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Contents

This book is dedicated to my son Jason.

Contributor contact details

(* = main contact)

Editor and Chapters 1, 2, 6

J. Devgun
Senior Consultant
USA

Email: jasdevgun@gmail.com

Chapter 3

J. LeClair
Dean School of Business and Technology
Excelsior College
7 Columbia Circle
Albany
New York 12203, USA

Email: jleclair@excelsior.edu

Chapter 4

M. Rawlings
General Engineer, D&D and Facility Engineering
Department of Energy, Office of Environmental Management
20400 Century Blvd.
Germantown, MD 20874
USA

Email: Mark.Rawlings@em.doe.gov

Chapter 5

J. P. Ordonez*
Deputy Manager, Nuclear Division, INVAP
Associate Professor, Balseiro Institute
Comandante Piedrabuena 4950
8403 Bariloche, Argentina

Email: jordonez@invap.com.ar

N. De Lorenzo
Senior Project Manager, Nuclear Division, INVAP
Assistant Professor, Balseiro Institute
Comandante Piedrabuena 4950
8403 Bariloche, Argentina

Email: delorenz@invap.com.ar

Chapter 7

C. Allen
United States

Email: allencw@missouri.edu

Chapter 8

H. P. Berg*
Department of Nuclear Safety
Federal Office for Radiation Protection
Willy-Brandt-Strasse 5
Salzgitter 38226
Federal Republic of Germany

Email: bilianaberg@abv.bg

P. Brennecke
Lortzingstrasse 27
Braunschweig 38106
Federal Republic of Germany

Email: peter.brennecke@gmx.de

Chapter 9

L. Noynaert
Expertise group Decommissioning, Decontamination and Waste Management
SCK•CEN
Boeretang 200
B-2400 Mol, Belgium

Email: luc.noynaert@sckcen.be

Chapter 10

J-J. Grenouillet
EDF – CIDEN
154 Avenue Thiers
CS 60018
69458 LYON CEDEX 06
France

Email: jean-jacques.grenouillet@edf.fr

Chapter 11

S. Walker*
U.S. Environmental Protection Agency
Office of Superfund Remediation and Technology Innovation (OSRTI)
Science and Policy Branch
1200 Pennsylvania Avenue, NW (5204 P)
Washington, DC 20460, USA

Email: Walker.Stuart@epamail.epa.gov

B. Donovan
U.S. Environmental Protection Agency
290 Broadway
New York, 10007, USA

Email: donovan.betsy@epa.gov

Melissa Taylor
US EPA Region 1
5 Post Office Sq
Suite 100
Mail Code OSRR 07-4
Boston, MA 02109

Email: taylor.melissag@epa.gov

M. Aguilar

Email: Aguilar.Mark@epamail.epa.gov

Chapter 12

D. Taggart
Taggart Quality Consulting
916 Amethyst Drive
Santa Maria
California
CA 93455, USA

Email: dataggart@taggart-quality.com

Chapter 13

P. Brennecke
Lortzingstrasse 27
Braunschweig 38106
Federal Republic of Germany

Email: peter.brennecke@gmx.de

Chapter 14

R. Ritzman
80 Beck Ave
Akron
Ohio 44302, USA

Email: raritzman@hotmail.com

Chapter 15

T. Varjoranta
Kivimaentie 62 A
00670 Helsinki, Finland

Email: tero.varjoranta@gmail.com

Chapter 16

M. Laraia*
International Atomic Energy Agency (IAEA) (retired)
Kolonitzgasse 10/2
A-1030 Vienna, Austria

Email: Michele.Laraia@aon.at

Claudio Pescatore
OECD/Nuclear Energy Agency
Radiation Protection and Radioactive Waste Management Division
Le Seine Saint-Germain
12 Boulevard des Iles
92130 Issy-les-Moulineaux
France

Email: claudio.pescatore@oecd.org

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Preface

As energy demand continues to grow, nuclear energy is expected to continue to play an important role in the world's mix of energy options. Prior to the Fukushima Daiichi accident, the nuclear power industry had been in the early stages of a 'renaissance', and it had been estimated that anywhere from 60 to 130 new power reactors may be built worldwide over the next 20 years. Even though the events at Fukushima Daiichi have dampened the nuclear renaissance, the existing fleet of commercial reactors in the world continues to provide a significant share of the electricity production and reactor construction projects are continuing, especially in the emerging economies. In addition to the commercial power industry, the nuclear field has extensive projects and activities in the area of research reactors, medical isotope production, decommissioning of nuclear facilities and remediation of contaminated sites.

Although extensive literature is available on the science, engineering and design aspects of nuclear power plants, there has been relatively little from the aspects of managing nuclear projects and covering a wider range of areas in the nuclear field. It is felt that a book covering a wider range and addressing aspects from the perspective of a manager with emphasis on the process, requirements and lessons learned will be timely and worthwhile.

This book comprises four parts: Part I Basic principles; Part II Managing reactor projects; Part III Managing radioactive waste, decommissioning and site remediation; and Part IV Regulation, guidance and emergency management. The contributors to the book are all distinguished professionals and managers with decades of experience in their respective fields. The book should provide valuable resource to managers, professionals and academics in the subject areas discussed above.

Part I: Basic principles

The four chapters in Part I of the book provide a general overview of the nuclear industry, basic principles for managing nuclear projects, nuclear safety culture and management of worker risk, training and management of complex projects.

The introductory sections in Chapter 1 provide an overview of current status of the nuclear industry, characteristics of the nuclear projects and impact of major power reactor accidents on the industry. Then, the chapter focuses on the project management fundamentals and what is different about nuclear projects. It discusses key areas that a manager needs to know for managing such projects. It also provides an overview of several relevant areas such as construction, modular designs, operation and maintenance, managing risk at a nuclear site, managing risk in field activities as well as lessons learned and future trends.

It is well recognized in the industry that safe operation of a nuclear site requires not only the proper design and operation of safety systems, but also a safety-conscious attitude of the workforce. To ensure safe operation at any workplace, employees, managers, employers and regulators have important roles to ensure safe working conditions for the employees and to ensure that safety of the plant operation is not compromised. This topic is the focus of Chapter 2, which describes key elements of nuclear safety culture necessary for safe operation and management of risk at a nuclear site. It provides definitions of terms used in the industry and information on various aspects of worker safety at a nuclear site including industrial safety and radiation protection and ALARA.

The focus of Chapter 3 is on training. Employees who are well trained, responsive and acutely aware of their roles and responsibilities are key to successful operation of a nuclear site. More than any other industry, nuclear training is not only necessary, but imperative for safe operations. Experience has shown that one of the primary concerns is to reduce incidents of human performance errors on the job, both from permanent and especially non-permanent employees. Chapter 3 discusses the mission of the training department at a nuclear facility in developing the knowledge, skills and attitudes of site employees. It also discusses fundamental issues for managing training programs at nuclear sites, systematic approach to training, learning from industry experience, leadership training, maintaining the organization as a learning organization and communicating organizational values.

The Office of Environmental Management (EM), within the United States Department of Energy (DOE), manages numerous, multi-billion dollar projects and facilities. Managing these large projects presents a number of unique challenges that must be overcome, and EM has gained a wealth of experience in this area. Chapter 4 uses the practices at the DOE-EM and specific examples as a backdrop to disseminate key information on managing complex projects and facilities. The discussion includes topics on DOE's approach to execution of projects, integrated project team, key performance parameters and management of risk.

Part II: Managing reactor projects

This section starts with Chapter 5, which addresses management of nuclear research reactor projects and the nuclear research reactor operation. With over

200 research reactors currently operating in over 50 countries, this is a significant area of the nuclear field. The variability of designs in research reactors is far larger than in nuclear power plants and many research reactors are one-of-a-kind facilities, designed for a given set of specifications. This chapter provides a brief description of the differences between research reactors and nuclear power plants, a classification of research reactors of different types and their characteristics, and the differences between the management of a research reactor construction project and the management of nuclear power plant projects. Operational aspects for research reactors from management perspectives are discussed including operating cycle, refueling, inspection, maintenance, and managing ageing, repair and refurbishment. The chapter gives selected examples of research reactors and concludes with emerging techniques and future trends.

Chapter 6 is a compendium of three specific topics important to operating commercial reactors. These areas are: modifications, power uprates and outage management. Like all aspects of the nuclear power plant operation, activities in these areas are also highly regulated. Specific regulatory requirements vary from country to country and the discussion in this chapter is primarily based on the US regulatory environment and the US nuclear power industry experience. The modifications section discusses the necessity to modify system, structures and components, regulatory aspects, key elements of a modification package and the design analyses required. The generic flow of activities and steps are illustrated through a process flowsheet. The section also discusses a manager's role in the modification process. The section on managing power uprates describes various types of uprates, analyses and modifications required for uprates, regulatory approval process in the US and a manager's role in planning and implementing an uprate. Discussion in the outage management section includes outage planning and coordination, key points for outage management and key points for managers and supervisors. Chapter 6 concludes with challenges and future trends for the operating reactors in this regard.

Chapter 7 focuses on managing medical radioisotope production facilities. The commercial production of radioisotopes concentrates on two main areas: medicine and industrial applications. The radioisotopes for medical purposes, such as ^{99}Mo, ^{125}I and ^{131}I, ^{133}Xe and ^{89}Sr, are better known than those for industrial purposes, such as ^{75}Se, ^{192}Ir, ^{169}Yb and ^{60}Co. The production is dominated by ^{99}Mo in medicine and by ^{60}Co in industry. Whereas ^{60}Co, applied in large quantities in food product gamma irradiation and medical instrument sterilization facilities, is primarily produced in nuclear power plants, ^{99}Mo is produced in medium to high power research reactors. Molybdenum-99 is often referred to as the 'workhorse' of the nuclear medicine community. Although this chapter focuses on molybdenum-99, much of the information presented is applicable to medical radioisotope production in general. The chapter also discusses the new production facilities, projects under construction, projects under development, accelerator-based production technologies, and issues and challenges in medical isotope production.

Management of nuclear-related research and development (R&D) is the focus of Chapter 8, which provides information on work being performed for nuclear installations in the German context. Such investigations are particularly designated to enhance the safety of nuclear power plants, nuclear facilities such as reprocessing plants and nuclear fuel element fabrication facilities as well as of radioactive waste management installations, for example conditioning facilities and repositories. Nevertheless, R&D work has always been performed to initiate or to support new technical and technological developments. This chapter covers fundamental issues for R&D management with perspectives from international organizations as well as from national organizations from Germany, the UK and the USA, EU, OECD/NEA and IAEA with a focus on R&D work in support of reactor safety and for the management of radioactive wastes.

Part III: Managing radioactive waste, decommissioning and site remediation

Chapter 9 presents the waste and spent fuel management principles. It stresses the importance of the Waste Management Plan of the facility where the wastes are generated. Based on the different waste streams identified, quantified and characterized in terms of physical, chemical, radiological and toxic and hazardous properties, it gives the opportunity to design and to select the facility and the treatment and conditioning techniques to be used. Available treatment and conditioning techniques are briefly presented as well as the techniques for waste minimization, and recycling techniques for metal and concrete. Different management options, that is open or closed cycles for spent fuels, are also described and discussed. The chapter provides examples from the Belgian industry and discusses fundamental issues, challenges and lessons learned from the management of radioactive materials, waste and spent fuel.

Decommissioning constitutes the last stage in a nuclear power plant lifecycle. Its objective is to shut down the plant, remove the spent fuel and the radiological contaminants from the facility and place the site in an end-state that is safe for the public and the environment. This is the subject covered in Chapter 10. The discussion is focused on power reactor decommissioning including fundamental issues for managing reactor decommissioning, transition from operations to decommissioning, cost management, risk management, procurement and supply chain management, and physical dismantling of the facility and large components with an example from the Chooz A nuclear power plant.

Chapter 11 covers the topic of managing site remediation with the United States Environmental Protection Agency (EPA) Superfund program as the backdrop. The chapter describes the EPA process and standards for cleanup of radioactively contaminated sites. It provides a brief overview of the approach used by EPA to conduct Superfund cleanups at contaminated sites, including those that are contaminated with radionuclides, to ensure protection of human health and the environment. The discussion includes how EPA Superfund determines whether a site poses a risk to human health and the framework used to determine the cleanup levels. The theme emphasized throughout the chapter is that within the Superfund remediation framework, radioactive contamination is dealt with in a consistent manner to chemical contamination, except to account for the technical differences between radionuclides and chemicals. This consistency is important as at every radioactively contaminated site being addressed under Superfund's primary program for long-term cleanup, the National Priorities List (NPL), chemical contamination is also present. The chapter discusses three Superfund sites as specific examples to illustrate how the approach is applied.

Part IV: Regulation, guidance and emergency management

Quality assurance (QA) and auditing programs are critical to the success of nuclear projects. Chapter 12 discusses quality assurance and audits in the nuclear industry with a perspective from the USA. It describes the elements of the QA program as well as a historical perspective of QA development in the nuclear industry. It further discusses the characteristics and objectives for QA audits in support of nuclear projects. The topics covered include types and application of audits, the phases of the audit process, senior management support for the audit process, industry standards associated with the nuclear audits and challenges associated with audits.

Chapter 13 provides information on licensing procedures for nuclear installations, the institutions involved, the regulatory interface and the experiences gathered in such procedures. Addressing various countries, the chapter first reviews the main elements of the legal framework, including international provisions such as from the European Union, the regulatory body and the general principles of licensing procedures. The chapter then discusses the regulatory bodies in several countries, and nuclear installation licensing in general, responsibilities of the applicant/operator, involvement of stakeholders, licensing decision aspects and the supervision activities.

A nuclear power plant is much like any other power plant in that steam is produced to run a turbine generator to make electricity. A major difference is that the heat that is used to make the steam is produced from uranium. When uranium atoms are split, in addition to heat being produced, radiation is also produced. Normally, a nuclear power plant releases very little radiation. The purpose of emergency management is to protect the health and safety of the public in the unlikely event of a nuclear accident that results in the release of radioactivity. As a condition of their license, operators of US nuclear power plants must develop and maintain emergency preparedness (EP) plans that meet comprehensive NRC requirements in this regard. Chapter 14 discusses these aspects with the USA approach as the backdrop.

Following the Fukushima accident of 11 March 2011, the topic of management of nuclear crises (accidents and lessons learned) is of great interest to industry, regulators and the public. As Chapter 15 discusses, a crisis is seldom, if ever, a result of one single major cause, but a result of many, often small things going wrong simultaneously or in sequence. Designers and operators try to think of everything and take all reasonable measures to avoid a severe accident. In nuclear safety, it is recognized that equipment fails, humans make mistakes and no design is perfect. Past accidents are carefully studied, lessons learned and shared to ensure that technical and human actions are improved to eliminate, as far as practically possible, the accident from reoccurring. This chapter discusses nuclear crisis management reflecting the three severe nuclear accidents: Three Mile Island, Chernobyl and Fukushima Daiichi. A severe accident in this chapter refers to an accident in which nuclear fuel in the reactor was at least partially melted. The three severe nuclear accidents are briefly described. Then lessons learned are divided into four crisis management phases: avoiding the crisis, preparing for the unexpected, managing the acute phase of a crisis and managing long-term and far-reaching aspects of the crisis. Finally, the importance of learning and sharing the lessons from each accident is highlighted.

