(s)

The roles of regulatory bodies involved with the operation of a nuclear facility, e.g., regulatory bodies with responsibilities for nuclear safety, environmental protection, workplace safety, will normally be clearly defined, and in many cases, be independent of each other. However, in a post-emergency phase, the regulatory roles, relationships, and responsibilities may need to change, and there may be a requirement to reorganize regulatory bodies to, for example, specifically deal with the regulatory aspects of a DNF. The occurrence of an accident is likely to create circumstances for which regulators have no previous experience, and roles that had been considered as clearly defined may now have blurred or overlapping responsibilities. In some cases, new legislation may be required to deal with the post-emergency situations.

A further aspect related to impacts on regulatory bodies as a consequence of an accident is that the regulators may gain a higher public profile, and possibly be expected by the public to take on public advocacy and data interpretation roles. If these roles are viewed as being appropriate for a regulator to assume, then the regulatory bodies may need to properly prepare for these added duties, e.g., through staffing and training initiatives. Finally, as discussed earlier in this publication, the regulatory licensing process as well as the relationship with the operator/licensee may need to be adapted and changed to make the regulatory approach more flexible in order to accommodate the unique challenges and abnormal conditions following an accident. A revised regulatory approach could include a more co-operative and less prescriptive framework that does not, at the same time, compromise regulatory independence or priorities with respect to safety.

Radioactive waste management organization (RWMO)

In those Member States having an organization with responsibility for managing radioactive waste, i.e., a RWMO, that organization is generally responsible for developing a radioactive waste management strategy and for the implementation of that strategy. However, in those circumstances involving DNFs or legacy facilities, the sudden requirement to deal with increased volumes and types of waste may require significant changes to the waste management strategy, e.g., a requirement to develop new disposal routes and waste acceptance criteria in order to accommodate the new waste streams arising from the DNF or legacy facility. These changes may necessitate a RWMO to increase both its personnel and funding requirements, and time may be required to affect the changes.

Local government / Stakeholders

Prior to an accident or incident, a local government may have a number of roles with respect to the operator of a nuclear facility, e.g., the local government may (i) serve as a liaison between the nuclear operator and the public, (ii) be involved in the permitting and planning process for new structures and infrastructure including demolitions, and (iii) play an important role in the preparation, revision, and approval of environmental impact studies.

In a post-emergency phase, the role and responsibilities of the local government are likely to substantially increase, particularly if (i) it becomes the official representative of the affected local population in negotiations with the national government, (ii) it is required to provide assistance to the local population, including the management of health concerns, and very importantly, (iii) it provides a channel of information between the national government, the operator, and the local population.

On a related subject, it is also likely that stakeholders, ranging from those at the local level to those at the national level, could be highly impacted by an accident in a variety of perhaps unexpected ways. The issue of stakeholder impacts is potentially complex and, consequently, it may be advisable to develop specific processes to identify and engage affected stakeholders and to manage their issues and concerns. The issue of stakeholder engagement is dealt with in more detail in Section 5.6.

Public–private sector contractual arrangements

As part of the dynamics involving an accident or incident at a nuclear facility, the affected nuclear facility undergoes a series of transitions moving from a normal operational phase, to an emergency phase, to a post-emergency phase with the latter being, in effect, a de facto, albeit unusual, decommissioning and cleanup phase. Under normal decommissioning circumstances, the private sector, where the required expertise is likely to reside, would be involved in the decommissioning process. Contractual and licensing arrangements vary by country, but are likely to be well established, and be based on good procurement and supply chain practices.

In the event of an accident, the plans and frameworks governing public–private contractual arrangements may no longer be meaningful for a variety of reasons, e.g., the capabilities, resources, and expertise of private sector suppliers may not be sufficient to meet the challenges of a post-emergency phase. In response to these challenges, new procurement and contractual arrangements may need to be established, for example, procurement policies and procedures may need to be changed to ensure that required resources are available in a timely fashion. Moreover, contractors may now require specific indemnification or other contractual clauses to deal with higher hazard situations. The large uncertainties associated with the post-emergency phase may preclude the use of certain types of procurement strategies, e.g., incentivization programmes and risk sharing and/or risk transfer programmes.

5.2.4. Summary of key points – impacts on organizational and institutional structures and responsibilities

Based on the previous discussions, the following key points emerge:

- Pre-accident organizational structures and responsibilities may be deemed inadequate during the reviews that take place during the post-emergency recovery phase, and may even be seen as being a precipitating event for the accident;
- It is likely that more than one organizational change may take place following an accident, and the case studies demonstrate that there may be multiple organizational changes. These reorganizations tend to develop organically, i.e., in direct reaction to changing situations, perceptions, and pressures, e.g., from public opinion. The changes that occur under these circumstances may be relatively unrelated to actual technical issues and developments at the accident site;
- Care needs to be taken that reorganizations do not become a method for creating the illusion of progress in the mitigation of hazards and risks at a DNF;
- The work required for the decommissioning and remediation of a DNF is likely to require levels of funding that may exceed previously established levels for these activities, and also require new short-, medium-, and long-term strategies to deal with funding issues. Changes in the governance of an organization may have the added benefit of providing improved financial oversight.

5.2.5. Case studies on organizational and institutional structures and responsibilities

Fukushima Daiichi NPS, Japan

Following the accident at Fukushima Daiichi NPS, a number of new organizations were established, and other organizations were reconfigured as a means of managing the accident response. Initially, the Prime Minister established an Integrated Response Office to ensure cooperation between the government and TEPCO. This office was dissolved in December 2011 after cold shutdown was achieved, and the Government-TEPCO Council on Mid-to-Long-Term Response for Decommissioning was established. In 2011, the Nuclear Damage Compensation Facilitation Corporation (NDF) was established to manage the funds required by nuclear facility operators.

The NRA was established in 2012 as an external regulatory agency under the Ministry of the Environment. The new arrangements under the NRA separated the responsibilities for nuclear energy promotion, which was moved to the Agency for Natural Resources and Energy (ANRE), and nuclear regulation, which was moved to the Nuclear and Industrial Safety Agency (NISA). Prior to the formation of the NRA, both ANRE and NISA were under the responsibility of the Ministry of Economy, Trade and Industry (METI), and while ANRE remains responsible to METI, the potential for any conflict of interest has been removed.

In February 2013, a further change established the Council for the Decommissioning of Fukushima Daiichi and the Government-TEPCO Council was dissolved. The objective behind this reorganization was to accelerate decommissioning preparatory work. However, continued leakage of contaminated water from storage tanks led to the reformation of the Council to become the Inter-ministerial Council for Contaminated Water Issue and Decommissioning.

In 2014, the mission of the NDF was expanded to include decommissioning of the damaged reactors, and at this time it became the Nuclear Damage Compensation and Decommissioning Facilitation Corporation. In mid-2017, the NDF Act was amended to create a reserve fund for use by TEPCO for the implementation of decommissioning work at Fukushima Daiichi.

Three Mile Island NPP Unit 2 (TMI-2), USA

Several organizational changes took place as a result of the TMI-2 accident, changes which affected the licensee as well as the NRC as the regulator. The initial organizational structure that was formed to manage the aftermath of the accident included a staff of nearly 2000 people located on-site, staff that were focused on the immediate effects of the accident, including leaders from across the U.S. nuclear industry. The second organizational structure, in place by 1980, was described as being more “departmental in structure” with additional focus being placed on radiological controls and issues given that the level of personnel protection required at the TMI-2 site was markedly more than that normally required at an operating power plant. The third organizational structure focused more on the “growing sophistication of project management in terms of understanding the requirements for recovery, the overwhelming organizational need to make the project work efficiently, and the fact that, with the plant in effective cold shutdown, the need for redundant organizations was eliminated”. The fourth organizational structure, established around 1985, was mostly focused on defueling operations. Organizational changes were made to the U.S. nuclear industry as a whole based upon recommendations of the Kemeny Commission, and as a result, the Institute of Nuclear Power Operations (INPO) was established in December 1979 with the mission “to promote the highest levels of safety and reliability – to promote excellence – in the operation of commercial nuclear power plants”.

As a consequence of the TMI-2 accident, the regulatory organizational arrangements and structures shifted from one based on operational NRC oversight, to an augmented interim structure which included an off-site emergency response component during the emergency phase, and ultimately to a new structure enhanced by a review of lessons learned following the emergency. The changes in the regulatory approach taken as a result of the accident were based on risk, safety significance, and the condition of the facility or nuclear materials. In addition to the newly formed TMI Program Office (TMIPO), which was created to provide overall direction for the TMI-2 cleanup operations and inspections, the NRC established the Office for Analysis and Evaluation of Operational Data (AEOD). The AEOD was given a wide reaching mandate to (i) analyse and evaluate operational safety data for all NRC licensed activities (reactor and non-reactor), and (ii) develop formal guidance for the agency concerning the collection, evaluation, and feedback of operational data.