Chapter 16 focuses on international nuclear cooperation. The foundation stone for this was laid by the famous ‘Atoms for Peace’ speech US President Eisenhower delivered to the UN Assembly in December 1953. That speech marked the birth of the International Atomic Energy Agency (IAEA), which was officially established on 29 July 1957. The IAEA is an autonomous intergovernmental organization dedicated to increasing the contribution of atomic energy to the world’s peace and well-being and ensuring that agency assistance is not used for military purposes. This chapter discusses information relevant to the IAEA’s role in international cooperation. Other organizations devoted to international nuclear cooperation including OECD/NEA and WANO are also described in this chapter.

1

Basic principles for managing nuclear projects

J. DEVGUN, Senior Consultant, USA

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Abstract: This chapter focuses on the basic principles for managing nuclear projects in the commercial power industry. It discusses characteristics of the nuclear projects, key areas that a manager needs to know and basic steps for managing such projects. It also provides an overview of several relevant areas such as management of risk as well as lessons learned and future trends.

Key words: nuclear projects, nuclear accidents, radiation protection, nuclear safety culture, nuclear quality, construction technologies.

1.1 Introduction

The nuclear industry is diverse and consists of many different fields. These include commercial nuclear power plants and electricity production, research reactors and nuclear R&D, nuclear instrumentation, nuclear medicine, defense applications, decommissioning of nuclear sites and remediation and cleanup of radioactive sites. Although some of the basic principles for managing nuclear projects are the same, special considerations will apply depending on the nature of the project, regulatory requirements in that area of application and the specific nature of the industry. The focus of this chapter is on the commercial nuclear power industry.

Nuclear energy currently provides about 13% of the world's electricity. This share is likely to continue to grow as the energy demand worldwide continues to grow, even though, in the post-Fukushima era, nuclear expansion has slowed in many countries.

Energy demand continues to rise and in projections from the International Energy Agency (IEA) on the change in power generation from 2010 to 2035, the need for electricity in emerging economies drives a 70% increase in worldwide demand (IEA 2012). The nuclear share in the projections has been scaled back following the Fukushima accident and the IEA reduced the nuclear capacity projections in the World Energy Outlook (WEO) 2011, and then further reduced them in WEO 2012 from earlier projections in 2010. By 2035, the nuclear capacity is anticipated to rise to 580 GWe, approximately 55% more than the current capacity. The currently operating reactors (over 430 commercial power reactors in 31 countries) have a combined capacity of 372 GWe. The 104 reactors in the USA make it the largest fleet of commercial reactors in one country and provide about

20% of the electricity generation. Over 60 reactors are under construction in 13 countries, with major construction activity in China, South Korea, Russia and India.

Prior to the Fukushima Daiichi accident, the nuclear power industry had been in the early stages of a 'renaissance' and it had been estimated that anywhere from 60 to 130 new power reactors might be built worldwide over the next 20 years. The net effect of the Fukushima accident on the nuclear renaissance will not be known for some time, but it has slowed the momentum of the nuclear renaissance in the near term. However, the emerging economies, especially in Asia, are expected to continue with their nuclear expansion because of the limited fuel options for energy production and a substantial need for energy now and even greater need projected in the future.

Even though failures of some of the key site features at Fukushima can be attributed to events that in the past would have been considered as beyond the design basis, the industry as well as the regulatory authorities are analyzing what features, especially passive features, should be designed into the new reactor designs to minimize the potential for such failures. It is also recognized that since the design of the Fukushima BWR reactors where the first reactor was commissioned in 1971, many advanced safety features are already a part of the newer reactor designs.

Nuclear construction projects are large and complex projects requiring large-scale resources, technical expertise and experienced project management. Each of the operating reactors in the world have many projects ongoing at any time related to equipment replacement, system upgrades, modifications, regulatory-driven actions, power uprates or refueling. In addition, there are about 240 research reactors operating in 56 countries. Nuclear reactors are also used in ships and submarines. There are numerous projects in the nuclear-related facilities as well as in the reactor and facility decommissioning area. In the USA, in the Department of Energy (DOE) complex alone there are numerous large projects related to deactivation of nuclear facilities, decommissioning and site restoration. All across the nuclear industry there is specific emphasis on safety and management of risk.

1.2 Characteristics of nuclear projects

Nuclear projects are unique because of the presence of radioactivity and radioactive materials. Nuclear reactors use the atomic fission process and criticality to harness nuclear energy, and involve complex technologies to use this energy for electricity production. Some of the unique attributes of nuclear projects are discussed in Section 1.3.

The nuclear industry is highly regulated, and nuclear sites and projects are under constant scrutiny by regulators and the public. Public perception of nuclear risk and radiation risk creates more fear and concern and hence more public interest in anything nuclear. In addition, the presence of nuclear fuel also requires safeguards policies to be put in place.

Although commercial nuclear power has been around for over half a century, three major accidents (discussed in Section 1.2.1) have raised concerns and focused negative attention on the industry. Since the Chernobyl accident in 1986, specific attention has been directed towards the human performance aspects in the nuclear industry. The nuclear safety culture now at nuclear sites is very specific and rigorous. Nevertheless, the 2011 Fukushima accident showed that unanticipated natural events can occur and cause substantial damage to a facility with large-scale consequences. Major accidents have occurred in every industry with substantial consequences; however, the nuclear accidents have led to more long-lasting negative perceptions.

On a safety and performance basis, the industry has made very substantial progress over the past two decades to a point where the capacity factors for plants are much higher, refueling periods are shorter, significant events are fewer and worker safety incidents are minimized.

1.2.1 Impact of major commercial accidents on the industry

Three Mile Island

The accident at Three Mile Island Unit 2 (TMI-2) on 28 March 1979 started with the loss of main feedwater. Per published accounts the safety systems shut down the main turbine and actuated the emergency feedwater system. The emergency feedwater pumps failed to deliver water to the steam generators because two valves on emergency feedwater line were inadvertently left closed following maintenance. As the reactor coolant system (RCS) pressure and temperature rose, the pilot-operated pressure relief valve opened. However, the valve did not reset, remaining stuck in an open position during the plant transient, and the RCS pressure decreased to the point where the safety injection (SI) was automatically initiated. As those in the control room had no indication of the position (open or closed) of the relief valve, the operators assumed incorrectly (because of pressurizer level) that the core was covered with the coolant and they drastically reduced the replacement water flow. The steam void formed in the upper part of the reactor vessel led to uncovering of the fuel and partial meltdown of the core. At the time of the accident, the reactor had been in operational status for only 3 months, after being granted the operating license in 1978.

TMI-2 has been classified at Level 5 on the International Nuclear and Radiological Event Scale (INES). The accident was the worst accident in the commercial nuclear power industry in the USA, and led to reshaping of the industry through technical improvements in plant systems design and operator training as well as improvements in the regulatory oversight and emergency preparedness.

Chernobyl

The 26 April 1986 accident at Unit 4 of the Chernobyl plant (RBMK 1000 design, graphite-moderated) was the result of a beyond design basis test being conducted and a series of operator actions, including the disabling of automatic shutdown mechanisms, prior to the test. The operators prepared the reactor for the test on 25 April prior to a routine shutdown with the purpose of determining how long the turbines would spin and supply bridging power (until the emergency diesel generators were sequenced to start) to the main circulating pumps following loss of the main electrical power supply. Later investigations of the accident by the International Nuclear Safety Group (INSAG) of the International Atomic Energy Agency (IAEA) concluded that the accident was the result of a flawed reactor design that was operated by inadequately trained personnel (IAEA 1992).

Issues related to interaction between the day shift, evening shift and the night shift as well as the request from the regional power grid prior to the test have been discussed in the literature. Based on published accounts during the test that started at 1:23:04 on 26 April, the coast down of the turbine generator began when the steam to the turbine was shut off. The turbine (when coasting down) provided power to four (of the total eight) circulating pumps, and diesel generators started and picked up loads sequentially by 01:23:43. During this period the circulating water flow rate decreased as the momentum of the turbine generator decreased, leading to increased formation of steam voids in the core. Because of the design of RBMK (positive void coefficient at low reactor power levels), formation of steam voids reduced the ability of the coolant water to absorb neutrons, which in turn increased the reactor thermal power output. With more water flashing into steam, it led to further power uptake and the reactor entered a positive feedback loop. The automatic control system counteracted this positive feedback, by inserting control rods into the reactor core. There is uncertainty as to when reactor scram was initiated. Within a few seconds a large power spike led to overheating of the core and an explosion. Some of the fuel rods fractured and control rods became stuck at partial insertion. According to some estimates further rapid increase to thermal power levels that were many times the normal output, eventually led to the second massive explosion accompanied by graphite fire. A large amount of radioactive material was released into the atmosphere. Two plant workers died from the accident and a further 28 people died within a few weeks as a result of acute radiation poisoning. Spread of the radioactivity was first detected two days after the accident at Forsmark in Sweden, some 1100 km from Chernobyl. In the subsequent days and years, residual radioactivity continued to be measured for impact on the environment. The IAEA has devoted considerable effort to keeping the focus on Chernobyl monitoring and lessons learned. Chernobyl has been classified at Level 7, the highest level on the INES scale.

Fukushima

On 11 March 2011, the eastern coast of Japan near Fukushima experienced a massive magnitude 9 earthquake and large tsunami waves that caused widespread devastation with about 20 000 lives lost (confirmed dead and presumed dead). In addition, the material damage could amount to several hundred billion dollars.

The natural disaster also caused a nuclear accident at the Fukushima Daiichi reactor complex. The Fukushima nuclear accident has been categorized at the highest rating on the INES scale, similar to the Chernobyl rating. The accident severely damaged the reactor complex.

All the Fukushima site's six Boiling Water Reactors (BWR) units were designed some 40 years ago, although there were design differences between them (Units 1–5 with Mark I containment and Unit 6 with Mark II containment). Units 4–6 were in outage and cold shutdown at the time of the earthquake. Units 1–3 were shut down automatically by the safety systems and emergency generators came online to provide power to control electronics and coolant systems. However, the tsunami that followed the earthquake quickly flooded the area and the rooms in which the emergency generators were housed. The height of the Tsunami was later estimated to be 14–15 meters. The generator failure led to a complete loss of power to the reactor cooling system pumps, leading to overheating of the core as a result of radioactive decay. Hydrogen explosions caused considerable damage to Reactor Units 1 and 3. Reactor Unit 2 had an internal explosion that appeared to have breached the secondary containment. Reactors 1, 2 and 3 were estimated to have undergone meltdown.

Seawater was eventually used for cooling of the reactors after initial concerns that it would permanently damage the reactor components. However, massive damage had already occurred by this time. In addition, the lack of cooling water to the spent fuel pools led to exposure of the fuel rods as the water in the pools boiled away and pool level dropped. Severe damage to the spent fuel in the pool resulted. Following the nuclear accident, authorities evacuated a 20-km radius zone around the plant (extended about a month later to 30 km in the north and northwest (approximately 380 000 people were evacuated in total). As of November 2012, only three towns were being opened for about 16 000 evacuees to return. It is anticipated that it may take up to 2020 for the entire evacuation zone to be reopened for return of the evacuees.

A year later, substantial progress had been made in stabilizing the plant, treating contaminated water and putting into action a long-term decommissioning plan. The IAEA served as the key source of official information following the Fukushima nuclear accident and the reader is referred to the agency's reports and updates in this regard. For example, the Fukushima Daiichi Status Report was issued on a nearly monthly basis (e.g. dated 28 December 2012).

Industry impact

Each of the accidents discussed above has led to re-examination of systems and processes in the nuclear industry.

The TMI-2 accident can be attributed to equipment failure and the inability of plant operators to correctly understand the reactor condition at certain times during the event. Even though the accident caused no injuries or deaths and the radiation released into the atmosphere was small, the industry took initiatives in operator training, plant operations, plant management and equipment reliability.

The Chernobyl accident has led to worldwide focus on the nuclear safety culture as well as the design issues for certain types of reactors. The IAEA continues to disseminate the lessons learned from Chernobyl some 25 years later through the INSAG series of reports and through forums and conferences on the topic.

The Fukushima accident of 2011 is still being assessed for technical design impacts. However, a number of actions have been taken already in most countries where the existing nuclear power plants and nuclear construction projects have been examined from a perspective of coping with extreme natural events. As examples, Japan has initiated stress tests for nuclear plants. In the USA, the Near Term Task Force (NTTF) was set up by the Nuclear Regulatory Commission (NRC) and it published its recommendations in July 2011 (NRC 2011). These build on the longstanding defense-in-depth philosophy and NRC has started issuing specific orders for specific areas based on the recommendations. Post-Fukushima lessons have led the industry to examine existing strategies and equipment related to loss of off-site power (LOOP), coping capability for station blackout, beyond-design-basis mitigation strategies, hardened vents for BWR plants and spent fuel pool cooling and instrumentation.

1.3 Basics a nuclear project manager needs to know

Basic project management is discussed in Section 1.4 followed by several specific areas of interest to a nuclear project manager. However, to begin with, a nuclear project manager must be familiar with three key areas that make nuclear projects different from other types of projects. These key areas are:

- Radiation protection and the As Low As Reasonably Achievable (ALARA) process.
- Nuclear safety culture.
- Nuclear quality.

1.3.1 Radiation protection and the As Low As Reasonably Achievable process

In the USA, the Nuclear Regulatory Commission's standards for protection against ionizing radiation resulting from activities conducted under licenses issued by the NRC are established in the 10 CFR Part 20 'Standards for Protection Against Radiation'. Section 20.1101 requires licensees to establish radiation protection programs commensurate with the scope and extent of licensed activities. It also requires the implementation of 'As Low As Reasonably Achievable' (ALARA) process. The concept of ALARA applies to all areas and aspects of the radiation protection program.

The dose limits for individual members of the public are contained in Subpart D (Section 20.1301). In general, the total effective dose equivalent (TEDE) to an individual member of the public from the licensed operation should not exceed 0.1 rem (1 mSv) in a year, exclusive of the dose contributions from background radiation (for complete details the reader is referred to the 10 CFR 20.1301).

Occupational dose limits for radiation workers are described in Subpart C (Section 20.1201). In general, the annual TEDE limit is 5 rem (0.05 Sv). Limits are also defined separately for any individual organ or tissue, lens of the eye, or the skin of the whole body and the skin of the extremities (for these and other details the reader is referred to the 10 CFR 20.1201). Finally, it should be noted that these descriptions are provided for general information purposes only – the reader should consult radiation dose limits in their own countries and the guidance on how these apply. Nuclear sites also use administrative limits that are much lower than the occupational dose limits. For example, power plant sites generally use 2 rem (0.02 Sv) as the administrative limit.

Internationally, the International Commission on Radiological Protection (ICRP) published scientific guidance in ICRP-60 as the 1990 Recommendations of the International Commission on Radiological Protection. The occupational exposure limit was stated as an effective dose of 2 rem (20 mSv) per year when averaged over 5 years, with the dose not to exceed 5 rem (50 mSv) in any single year. The dose limit for a declared pregnant woman worker was 0.1 rem (1mSv). ICRP-103 was published in 2007 (ICRP 2007) and supersedes ICRP-60. It was issued to update, consolidate and develop additional guidance on the control of exposure from radiation sources issued since 1990. The dose limits have remained unchanged from ICRP-60. The reader is also referred to a report from the US organization, the National Council on Radiation Protection and Measurements (NCRP). The NCRP Report No. 116, published in 1993 (NCRP 1993), provides the limitation of exposure to ionizing radiation (it is a refinement of the system enunciated in Report No. 91, published in 1987).

At the power plant site, the areas where radiation is present are marked and access is controlled. Such areas are generally termed Radiation Controlled Areas (RCAs) and may be classified as a Radiation Area, High Radiation Area, or Very High Radiation Area (or Locked High Radiation Area) depending on the radiation dose hazard present in the area. Appropriate access requirements for these areas are defined in the station procedures and access must be by permission and under the supervision of the Radiation Protection Technician or Health Physicist.

The Radiation Protection Manager and the Radiation Protection (RP) department are responsible for ensuring procedures, personnel, training and equipment are in place to control radiation areas as well as providing up-to-date radiation surveys of areas where work may need to be performed by a project. The RP department provides devices such as TLDs (Thermoluminescent Dosimeters) for personnel monitoring. A TLD is used to record the amount of radiation an individual receives while in a radiation area and provides a permanent dose record for the worker. The TLD must be processed in order to determine the dose received by the individual. Whereas larger sites may operate a dosimetry laboratory for processing of the TLD badges, many sites use contracted services from an accredited laboratory. Nuclear sites also use Electronic Dosimeters (EDs) that provide a visual display of the amount of gamma radiation an individual receives when in a radiation area. The ED also has audible alarms to alert the worker if he or she is approaching Radiation Work Permit limit. Both TLDs and EDs are small devices that the worker can carry on their person as per site RP procedures. The RP department is also responsible for selecting other technologies and monitoring devices if necessary for alpha, gamma, beta and neutron radiation.

Vital areas in the nuclear power plant are protected and access is strictly controlled by badge requirement (requires a badge issued by security), detection devices, searches and X-ray of hand-carried items. In addition, portal monitors are used prior to exit from the vital area, which check personnel for radioactive contamination. The RP department is responsible for maintaining these portals. In addition, the portal monitors or other whole body contamination monitoring may be employed at the RCAs, and Small Articles Monitors (generally known as SAMs) are also used to ensure that contamination is not carried out of the RCA on small items (such as tools, notebook, camera) brought into the RCA.

Basic principles of minimizing radiation protection at an individual level are well known in the form of Time, Distance and Shielding: minimize time in the area that contains radiation fields, maximize your distance from radiation sources, and use shielding to reduce the dose you may receive. Nuclear sites use formalized ALARA programs as their commitment to minimize personnel doses as well as to keep the overall dose record for sites as low as possible.

Radiation protection is a specialized area and a nuclear project manager must rely on the Radiation Protection department to provide support to any projects and activities at the site that involve RCAs or SSCs that contain radioactive materials.

1.3.2 Nuclear safety culture

A nuclear work environment requires that a nuclear safety culture be developed, maintained, and monitored for enhancements and corrections as necessary. Nuclear site operations involve risks and hazards related to radioactive materials and radiation, in addition to the industrial hazards of any large-scale operation. Nothing can be regarded as routine activity, and constant vigilance towards the risks is necessary.

A safety-conscious work environment (SCWE) is regarded as an integral part of a strong nuclear safety culture. It ensures that the work-related hazards are minimized and that the operation of the facility is conducted in a safe manner and in compliance with regulations and policies. Attitudes towards safety are as important to successful operation of a nuclear site as are design of the systems and safety mechanisms. Lessons learned from past major accidents at nuclear sites, as well as from the many smaller incidents, show that in most cases human performance issues are the major cause.

The management organization must ensure a culture and environment that promotes safety. As a part of nuclear safety culture, site management should consider the following, among other factors:

- Safety programs and reviews must have attention and support of the top levels of the organization.
- Encourage safety culture in every task to be performed and ensure an understanding of what nuclear safety culture involves.
- Provide resources so that teams and individuals can perform their tasks safely and successfully.
- Encourage a questioning attitude at all levels of the workforce and provide adequate training.
- Apply lessons learned from industry experience.
- Safety must come first as a priority over schedules for the tasks.
- Conduct self-assessments to monitor site performance in this regard, recognizing that regulatory authorities will be looking to ensure that nuclear safety is not compromised.
- Periodic assessments or audits by outside organizations are beneficial in providing independent review and highlighting where improvements are necessary.

1.3.3 Nuclear quality

Nuclear quality assurance is intended to provide adequate confidence that a structure, system, or component (SSC) will perform satisfactorily in service and that the program provides control over activities affecting the quality of the SSCs to an extent consistent with their importance to safety.

In the USA, the requirements for quality assurance related to nuclear power plants are codified in Appendix B to 10 CFR Part 50, ‘Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants’. The applicant for licensing is required to establish at the earliest practicable time, a quality assurance program that complies with the requirements of this appendix. This program is required to be documented by written policies, procedures, or instructions and is required to be carried out throughout the plant life in accordance with those policies, procedures, or instructions.

Key elements of the Appendix B program consist of: design control; procurement document control; instructions, procedures and drawings; document control; control of purchased material, equipment and services; identification and control of materials, parts, and components; control of special processes; inspection, test control; control of measuring and test equipment; handling, storage and shipping; inspection, test, and operating status; non-conforming materials, parts, or components; corrective action; quality assurance records; and audits.

The industry uses American Society of Mechanical Engineers (ASME) standard Nuclear Quality Assurance-1 (NQA-1), which provides requirements that prescribe the extent of controls needed in specific areas of nuclear quality. The 18 requirements described in the Appendix B program requirements are applicable during siting, design, construction, operation and decommissioning of nuclear facilities. Over the years, NQA-1 has been updated several times, with NQA-1-2008 and two addenda, NQA-1a-2009 and NQA-1b-2011, as the current versions in 2012.

The Department of Energy's (DOE) requirements for quality assurance are described in DOE Order 414.1D and the nuclear safety management is codified in 10 CFR 830. The DOE G 414.1–2B provides the quality assurance program guide.

Internationally, the IAEA in the Safety Series No. 110, Safety of Nuclear Installations (IAEA 1993), stated:

> Quality assurance practices are an essential part of good management and are to be applied to all activities affecting the quality of items, processes and services important to safety. Inherent in the achievement of quality is the adoption of a quality assurance program, which includes the planned and systematic actions necessary to provide adequate confidence that specified requirements are satisfied. Implementation of the quality assurance program involves managers, performers of tasks and those responsible for verification and assessment of the effectiveness of the program. It is not a sole domain of a single group. However, management has the key responsibility to ensure that the program functions properly and to establish and cultivate principles that integrate quality assurance practices with daily work activities.

It also states that 'Quality needs to be verified by a disciplined approach'.

1.4 Project management fundamentals for nuclear projects

1.4.1 Project basics

Going back to the basics, the Oxford Dictionary defines a project as 'an individual or collaborative enterprise that is carefully planned to achieve a particular aim', and as examples it lists 'research project' or 'project to build a new power station'. As for the definition of project manager, it cites 'the person in overall charge of the planning and execution of a particular project'. In essence, a project is a group of activities towards a defined objective that requires integration of tasks, knowledge, skills, and experience, and consists of milestones, a budget, a scheduled end and the deliverables.

Historically, project management is not new, it has been practiced for projects big and small for thousands of years. One just has to look at the Great Wall of China, portions of which were built between 220 and 206 BC, which has been enhanced, re-built and maintained over the centuries. In modern times, projects such as the International Space Station, human landing on the Moon and the robotic missions to Mars show the complexity of projects of which humans are capable, wherein all elements must fit and perform as designed for the success of the mission.

For the nuclear area, very early efforts in the nuclear fission area in the USA were focused on military development as the Manhattan Project. The 1954 amendment to the Atomic Energy Act encouraged development of the private sector in harnessing nuclear power. The Shippingport Reactor in Pennsylvania served as the first prototype for commercial nuclear power generation in the USA. It came on-line in December 1957 and remained in operation until October 1982. Currently, 104 commercial power reactors are licensed in the USA contributing about 20% of the electricity generation in the country. It is the largest commercial nuclear fleet of reactors in the world. Overall, 439 nuclear power reactors were in operation worldwide in various countries at the beginning of 2012.

Nuclear power plant construction projects are very large projects that involve large-scale investment (several billion dollars) extending over several years. These projects require highly qualified and experienced engineering staff and workers, specialized vendors providing nuclear reactor design, specialized vendors providing Balance of Plant (BOP) design and extensive procurement and construction logistics. But even for projects at an existing power plant site, nuclear project planning is a major undertaking involving a great variety of activities and organizations. It is not unusual for power plants to retain specialized contractors with technical expertise to provide the engineering design for specific projects, for example modifications or replacement of major equipment, or to address system-degradation issues or to address regulatory-driven actions. The licensee (plant owner) retains the overall project control, regulatory responsibility and, in many cases, the actual implementation of the project.

Nevertheless, all projects, large or small, nuclear or non-nuclear, have basic phases and steps. These are discussed below.

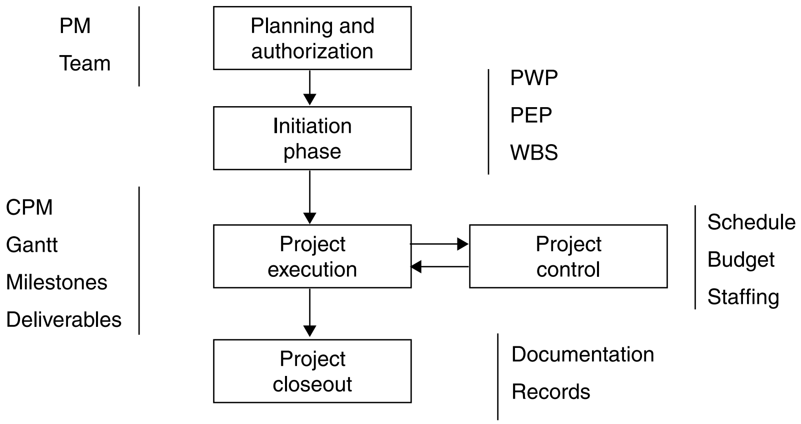
Basic steps

The basic steps of the project management process are well known and generally apply to the nuclear projects with some additional steps and constraints added.

- Project planning and authorization.
- Project initiation.
- Project execution/project control.
- Project closeout.

A representation of the basic steps is provided in Fig. 1.1.

Lessons from past project successes and project failures can provide useful guidance. Especially useful is a review of project failures to understand what to



1.1 Basic steps for projects.

avoid, what the pitfalls are and what to correct in the planning process. Project failure can be characterized by a number of criteria or their combinations, such as: deadlines and milestones not met, over budget, poor quality, inability to meet client expectations and inability to meet regulatory requirements. In general, causes for lack of success of projects can be briefly summarized as follows:

- Project scope is not clearly defined (it impacts the project cost and schedule).
- Unrealistic schedule.
- Project risks are not objectively identified or assessed.
- Poor communication with team, stakeholders and client.
- Ineffective project controls.
- Poor management oversight.
- Inadequate knowledge of regulatory requirements or insufficient regulatory direction or oversight.

The project manager needs to avoid potential pitfalls in the schedule through considerations such as that training time is built into the schedule, the schedule is developed on realistic work effort and that workers are not generally scheduled more than 80% (for example) of their time.

The Project Work Plan, at a minimum, should include: purpose of the project and background, project scope, project organization, project phases, Work Breakdown Structure (WBS), project assumptions and limitations, critical interface points, schedule, project risk evaluation, project unique requirements (QA, software, etc.), project deliverables and project monitoring and reporting mechanisms. The WBS is critical to the definition of the project, organization of the project activities and development of the baseline schedule and cost. It also allows the project control to be applied to discrete activities or tasks. The WBS is a living document throughout the life of the project and must be updated as project changes occur. The WBS and schedule go hand in hand as the schedule generally reflects the individual WBS activities or tasks and the steps required to accomplish these tasks. The schedule shows the linkages to major milestones and the activities. The WBS and schedule can start at Level 1 (higher-level activities) and progress to Level 5 (with very detailed breakdown of tasks or subtasks).

Level 1 schedule is developed early while scoping the project and lists key milestones or deliverables for the whole project, sets its strategy and consists of typically only a few pages. Level 2 shows the overall project broken down into its major components by area or summary activities and can be used for higher-level project reporting. Level 3 schedule provides a level of detail generally suitable for monthly reporting to management or clients.

Level 4 is a detailed working level schedule, which is resource-loaded and provides details for each major activity such as design, procurement, licensing and commissioning at field level. The level of detail is generally at a weekly basis, and the schedule includes a two-week or three-week look ahead. Critical Path Method (CPM) is generally applied to ensure coordination of interrelated activities.

The CPM analysis is used to determine how critical an activity or milestone is to the project based on the time period (e.g. days) that the activity or milestone can slip without impacting the completion date of the project. The time period (e.g. number of days) an activity can slip without impacting completion date of the project is the float for that activity. The critical path is the longest continuous path duration of activities through a project based on the completion date. In multiple paths between start to finish, activities on critical path have zero float.

Level 5 provides further breakdown of the activities at Level 4 and provides details of the tasks almost at a day-to-day level. For larger projects, such as the reactor construction or reactor decommissioning, Level 5 schedule could include thousands of activities. Computer software programs such as Primavera P6 are generally used as project planning tools.

The Project Execution Plan provides a roadmap for who, what, when, why and how project deliverables will be achieved. It facilitates decision making, identifies issues and actions, provides coordination and control in a complex project, establishes change control procedures, provides for monitoring and reporting mechanisms and retention of records. It may also contain other plans (e.g. a Risk Management Plan) unless such plans are individually prepared and issued (e.g. for larger projects).

A project manager will have knowledge of project management principles, decision making ability, integrity, ethics, organizational skills, teamwork spirit, training, performance attitude, business and budget management skills, communication skills, time management skills, analytical skills and problem solving skills.

A project manager's authority level may vary (low, medium or high) depending on a number of factors such as an organization's business philosophy, size and complexity of the project and the matrix organization/interface with other technical organizations. For nuclear projects, the project manager's authority level needs to be high.

Nuclear projects

Because of the unique nature of nuclear projects, a project manager will need to have the technical ability to understand the projects even though he or she may not be a technical expert in the area. Understanding the nuclear safety culture is also a key attribute.

For nuclear projects, in addition to the standard project management considerations, there are several considerations that need to be taken into account right from the planning stages. These include:

- Radiation protection.
- Is prior regulatory approval required? This process in the USA is controlled through the 10CFR 50.59 Screening.
- The team must also include health physics or radiation protection staff.
- During the initiation phase, other stakeholders must be included such as the various departments at the nuclear site which may be impacted or whose services may be required.
- In project execution, safety comes first. Because of the unique nature of nuclear projects, all aspects of safety must be considered and procedures and policies for the work must be adhered to.
- Most of the nuclear records are required to be maintained for a long period of time or until the license is terminated by the regulator (after the facility has been decommissioned).