Unit 4 Chernobyl NPP (ChNPP), Ukraine

Prior to the accident, the management of the Chernobyl NPP was the responsibility of the USSR Ministry of Atomic Energy. In the initial period following the accident, the Soviet government established a governmental commission to manage the mitigation initiatives, and the responsibility for all activities at the Chernobyl NPP was assigned to a Special Construction Board under the authority of the Ministry of Medium Machine-Building Industry. Following the completion of the shelter structure in 1986, the Construction Board was dissolved, and a group of researchers from the Kurchatov Institute of Atomic Energy (KIAE) in Moscow were given the mission of coordinating scientific work as well as performing planning and supervision of additional construction works at the shelter structure. This initiative was established by an Order of the Ministry of Medium Machine-Building, and the primary objective of the mission was to conduct R&D studies at the shelter structure. As a means of providing support for shelter structure operations, a separate reactor shop at Unit 4 (RS-4) was established on 26 October 1986, as part of the Chernobyl NPP.

With the formation of an independent Ukraine in 1991, the Ukrainian government assumed responsibility for the shelter structure, and in 1992, the Inter-Branch Scientific and Technical Centre "Shelter" of the Academy of Sciences of Ukraine (ISTC Shelter) was established. The ISTC Shelter provided scientific support and also managed the building and construction initiatives being undertaken at the site. In 1993, the shelter structure organization was merged with that of the Chernobyl NPP, and since that time, the Chernobyl NPP organizational structure includes a separate subdivision that is responsible for safety and the management of all activities at the shelter structure.

A1 NPP, Slovak Republic (previously Czechoslovakia)

Following the accident at the A1 NPP site, three State companies assumed responsibility for the decommissioning programme:

— 1979 – 1994: Slovak Energy Company (Slovenský energetický podnik, š.p.);
— 1994 – 2006: Slovak Electric Company (Slovenské elektrárne, a.s.), a specific branch SE-VYZ; and,
— 2006 – present: Nuclear and Decommissioning Company (Jadrová a vyraďovacia spoločnosť, a.s. – JAVYS, a.s.). The Ministry of Economy is the sole shareholder for JAVYS.

JAVYS is responsible for the assessment of technical, safety, financial, and socio-economic issues related to the decommissioning of all reactors in the Slovak Republic, including A1 NPP. JAVYS is also responsible for the management of radioactive waste and spent fuel, and works with specialized contractors from the European Union and the Russian Federation. In the case of A1 NPP decommissioning, it was decided that the most suitable approach was to utilize a general contractor selected through a competitive bidding process. On the basis of the procurement process, VUJE, Inc. was chosen as the general contractor for Stage I and II of the A1 NPP decommissioning project.

First Generation Magnox Storage Pond (FGMSP), Sellafield, UK

The Nuclear Decommissioning Authority (NDA) was created in 2005 to deal with the nuclear legacy sites in the UK with the required funding being primarily provided by the Government, i.e., the taxpayer. The legacy sites in question were previously the responsibility of the UKAEA and BNFL, but it was deemed that the liability arrangements for the organizations were not adequate; consequently, the NDA took ownership of the sites on behalf of the Government. The NDA subsequently implemented a "Parent Body Organisation" (PBO) model for the operation of its nuclear sites. Under this model, the site license companies manage the sites under managerial and operational contracts with the NDA. The NDA sets strategic objectives for the sites, and the site license companies are responsible for delivering those objectives.

In the case of Sellafield, the NDA appointed Nuclear Management Partners Limited as the PBO for Sellafield Limited in 2008. However, in January 2015, after a strategic review of the Sellafield PBO model, the NDA announced its decision to change these arrangements due to the complexities of the site, particularly in relation to the "Legacy Ponds and Silos" of which FGMSP is one. The rationale behind moving to a different model was based on the realization that an approach was required that would enable better planning for uncertainty and long-term outcomes, and it was judged that the PBO model was not the most suitable approach for achieving these ends.

A new, somewhat simpler and more flexible delivery model was developed and implemented in April 2016 under which Sellafield Limited becomes a subsidiary of the NDA. Cleaning up the Sellafield site requires an enormous investment of public money, and the new model is intended to give Sellafield Limited the maximum opportunity for improving performance in decommissioning and delivering value for money to the UK taxpayer. Sellafield Limited will continue to benefit from private sector support and expertise, but that support will come directly through the supply chain rather than from a private sector owner.

Marcoule Nuclear Centre, France

The original operator of the UP1 reprocessing plant did not undertake decommissioning activities following its shutdown. Strategic planning for the decommissioning of the UP1 facility was undertaken by Areva until 1996, then by CODEM (a consortium of CEA COGEMA, and EDF) until 2004, and finally by the Decommissioning Division of CEA which subcontracted the work to AREVA under a management and operating contract in 2005. After some difficulties in 2000, an integrated approach was adopted for the UP1 plant whereby experienced facility operators, personnel with experience in maintenance and nuclear decontamination, and external contractors were brought together to form a synergistic and effective decommissioning team.

Al-Tuwaitha Nuclear Research Centre, Iraq

Subsequent to the damage caused to the Al-Tuwaitha facilities and the breakdown of the national infrastructure, the Iraq Decommissioning Project (IDP) was established by the IAEA in 2006 with objectives which included developing Iraq's nuclear regulatory framework, operational capability, and infrastructure. The decommissioning organization initially comprised the IDP manager, the Iraqi Decommissioning Centre (IDC) manager, a radiological measurement section, and two project managers. In the intervening time, numerous changes have been implemented to meet the requirements of each stage of the project, particularly when the number and type of facilities to be decommissioned was increased. In 2006, a major organizational change took place when the Radiation Protection Centre (RPC), originally established in 1971, assumed a lead regulatory role with control over all decommissioning activities. Furthermore, a separate Iraqi Radioactive Sources Regulatory Authority (IRSRA) was established in 2004 as an independent authority for radioactive sources.

Currently, the decommissioning of Al-Tuwaitha is being carried out under the organizational structure described below. At the beginning of the post-emergency phase, the organization responsible for decommissioning was limited to the IDP manager (represented by the deputy minister), the IDC manager (including the radiological measurement section), and two project managers. Over the past eight years, numerous changes have been implemented to ensure that the size, structure, and resources of the decommissioning oversight organization is appropriate to the stage and the activities of the decommissioning projects. During the early stages of the decommissioning plan, only two projects were included, i.e., the Geo-Pilot Plant and the LAMA hot cells. As decommissioning initiatives progressed, the responsibilities of the Iraqi Decommissioning Centre expanded to include (i) laboratories, (ii) project implementation, (iii) field measurements, (iv) managerial planning and follow-up, (v) documentation control, (vi) quality assurance, (vii) utilities, and (viii) administration and finance, and the IDC was subsequently named the “Iraqi Decommissioning Directorate” (IDD). During this time, the scope of the decommissioning work was further expanded to include the Radioactive Isotopes Production Laboratory (RIPL). With an increase in the demand for detailed characterization activities, and the need for routine health monitoring of workers, the laboratory department rapidly expanded and became the Central Laboratories Directorate (CLD), and for the purposes of internal oversight, the Nuclear and Radiological Safety Directorate (NRSD) was created. In terms of the overall organizational structure, IDD, NRSD, and CLD are separate directorates, and report to the Ministry of Science and Technology (MoST).

The programme manager representing MoST provides the primary level of supervision for the IDP along with additional consultants and experts who are responsible for (i) developing strategic plans, (ii) managing funding issues, and (iii) coordinating communications with national and international parties. The primary duties of the manager of the IDD include (i) revising project management plans and/or decommissioning plans, (ii) submitting any revised plans for regulatory approval, (iii) monitoring decommissioning progress, (iv) coordinating communications with regulators and the managers of other supporting directorates, and (v) supervising the financial, commercial, managerial, planning, and administrative functions. Project managers are responsible for developing project management plans and decommissioning plans and provide information on project progress as well as coordinating communications with other supporting departments. The project managers have the primary responsibility for ensuring that quality assurance and safety principles are being applied at the project level.

5.3. STRATEGIC PLANNING FOR DECOMMISSIONING

This section is intended to examine how strategic plans for decommissioning may be impacted as the result of an accident as well as how these impacts have been addressed in Member States with DNFs. This section also explores what changes have been made in terms of decommissioning planning by some Member States in response to the circumstances leading to DNFs.

5.3.1. Introduction

One of the major impacts resulting from an accident at a nuclear facility is the subsequent requirement to develop a new overall decommissioning strategy which explicitly includes the DNF.

In accordance with Requirement 10 of GSR Part 6 [4], each nuclear facility would generally be expected to have a decommissioning plan based, in large measure, on a corresponding waste management strategy. Furthermore, under most circumstances, this plan would have been regularly updated during the operational phase of the facility to reflect any changes that had occurred due to, e.g., minor incidents, changes in the facility configuration, the addition of new facilities, or new waste streams. To ensure that the decommissioning plan and strategy are practical and are capable of being implemented in a Member State, it is important that the plans had been developed in line with the government’s policy on waste management and decommissioning. The terms ‘strategy’ and ‘plan’ are used in the discussions surrounding strategic planning, and while there is clearly an overlap in the use of these terms, for the purposes of these discussions, a strategy will be considered as being more likely to contain decommissioning policies, while a plan will contain detailed actions associated with the process of decontamination and dismantlement. For the purposes of this publication, ‘policy’ is generally treated as established goals and requirements set out in national policies for decommissioning, and 'strategy' is taken to mean how the goals and requirements set out in the national policy for the decommissioning will be achieved. The strategy may (in theory) have clear policies on:

— Allocation of responsibilities;
— Provision of resources;
— Decommissioning approaches;
— Safety and security objectives;
— Radioactive waste management, e.g., waste minimization;
— Public information and participation.