1.4.2 Construction, operations and maintenance

Major construction projects such as building of a power plant require large-scale construction project experience at company and project manager levels. Past experience with construction of nuclear power plants has been the subject of much debate in literature. The plants completed in the late 1980s in the USA have cost as much as 5 billion dollars compared with plant costs in the early 1980s at less than 2 billion dollars. Continued escalation in capital costs has been a major concern in the nuclear industry. Cost overruns have been attributed to construction schedule delays, changing course during construction, escalation in labor costs, stricter regulatory requirements and other factors such as litigation-related delays.

After a hiatus in nuclear construction for two decades, new reactors in the USA are being considered for construction. Two projects where Combined License (COL) for construction and operation has been issued by the NRC are Vogtle 3 and 4 and Summer 2 and 3. Site work at the two sites is at various stages. The project costs for the two units at Vogtle are reported to be 14 billion dollars and for the two units at Summer 9.2 billion dollars (WNA 2012).

Cost estimates depend on a number of factors including financing mechanism in addition to the engineering, hardware and labor costs. Controlling capital costs is a significant issue for nuclear to remain competitive as an energy source with other sources such as fossil fuels.

Advanced commercial reactor designs where design certification has been issued by the NRC include General Electric's Advanced Boiling-Water Reactor (ABWR) and Westinghouse's AP1000 pressurized water reactor (PWR). Design certifications are pending for the US EPR from AREVA and US-APWR from Mitsubishi. The units under construction at the Vogtle site and at the Summer plant site are AP1000 reactors. Internationally, several AP1000 units are being built in China along with the local CPR-1000 design.

In recent years, there has been an increasing interest in Small Modular Reactors (SMR) and various designs are being developed ranging in output from 50 MWe to 300 MWe.

Modular designs of systems

Construction practices for nuclear power plants in the past have involved fabricating many of the mechanical and electrical systems at the site and only after the structures have been constructed. Current reactor designs allow for modular construction of structures and systems. This allows many of the activities to proceed in parallel and many large and small mechanical, electrical and I&C system modules can be built off-site.

As an example of the modular design, the AP1000 reactor design consists of approximately 350 structural and mechanical modules. Complete system modules or subsystem level modules can be fabricated off-site, transported to the site and assembled in place. This has significant cost and schedule advantages. The construction time for an AP1000 plant is anticipated to be 48 months, much shorter than the standard PWR construction schedule in the past. The design approach also reduces the number of components by approximately 50% from a standard 1000 MWe PWR. Modular construction of systems and structures for eventual deconstruction and decommissioning has been discussed previously by the author (Devgun 2010).

Modular designs of structures

Most current reactor designs allow modular construction of the plant structures. An example of modular AP1000 construction is the Sanmen Unit 1 in China where construction began in 2009 and which has been projected to go on-line in late 2013. The largest structural module measured 20 m long, 14 m wide and 20 m high, and weighed approximately 900 tonnes. More than 18 modules weighed more than 500 tonnes, whereas another 50 weighed in excess of 100 tonnes. Very high lift (VHL) capacity cranes make this large-scale modularization possible.

For modular design and construction, the key points are as follows:

- Modular construction presents bigger logistical challenges. This involves construction or fabrication of modules at off-site facilities and transportation over long distances. Transportation by barge is the preferred route for large modules. Land route transportation restrictions may limit design and size of the construction modules.
- Modularization and off-site fabrication may require setting up or expanding existing factories or manufacturing facilities to accommodate the module size and scope. This may involve additional expenses.
- Larger modules may need to be designed and fabricated as multiple sub-modules, which can then be assembled at the site.
- Modularization at nuclear power plant construction involves the use of VHL cranes. The VHL cranes are costly equipment to erect and operate at the site.
- Some activities may involve first-of-a-kind engineering activity.

Advanced construction technologies

Advanced construction techniques such as slip forming and open top construction (in combination with the modularization approach) require considerable advance planning and detailed engineering to support the fabrication and assembly of large modules for the structures and systems. Open top construction methods also require the use of temporary weather covers during the construction period.

There are many advantages of the advanced construction techniques in conjunction with the modular design as discussed below:

- Reduction in manpower needs at the project site.
- Reduction in project schedule by allowing parallel construction activities on system modules and structural modules.
- Uniformity in systems modules and structural modules for multiple units at the same site and/or of the same design at different sites.
- Better quality control through initial testing of the components at the fabrication facility.
- Reduction in facility footprint.
- Reduction in system components.
- Reduction of work congestion at the construction site.
- Mass production capability providing economies of scale.
- Significant cost savings.

1.4.3 Operations and maintenance

The operations department and maintenance department are crucial to the workings of a nuclear site such as the nuclear power plant. Department managers and other managers in such departments are generally seasoned managers who have substantial experience in a nuclear power plant setting and many have held the Senior Reactor Operator license. They have extensive knowledge of the plant systems and components. Shift supervisors reporting to an operations manager also generally have substantial experience in the power plant operations.

A maintenance manager is responsible for ensuring that scheduled and periodic maintenance and testing on equipment is performed. It is crucial that the maintenance procedures are in place, easily understood by the field crew and are consistently applied. It is a major challenge to ensure that planning, scheduling and field coordination occur in a timely fashion. Equipment breakdowns can occur and timely repairs are expected. In a major component breakdown situation, it can lead to a forced shutdown of the reactor causing a loss in revenue, and major repairs or replacements may be necessary on a tight schedule. Maintenance personnel should know the basic functions of the systems, the maintenance procedures and practices, and should have the craftsman skills for the task. Field Engineering assistance should be obtained, where necessary.

The operations and maintenance staff ensure that if conditions are found that potentially impact the safe operation or continued reliability of an equipment or system, this is promptly reported to supervision so that appropriate actions can be taken. The maintenance department also has a major role in implementing the corrective actions under the Corrective Action Program (CAP) where plant systems, equipment and components are involved. During refueling outages, the maintenance department is extremely busy with scheduled activities for testing of equipment, repairs and providing support to modifications.

Nuclear power plant sites use a concept of System Engineers who are responsible for up-to-date status and knowledge of a particular system; for example System Engineer for the Reactor Coolant System (RCS). In addition, specific programs (spanning across the systems) are in place for specific groups of equipment, components or issues. Each has a program manager who is responsible for generic issues and improvements for that program; for example the Air Operated Valves (AOV) Program, Motor Operated Valves (MOV) Program and Flow Accelerated Corrosion (FAC) Program, to name a few.

1.5 Managing costs

Cost estimation for larger nuclear projects is a difficult area. Only general information is provided here and the reader is referred to international guidance from IAEA, NEA and the Association for the Advancement of Cost Engineering International (AACEI). Additional information may be available from the Project Management Institute (PMI), American National Standards Institute (ANSI), US Department of Energy (DOE).

For any project, preliminary estimates are developed during the conceptual stage and can range from order of magnitude costs to better estimates depending on the information available. Detailed costs are developed when the design is in the final form. Costs may still need to be adjusted based on the specifications of equipment and services when the procurement process occurs and implementation planning is in progress.

A formalized Earned Value Management System (EVMS) is generally used for large-scale projects (e.g. based on the guidance in ANSI.EIA-748-B). EVMS is built on the WBS elements and it provides a means for assessing performance measures against the baseline. It tracks the planned value (PV) of the work to be performed, Earned Value (EV) of the actual work performed and Actual Cost (AC) of the work done. The variances such as Cost Variance (CV) and Schedule Variance (SV) in percentage terms or in dollar values are used to determine the progress of the project, and corrections to the course of the project can be made when necessary. For costs of a general nature such as supportive activities, Level of Effort costs can be used. Computer software programs are commercially available that can be used to produce cost performance reports (CPR) or status at a glance (SAG) reports.

In developing project cost estimates it is important that records are kept as to how the estimates are derived, what the assumptions are and what tools were used. Contingencies must also be planned for and added to the costs. As the project proceeds from conceptual or feasibility study stage to detailed design, the costs can be appropriately updated for management approval prior to start of the detailed design work and implementation of the project.

If a portion of the work is subcontracted, the project manager must ensure that the scope, cost, deliverables, quality, schedule and the change process are all defined in the contract. If the work is being done by multiple organizations and has inter-dependencies, it is also important that a Design Interface Agreement (DIA) is in place to provide the specifics of who is responsible for what.

1.6 Managing risk in nuclear projects

Risk Management involves assessment of risk, risk mitigation strategies and decision making on the course of action. The risk assessment may conclude that risk is avoidable and those actions necessary to accomplish this are feasible. Alternatively, it may be concluded that risk is acceptable because its impact is low or manageable. Risk mitigation may be employed in other cases. In certain cases, it may be possible to transfer the risk. An example of this is in case of financial risk that may be transferred to contractors/subcontractors or to the insurance. It should be noted that project risks can change with the progression of the project and that it is necessary to assess and update risks on a regular basis through use of tools such as the Risk Register for the project.

It should be recognized that the focus of this section is on project risk. Risks at a nuclear power plant site can range widely in scope and the urgency of action. It is not the purpose of this section to provide details of all potential risks at a site but to develop some familiarization with the fact that depending on a variety of factors, various risks exist at a reactor site. Range of risks can include degradation of systems and components leading to degradation of reactor operation or reactor scram, potential release of radioactivity from the containment, potential contamination events and potential exposure of workers. Safety of nuclear reactors is of utmost priority in their design, engineering and operation, and every effort is made to minimize these risks. In fact, a significant proportion of the cost of a typical reactor goes towards the safety systems and safety structures.

In the USA, the general design criteria for nuclear power plants are available in Appendix A to 10CFR Part 50. The 10CFR Part 20 provides the standards for protection against radiation. Although radiation exposure limits are provided, it also requires licensees to make every reasonable effort to maintain exposures to radiation as low as is reasonably achievable. The NRC is also using a risk-informed, performance-based plan for integration of risk assessment and performance into the regulations.

From a project manager's perspective, multiple considerations are necessary, including: reducing nuclear risk, reducing risk to worker's health and safety, reducing risk of radiological contamination, reducing risk to plant operations and other stakeholders, reducing programmatic risk, reducing licensing risk and reducing financial risk. Risk assessment tools can provide input for project managers but a mature judgment is equally important.

For large and medium size projects, a formal Risk Management Plan may be necessary. As mentioned earlier, one tool that is invaluable is the use of a Risk Register. For larger projects, specific breakdown of risks may be kept as a living document in the form of a spreadsheet that captures the risks, their drivers, their numerical priority number (such as Risk Priority Number (RPN)). It is frequently (e.g. weekly) updated to allow management to address priorities and allocate resources where needed.

A project manager should ensure that risk management planning is comprehensive, remains up-to-date during the course of the project and that risk mitigation strategies are applied in a timely fashion when needed.

1.6.1 Design risk analysis

For a design change such as modifications to SSCs, risk analysis will involve analyzing design objectives and requirements, scheduling requirements (such as for modifications that can only be implemented during reactor outage), implementation constraints, critical parameters for work activities and consideration of the existing operating experience. A simpler application of Failure Modes and Effects Analysis (FMEA) may be used.

Potential failure modes for each activity are defined. For each potential failure mode, the failure mode or the activity leading to the failure mode is defined and its impact or effect on the outcome is determined. A probability of occurrence number is assigned (e.g. on a scale of 1–5) and a severity of consequence number is also assigned (e.g. on a score of 1–5). Based on a Risk Grid then, the risk is assessed as High (high probability of occurrence × high severity of consequence; for illustration purposes only, e.g. 15–25) or Medium (for illustration purposes only, e.g. 10–12) or Low (for illustration purposes only, e.g. 1–5). As far as the disposition of risk is concerned and from the perspective of risk response for each failure mode, it may be assessed as avoidable, as acceptable (e.g. based on information, test data or certification from the vendor on equipment) or as requiring mitigation (or requiring transfer). It is also important to designate a person who will be responsible for disposition of the risk.

1.6.2 Managing risk at a nuclear site

Many of the elements discussed in previous sections are a part of the mechanisms for managing risks at a nuclear site. Essentially, a manager needs to recognize that a nuclear site presents nuclear and radiation risk in addition to the industrial hazards. Industrial accidents present more risk in the day-to-day operation of a nuclear power plant. In the past decade, the nuclear industry has made significant progress in this area. The US nuclear industrial safety accident rate (one-year industry values, number of accidents resulting in lost work, restricted work or fatalities per 200 000 worker hours) has successively declined from 0.38 in 1997 to 0.06 in 2011 as per data reported by NEI (NEI 2012).

Nuclear sites have comprehensive sets of policies and procedures ranging from a worker's fitness to do the tasks, training, radiation protection and human performance skills for conduct of operations, maintenance activities, engineering changes and emergency procedures. First and foremost, managing overall risk at a nuclear site requires strict adherence to site policies and procedures as well as meeting the regulatory requirements. Reducing risk also entails using the best available people, qualified for the tasks and using the best available technology for the work. Worker safety is the utmost priority. In any nuclear project, all stakeholders must have the right information at the right time. Support organizations must have the resources and scheduled time to assist their projects.

One invaluable resource for the manager, engineer and nuclear worker is the past Operating Experience (OE). Summary digest and descriptions on specific events and specific technical issues are disseminated by the NRC, the Nuclear Energy Institute and the Institute of Nuclear Power Operations. In the USA, the NRC communicates significant technical issues through Generic Letters (GL), Information Notices (IN), Bulletins and Regulatory Issues Summaries (RIS).

For illustration, GL 2004-02 dealt with Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized Water Reactors. IN 2012-16 issued on 29 August 2012 dealt with Preconditioning of Pressure Switches before Surveillance Testing. RIS 12-11 issued on 26 September 2012 was titled 'NRC Staff Position On Dispositioning Boiling Water Reactor

Licensee Noncompliance With Technical Specification Requirements During Operations With A Potential For Draining The Reactor Vessel'.

NRC has also issued Generic Issues or Generic Safety Issues that require industry-wide assessment and response. An example is the GSI-191, Assessment of Debris Accumulation on Pressurized Water Reactors (PWR) Sump Performance.

Since 2001, NRC has implemented a program to monitor trends of industry performance in its Industry Trends Program (ITP). The performance indicators for operating plants (which for many years were previously monitored and then published in NUREG series) include: Automatic Reactor Scrams, Significant Events, Safety System Actuations, Safety System Failures, Forced Outage Rate, Equipment Forced Outage Rate and Collective Radiation Exposure. After the NRC assesses adverse trends for safety significance, it responds as necessary to any identified safety issues, including adjustments to the inspection and licensing programs. The annual results of the ITP are available in the SECY Commission Papers; for example the SECY-12-0056 issued on 9 April 2012 summarized the results for the Fiscal Year 2011.

NRC also monitors other parameters under its Reactor Oversight Process, generally specific to certain systems, such as the reactor coolant system activity, reactor coolant system leakage. In addition, NRC has other programs such as the Accident Sequence Precursor (ASP) Program and the Baseline Risk Index for Initiating Events (BRIIE) that monitors other specific parameters.

NRC requires an Emergency Preparedness (EP) plan to be in place at the nuclear site and requires that the nuclear power plant operator is capable of implementing adequate measures to protect public health and safety in the event of a radiological emergency. The emergency events at the site are classified as Notification of Unusual Event, Alert, Site Area Emergency and General Emergency. The General Emergency is the most serious category involving actual or imminent substantial reactor damage and where the population surrounding the plant site may be affected and protective measures (such as evacuation) may be required. A nuclear project manager and the project staff will learn the relevant information on emergency planning for the site as a part of their Nuclear General Employee Training at the site. Emergency planning and preparedness is a specialized area and is managed by the specific organizations at the site.