Under normal circumstances (pre-emergency), and generally based on national policies, an implementation strategy (or strategies) is developed by those organizations having primary responsibility for decommissioning, i.e., the utility operator and the waste management organization, both of which will be functioning within an existing regulatory framework. However, depending on the nature of the accident, the decommissioning strategy and associated plans may need to be substantially modified or even abandoned, and a new approach developed.

The preparation of a revised approach to decommissioning following an accident can be an important step in defining the path forward in the post-emergency phase, and for this reason it may be important to revise the strategy as early as possible. However, it needs to be recognized that the revised strategy will depend on a wide variety of factors, many of which will change over time as improved data about the DNF becomes available. Therefore, a flexible approach to the development and implementation of revised decommissioning strategies and plans may need to be adopted. One approach to a flexible process involves establishing interim milestones (hold points) throughout a project management plan, but with the recognition that these milestones may themselves need to be revised based on stakeholder inputs and the results of R&D and characterization activities. The revised decommissioning strategy may also need to be integrated with regional and national planning, as well as with the national waste management strategy. Furthermore, there needs to be an ongoing process for incorporating the experience, practices, and lessons learned found from national stakeholders, and the international community.

In general, a decommissioning strategy is developed in a manner that is intended to support underlying decommissioning policies, and that these policies are in turn based on fundamental national policies. In the case of a DNF, it is possible that the reverse may happen whereby the development of a new decommissioning strategy in response to an accident may also necessitate the development of broader overarching national and governmental policies. Based on an examination of (i) the UK NDA approach to strategy development, (ii) the approach used by NDF for the Fukushima Daiichi cleanup, and (iii) the approaches used in other case studies, the following major topics need to be addressed as part of developing a new strategic approach to decommissioning:

— The methodology that will ensure that the inputs from a variety of stakeholders concerning the new strategy are taken into account;
— The overall decommissioning strategy for the damaged facility covering:
  - The site end state;
  - Possible interim site states, given that an ideal end state may not be achievable for many decades or longer;
  - The possible use of entombment as an option, which the IAEA considers a solution only under exceptional circumstances [4].

- A spent fuel management strategy, covering:
  - Damaged fuel and fuel debris;
  - Undamaged fuel.
- A waste management strategy, covering:
  - Liquid and gaseous waste treatment and discharges;
  - Solid low and intermediate level waste disposal;
  - Solid very low level waste disposal; and,
  - Clearance levels and non-radioactive waste disposal.
- A risk reduction strategy;
- Project planning and treatment of uncertainty and programme risk;
- Requirements for additional infrastructure and the maintenance of existing assets;
- R&D activities;
- Provision of skills and other human resources over the lifetime of the activity;
- Transport and logistics;
- Procurement approaches and the use of supply chains at both the national and international levels;
- Socio-economic and stakeholder engagement;
- Required changes to regulatory and legislative frameworks;
- Document control and knowledge management;
- Financial implications of the new strategic approach; and,
- Changes and impacts of the type discussed in this publication.

In developing a revised strategy, NDA and NDF used structured approaches which led to the publication of a single document with updates being issued on a periodic basis. In summary, the process used in developing a revised decommissioning strategy involved the following steps:

- Taking into account the progress and changes that have occurred since the last strategy was developed;
- Considering the options and potential implications of implementing the strategic approaches contained in the strategy document;
- Employing a method that involves formal discussions with stakeholders in developing an agreed upon strategy and implementation plan.

In the case of the NDA, the strategy is revised every five years. In the case of Fukushima Daiichi, it is revised on an annual basis. However, the important point is that, in the early phases of strategy development, a certain degree of flexibility and iteration may need to be permitted in order to avoid a situation whereby an unsuccessful plan cannot be changed or revised. Once a strategy is in place, its detailed implementation can be undertaken by specialized organizations, some of which may need to be brought in from outside the country. Implementation of the strategy, i.e., the decommissioning plan, will likely be DNF specific and, to the extent possible, employs well-developed project management principles in the execution of the plan.

The final goal of any decommissioning strategy is to achieve a defined end state for the site. Subject to national legal and regulatory requirements, this end state is a result of conducting decontamination and/or dismantling, management of waste and cleanup, leading to the release of the facility from regulatory control with or without restrictions on its future use. However, it has to be recognized that the planned end state prior to the accident may no longer be achievable after the accident, and that, while it is important and necessary to define a new end state, this may not be possible until the full extent of the impacts of the accident on the site are known.

5.3.2. Determination of interim states and end states

Prior to an accident, and as part of normal decommissioning planning, it would likely have been standard practice to reach an agreement with all concerned stakeholders about an acceptable end state for a nuclear facility. Current practices are such that new nuclear plants are generally required to have decommissioning plans in place even before startup, and that these plans include a definition of the planned final end state. However, depending on the nature of the accident, conditions may be such that the original end state can no longer be achieved, or that it can only be achieved at significant expense. Therefore, a new end state may need to be defined with agreement from stakeholders, particularly the regulatory bodies and the local community. To effectively support such an initiative, it may be advantageous to undertake a pragmatic, risk informed, transparent approach that weighs the advantages and disadvantages of the various options and ensures that concerned stakeholders are involved in the decision making processes. NW-T-2.7 [2] describes approaches for specifying a new end state.

Depending on the regulatory framework in place, the original proposed end state may have been based in large measure on plans for the future use of the site, e.g., industrial use, public use, or agriculture. As a consequence of the accident, the original planned end use of the site may no longer represent a credible scenario, and the end state for the site may need to be changed accordingly.

It should be recognized that discussions about credible end states may not be realistic or practical until decades after an accident, because there is insufficient data about the site to enable a credible safety assessment case to be prepared. Under these circumstances, or when agreement cannot be reached on an end state, it may be useful or necessary to consider the use of milestones, where each milestone represents progress towards reaching a stable interim state where there is measurable reduction in environmental and safety risks and hazards. Agreement on these milestones can be of key importance as they can provide insight and direction into what long-term courses of action are required as well as the associated cost. In addition, the attainment of key milestones can be important in demonstrating to stakeholders, the public, and decommissioning workers that progress is being achieved.

Assuming that these key milestones represent stable states, once having been reached, decisions can be made as to whether to proceed with immediate decommissioning or move into a deferred decommissioning state. If key milestones are used, it is important that the steps to the next milestone (next stable state) be clearly established to aid in determining whether to choose immediate or deferred decommissioning. In all cases, a decommissioning strategy will likely need to be based on the use of systematic risk analysis and assessment to produce a prioritized approach for dealing with risks and hazards.

Decisions concerning whether to use an immediate or deferred approach to decommissioning are generally made through a systematic comparison of the two options (immediate versus deferred dismantling) taking into consideration factors related to:

- Radioactive decay;
- Radiation exposures;
- Availability of waste management resources and facilities;

— Resource availability (human, technical, and financial); and,
— Knowledge retention considerations.

In some cases, the condition of a DNF may be such that it becomes necessary to consider an entombment strategy, although GSR Part 6 [4] in paragraph 1.10 explicitly states that entombment "is not considered a decommissioning strategy and is not an option in the case of planned permanent shutdown. It may be considered a solution only under exceptional circumstances (e.g., following a severe accident)".

5.3.3. Summary of key points

Following an accident at a nuclear site, existing national waste management and decommissioning strategies may require significant revisions to address the impacts and consequences of the accident. In cases where there were no waste management and decommissioning strategies prior to the accident, they may need to be created. The ability to successfully implement a decommissioning strategy generally depends on the availability of resources and experience, and in some cases external assistance may be required.

In those cases where there is only a limited amount of experience available in performing decommissioning work, it can be useful to gain the required experience by first undertaking decommissioning initiatives in those areas where there are low levels of radiological hazards, and then progressing to areas with higher radiological hazards. However, this approach may not be appropriate in those circumstances where immediate action is required to address high risk situations.

As part of revising decommissioning strategies subsequent to an accident, it is likely that plans and assumptions concerning final site end states may also need to be revisited and be based on the realities of new (post-emergency) site conditions.

5.3.4. Case studies on strategic planning for decommissioning

Fukushima Daiichi NPS, Japan

As of 2018, neither a reuse and recycling programme nor a proposed final site end state have been addressed as part of a decommissioning plan for the Fukushima Daiichi site; however, these topics will most certainly be considered as the planning process evolves.

The Inter-Ministerial Council for Contaminated Water and Decommissioning Issues has responsibility for making decisions on the policies for future decommissioning work as applied to risk reduction and ensuring safety. In September 2017, this council published the fourth revision of the document entitled "Mid- and Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station". The fourth revision addressed (i) the general approach to risk reduction and ensuring safety, (ii) specific efforts directed at ensuring safety, and (iii) new regulations and more effective systems in support of conducting mid- and long-term decommissioning work.

In some cases, circumstances may demand that, to reduce on-site and off-site risks, it becomes necessary to accept a temporary increase in short-term risks to enable decommissioning work to take place in an expeditious fashion. In those cases where new issues and risks suddenly arise, it may be necessary to adopt a non-standard approach to their mitigation; under these circumstances, however, it is also very important to communicate with all affected stakeholders to ensure that the circumstances are correctly understood.

Decommissioning programmes have been prioritized into three broad risk categories based on input from NDF and NRA, categories which take into account the types of radioactive material requiring actions: (i) high risk involving high priority radioactive materials such as highly contaminated water and fuels in the SFP, (ii) potentially high risk involving material such as fuel debris, and (iii) materials associated with potential releases to the environment. Other risks that may affect off-site areas are also evaluated and prioritized.

In terms of ensuring worker safety, effective measures are also required to prevent workplace industrial accidents caused by, e.g., (i) an increased number of workers, (ii) congestion within the working environment, and (iii) the inherent risks found with damaged structures and debris in a post-emergency environment. The elevated risks from industrial accidents may also call for improvements in medical preparedness and in the efforts dedicated to maintaining and improving the reliability and durability of equipment. Further changes to the decommissioning strategy and plans include securing formal approvals from a government office for discharging liquid wastes to the sea and preventing unauthorized intrusion on the site.

As a direct consequence of the circumstances and conditions that resulted from the accident, i.e., (i) the need to undertake new and challenging tasks and (ii) a requirement to manage unique and problematic waste forms such as fuel debris, a number of agencies such as NDF, TEPCO, ANRE and NRA engaged with each other, and new organizations have been formed, e.g., TEPCO has established the Fukushima Daiichi Decontamination & Decommissioning Engineering Company specifically to lead the decommissioning and cleanup of the site.

Three Mile Island NPP Unit 2 (TMI-2), USA

Following the accident, strategy assessments were prepared for use in regulatory oversight, decommissioning, waste management, and lessons learned processes. A TMI Program Office (TMIPO) within the NRC provided overall regulatory direction for cleanup operations, and inspections, and the TMI-2 license was amended to a “possession-only” license which allowed the facility to enter a PDMS state until the site is eventually decommissioned, i.e., after TMI-1 ceases operations. This approach to licensing represented a unique strategy that is currently only in place at TMI-2. Unique strategies were also required to address some of the waste resulting from the accident, and in 1981, an MoU was concluded between the NRC and the DOE with respect to solid nuclear waste which ensured that the site would not become a disposal facility. A 1982 revision of the MoU established that the DOE would accept the entire core for R&D, and that it would be subsequently stored at a DOE facility. The terms for the ultimate disposal of the core will be negotiated between the DOE and the TMI utility.

Several investigations were completed, and several committees were formed to address the lessons learned that arose from the accident, including the Kemeny Commission which conducted a comprehensive investigation of the accident, and made recommendations. Similarly, the NRC sponsored the Rogovin Committee, which looked at the causes and implications of the accident, and created a Lessons-Learned Task Force which considered licensing implications at other nuclear power plants. Another outcome of the accident was the establishment of a number of groups with varied interests such as dose assessment, NPP site location requirements, and emergency preparedness.

Unit 4 Chernobyl NPP (ChNPP), Ukraine

Prior to the accident at Unit 4, there was no decommissioning strategy in place for ChNPP, and in general, this represented the case for all RBMK reactors, i.e., decommissioning was viewed as an issue that did not need to be addressed until the end of the planned lifetime of an NPP. Since the accident, efforts at Unit 4 have focused on containing the hazard, initially with the construction of the shelter structure under the Shelter Implementation Plan, and then more recently with the New Safe Confinement (NSC) structure. It is important to recognize that these structures are intended to be a temporary measure, albeit long-term, and that the ultimate decommissioning strategy is to retrieve the wastes and dispose of them.

A1 NPP, Slovak Republic (previously Czechoslovakia)

Prior to the A1 NPP accident, there was no legislation, strategies, or plans in place that addressed the issue of decommissioning a nuclear facility, and furthermore, there was a lack of experience within the Slovak Republic concerning the topic of decontamination and dismantling. The lack of a legislative framework, experience, strategy, and specific plans to support the decommissioning of the damaged A1 NPP meant that it was treated as an abnormal situation and consequently activities were undertaken on the basis of safety priorities and available finances. Further complicating the situation was the fact that a repository for low and intermediate level radioactive waste was not available.

Three decommissioning strategies for the A1 NPP were evaluated in 1997: (i) restoration of the site to a green field end state, (ii) safe containment for 30 years, and (iii) decommissioning with surveillance over a period of 30 years. Decommissioning to a green field end state was selected as the preferred strategy, and extensive discussions were initiated concerning the timing of activities, the management of radioactive wastes, and the definition of the final end state.

As a result of these discussions, a modified option was developed, and it was this option that was included in the EIA. The primary differences between the modified strategy and the original strategy were (i) the turbine hall would be retained for radioactive storage, (ii) the decommissioning process would take longer than originally envisaged and would involve a "cold to hot" approach whereby decommissioning would move from areas of low contamination to areas of high contamination, and (iii) the site would be taken to a brown field final end state. This strategy has been accepted by the regulatory authorities and is based on the premise that the site will not be used in the future for agricultural or residential purposes.

First Generation Magnox Storage Pond (FGMSP), Sellafield, UK

The NDA is responsible for developing UK waste management and decommissioning strategies within the context of the national policy framework. It has developed a prioritization system under which the legacy ponds and silos at Sellafield, of which FGMSP is one, have been established as the number one decommissioning priority. Sellafield Limited has published a set of strategic objectives for FGMSP: (i) maintain safe storage of the radioactive inventory, (ii) retrieve, export, and immobilize the sludge, (iii) retrieve and passivate solids, (iv) decommission all facilities, and (v) demolish the pond to the base slab.

The scope of the programme is to progressively retrieve and treat the radiological inventory residing within the facility by first reducing the risk posed by its ongoing storage, and then by reducing the inherent hazard of the materials. Expectations that the site can be fully delicensed may be difficult to meet due to potential difficulties in removing ground contamination, and as a result it is possible that some form of long-term institutional control for the existing facility footprint may be required. It is also possible that some aspects of the facility may utilize an in-situ disposal methodology; however, since the final end state is not yet defined, these possibilities remain speculative.

Marcoule Nuclear Centre, France

Mathematical modelling indicated that without mitigative measures being taken at the Marcoule site, there was a high probability for significant off-site radiological impacts on the environment. Therefore, initial decommissioning efforts focused on those facilities containing plutonium. To the extent possible, decommissioning was carried out in combination with final shutdown operations to minimize interim monitoring and surveillance costs, and to take advantage of the knowledge and skills of the operating personnel in those facilities being decommissioned.

In the case of Marcoule, decommissioning activities are proceeding without a final agreement between the licensee and the regulator as to the final end state of the site, a situation with its origins in the fact that there is currently insufficient information about the site to enable an end state to be definitively established.

Industrial Uranium Graphite Reactors (IUGRs), Russian Federation

Decommissioning strategies and plans for the IUGRs were not developed during their design or operational periods. Furthermore, they were sited in remote areas where it was expected that the land would not be used for subsequent industrial or agricultural purposes. As a result, two decommissioning strategies were considered for the IUGRs: (i) deferred dismantling with interim storage over a period of 70 to 100 years, and (ii) dismantling and removal of equipment followed by partial demolition of the buildings and then in situ disposal of the reactor core.

In assessing these two options, factors including the high cost of the safety and security measures required for prolonged storage, the lack of necessary decommissioning funds, and the absence of adequate radioactive waste disposal facilities led to the choice of in situ disposal for the Tomsk IUGRs which are located in a natural clay geology, and for the Krasnoyarsk IUGRs which are located inside a mountain. The decommissioning strategy for the Mayak IUGRs is deferred disposal.

Al-Tuwaitha Nuclear Research Centre, Iraq

The destroyed nuclear facilities and sites in Iraq represent significant hazards to the environment, the public, and workers as a consequence of radioactive material being released to the environment due to the loss of the containment measures. The dangers were further aggravated by the unsafe condition of the structures located at the DNF sites. Based on a consideration of the nature and type of hazards found at these sites, a prioritized decommissioning plan was developed in cooperation with the IAEA to mitigate the risks. The basis of this plan was to dismantle the facilities in three phases discussed below.