1.6.3 Managing risk in field activities

Field activities at a nuclear site require special care and caution because of the potential radiation hazards as well as the presence of industrial hazards. Nuclear sites have specific policies and procedures in place for conducting field work, and the plant staff, as well as the contractor staff, are required to adhere to these policies and procedures. In some cases the contract or engineering companies may have additional procedures for their staff who may perform work at different nuclear sites on a regular basis.

The manager must be cognizant of the safety requirements and procedures and ensure that the workers follow these requirements and procedures. The basics in this area include:

- Ensure workers are trained for the tasks.
- Workers must know the policies and procedures at the site and take responsibility for their personal safety.
- Ensure that a pre-job brief is conducted and a job hazard analysis is completed.
- Ensure that a site-specific or task-specific safety plan is followed.
- Workers must know the 'lockout-tagout' procedures for the equipment (when in place) to prevent inadvertent energizing of such equipment.
- Workers must wear appropriate safety equipment and appropriate clothing (such as personnel protective clothing).
- Workers must be alert to potentially hazardous conditions and to the posted warning signs, such as the Radiation Control Areas.
- Distraction should be minimized when in hazard areas or radiation areas.
- Workers must know the fatigue or heat stress symptoms and take appropriate actions for their safety and that of their co-workers.
- Workers should enter restricted Radiation Control Areas only if authorized for a purpose or task, and after meeting the access requirements and a job briefing.

A manager should recognize that field activities can range from short walkdowns by the design engineering personnel to collect data (measurements, photographs) in a specific location of the plant to full-scale implementation of modifications, installation of equipment or system testing. Based on the scope of the field activities, appropriate planning, coordination and minimization of worker risk will be necessary.

1.7 Challenges and lessons learned

Nuclear projects are under constant scrutiny from the regulators and are in the public spotlight much of the time and thus require constant vigilance from the manager.

A nuclear manager needs to recognize the unique nature of the nuclear projects and specific attention must be paid to nuclear safety, radiation protection and ALARA and the nuclear quality. A nuclear manager must have the necessary technical knowledge, project management skills, communication skills, licensing and regulatory awareness and the knowledge of the site's processes and procedures. Many nuclear projects have components that utilize contractors for specialty technical services and specialty vendors for nuclear grade equipment. A project manager must have the ability to effectively manage the workflow from subcontractors and vendors.

Many lessons have been learned from the past experience in construction, operation and maintenance of power reactors. These are regularly disseminated by the industry organizations as well as the regulators, and are an invaluable resource for a manager on current information relevant to technical issues and how other plants and organizations are dealing with these. Lessons have also been learned from the nuclear accidents at Three Mile Island, Chernobyl and Fukushima. The Fukushima accident of 11 March 2011 caused by a large earthquake and tsunami has led to a re-examination of the design basis for a nuclear plant for natural events. In the USA, recommendations from the Near Term Task Force (NTTF) set up by the NRC were published in July 2011. These build on the longstanding defense-in-depth philosophy. The NRC is requiring the industry to comply with the orders as they are issued based on these recommendations. Three Orders originating from the NTTF issued in 2012 include: Order EA-12-049 (Mitigating Strategies), EA-12-50 (Hardened Vents) and EA-12-51 (Spent Fuel Pool Instrumentation).

1.8 Future trends

The role of nuclear power as a component of the worldwide energy mix will continue as the energy demand continues to grow. In Asian economies such as China and India where energy demand is growing more rapidly and where the governments are aggressively pursuing nuclear power, many reactor projects are currently under construction and in planning stages.

The current designs of commercial reactors are more modular, incorporate passive safety features and are expected to reduce construction time, schedule and cost. In the USA, the NRC has streamlined the licensing process with the licensing application process combining the construction and operation licensing steps into one step.

There is renewed interest in small modular reactors for electricity generation because of the reduced capital costs and capability for use with smaller electrical grids. Diverse technologies are being pursued. In the USA, the DOE has been supporting the research and design effort in this area for the past several years.

Knowledge transfer and training are other areas that are commanding more attention at the national and international level. Many countries are now concerned that, as the current workforce is retiring or approaching retirement, there is not enough supply of young nuclear professionals entering the field. In addition, global workforce mobility can also lead to skills shortage in certain countries. International and national organizations are taking new initiatives to preserve nuclear technical knowledge, provide technical training and train younger professionals in the nuclear project management.

1.9 Sources of further information

ANSI, Earned Value Management System, American National Standards Institute, ANSI/EIA-748-B, 10 September 2007.

DOE, Earned Value Management System (EVMS), US DOE G-413.3–10a, 13 March 2012.

IAEA, The Management System for Nuclear Installations, Safety Standard Series No. GS-G-3.5, Vienna, 2009.
IAEA, Project Management in Nuclear Power Plant Construction, Guidelines and Experience, IAEA Nuclear Energy Series No. NP-T-2.7, Vienna 2012.
IAEA, The Management System for Facilities and Activities, Safety Standard Series No.GS-R-3, Vienna, 2006.

Web-based resources (various organizations)

International Atomic Energy Agency, www.iaea.org.
Organisation for Economic Co-operation and Development/Nuclear Energy Agency, OECD/NEA, www.oecd-nea.org/.
World Nuclear Association, www.world-nuclear.org.
Nuclear Energy Institute, www.nei.org/.
US Nuclear Regulatory Commission, www.nrc.gov.

1.10 References

Devgun, J. 2010, Modular Construction for Eventual Deconstruction and Decommissioning, Proceedings of the Waste Management Conference 2012, Waste Management Symposia, 7–11 March 2010, Phoenix, AZ.
IAEA 1992, The Chernobyl Accident: Updating of INSAG-1, Safety Series, No. 75-INSAG-7, Vienna, 1992.
IAEA 1993, The Safety of Nuclear Installations, Safety Series No. 110, Vienna, 1993. (Reader is referred to IAEA website for current information as IAEA is replacing Safety Series with other documents; April 2013.)
ICRP 2007, The 2007 Recommendations of the International Commission on Radiological Protection, ICRP Publication 103, Annals of the ICRP 37 (2–4), 2007.
IEA 2012, World Energy Outlook 2012, International Energy Agency, OECD/IEA France 2012.
NCRP 1993, National Council on Radiation Protection and Measurements, NCRP Report No. 116, Limitation of Exposure to Ionizing Radiation, ISBN 0-929600-30-4, 1993.
NEI 2012, U.S. Nuclear Industrial Safety Accident Rate (1997–2011) graph file, under Nuclear Statistics/Safety and Regulatory, Nuclear Energy Institute, www.nei.org, 2012.
NRC 2011, Recommendations for Enhancing Reactor Safety in 21st Century, Near-Term Task Force, SECY-11-00934-Enclosure, 12 July 2011.
WNA 2012, Nuclear Power in the USA, Updated November 2012, under Country and Regional Briefings, http://www.world-nuclear.org, 2012.

2

Safety culture and managing worker risk at nuclear facilities

J. DEVGUN, Senior Consultant, USA

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Abstract: It is well recognized in the industry that safe operation of a nuclear site requires not only proper design and operation of safety systems, but also a safety-conscious attitude within the workforce. This chapter focuses on the key elements of nuclear safety culture necessary for safe operation and management of risk at a nuclear site. It provides definitions of terms used in the industry and information on various aspects of worker safety at a nuclear site.

Key words: nuclear safety culture, safety-conscious work environment, pre-job brief, occupational exposure, ALARA, OSHA.

2.1 Introduction and definition of safety culture

Safe operation and management of risk are a part of any industry and most countries have established guidelines and requirements in this regard. For example, in the USA, the Occupational Safety and Health Administration (OSHA) requires adherence to mandatory safety and health rules for the protection of employees. To ensure safe operation at any workplace, employees, managers, employers and regulators have important roles to ensure safe working conditions for the employees and to ensure that safety of the plant operation is not compromised.

In the nuclear industry, emphasis on safety and management of risk is driven by the unique nature of the industry in terms of the generation of electricity through nuclear fission, presence of radioactivity and the presence or use of radioactive materials.

Specific to the subject of safety culture, there is no universal definition as it can span a continuum of attributes, activities, and stakeholders depending on the nature of the activity and the industry. For the nuclear industry, the term gained a greater significance after the Chernobyl nuclear accident in 1986.

The International Nuclear Safety Advisory Group (INSAG) of the International Atomic Energy Agency (IAEA) issued a series of reports on the Chernobyl accident and in INSAG-4 (IAEA 1991) defined safety culture as: ‘Safety culture is that assembly of characteristics and attitudes in organizations and individuals which establishes that as an overriding priority, nuclear plant safety issues receive the attention warranted by their significance’.

The Organisation for Economic Co-operation and Development (OECD)/ Nuclear Energy Agency (NEA) in NEA/CSNI/R(2012)13 (OECD/NEA 2012) states that both regulators and the nuclear industry recognize the need for licensees to develop a strong, positive safety culture to support successful and sustainable nuclear safety performance.

In the United Kingdom, the definition developed by the Advisory Committee on the Safety of Nuclear Installations (ACSNI) of the Health and Safety Executive (HSE 2005) states: ‘The safety culture of an organization is the product of individual and group values, attitudes, perceptions, competencies and patterns of behavior that determine the commitment to, and the style and proficiency of, an organization’s health and safety management’.

The US Nuclear Regulatory Commission’s (NRC) nuclear policy statement (NRC 2011) states: ‘The Safety Culture Policy Statement defines nuclear safety culture as the core values and behaviors resulting from a collective commitment by leaders and individuals to emphasize safety over competing goals to ensure protection of people and the environment’. The US industry has worked through the Nuclear Energy Institute to standardize programs across the operating nuclear plants to assess nuclear safety culture on a regular basis and to implement improvement programs as necessary.

2.2 Key elements of safety culture and the management of worker risk

2.2.1 Safety-conscious work environment

Safety-conscious work environment (SCWE) is an integral part of a strong nuclear safety culture. It has been recognized for over two decades now that safe operation of a nuclear site requires not only the proper design and operation of safety systems, but also a safety-conscious attitude of the workforce. The basic idea is that the organization as a whole must have a culture and environment to promote safety.

Following are the key elements of a SCWE:

- Site management cultivates and promotes SCWE.
- Each worker is personally responsible for safety.
- A questioning attitude is encouraged.
- Organization demonstrates strong commitment to safety.
- Workers can raise safety concerns without fear of reprisal.
- Safety has highest priority in decision making.
- Safety training is provided and continually updated.
- Because nuclear sites contain radiation hazards, nuclear sites have unique training requirements.
- In addition to safety of workers, the safety of public near the site is given proper consideration.

- Open (and free of reprisal fear) flow of information on safety-related issues.
- A formal process is established for Differing Professional Opinions (DPO).

At a nuclear site, a SCWE is a major element of the overall safety plan to reduce risks. A SCWE ensures that the work-related hazards are minimized and that the operation of the facility is conducted in a safe manner and compliant with the regulations and policies. In a nuclear site work assignment there is nothing that can be regarded as routine. Risks and hazards need to be recognized and evaluated prior to performing the task, even if similar tasks have been done before. Many nuclear organizations define it as the Nuclear Safety Culture (NSC) to emphasize this point.

The management has to continually balance the operational challenges with the minimization of risk. A no-risk option may be the first choice but is generally not feasible. Thus, risk-significant activities must be defined, planned, challenged and controlled appropriately.

2.2.2 Monitoring and maintaining a successful safety culture

A successful safety culture is continually monitored and adjustments are made as necessary. Many nuclear organizations include nuclear safety culture monitoring processes as part of the overall Human Performance monitoring process. In more formal processes the performance indicator matrices can be used to evaluate the effectiveness of the safety culture programs and the SCWE.

Some measure of effectiveness of the above can be provided by the indicators listed below:

- Positive or negative trends in workplace safety data.
- Deficiencies and violations.
- Positive or negative trends in worker attitudes.

Organizations can trend the data at the department level or at the site level and the lessons are generally shared throughout the organization. The organization may also use some of the same tools that are used to raise/document/resolve the equipment or process deficiencies at a nuclear site. An example of such a process is the Corrective Action Program (CAP) that is routinely used at nuclear sites.

In addition, organizations can use self-assessments or surveys at a reasonable interval (for example, twice a year) to judge the effectiveness of the safety culture and SCWE programs. Sampling can be performed on a random basis or all employees can be included in the surveys.

Questionnaire-based tools are very effective. These require the respondent to answer questions using a rating scale. Many tools focus on measuring the attitudes and perceptions held by employees towards the safety climate at the site.

Examples of such questions are listed below:

- Are you able to raise concern about safety without fear?
- Do you believe you have adequate training to perform the tasks safely?

- Is a pre-job brief conducted for each major task?
- Is job hazards analysis done prior to initiating a major task?
- Did your manager/supervisor clearly define the task?
- Did job planning consider operating experience?
- Did you have the adequate resources to do the job right?
- Does the supervision/management trust you with the tasks assigned to you?
- Are you able to do the job right first time around?
- Does your organization share lessons learned with other departments?
- Does the site organization share lessons learned with the industry in general?

It is worth noting that although the design of the systems installed at a nuclear site and the safe operation of the systems have requirements set by the regulatory authorities, safety culture and its effectiveness are a site responsibility. Safety culture-related measures or indicators are difficult to take into account in risk analysis. Additionally, there is no wide consensus on how the regulator's role should be defined as far as the supervision of the program implementation is concerned. Some guidance on establishing such programs is available from national and international organizations. Some work has also been done in the area of establishing practical approaches for regulatory oversight in the area of safety culture.

2.2.3 Safe workplace

In practice, establishing a safe workplace is a question of ensuring compliance with the safety regulations as well as promoting strong safety culture at the site.

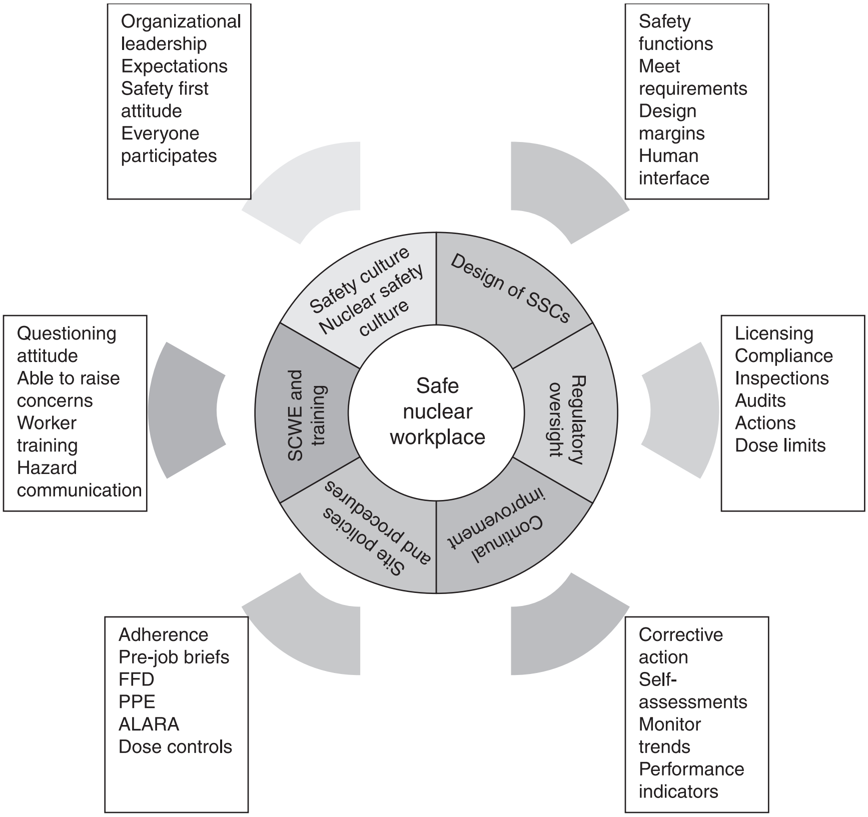
At a nuclear site, the work control processes should emphasize the NSC. Some key elements of NSC are:

- SCWE.
- All work is performed in compliance with the licensing conditions and regulations, and by adhering to site procedures.
- Tasks and roles of the personnel are clearly defined.
- Nuclear safety-related issues are promptly identified.
- Nuclear safety-related issues are promptly entered into the site's CAP for timely resolution.
- Pre-job briefs are conducted.
- Human performance is given appropriate attention, especially error prevention techniques.
- The site's safety program is continuously monitored and improved as necessary.