Phase (1) represented a short-term decommissioning programme aimed at the demolition of three facilities with low levels of radiological risks, i.e., LAMA, Geo-Pilot, and RIPL. Phase 1 is now complete. Phase (2) was originally planned to take place over a 5 year period, but delays have been encountered, and work is still underway. Phase (2) work focuses on facilities with intermediate and high level radiological risks, for example, the Tammuz-2 research reactor and the Fuel Fabrication Facility. Phase (3) constitutes a long-term project and has not yet started. Based on current projections, the goal is to complete Phase (3) by 2025 during which time work on the remaining nuclear facilities as well as on the entire site of the Al-Tuwaitha nuclear research centre is scheduled for completion.

The proposed end state for the Al-Tuwaitha nuclear research centre involves the creation of two areas, i.e., (i) an area outside the site boundary which will be cleaned up to background levels, and (ii) an area inside the site boundary and which will be divided into two zones. The first zone within the site boundary will be cleaned to a restricted release level and is scheduled to contain future radioactive waste storage bunkers, waste storage facilities, and future nuclear facilities. The second zone within the site boundary will be cleaned up to an unrestricted release level and as such may continue to be used to contain the administration buildings which are currently located in this area.

5.4. DECISION MAKING

5.4.1. Discussion and case studies

This section considers how the decision making processes used in a Member State may be impacted by the circumstances surrounding to a DNF, and whether there may need to be changes in the established decision making processes to accommodate the situations found in a post-emergency phase. In the case of normal operations, agreements concerning decommissioning end states may have been reached between the operator, regulator, government, and local communities. However, in the case of DNFs, the previously agreed end states may no longer be realistically achievable due to the levels of contamination remaining even after extensive cleanup initiatives. Furthermore, additional major decisions will likely be required about related issues concerning, for example, the nature and location of new waste storage, treatment, and disposal facilities. An underlying fact is that just as the regulatory framework may require changes to address a post-emergency phase, the same may apply to the dynamics of decision making. For example, it may be necessary to streamline a decision making process if delays caused by the process are contributing to increased safety risks.

One possible impact on the decision making process may be that additional stakeholders either need to be, or expect to be, engaged in the decision making process, and in some instances the final decision maker may be changed as a result of an accident, e.g., the national government or local government, rather than the operator. The ultimate question may be whether the existing decision making process is or is not suitable for the new post-emergency situation.

In the case of TMI, it was found that the pre-emergency decision making process was adequate for the post-emergency phase because the NRC was able to utilize the existing licensing process to make progress at the site. Furthermore, politically appointed investigation and research committees further enhanced the efficacy of the decision making process. Other than addressing the issue of emergency response through the formation of special teams, there were no additional special measures found necessary in terms of the decision making process.

As a direct consequence of operational priorities at the Sellafield site, the decommissioning of the First Generation Magnox Storage Pond (FGMSP) was not progressing as quickly as required, and as a result, there was further deterioration of the site with a corresponding increase in risk, on-going discharges, and secondary waste generation. Following the creation of the NDA, a system of prioritization was introduced whereby an assessment of the potential hazard of a facility determines the priority with respect to which actions are performed.

5.5. FINANCIAL ISSUES

5.5.1. Introduction

This section considers the changes to funding arrangements that may be necessary as a consequence of the liabilities associated with a DNF or legacy nuclear facility. The magnitude of DNF liabilities can often result in a greater level of government oversight and, in certain cases, to a greater level of direct governmental involvement in the development and implementation of the decommissioning activities relative to the levels typically found for a facility that has undergone a normal planned shutdown. This heightened level of oversight and involvement can be the result of increased public and political concern at the local, national, and international levels, and by the fact that direct financial support at a national level and/or international level may be necessary to deal with a DNF. In addition, a government may wish to exert a greater level of oversight to help ensure (i) the optimal use of taxpayer and contributed funds, and (ii) the appropriate use of private sector expertise for strategy implementation.

The financial arrangements that are in place for decommissioning prior to an emergency may need to be changed to adequately provide for the long-term management of the post-emergency phase. Current practices are such that new nuclear plants or facilities are generally required to have decommissioning plans in place even before startup, and that these plans include detailed financial analyses and provisions, such as (i) a systematic estimate of the costs of decommissioning the facility taking into account factors such as inflation, etc., and then (ii) a proposed mechanism by which a financial provision is established so that the required level of funding is available for decommissioning following a planned shutdown, i.e., a financial guarantee.

In some cases, the decision as to whether or not to proceed with a nuclear project may depend on the estimated decommissioning costs, the financial analyses, and the acceptability of the financial guarantee mechanism. However, in a post-emergency situation, those original cost estimates and financial mechanisms are likely to be invalid, and it may be necessary to re-estimate the implementation costs of a new decommissioning strategy taking into account various factors related to the accident and the increased uncertainties. These new factors will include: (i) changes to the nature and amounts of waste arisings, (ii) the potential impacts of using new and possibly unproven technologies for decommissioning, (iii) requirements for new storage and disposal facilities, and (iv) possible compensation payments to offset economic impacts to the local community.

As noted above, one method for establishing a decommissioning fund for a facility following its planned shutdown involves establishing a financial provision to cover decommissioning and waste management liabilities. This provision could be established by, e.g., regularly contributing to a segregated fund, or through financial arrangements set up in accordance with national requirements, e.g., a financial guarantee. However, following an accident, it is highly likely that these provisions will not be sufficient to meet the full costs of decommissioning and waste management. The resulting shortfall may need to be addressed using (i) other assets belonging to the operator, (ii) insurance payments, and (iii) direct contributions from a governmental budget or from international sources, such as the European Bank for Reconstruction and Development or other development banks. As part of the new financial structure, new governance arrangements may need to be put in place to manage the disbursements.

5.5.2. Summary of key points

Sources for the financing of post-emergency decommissioning activities can include:

- Existing decommissioning funds supplemented, where necessary, by special agreements;
- Insurance payments;
- Government funds;
- Utility resources and assets; and,
- International funding sources, e.g., regional banks.

Nuclear third party liability arrangements under various international conventions do not cover reparation of on-site damage, only off-site impacts.

5.5.3. Case studies on financial issues

Fukushima Daiichi NPS, Japan

In 2014, TEPCO made exhaustive revisions to its previous business plan, and upgraded it to the New Comprehensive Special Business Plan (the "New Plan"). The objective of the upgrade was to be in a position to remain responsive to subsequent changes in the business environment, and to reflect government policy regarding the separation of roles between the national government and TEPCO. The national government plays a proactive role in financially supporting priority decommissioning projects and specific initiatives where there are significant technical challenges, for example, the installation of frozen soil barriers at the site. The national government also provides financial support for the cleanup of contaminated water, and for the medium- and long-term development of human resources and R&D.

TEPCO's original (pre-emergency) cost estimate for the decommissioning of Units 1 to 4 following a normal planned shutdown was 185 billion yen (approximately US $1.7 billion). Currently, TEPCO has no estimate for the cost of post-emergency decommissioning work, but it has set aside approximately one trillion yen (approximately US $9.1 billion) to cover decommissioning and remediation work, and has also committed to a ten-year expenditure of more than 1 trillion yen.

Three Mile Island NPP Unit 2 (TMI-2), USA

The funding for the TMI-2 effort is directed at two components: accident remediation and final decommissioning. Remediation of the accident is now complete, and TMI-2 currently exists in a post-defueled, monitored storage state. TMI-2 is expected to be fully decommissioned at a later date, i.e., after the expiration of the TMI-1 license.

An initial estimate of the cost to "decontaminate and repair the damaged nuclear reactor and related facilities" was US $500 million to US $600 million, but the actual cost to remediate TMI-2 was approximately US $1 billion. Approximately two thirds of this cost was covered by the licensee via utility shareholders, customers, and insurance underwriters, while the remaining amount was provided by the DOE, the electric power industry, the States of Pennsylvania and New Jersey, and the Japanese government/nuclear industry (approximately US $18 million for research, knowledge management, and training purposes).

A decommissioning fund is currently maintained by the licensee to be used to complete the final decommissioning of the site. An annual funding status report is provided to the NRC, and the latest report indicates that the site-specific TMI-2 radiological decommissioning cost estimate is US $1.18 billion (escalated to 2014 dollars).

Unit 4 Chernobyl NPP (ChNPP), Ukraine

At the time of the accident in 1986, the USSR had not established any special funds for decommissioning and waste management, and the only financial resources available for use in remediation and decommissioning were from the USSR national budget until such time that Ukraine gained its independence in 1991.

Immediately following the accident, there was no accurate estimate of the funding that would be required to remediate the site; however, a later comprehensive estimate of the remediation costs were on the order of US $110 billion. Over the course of several years, approximately 10% of the USSR national budget was spent on cleanup and remediation activities.

After the collapse of the USSR in 1991, all activities at the accident site became the responsibility of the government of Ukraine. However, specialized support activities such as those associated with the design and construction of the shelter structure remained in Russia.

Resources within Ukraine were not adequate to address the issues arising from the accident, nor were there sufficient funds available for the remediation project. Consequently, further work at the accident site was carried out with assistance from the international community.

The Chernobyl Shelter Fund was established in 1997 to finance the work for the remediation of the DNF with the European Bank for Reconstruction and Development having the responsibility for administering the fund. The Chernobyl Shelter Fund is financed through voluntary contributions by more than 40 donor countries as well as the European Union and Ukraine. The New Safe Confinement (NSC) is expected to cost US $2.5 billion with the costs required for NSC maintenance and ensuring safety being assumed by Ukraine.

Further work to convert the shelter structure into an ecologically safe system through dismantling of the shelter structure, retrieval of FCM etc., is beyond the financial resources of Ukraine and may require further international involvement in financing.

A1 NPP, Slovak Republic (previously Czechoslovakia)

Funding for the decommissioning of the A1 NPP is currently ensured through the National Nuclear Fund, which is an independent legal entity managed by the Ministry of Economy, and which has its own governance structure. Funding for A1 NPP decommissioning is provided through charges that are levied as part of electricity prices, and the income from these charges is placed into a subaccount of the National Nuclear Fund.

First Generation Magnox Storage Pond (FGMSP), Sellafield, UK

Funding for the NDA programme is currently a combination of direct government funding (grant-in-aid) and income from commercial reprocessing, a funding mechanism which ends in 2018. At Sellafield, the nuclear decommissioning estimate combines the cost projections provided in the site performance plan (known as PP14) with management estimates of both near-term and very long-term costs. The NDA estimate of the lifetime cost for the decommissioning and cleanup of Sellafield has been increasing in recent years. As of 31 March 2017, the NDA undiscounted estimate of the financial provision required for Sellafield was 74% of the total NDA nuclear provision of £119 billion over 120 years (with a range between

£97 billion and £222 billion). The NDA treats the increase in the lifetime cost estimates as primarily being a result of gaining a better understanding of the scale and nature of the risks and challenges on the site, and that it also reflects a more realistic assessment of the level of efficiencies achievable within the plan.

The estimated completion date for the FGMSP decommissioning programme was extended significantly between 2007 and 2010, and was further extended when the NDA agreed to the 2010 performance plan. The revisions to the completion date reflect slower progress than expected over recent years, and an improved understanding on the part of Sellafield Limited about the challenges that may be involved.

Marcoule Nuclear Centre, France

When the reprocessing plant UP1 was shutdown, Areva, EDF, and CEA had no financial provisions in place for decommissioning, and therefore all decommissioning tasks, as well as the operation of the facilities themselves, were financed through the "Dedicated Marcoule Defence Fund". Starting in 2005, CEA became the operator of the Marcoule site and hired 300 Areva employees. As of 2010, CEA became the contracting authority for decontamination and dismantling operations at UP1. As part of this process, a matrix organization was established within CEA whereby Areva became a subcontractor. The Dedicated Marcoule Defence Fund became exhausted in 2015, and currently the decommissioning of UP1 is financed by an annual subsidy from the French government.

Industrial Uranium Graphite Reactors (IUGRs), Russian Federation

The funding for the decommissioning of the IUGRs was included as part of government funding and was identified as "Insurance of Nuclear and Radiation Safety of the Russian Federation for 2008 to 2015". In practice, this arrangement is such that funding is provided as part of the national budget.

Al-Tuwaitha Nuclear Research Centre, Iraq

The Ministry of Science and Technology (MoST) is responsible for estimating the funding required for decommissioning, and for submitting a request to secure this funding. Funding typically comes from three different sources: (i) the government (Ministry of Planning), (ii) from investments, and (iii) from technical cooperation agreements with various international sources for, e.g., training, fellowships, etc. The majority of the funding depends on support from the Iraqi government and the Ministry of Planning, but the budget does not include staff salaries and the costs of radioactive waste management.

5.6. STAKEHOLDER AND SOCIO-ECONOMIC ISSUES

5.6.1. Introduction

This section is intended to examine how stakeholder involvement with a nuclear facility may be affected as the result of an accident, and also explores what actual changes have been made in terms of stakeholder involvement by Member States as a result of accidents. Under normal circumstances, decommissioning and waste management initiatives generally involve stakeholder engagement activities. These activities may be part of a formal EIA process carried out prior to the commencement of decommissioning, or as part of routine information exchanges between operator, regulator and local community that take place through local stakeholder groups.

In a post-emergency phase, the established routes of stakeholder communication may not be adequate, and it may be necessary to establish new arrangements to ensure that there is an effective mechanism in place for accurate, timely, and regular information exchange. In the circumstances following an accident at a nuclear facility, interacting and communicating with stakeholders may prove to be an extremely important and key activity by which to provide reassurance, restore and maintain trust, and to ensure that informed inputs are a part of decision making and strategy development. For example, the local community may reasonably be expected to have strong views on the remediation of off-site contaminated land, and on the disposal of very large quantities of very low level waste in new facilities. Another area that may garner public concern is changes to the proposed end state of the site as a consequence of the accident. For example, prior to the accident, the proposed end state may have been unrestricted release, i.e., suitable for public or agricultural use. However, as a consequence of the accident, this end state may no longer be achievable, and agreements will need to be reached about interim or new end states. As part of the process to gain new agreements on, for example, revised end states, it may be crucially important that the stakeholders, particularly the public, fully understand the circumstances surrounding the accident, and the limitations that are now dictated by these circumstances in terms of future options. Providing all stakeholders with a thorough understanding of post-emergency conditions may be key to securing their approval for a revised strategy. Characteristics of an effective communication strategy include transparency, clear messaging, accuracy, and an openness to input. While the communications taking place during the confusion of the emergency phase may be less than optimal, it is important to ensure that this is not the case during the post-emergency phase. IAEA Safety Standards Series No. GSG-14, Arrangements for Public Communication in Preparedness and Response for a Nuclear or Radiological Emergency [18], provides recommendations in developing arrangements for communicating with the public and media and coordinating official information in the response to an emergency, including the transition phase.

Following an accident at a nuclear facility, affected communities may lose confidence not only in facility management and operational staff, but also in governmental oversight organizations such as regulatory bodies, and rebuilding this confidence may represent a major challenge. This could be particularly problematic if, for example, the actions required of the public during the emergency phase were particularly disruptive, for example, temporary or even permanent evacuations. Depending on the nature and severity of the impacts, it is possible that some form of reparation may be required to compensate the affected populations. However, based on the experience gained at Chernobyl, and to a lesser extent at Fukushima Daiichi, care may need to be taken to not create a 'compensation culture' based on perceived harm, and that the level and scope of the reparation be realistic and objective. Moreover, analysis of these situations also seems to strongly suggest that part of the reparation process should involve a degree of self-help. Dealing with reparations is clearly a complicated issue and may require the help of organizations that have specialized experience in this field. Furthermore, it is important to realize that there may be a wider community which, although not physically affected by the accident, may suffer indirect adverse effects from, for example, the loss of tourism or a decrease in food exports due to being associated with the accident or the accident site. Under these circumstances, extra financial assistance to such wider communities may be required in addition to that provided to the communities that were directly affected.

5.6.2. Case studies on stakeholder and socio-economic issues

Fukushima Daiichi NPS, Japan

Actions taken following the accident at the Fukushima Daiichi NPS to address compensation and reparations were based on the "Act on Compensation for Nuclear Damage", and resulted in the Ministry of Education, Culture, Sports, Science and Technology (MEXT) establishing the Dispute Reconciliation Committee for Nuclear Damage Compensation. This committee arranged settlements for damages, and formulated guidelines for the extent of compensation based on the nature of the damages. The guidelines address (i) evacuation expenses, (ii) business damages, (iii) damages arising from being incapacitated, (iv) loss or reduction of property value, (v) medical examination and inspection expenses (human and material), (vi) injury or death, (vii) mental anguish, (viii) temporary access expenses, (ix) homecoming expenses, and (x) methods for calculating compensation for evacuation expenses and for mental anguish arising from having lived as an evacuee.

In 2011, the committee established interim guidelines that provided general policies and included a mechanism for prompt out of court settlements for compensation claims. The compensation policy applies to those people ordered to evacuate, and also covers impacts on (i) livelihood and way of life, (ii) loss of profits due to restrictions, (iii) loss of trust by consumers, and (iv) changes to the infrastructure that affect people remaining in the area. In addition, there are specific provisions for parents with young families and for pregnant women. A supplement to the interim guidelines was also issued to cover voluntary evacuation, i.e., evacuations not based on government instructions issued on 6 December 2011. In order to ensure that TEPCO can meet its obligations to the victims of the accident, financial support is being provided to TEPCO by NDF, and NDF is becoming the controlling shareholder of TEPCO.

Three Mile Island NPP Unit 2 (TMI-2), USA

In addition to the funding required for remediation and decommissioning initiatives, there was a requirement to provide compensation to the affected members of the public in accordance with the requirements of the 1957 Price-Anderson Act which provides liability insurance to the public. This legislation placed a cap on the total amount of liability that each nuclear power plant would face in the event of an accident, and was intended to encourage private investment in the nuclear power industry. At the time of the TMI-2 accident, private insurers had approximately US $140 million of coverage readily available, and funds were provided to evacuated families to cover their living expenses. The insurance funds were also used to reimburse more than 600 individuals and families for wages lost as a result of the accident, and later to settle a class-action suit related to losses encountered by residents near to the TMI-2 site. In total, insurance funds paid approximately US $71 million in reparations for claims and litigation associated with the accident.