A summary of key elements of a safe nuclear workplace is depicted in Fig. 2.1.

Role of the Occupational Safety and Health Administration in the USA

In the USA, the Occupational Safety and Health Act of 1970 is implemented by OSHA, which sets and enforces protective workplace safety and health standards.



2.1 Key elements of a safe nuclear workplace.

It also provides information, training and assistance to workers and employers. It provides a process for workers to file a complaint to have OSHA inspect their workplace if their workplace is not following OSHA standards, or if serious hazards exist at the workplace that are not properly addressed by the site. OSHA allows states to develop and implement their own job safety and health plans (with approval and oversight from OSHA) so long as the standards implemented are comparable to the federal standards. Several states are using this mechanism.

Regulations from the OSHA are contained in the Code of Federal Regulations under Title 29 in various parts in the 1900 series. The most relevant parts are the 29 CFR Part 1910, Occupational Safety and Health Standards, and 29 CFR Part 1926, Safety and Health Regulations for Construction. From 29 CFR Part 1910, relevant to the discussion in this chapter, two areas of interest are: Subpart I – Personal Protective Equipment, and Subpart Z – Toxic and Hazardous Substances, within which the 1910.1200 Hazard Communication requires that workers be made aware of the workplace hazards.

Of the four groups of OSHA standards: General Industry, Construction, Maritime and Agriculture, General Industry is the set that applies to the largest number of workers and worksites. These General Industry standards, along with the Construction standards, are most relevant to the nuclear sites.

Nuclear sites in the USA are licensed and operated under the jurisdiction of the US NRC. The 1999 Memorandum of Understanding (MOU) between the NRC and OSHA ensures that worker protection at NRC-licensed sites is provided while avoiding duplication from the two agencies. It is not always practical to sharply identify boundaries between NRC's responsibilities for nuclear safety and OSHA's responsibilities for industrial safety. Thus, the MOU ensures that there are no gaps in the protection of workers irrespective of the agency jurisdiction. The MOU provides general procedures for the coordination of interface activities and exchange of information between the NRC and OSHA.

A nuclear site is also an industrial and construction site at which many of the same activities take place on a daily basis in addition to the concerns of nuclear safety, nuclear materials and nuclear systems. Thus, it is important to recognize what the OSHA data over the years have shown, that the areas where safety concerns and violations occur include: scaffolding, fall protection, hazard communication, respiratory protection, electrical wiring, falling objects, powered industrial tools and machine guarding.

The success of OSHA and implementation of safety practices in the general industry is in the fact that, by 2012, workplace fatalities had been reduced by more than 65% and occupational injury and illness rates had declined by 67% since the 1970s, even though the workforce has almost doubled since then.

2.3 Managing safety at a nuclear site

Although there are many safety management-related areas of interest at a nuclear site, the focus of this section is on worker safety and selected topics are discussed here. Occupational exposure to radiation at a nuclear site is discussed in Section 2.4.

2.3.1 Worker training and other requirements

General Employee Training (GET) and Plant Access Training (PAT) are fundamental training for all workers at a nuclear site. This provides workers with the basic familiarity of the site layout, function of major departments, site policies, site quality program, site emergency planning, radiation areas at the site, basic radiation protection and basic industrial safety. Specific training such as radiation worker training and detailed training is provided to the workers who are required to do those specific tasks.

2.3.2 Fitness for duty

Nuclear sites require that the workers at the site be able to perform their duties without any physical or mental impairment. As a part of the badging process and allowing unescorted access to the site the workers must meet the Fitness For Duty (FFD) requirements. In the USA, federal law requires an operator of a nuclear facility to provide reasonable assurance that plant personnel are reliable and trustworthy and are not under the influence of alcohol or any legal or illegal drugs, nor are mentally impaired from any cause that may adversely affect their ability to safely and competently perform their duties. The site operator must establish a FFD program to achieve compliance with the above and to provide assistance for any FFD-related problems. It is also recognized that fatigue or illness may affect fitness for duty and supervisory personnel have a key role in ensuring the FFD application.

2.3.3 Job briefings and job hazard analysis

This is generally referred to as the pre-job brief or PJB for short. The PJB is conducted prior to the start of a task. A job brief should take place between the Supervisor/Manager or the Work Lead and the work crew and should include a discussion of specific hazards involved with the work or the task, tools and equipment to be utilized, and any special safety precautions to follow. Participation by other departments/personnel such as the Radiation Safety Technician is included as necessary. In a more formalized structure, a Job Hazard Analysis (JHA) for the task is prepared in a JHA form, which captures the important information.

During the PJB, the management also ensures as a check that assigned personnel have appropriate training. Note that it is expected that the supervisor responsible for the work will assign personnel who are appropriately qualified and trained for the work.

In the radiation work environment specific safety precautions will include having dosimeters, knowing the dose rates in areas, dose surveys of areas (and knowing low-dose areas and high-dose areas), dose limits and emergency communication. Thus, PJBs should also consider potential job risks and ensure contingencies are in place if problems are encountered in the field while performing the work.

2.3.4 Hazard communication

Most sites dealing with hazardous materials, including nuclear sites, will have a written Hazard Communication Program. The requirements of 29 CFR 1910.1200 (often called HAZCOM) in the USA require that workers be made aware of hazards in the workplace. These include toxic and hazardous substances, availability of Material Safety Data Sheets (MSDS), labels and warnings (e.g. 'flammable'), as well as the Permissible Exposure Limit (PELs) for the hazardous material.

2.3.5 Personnel protective equipment and anti-contamination clothing

To protect against hazards that may be encountered when performing a task, appropriate personnel protective equipment (PPE) should be worn as required by the procedures and the task requirements. Examples of safety attire include: hard hat, safety goggles, gloves, safety footwear, PPE and respiratory protection.

At a nuclear site, an important safety attire requirement is anti-contamination clothing to work in an area where radiological material is present. Different levels of anti-contamination clothing are used. At a minimum it includes, modesty garments, cloth glove liners, coveralls, rubber gloves, hood, cloth bootees, elastic straps and rubber shoes. Respiratory protection is also included, if necessary.

Workers are trained in how to don and remove anti-contamination clothing.

2.3.6 Chemical safety

Workers should be trained in basic chemical safety programs and policies at the site, and should have access to information on the risks, hazards, safe handling and disposal of any chemical substances with which they have to work. This includes chemical labeling, MSDS, chemical permits and any specific procedures related to handling and disposal of chemical wastes.

2.3.7 Scaffolding and platforms

Scaffolding is frequently used at industrial sites, including nuclear sites, to access higher elevation areas for construction work, repair work and other work. Scaffolding safety programs ensure that scaffolding is of sufficient strength and rigidity to support appropriate weight requirements. Only a qualified scaffold builder is allowed to build, modify or remove scaffolding, and the program ensures that the regulatory requirements are met (e.g. OSHA in the USA). Construction details ensure that scaffolding is equipped with toe-boards and guardrails and other precautions that may be necessary. For those situations where metal scaffolding could become energized as a result of induced voltage or physical contact, the scaffold would need to be grounded to the building ground.

Safety chains or guard rails should be used on all work platforms and should remain secured at all times except for access, that is passing through the opening.

2.3.8 Confined space entry

Workers who will be performing any tasks in a confined space will need to be specially trained, and regulatory requirements for entry to confined space must be met. The OSHA regulations under 29 CFR 1910.146 define confined space, authorized entrant and entry conditions, permits required for confined space entry, equipment required, testing and monitoring, ventilation, communication, lighting, PPE, as well as other requirements.

2.3.9 Power tools

Tools are used every day at nearly every workplace. Special precaution is necessary while using power tools as they have the potential to cause serious injury or even fatality. Workers that use special tools, power tools and shop equipment must be appropriately trained. Appropriate safety equipment, such as eye protection and hand protection, must be worn.

2.3.10 Lock out/tag out

Lock out/tag out is an essential part of a safety program at nuclear site because of the presence of energized equipment all over the site. The OSHA regulations under 29 CFR 1910.147 require that unexpected energization of machinery and equipment must be avoided. This includes mechanical, electrical, hydraulic, pneumatic, thermal or chemical energy. Specifically, the unexpected energization of mechanical and electrical equipment at a nuclear site is a potential high risk because of the large quantity of such equipment at the site. When taken out of service for any reason (e.g. repair), placement of a lockout device on the equipment ensures isolation of the energy device and avoids its inadvertent energization. Placement of a tagout device or placard serves as a warning not to energize that device.

2.3.11 Other considerations

In addition to the areas discussed above, other considerations may be required in a power plant environment. These include high noise, heat stress, trip or fall hazards, electrical hazards, steam leaks, radioactive materials, compressed gases and moving equipment. Another area of consideration is the clear communication with workers on the task scope. Many nuclear sites emphasize the three-way communication, where supervisor (Initiator) gives instructions to the worker (Receiver) and then the worker (Receiver) repeats the instructions back to the supervisor (Initiator) to ensure that he/she understood them correctly.

2.4 Managing worker risk at a nuclear site

Discussion in earlier sections of this chapter covered the topics of safety culture and safety in the workplace, and they fully apply to managing risks to workers at a nuclear site because by its very nature a nuclear site is also an industrial site. The focus in this section is on managing radiation risks to workers and selected topics are discussed. The discussion is inherently qualitative in nature because the specific requirements will be based on the national regulatory requirements and the site administrative policies.

2.4.1 Application of As Low As Reasonable Achievable

Adherence to site procedures, policies and requirements is expected of the workers at a nuclear site. However, one of the fundamental tenets of radiation protection is that radiation exposures be kept As Low As Reasonable Achievable (ALARA). All workers at a nuclear site have basic training in radiation protection and ALARA. Thus, they are aware of radiation hazards and minimization of radiation exposure through time, distance and shielding, that is minimizing time spent near the radiation source, keeping as much distance from the source as possible and use of shielding, when necessary.

As a part of the ALARA management or ALARA program, a nuclear site will typically take actions on individual exposure reduction as well as initiatives for the overall site collective dose reduction. The goal is to maintain personnel Total Effective Dose Equivalent (TEDE), both individually and collectively, ALARA. Nuclear sites are required to meet the regulatory limits on occupational exposure, and typically the administrative limits set by the site are much lower than the regulatory limits. An ALARA program is applied in addition to the limits to minimize exposure at the individual level, which in turn also helps in reducing the collective site radiation exposure.

The workers who have to perform tasks in a radiation controlled area (RCA) or have to work with radioactive materials are trained as radiation workers (also called radworkers). In addition to the initial radworker training, they are required to undergo annual radworker requalification. ALARA awareness is highlighted in the training and many qualification programs also include simulated exercises to ensure that workers know the actions to be taken when faced with changing radiological conditions.

2.4.2 Occupational dose control

Dose limits for workers at a nuclear site are set by the regulatory authorities and are generally in the form of occupational dose limits. In the USA, reactors are licensed under the provisions of 10 CFR Part 50, and Section 50.120 provides the training and qualification requirements of nuclear power plant personnel.

The dose limits are defined in 10 CFR Part 20, Standards for Protection Against Radiation. Specifically, Section 20.1101 requires establishment of radiation protection programs commensurate with the scope and extent of licensed activities. Section 20.1201 provides the occupational dose limits for workers and requires the licensee to control the occupational dose to individual adults (except for planned special exposures under Section 20.1206) to the dose limits specified in the Section. The annual limit is defined as the TEDE of 5 rems (0.05 Sv). It should be noted that the nuclear sites set Administrative Dose Limits that are much lower, generally, at 2 rem (0.02 Sv), consistent with national/international guidelines. In addition, ALARA is applied to remain below the Administrative Dose Limits for individual exposure.

2.4.3 Other activities in support of reducing occupational exposures

Other activities in support of reducing occupational exposures include the following:

- Source term reduction: For example, the activity in piping or other components can be reduced or removed through various decontamination processes.
- Contamination control: Cross contamination is avoided; spills are properly contained and cleaned up.
- Radioactive materials control: Inventories are maintained and monitored. Areas containing radiation or radioactive materials are designated as RCAs.
- Radworker training and practices: Radworkers are properly badged for plant access and access to the areas of radiation work. Radworkers are properly trained to work in the radiation environment and safe work practices are encouraged and expected. A system of Radiation Work Permits (RWPs) is used.
- Emergency preparedness: Plans are available in case of emergency during radiation work. Site Area Emergency Plans are in accordance with the regulatory requirements.
- Radiation control for workers: Effective dose control measures are maintained. It is ensured that workers are properly trained.
- Exposure trending: If conducted on a weekly/monthly/annual basis, trending analyses allow monitoring and adjustments to the radiation protection programs and safety measures.
- Reduction of occupational doses during outages: As most plant modification work is performed during outages, tightly controlled dose budgets for activities reduce the overall cumulative dose exposure of the site.
- Mock-ups: When modifications (to plant systems or equipment) are done in the area of significant radiation exposure, mock-up activities help personnel become familiar with the installation prior to actual installation to minimize the possibility of mishap and to minimize the time taken in the field.
- Structures, systems and components inspections and review: SSCs are reviewed on a scheduled basis and any adverse findings are addressed in a timely fashion.
- Corrective Action Programs: Issues related to nuclear safety, equipment deficiencies or performance degradation are promptly identified, evaluated and actions are taken to remedy the issues.

Nuclear power plants use, as human performance tools, key cards with reminders on the same lanyard as the badge. These key cards have simple reminder messages such as Pre-Job Brief, Stop-Think-Act-Review, Questioning Attitude, Procedure Adherence and Effective Communication. For supervisors and managers these and additional messages related to risk reduction, work management, and performance may be included.

Overall, one measure indicative of the success of the safety management and safety couture programs is the data in the performance factors for the plant. Over the past three decades the capacity factors for the plants have increased significantly, the industrial safety accident rate at the nuclear sites has continually decreased and the significant events (such as Licensee Event Reports) have steadily decreased.

2.5 Challenges and lessons learned

The examination of the Chernobyl accident by organizations such as the IAEA led to the formal induction of safety culture into the policies and workings of most nuclear sites, even though many of the elements and their application have existed in one form or another for a long time.

The Chernobyl accident happened on 26 April 1986 at Unit 4, a 1000-MWe graphite-moderated light water reactor of RBMK design. The accident had global impact in addition to the devastation at the site and was the only classification 7 (Major Accident) on the International Scale until the 11 March 2011 accident at Fukushima Daiichi plant caused by the great Japan earthquake and the tsunami that followed.

It should be noted that detailed analyses of the Chernobyl accident have been conducted over the past two and a half decades to determine root causes and lessons learned. It is not the purpose here to discuss any of the detailed technical lessons; instead, relevant to the focus of this chapter some conclusions can be summarized. The reviews identified a series of issues that contributed to the accident directly or indirectly. These included a design that was deficient in safety standards, deficient safety analysis, deficient operating procedures, inadequate understanding/knowledge of the operators and inadequate regulatory oversight. At Chernobyl, workers chose to conduct a test and operate equipment outside the procedures that were designed for the reactor's safe operation.

The post-accident reviews pointed to a general lack of safety culture in nuclear matters at the station.

2.6 Conclusion and future trends

Safety-related performance of systems and components at nuclear sites has always been monitored and quantified across the design criteria and functional requirements of those systems and components. There are extensive data that can be tracked and trended to identify vulnerabilities. Inspections and reviews by the regulatory authorities also use performance measures that can quantify how well the systems and components continue to perform their functions. Similarly, methodologies are available and are utilized in the industry to quantify potential risk of failure of a system or component.

However, the topic of safety culture, like many other human performance-related topics is not a hard science and engineering item and it is inherently difficult to measure and quantify. Regulatory authorities have moved in a direction where requirements for safety culture are included in the regulatory regime, but no performance measures can be easily assigned to this regime. There are tangible ways through which the success of such programs can be ascertained. These include general industrial accident trends, nuclear incident trends, employee satisfaction surveys and lost work days as a result of accidents and absenteeism. There is recognition in the industry that the nuclear sites have the onus to maintain their safety culture programs and initiatives in the best possible form and ensure that they are continually examined and updated as necessary.

2.7 Sources of further information

IAEA, The Management System for Facilities and Activities, Safety Standard Series No.GS-R-3, Vienna, 2006.

IAEA, Safety Guides, Application of the Management System for Facilities and Activities, Safety Standard Series No. GS-G-3.1, Vienna, 2006.

IAEA, The Management System for Nuclear Installations, Safety Standard Series No. GS-G-3.5, Vienna, 2009.

IAEA (1991), The Chernobyl Accident: Updating of INSAG-1, Safety Series, No. 75-INSAG-7, Vienna, 1992.

United States Occupational Safety and Health Administration (OSHA), 29 CFR Part 1910 and 29 CFR Part 26.

Web-based resources (various organizations)

International Atomic Energy Agency, www.iaea.org.

Organisation for Economic Co-operation and Development/Nuclear Energy Agency, OECD/NEA, www.oecd-nea.org/.

World Nuclear Association, www.world-nuclear.org.

Nuclear Energy Institute, www.nei.org/.

US Nuclear Regulatory Commission, www.nrc.gov.

US Occupational Safety and Health Administration, www.osha.gov/.

2.8 References

HSE (2005) A review of safety culture and safety climate literature for the development of the safety culture inspection toolkit. Research Report 367, HSE, UK, Norwich, 2005.

IAEA (1991) Safety Culture, A report by the International Nuclear Safety Advisory Group, Safety Series, No. 75-INSAG-4, Vienna, 1991.

NRC (2011) Final Safety Culture Policy Statement Federal Register /Vol. 76, No. 114 / Tuesday, June 14, 2011 /Notices, [NRC–2010–0282] Final Safety Culture Policy Statement.

OECD/NEA (2012) Oversight and Influencing of Licensee Leadership and Management for Safety, Including Safety Culture – Regulatory Approaches and Methods (Proceedings of an NEA/IAEA Workshop), NEA/CSNI/R(2012)13,OECD/NEA, June 2012.

3

Training in the nuclear industry

J. A. LECLAIR, Dean, Excelsior College, USA

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Abstract: This chapter discusses the importance of training in the nuclear industry. Nuclear training is not simply necessary, but imperative for successful operations. At a nuclear facility, managers and employees who are well trained and acutely aware of their roles and responsibilities are the most important keys to both safety and efficiency. Therefore, the primary mission of the nuclear training department is to develop employee knowledge, skills and attitudes to achieve high levels of safety and effectiveness. The responsibilities and purpose of the training department are daunting, but offer many opportunities to promote an effective, efficient and safely operating organization.

Key words: nuclear industry, safety, training, roles and responsibilities.

3.1 Introduction

One of the keys to a safe and effective nuclear facility workforce is managers and employees who are well trained, responsive and acutely aware of their roles and responsibilities. More than any other industry, nuclear training is not simply necessary, but imperative for successful operations. Experience has taught us that one of the primary concerns is to reduce the incidence of human performance errors on the job, both from permanent and, particularly, non-permanent employees. The primary mission of the training department at a nuclear facility is to develop the knowledge, skills and attitudes necessary in site employees to achieve high levels of safety and effectiveness. To accomplish this, the training department must impart knowledge of safety, operations, maintenance, health physics/radiation protection, chemistry, engineering, emergency preparedness and security.

It is also recognized that any human performance errors must serve as a learning experience for the entire industry. With that in mind, training should also include the familiarization of workers with situations that have occurred in other facilities around the globe. From those situations, much can be learned with the aim of preventing reoccurrence of similar errors in future.

Although effective workforce training is necessary for plant success, the skills and attitudes of the individuals that lead and manage the workers are essential. Ongoing leadership training sessions, often labeled Leadership Academies or School of Nuclear Energy Management training, for those in or soon-to-be in leadership positions enhance and update leadership skills. Managers at all levels of the organization must be able to communicate organizational values, motivate and engage employees, and recognize and reward employee performance. Their ability to monitor and manage workforce behavior and continually evaluate identified needs is the key to maintaining the organization as a learning organization, capable of identifying opportunities for improvement and implementing appropriate interventions and solutions in a systematic manner, while continually evaluating the results.

Taken together, the responsibilities and purpose of the training department at a nuclear facility are daunting, but offer many opportunities to promote an effective, efficient and safely operating organization.

3.2 Fundamental issues for managing training programs at nuclear sites

Line and training managers have numerous responsibilities to carry out for training and qualification of personnel. Their ultimate goal in the training arena is to develop and maintain training programs that produce qualified workers to operate and maintain nuclear facilities.

Line manager responsibilities include selection and development of workers, personnel training and qualification of workers, including both permanent and non-permanent personnel, on-the-job training and evaluation, engagement in curriculum committees, and strong involvement in the Systematic Approach to Training (SAT) process, in all phases of this process, from identifying training needs, materials review, to training observations. The line manager's role in training and qualifying assigned workers is a core responsibility. Training manager responsibilities include working with line managers to ensure the line's training needs are met and training improves personnel performance. Workers are responsible for completing training and qualification prior to working independently, identifying training needs and providing timely feedback on training, and participating in training curriculum committees.

The perceived need for training or change can stem from a number of activities within the organization. They can range from training on new equipment to training on new regulations. After a facility has been constructed, it almost immediately begins the process of upgrading equipment and materials. Some of the new equipment can come as a result of new regulations, and modifications to equipment may be made that make it more efficient or safer. When an event occurs at a plant, often times the resolution at that plant will be used at another site to prevent the event from happening again. This also requires training on the corrective action, procedure or equipment. Training may also be required as a result of feedback from the members of the staff or their managers who have identified a problem, or through a result of self-assessment. The perceived need for training can also result from a root cause analysis, a perceived weakness in the training process, or results or feedback from worker performance. Finally, training may result from environmental issues or as a reaction to external incidents, either actual or anticipated.

Training managers in the nuclear industry need senior management endorsement for, and communication of, the importance of training. Training managers must ensure written training procedures are used and supported. Line managers are the owners of the training programs, however, and first line supervisors should work with the training department to identify training needs, assist in the development of the training, as well as review the training prior to implementation. In order to do this, line managers must understand the SAT process and be able to demonstrate that the training meets the performance requirements for worker qualification. The training manager should work closely with plant management to receive feedback and work with review committees to receive feedback on training programs.

The training organization must ensure several things take place prior to developing the training. Individuals selected for positions must meet the educational and experience requirements for their position. The individuals selected must also possess the attitudes and values appropriate for work in the nuclear field. Training at a nuclear facility can take place either at the training center in the classroom, laboratory or simulator environment or on the job as the training setting has been identified. Depending on the material to be delivered, the training sessions may also be delivered at an off-site facility. By delivering the required training, workers will obtain the necessary skills to accomplish their assigned tasks in a safe and efficient manner. These individuals, once qualified, can then work independently at their tasks. In so doing, the increased efficiency will lead to improved performance.

3.2.1 Systematic approach to training

Still other components must be in place prior to the actual training. In addition to having individuals suited for their positions, initial training and qualification programs must be developed based on job tasks and responsibilities. For training to be effective, it must come from a training program that has been thoughtfully designed and implemented to meet the needs of the workers at that specific facility. A systematic process must be used in designing an effective initial training program, and continuing training must be designed and developed to ensure personnel maintain the knowledge and skills necessary to perform their job successfully. As mentioned before, this process is often referred to as SAT or the ADDIE (analysis, design, development, implementation and evaluation) process. If properly utilized, those components will yield an effective training program to produce competent workers.

The first component in the SAT process is an analysis of the job and the training needs. Three activities – needs, job and task analysis – make up the analysis phase of the SAT. These activities are key to developing initial and continuing training programs, as well as improving performance in existing programs.

A needs analysis identifies whether or not training or a management initiative is the appropriate solution for a situation. Whether for development of new training tasks or programs, needs analysis identifies if a training or non-training initiative is needed by asking questions regarding policy, equipment or barriers that are present when performing the task. It must be continually noted that only insufficient knowledge, skills or attitude identify training as the possible solution, whereas other causes identify non-training solutions such as management initiatives or procedures, for example. If determined that training is needed for the task, a plan is developed to identify time and resources to develop the training. When used to improve existing programs, performance analysis is used to identify issues that requires appropriate training or management interventions to correct the identified deficiency.

A job analysis is conducted by gathering information from job data and personnel to identify all the tasks within a job that exist, and identifying those selected for training based on difficulty, importance and frequency. Infrequently performed tasks are generally selected for initial and continuing training, with those tasks of high importance often selected in addition for 'just-in-time' training. Indicators of job performance are identified at this time, as well as expectations and outcomes. These performance expectations identify the expected outcomes and characteristics that employees should exhibit on the job. Job analysis data must be validated to ensure accuracy.

A task analysis is conducted on those tasks that were selected for training during the job analysis. Actions, conditions and standards for task performance are identified at this time, as well as the knowledge, skills and attitudes for correct task performance, and the steps or elements necessary for accurate task performance.

The next component of the SAT process is design. The design phase uses the information from the analysis phase to identify in measurable terms the knowledge, skills and attitudes that will be used to design the training. Measures for task performance are designed for each task. The training setting for each task, whether classroom, laboratory, simulator or in-plant on-the-job training is identified in the design phase. Learning objectives are developed for tasks (or groups of knowledge- and skill-related tasks). Learning objectives identify under what conditions the task will be performed, state the action in measurable terms and identify how well the task must be performed when on-the-job. It is in the design phase that tests are developed to measure the level of employee competence at the task. These measures of observable employee behavior are the essentials of the design phase. Further in the design phase, pre-requisite skills and knowledge must be identified, as well as development of a training plan.

The third phase in the SAT process is the development of the training. In this phase, the instructional materials needed to achieve the training are organized. Learning activities are developed that describe what the instructor and trainee will do during the training to achieve the objectives. Training methods are selected that best suit the task, and performance-based training materials and lesson plans are developed. Training materials must be reviewed and piloted (preferably with a group of trainees and a supervisor), and revised as needed. This includes the logistics of the training, which is not limited to the classroom environment, technical equipment, transportation of the learners (if off-site), arranging schedules and preparing any training aids or print material.

Implementation is the next phase in the SAT process ADDIE. Once the training program has been analyzed, designed and developed, it is implemented. Instructors are identified, trained and the trainees, facilities and resources are secured. In-training evaluation occurs in this phase of the SAT process. The evaluation measures whether the trainees have met the measurable training objectives. Both instructors and trainees are evaluated for performance. Trainees must demonstrate they meet course objectives while the instructor must demonstrate competence in providing quality instruction. Documentation is important because if the training is not documented, there is no proof of occurrence. It is this stage of the training process that produces trained employees.

The final step in the process is evaluation. The evaluation phase ensures that training has, indeed, produced qualified employees. Several key training system performance indicators must be monitored to ensure the training has met the needs of the individual and the organization. Job and plant performance must be monitored, along with other indicators such as operating experience, feedback, procedure changes and post-training feedback. The information obtained through these indicators must be analyzed using the simplest means available such as frequency distributions, exception analysis and content analysis, identifying key issues. Identification of the cause of the problem is the determining factor as to whether it can be resolved by training or another management initiative. Changes should be initiated to resolve performance deficiencies once the appropriate solution is identified. When corrective actions to address these concerns are completed, program recommendations, performance deficiencies and human resource requirements may need to be improved. Few newly designed programs are without fault and it can be expected that some program improvements will be needed. Although this will come from observations of those delivering the program as well as feedback from the students, the indicators that are monitored are an integral part of training evaluation.

Both the training and line management are responsible for the transfer of training, that is the use of the knowledge, skills and attitudes back on-the-job that were learned during training or an intervention. Training and line management must work together to overcome any obstacles related to successful transfer back to the job. They must overcome obstacles such as lack of support, perceived low value for training or misalignment of training with the work environment, or lack of reinforcement of the training back on the job. Resistance to change and either real or perceived time pressure can also act as barriers to successful transfer of training. To overcome the obstacles, training and plant managers and first line supervisors are responsible before the training to ensure they have reviewed the training materials, have supported training attendance and ensured that there is alignment of the environment and the training. Managers should check with instructors and trainees during the training to ensure their training needs are being met and they are actively engaged in the training activities. Following the training or intervention, the work environment should be evaluated to see if any barriers exist that impact successful transfer of the training and observe trainees back on-the-job to evaluate post-training task performance.

3.2.2 Leadership and management training

An important aspect of training in the nuclear environment is that which is provided to the leaders, managers and supervisors at the facility. Although effective training is necessary for the workforce, it is even more important for those who lead them. This is especially true in the nuclear environment where safety and ethics are so important. Leaders set the stage and provide a model for ethical behavior, safety and the overall expectancy for quality work and attention to detail. Leaders also are the prominent drivers when a change activity is deemed necessary at the plant.