New NRC regulations which were enacted as a result of the TMI-2 accident also require licensees to maintain a minimum of US $1.06 billion in on-site property insurance at each reactor site. This insurance is required to cover licensee obligations to stabilize and decontaminate the site after an accident.

Unit 4 Chernobyl NPP (ChNPP), Ukraine

The areas most affected by the Chernobyl accident were Ukraine (37 000 km^2), Belarus (46 000 km^2), and Russia (57 000 km^2). In 1986, at the time of the accident, there were approximately 5 million people living in these locations, of which approximately 400 000 lived in the more highly contaminated regions. In total, 116 000 people were evacuated from the exclusion zone surrounding the accident site during the spring and summer of 1986, and an additional 220 000 people were resettled during the subsequent years.

In addition to members of the general public who were affected by the accident, it has been estimated that during the initial efforts to mitigate the effects of the accident in the period between 1986 and 1987, approximately 240 000 emergency response workers from the army, nuclear power plants, and local law enforcement and firefighting agencies were involved in major activities located close to the reactor and within a 30-km exclusion zone.

Other impacts from the accident included the removal of 784 320 hectares of agricultural land from use, and the cessation of the construction of the Chernobyl NPP third generation Units 5 and 6 which were at a completion level of about 70–80% at the time that construction was stopped.

Following the accident, large-scale restoration measures were adopted. To accommodate the relocated population, considerable funds were invested in the construction of housing, schools, and hospitals, as well as in physical infrastructure including roads, water, energy sources, and sewage systems.

As part of the restoration initiatives, the town of Slavutich was established to house 26 000 people, and a "special economic zone" has been created at Slavutich to provide preferential conditions that support regional economic development.

In 2016, a decision was made that the Chernobyl NPP and the exclusion zone territory could be used for investment projects, e.g., projects relating to renewable energy sources such as solar and wind power plants, the growing of energy related crops, etc.

The current strategy is to re-use the ChNPP site for industrial purposes. One potential and well suited use for the ChNPP site, the exclusion zone, and the existing infrastructure could be the establishment of facilities for the processing of radioactive waste and spent nuclear fuel. Utilizing the site in this manner could help ensure the economic development of the impacted region.

A1 NPP, Slovak Republic (previously Czechoslovakia)

In 1995, the Slovak Republic acceded to the Vienna Convention on Civil Liability for Nuclear Damage [19], thereby establishing provisions for financial compensation for liabilities incurred as the result of nuclear accidents. The international obligations of the Vienna Convention were subsequently incorporated into the national law of the Slovak Republic in 1998 and updated in 2004. In 2015, a separate Act on Civil Liability for Nuclear Damage and on its Financial Coverage was passed, which provides additional details concerning the provision of financial compensation for damages resulting from nuclear accidents; however, the 2015 law did not contain retroactive provisions for damages suffered in the A1 NPP accident.

Marcoule Nuclear Centre, France

The decommissioning of the Marcoule Pilot Plant for nuclear fuel reprocessing (APM) and the Phénix reactor require public engagement and periodic presentations to local authorities. However, this is not the case with UP1 and G1 which are defence facilities. The primary concern for local stakeholders is that Marcoule might become the site of a deep geological repository for radioactive waste. At the same time, stakeholders understand that the challenge for the companies located at Marcoule involves securing roles in national and international projects. Insight into the current stakeholder attitudes concerning the latter point can be found in their active participation in the creation of the Centre for the Conversion of Industrial Sites Marcoule (PVSI) which has four objectives: (i) undertake technological research, (ii) promote industrial development, (iii) provide training, and (iv) establish a world class reputation. The continued operation of the PVSI is sustained by making use of currently available expertise and networks including, for example, (i) mature and innovative technologies suitable for industrial applications, (ii) an effective network of communications with research organizations and institutions of higher education, (iii) broad expertise in sustainable chemistry and environmental cleanup techniques that utilize biological processes, (iv) education programmes ranging from the baccalaureate level to technological and university degrees, (v) recognized regional experience in supporting and funding innovative initiatives, and (vi) a growing network with small and medium sized companies.

Industrial Uranium Graphite Reactors (IUGRs), Russian Federation

The local population, employees at the IUGR sites, and local companies are extremely supportive of the decommissioning of the IUGRs as it provides jobs and promotes environmental protection. At Tomsk, a skills and demonstration centre for the decommissioning of IUGRs has been established that provides training and has stimulated the development of technologies for radioactive waste management. Similar initiatives have been adopted at other sites including the power reactors at Beloyarsk NPP. Proposal is in place to develop a deep geological disposal facility for intermediate and high level radioactive waste.

Al-Tuwaitha Nuclear Research Centre, Iraq

The bombing and destruction of Al-Tuwaitha was treated as a unique situation and, consequently, compensation was not provided. While there was no official order for members of the local community to evacuate, many people did leave the area following the destruction due to concerns about unsafe conditions at the Al-Tuwaitha site. In considering the unique situations surrounding the Al-Tuwaitha destruction, it was viewed as being particularly important to address any concerns from members of the local community, and therefore stakeholder engagement was undertaken prior to the start of the decommissioning project. The relevant stakeholders were considered to include, members of the public, MoST, the Iraqi regulatory bodies, local governments, and members of the press. As an example of stakeholder engagement, in 2008 MoST held a conference in Baghdad to announce the start of the decommissioning project. The objective of this conference was to explain the importance of this project for both the Iraqi people and the environment. Many members of the Iraqi parliament, press, regulatory bodies, and members of the public participated in this conference, and in addition, experts from the IAEA, Texas Technical University, and Sandia National Laboratories attended.

5.7. EPIDEMIOLOGY

Following a major nuclear or radiological accident, particularly when there are off-site impacts, it may be beneficial to perform epidemiological studies of the affected population, including both workers and the general public. Epidemiological studies were undertaken following both the Chernobyl accident and the Fukushima Daiichi accident.

6. OBSERVATIONS AND CONCLUSIONS

The objective of this section is to summarize the salient points contained in this publication as identified by each of the three working groups, i.e., those working groups examining (i) regulatory issues, (ii) technical issues, and (iii) strategic planning.

6.1. GENERAL OBSERVATIONS

The contents of this publication identify the differences that are found in terms of the regulatory, technical, and strategic planning challenges generally found with the decommissioning and remediation of facilities that have undergone a normal planned shutdown or where there have been no major accidents, as compared to the regulatory, technical, and strategic planning challenges found in the case of facilities where there has been a major accident or incident or where circumstances have resulted in legacy facilities.

An extensive knowledge base is available concerning the lessons learned from nuclear accidents. An extensive base of knowledge also exists describing the decommissioning and remediation activities that have been applied during a post-emergency phase.

In each of the case studies presented in this publication, issues and challenges were identified concerning regulatory, technical, and strategic planning matters.

The case studies contained in this publication provided the three working groups with valuable information about (i) the nature of the challenges and issues that arose following an accident or with a legacy facility, and (ii) the approaches used in addressing the challenges and issues. As the working groups examined the case studies in detail, various observations and conclusions were often found to be common to all of the cases. As a means of effectively communicating the findings of the working groups, it was decided that it would be beneficial to summarize these key observations and conclusions, and that the summary could help direct readers to those sections in the main body of the publication containing more details about the observation or conclusion.

6.2. KEY OBSERVATIONS ON REGULATORY ASPECTS

Serious accidents can drive significant changes in regulatory frameworks and in the laws and regulations included as part of that framework.

A risk based regulatory approach that balances near-term risk and long-term risk may enable a faster response in terms of hazard and risk mitigation. A shared understanding of risk based decision making by both the licensee and the regulator may aid in the effective development, approval, and implementation of a prioritized action plan based on risk levels and risk assessments.

The regulatory process needs to be flexible and responsive to enable a licensee to make changes to any pre-accident decommissioning plans. A rigid, prescriptive regulatory regime characterized by, for example, a long and complex approval process, could prevent regulatory bodies from providing approvals and decisions on timely basis, and as a consequence, slow progress on hazard and risk reduction could result. The issue of inflexible regulatory responsiveness could be dealt with by, for example, (i) reducing or changing formal regulatory stages, e.g., approval points, or (ii) by providing an increased level of regulatory oversight as an alternative to formal approvals. Provisions for making specific changes in regulatory frameworks could be such that they could only be invoked under set circumstances, e.g., in response to a nuclear accident.

Applying safeguards requirements in the same manner as they are applied to normally operating facilities or to facilities that have undergone a planned shutdown can be extremely challenging for DNFs due to an inability to inspect, quantify, characterize, or even locate the inventory. Under these circumstance, realistic requirements for the practical accountancy of nuclear material are needed.

Establishing final end states for a DNF may not be practical until sufficient information is available about the condition of the facility. In response to this issue, the case studies reveal that some jurisdictions have defined interim end states, whereby the achievement of an interim end state represents a significant step change (i.e., reduction) in risk, and the attainment of a stable, sustainable state.

6.3. KEY OBSERVATIONS ON TECHNICAL ASPECTS

The observations and conclusion presented below were derived from the case studies presented in this publication and provide both insight into the technical challenges that were encountered in the remediation and decommissioning of DNFs, as well as some of the methods that were employed in addressing these issues. The extremely unique circumstances that result in a DNF mean that the challenges and solutions discussed below are not all-inclusive.

Given the unique aspects of a DNF, it may be beneficial to undertake a “pre-planning” stage prior to establishing a plan for post-emergency actions in order to identify those issues that may require significant resources, R&D, long lead time procurement, or construction.

While, in general, the analytical tools used to characterize DNFs are the same as those for facilities unaffected by accidents or neglect, the collection, analysis, interpretation, and use of the resulting data may differ significantly. The case studies show that the technologies available for characterization under normal conditions may not be useful in conditions characterized by high radiation fields, accessibility constraints, and new or unique hazards. Therefore, the deployment and/or development of adapted, advanced or non-standard characterization techniques may require the use of advanced remote handling techniques.

Equipment required for the environmental monitoring of a DNF may be available from other DNFs facing or having faced similar monitoring and analysis requirements. It may be advisable to assume that all safety systems in a DNF are non-functional, and that temporary methods for monitoring critical parameters will be required. This is particularly true for parameters involving (i) criticality control, (ii) heat dissipation rates, (iii) radiological conditions, and (iv) structural integrity. Additional measures, such as the provision of a new confinement system, may be required to support decommissioning and remediation.

The contamination found at a DNF is likely to constitute an environmental hazard. To mitigate these hazards, it may be necessary to establish an exclusion zone, and to include provisions within the exclusion zone to prevent the release of water from the zone, and to prevent flood water from entering the zone.

In order to successful manage the radioactive material generated as part of remediation and decommissioning initiatives, it is generally necessary to thoroughly understand its origins and characteristics to facilitate its classification and downstream processing and disposition paths. However, a potentially complicating matter is the fact that waste forms of unexpected types (e.g., fuel debris) may be present at a DNF or legacy site, and that these types of waste may either not comply with existing regulatory requirements and WAC, or represent a type of waste for which there are no WAC. Consequently, the pre-accident waste management infrastructure within a Member State could require significant changes, and unexpectedly large quantities of solid and liquid wastes may necessitate new or expanded volume reduction and processing facilities as well as new disposal routes.

The management of damaged fuel, fuel debris, and FCM is essential for hazard mitigation and the reduction of potential radiological consequences. The requirement to manage large quantities of damaged fuel and FCM may not have been part of pre-accident decommissioning planning, and therefore R&D initiatives may be required to develop methods and techniques to handle this material, and to develop waste management strategies, including retrieval and downstream processing.

The use of robotics and remote handling technology has proven to be an important tool in the remediation and decommissioning of DNFs. However, robotic and remote handling equipment capable of functioning in areas with high levels of radioactivity, or where access is particularly problematic may not always be possible with off-the-shelf equipment, and developmental work will likely be required. Likewise, the use of robotic and remote handling equipment may require highly developed skills, and therefore training programmes will be necessary. Experience contained in the case studies shows that to maximize safety and effectiveness with the use of remote handling systems, the training is best carried out in the actual facilities where the equipment will be used, or through the use of realistic mock-ups.

The decontamination technologies employed with DNFs may be similar to those used in the remediation and decommissioning of facilities that have gone through a normal planned shutdown. However, the decontamination processes may be more difficult to carry out due to, for example, high radiation fields and access issues, and the wastes resulting from the decontamination procedures may be greater in volume and different in nature than those found with facilities in a normal planned shutdown state. Therefore, the decontamination methodologies may require R&D support, and the activities themselves may require extra measures to minimize radiation exposures to workers. Attention should be paid to the generation and processing of secondary waste generated during the decontamination activities.

As part of the emergency planning process, provisions for the availability of sufficient quantities of decontamination supplies may warrant inclusion.

6.4. KEY OBSERVATIONS ON INSTITUTIONAL FRAMEWORK AND STRATEGIC PLANNING

Based on the information provided in the case studies, there is a high probability that an accident at a nuclear facility will bring about changes to organizations that were involved with, even peripherally, the nuclear industry. In some cases, the accidents have led to concerns that pre-accident organizational structures may have contributed to the circumstances leading to the accident.

In examining examples of the organizational changes that resulted following an accident, it becomes apparent that the changes often occur through a series of small reorganizations rather than a single large reorganization. The changes to organizational structures can be driven by considerations surrounding technical aspects of the DNF, but in several instances it is clear that the changes were the result of external drivers, e.g., political pressure, public opinion, funding and liability issues, or international pressure.

While organizational changes may be important, not all reorganizations contribute directly to the mitigation of risks at a DNF. Therefore, care may need to be taken to ensure that organizational changes do not create an inaccurate impression of progress towards risk mitigation.

In the majority of cases, an accident will require additional levels of funding and revised financial oversight relative to pre-accident plans. In some cases, the organizational changes discussed above will provide improved financial oversight.

National policies and/or strategies for radioactive waste management and for decommissioning may or may not have been in place prior to the accident. However, in either case, it is likely that an existing strategy will need to be revised, or a new strategy developed to accommodate the liabilities associated with a DNF. The successful development and implementation of new or revised strategies can very much depend upon the resources, i.e., human, financial, and technical that are available within a Member State, and in some cases it may be necessary to utilize international expertise and resources.

In those cases where there is limited expertise in a Member State in terms of the decommissioning process, it may be advisable to undertake initial activities in areas with low levels of radiological hazards, and then as experience is gained, progress to activities in higher hazard areas. However, in some cases it may be necessary to immediately secure experienced resources to address risks requiring immediate attention, and then subsequently proceed with the above approach.

Pre-accident plans for facility end states may need to be revised to include the conditions found at a DNF. For example, prior to an accident, plans may have been for the unrestricted release of a site, but this end state may no longer be realistic for a DNF.

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ABBREVIATIONS

AEOD	Office for Analysis and Evaluation of Operational Data
AEV	armoured engineering vehicles
ANDRA	French National Radioactive Waste Management Agency
ANRE	Agency for Natural Resources and Energy
APM	pilot plant for nuclear fuel reprocessing
BNFL	British Nuclear Fuels Limited
CCB	cask custody building
CCD	closed circuit digital
CEA	Commissariat à l'Energie Atomique et aux Energies Alternatives
ChNPP	Chernobyl NPP
CLD	Central Laboratories Directorate
CSFS	common spent fuel storage
CSKAE	Czechoslovak Atomic Energy Commission
DNF	damaged nuclear facility
DOE	U.S. Department of Energy
DWP	defueling work platform
EIA	environmental impact assessment
FCM	fuel containing material
FGMSP	First Generation Magnox Storage Pond
FHP	fuel handling plant
ICSRM	industrial complex for solid radioactive waste management
IDC	Iraqi Decommissioning Centre
IDD	Iraqi Decommissioning Directorate
IDP	Iraq decommissioning project
INES	International Nuclear and Radiological Event Scale
IRSRA	Iraqi Radioactive Sources Regulatory Authority
ISTC "Shelter"	Inter-Branch Scientific and Technical Centre "Shelter" of the Academy of Sciences of Ukraine
IUGR	Industrial Uranium Graphite Reactor
JAVYS	Jadrová a vyraďovacia spoločnosť, a.s.
METI	Ministry of Economy, Trade and Industry
MEXT	Ministry of Education, Culture, Sports, Science and Technology
MoST	Ministry of Science and Technology
NDA	Nuclear Decommissioning Authority
NDF	Nuclear Damage Compensation Facilitation Corporation
NII	Nuclear Installations Inspectorate
NISA	Nuclear and Industrial Safety Agency
NRA	Nuclear Regulation Authority
NRC	U.S. Nuclear Regulatory Commission
NRSD	Nuclear and Radiological Safety Directorate
NSC	new safe confinement
ONR	Office for Nuclear Regulation
PBO	parent body organization
PEIS	programmatic environmental impact statement
PCV	primary containment vessel
PDMS	post-defueling monitored storage
PPE	personal protective equipment

RIPL	Radioactive Isotopes Production Laboratory
ROV	remote operated vehicle
RPC	Radiation Protection Centre
RPD	Radiation Protection Department
RPE	respiratory protection equipment
RPV	reactor pressure vessel
RS-4	reactor shop at Unit 4, ChNPP
RWMO	radioactive waste management organization
SFP	spent fuel pool
SIXEP	Site Ion Exchange Effluent Plant
SNM	special nuclear material
SPP1	sludge packaging plant 1
SSC	structures, systems and components
TEPCO	Tokyo Electric Power Company
TMIPO	Three Mile Island program office
UJD SR	Nuclear Regulatory Authority of the Slovak Republic
UKAEA	United Kingdom Atomic Energy Authority
UP1	fission product concentration facility
WAC	waste acceptance criteria

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