The training and education obtained by leaders can come from a variety of sources including traditional colleges, professional development and self-improvement. However, one of the best methods for training leaders is through executive management training for senior managers or the leadership academy format for middle and first line managers. Whereas executive management training generally is provided through an outside agency or consultant group, leadership academy training often is provided off-site through a corporate training group, and follows a preset schedule of topical areas over several days in a classroom setting. Middle and first line managers are exposed to a variety of topics ranging from ethics and effective management techniques to the latest in human resource issues, knowledge management and safety. The topics are selected following a needs analysis working in conjunction with the respective consultant group developing the training. In the past a variety of tasks have been identified as deficiencies in nuclear supervisor performance. These include ineffective oversight, not addressing inappropriate worker behaviors, lack of engagement in worker improvement, competing priorities, high workload and perceived lack of management support. Once the training topics are selected, the choice would then be made as to the location for the training and if the training should be done with in-house personnel, consultants or a combination thereof.

There have been changes in the nuclear community, including the changes brought on by the nuclear renaissance, and a leader must be able to successfully navigate the uncertain waters that change brings about. Therefore, strong emphasis must be placed in leadership training as to how to handle change and avoid any resistance to that change. Leaders must become aware of the benefits of open communication with employees, share the need for any change initiative, be inclusive of member inputs and identify successful avenues to bring people on board to move forward.

Leaders and managers at nuclear plants not only face the myriad issues associated with leading a workforce under day-to-day circumstances, planned and unplanned outages and a variety of other business circumstances such as corporate mergers, but must also deal with the special complexity of leadership and management in the highly regulated nuclear environment. By providing leadership training in the form of executive management or middle and first line supervisory training, those in leadership and management positions will be better equipped to work successfully with the workforce.

3.2.3 Performance improvement

The effective training of site workers and those who lead them is part of the path towards the overall improvement of plant performance. By improving performance, the plant improves its overall efficiency, decreases unscheduled down time, reduces time in refueling outages, improves the safety record and, in the end, lowers operating costs thereby increasing the bottom line for the organization. A well-functioning organization, one that is constantly seeking to improve, will, as a byproduct, increase the trust, faith and goodwill from shareholders, stakeholders and the general public.

Improving the performance of an organization is an interwoven and complex task that involves integration of all aspects of the organization to ensure effectiveness and efficiency. Activities at the strategic, procedural and job level all have an impact on performance as does an organization’s culture and the ongoing focus on human performance.

Senior leaders deal with most of the issues at the strategic level. Their job is to set the goals of the organization and design the strategies and structure that will accomplish these goals and see to it that the necessary resources are available. Leaders also need to develop a process to reduce errors and create a culture of safety orientation at the plant. In working to achieve this, leaders must establish several items:

- Open lines of communication.
- Sense of teamwork.
- Culture of community.
- Focus on safety culture.
- Human performance improvement.
- Respect for procedures and processes.
- Adherence to documentation.
- Assessment program.

Open lines of communication

Open and honest communication is vital for the success of any organization, and that communication line needs to work two ways. Leaders need to have inputs from their employees, and workers need to be able to trust what is being asked of them. If there is no trust, or leaders are isolated from the work taking place in the organization, there will almost certainly be a breakdown.

Sense of teamwork

Leaders must work to establish a sense of teamwork on the site as well as a sense of community. Teamwork is essential for success in the workplace. More and more organizations are finding that teams get work done efficiently. By working together towards a common goal and getting the members of the workforce to combine their talents, performance can be improved throughout the work site.

Sense of community

Likewise, establishing a sense of community is also important. Extending teamwork to encompass the site as a whole, where all the members at the station see themselves as one entity, one site community, working for the common good and benefit of not only the station but the organization's stakeholders and the supporting community.

Safety culture

A strong safety culture needs to be developed and maintained in all nuclear organizations so that the core values and behaviors resulting from both leader and individual commitment emphasize safety over competing goals. The expectation is that individuals and organizations working on regulated activities establish and maintain a safety culture equal to the significance of their activities in a nuclear organization. Additionally, a safety-conscious work environment where employees are able to bring forth safety concerns without fear of retaliation and have them reviewed and resolved as appropriate in a timely manner is an important attribute of nuclear safety culture.

Human performance improvement

Human performance initiatives are not always successful and may need to be revisited. One of the most important ingredients is to evaluate the program and determine if it is on a successful path. Changes may have to be made along the way to success, but unless the deficiency is determined, the changes cannot be made.

Respect for procedures and processes

At nuclear stations, the importance of procedures and following them religiously cannot be understated. Nuclear stations are complex, highly technical installations where deviations from accepted norms can result in equipment failure, reactor shutdown, loss of revenue, safety issues for personnel and, in the worst case scenario, total catastrophe at the site. If procedures are followed, to the letter, the danger of such events happening will be minimized.

Adherence to documentation

Documentation must be current and strictly adhered to. Nuclear stations are constantly undergoing safety changes, revisions and system upgrades to enhance their performance. As each change is made, the change is documented for safety and for future reference. For those reasons, documentation needs to be reliable, accurate, and current for safe operation of the plant. Without training documentation, there is no evidence that training has occurred.

Assessment program

Assessment is at once both easy and difficult to accomplish. There are numerous tools and programs of which an organization can take advantage for conducting self-assessments. These programs provide a step-by-step process in discerning goals, how well they are being achieved, what gaps exist and suggestions as to what may be needed to close those gaps. The difficulty exists in the ability of the organization to be self-critical in its self-analysis. There is a propensity for self-protection in organizations, compounded by the silo effect of departments not willing to share information. If organizations are reluctant or unwilling to be transparent, honest and forthright in their self-evaluation process, the root cause of issues preventing the organization from improving their performance will not be addressed nor necessary improvements made.

Although the senior leaders are tasked with developing these systems within the organization, it is the middle and first line managers who must implement these strategies within the work force on a day-to-day basis, during outage periods and under varying plant conditions. It is for these reasons that the need for leadership and managerial training is so important.

3.3 Training permanent staff and contractors

Although unusual events often stem from equipment failure and human performance errors of plant personnel, a number of significant events have been caused by both long-term and short-term supplemental staff (non-permanent staff, contractors). These individuals are often on-site as subject matter experts (SMEs) for a prescribed length of service or to assist with outage-related activities. Special problems are posed by supplemental staff for training organizations. Often by using both general and specific solutions, training departments are able to remedy the situation.

3.3.1 Balancing training, supervision and procedures

Training is only one of many processes which, in an integrated manner, affect the quality of ongoing work at a nuclear facility, either when operating or in an outage. By integrating three crucial processes – training, supervision and procedures – in balance with one another, work may be accomplished efficiently and effectively in an error-free way.

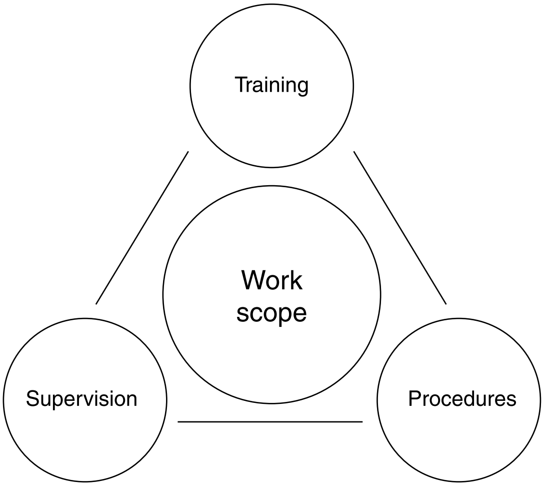
Training refers to those activities which not only prepare site personnel for the jobs they are to perform but also monitor job performance and make adjustments to the training programs to improve that performance. Supervision refers to the entire management chain, from the senior leadership to the first line supervisor.

Procedures refers not only to the physical documents by which workers are guided in a step-by-step manner, but also the myriad processes governed by those procedures, which are necessary to ensure proper work flow and execution, monitoring of those activities and incorporation of lessons learned from both successes and failures.

These three processes are envisioned as working together, the area of which represents the scope of work, whether for a single task, for a department or for the entire site. In this model the scope of work is presumed, initially, to be a constant. The three processes are the variables in the model. Because the processes are integrated, a change in one affects the other two. For example, consider the case in which – for whatever reason – procedures are not kept up-to-date or are badly written. This could result in an unbalanced system (Fig. 3.1).

Recall that a key presumption for this model is that a balance must exist among the three processes to ensure the assumed scope of work is accomplished. Unfortunately, if there are problems with the work-related procedures then training and supervision must adjust to account for those problems. This is not something that happens quickly – it is a slow process, taking place over periods of time sufficiently long as to mask the changes which occur. Site personnel are generally unaware of the shifting balance, generally viewing events, sometimes of increasing frequency and severity, which require some adjustment to all three of the processes. The system is out of balance and the personnel involved are not aware of the imbalance or its potential consequences.

With weak supervision, training and procedures must adjust to account for management failures. With weak training, procedures and supervision must then adjust. Assuming that the three – training, supervision and procedures – are in balance, if the work scope changes, the balance can again be adjusted or become off balance. Any number of things can result in a change in the scope of work undertaken by an individual, a work crew, a department or an entire facility.



3.1 Balancing training, supervision and procedures.

Among the most common are such activities as station modifications and refueling outages. The ways by which these activities affect the balance of crucial site processes, particularly training, are manifold. The introduction of something new into the mix such as a new plant system being added or a new or replacement component installed, or an influx of new, temporary personnel who arrive to support a major maintenance or refueling outage are enough to once again throw off the balance of these three integrated processes unless management is aware of this balance.

As seen in past circumstances, unusual events are more likely to occur during transitions at a nuclear station. Refueling and extended maintenance outages in the nuclear industry represent a significant increase in the amount and scope of work performed on a daily basis, but the work is made more complex in terms of the schedule coordination necessary to reduce potential risks and hazards while important safety and backup equipment is out of service and unavailable. Many of the tasks are infrequently performed, such as vessel or turbine disassembly, and extended operating cycles exacerbate this situation. Some tasks are no longer within the sphere of experience or expertise of the permanent staff, both as a result of the infrequent nature of the work and the economics of maintaining on-site expertise. Consequently, refueling and extended maintenance outages result in significantly more personnel on-site contributing to the completion of that work.

With that in mind, it becomes obvious that non-permanent workers who are on-site to perform a specific work task must be thoroughly briefed beyond what is normal for a permanent employee, as well as supervised before and during the activities they are scheduled to perform.

A general resolution to these issues is, of course, to keep in balance the three processes of training, supervision and procedures as a proven method to ensure efficient, effective and error-free execution of work. These interrelations can serve as indicators of potential solutions which can be tailored to specific situational needs. Consider the three separate processes, training, supervision and procedures, but also the possible relationships between them: training and procedures, procedures and supervision, and supervision and training. Although not intending to downplay the role of procedures or supervision, the role of training within these manifold relations cannot and should not be underestimated. Using the relation 'training and procedures', it can be seen that the two have to work together in the face of weak supervision in order to restore balance to the system. In a similar way, the relation 'training and supervision' will also work together in the face of weak procedures and processes to restore and maintain a balanced system. The key is to recognize when the relations must be put to work to resolve a shortcoming. If there is a conscious effort to utilize a systematic approach to training or a variant that is holistic in nature, the balance can be maintained, accidental issues avoided and performance enhanced.

3.3.2 Contractors

Nuclear power stations are staffed by highly trained, skilled and professional workers. Shifts work around the clock to provide safe, abundant and reliable energy to the public. On occasion, particularly during refueling outages, the permanent staff is augmented by contractors. These individuals are often hired as non-permanent or temporary workers because they are current on the subject, aware of the latest information and they are experts on specialized processes or equipment. In many cases it is cost-prohibitive to have these experts as permanent plant personnel, as their unique skills are needed only on a very limited basis.

In determining the need for a contractor, several items are considered:

- Task that needs to be performed.
- Availability or lack of in-house talent.
- Cost.
- Availability of contractors with respect to time line of project.
- Additional resources that will be required.
- Recommendations of in-house staff.

Generally, contractors are part of a recognized organization that specializes in a particular aspect of the nuclear process. The organization certifies that its contractors are well trained and versed in the processes in which they will participate or, in some instances, oversee at the host site. When selecting a contractor, several considerations need to be made:

- Reputation of contractor.
- Reliability.

- Technical expertise.
- Previous work history.
- Cost.

When they arrive at the site, contractors may be exempted from some elements of training depending on the time frame of their last plant employment and/or their intended location at the site, but are trained on particular site policies, procedures and any material relevant to the task to which they are assigned. Unless specifically designated and qualified, contractors do not have authority over permanent workers and are carefully supervised by qualified plant personnel who hold the ultimate responsibility for the actions of the contractor. Project managers oversee the activity of the contractor as well as assessing and noting performance, adherence to task completion and authorizing payment for completed stages of work.

Contract workers are a necessity in the nuclear environment because of their unique expertise and qualifications. They supplement the permanent staff when their talents are needed for specialized tasks and help see to the safe and efficient completion of the required work.

3.3.3 Plant access training

Plant Access Training(PAT) equips new employees with the information to safely operate in a particular nuclear station. The training covers a wide variety of topics ranging from safety to emergency procedures. The process imparts to the new employee or supplemental worker the ability to become functional in his or her new environment.

Training usually begins with orientation to the site. This will include identification of specific buildings including turbine building, reactor building, security and safety buildings, and first aid areas. This can be followed by classes in the general overview of how a reactor works, steam is generated and transmitted, and electricity generated. This would be followed by emergency procedures, security procedures and radiation protection. Good housekeeping would be emphasized, as well as good recordkeeping. Training should also include the importance of communication, attention to briefings and the importance of adherence to the self-verification STAR (Stop, Think, Act, Review) process.

Safety is, of course, the primary concern at nuclear stations so an emphasis is placed on safety within the plant. This will cover a wide variety of safety issues including:

- Safe and unsafe working conditions.
- Fire safety.
- Near misses.
- First aid.

- Personal protection.
- Working in confined spaces.
- Tripping hazards.
- Noise and heat dangers.
- The importance of safety glasses, hard hats and protective footwear.
- Safety tags and signs.
- Safety barriers.
- Radiation Work Permits.

Workers who do not perform tasks in high radiation areas will still receive basic training on radiation issues. They will learn about:

- Radiation: What it is and how it can affect them.
- Contamination: Is radiation not contained where it should be?
- Dose: The amount of radiation to which one is exposed.
- Dosimeter: Devices that detect and measure the amount of radiation to which an employee is exposed.
- Monitors: Devices that detect and alert the presence of radiation in areas where it should not be.

Employees will also be trained on the health hazards associated with working at a nuclear facility. Everyone is exposed to radiation on a daily basis from natural sources. Some occupations are more risky than others. For example, airline personnel receive two to three times more radiation than the average worker at a nuclear station. Miners also are exposed to increased levels of radiation and those who mine for uranium are especially vulnerable. Simply taking a daily walk in the sun increases a person's exposure over time.

Plant workers should be made aware of the inherent risks at a nuclear station and the health concerns associated with it. They will learn that short-term exposure to limited amounts of radiation has a minimal effect, whereas long-term exposure to low levels can increase the risk of cancer.

Finally, as part of their training, non-radiation-related employees will be made aware of the various signs warning of potential radiation presence and boundaries that are usually indicated with rope or tape. The safety and security of the site and the safety of the individual employee are of great concern.

3.3.4 Fitness for Duty training

Fitness for Duty (FFD) training prepares personnel to identify if an employee is fit for duty and ensure that they are fit both mentally and physically to competently and safely perform their job. There are a number of reasons why an employee might be considered impaired.

Substance abuse is a major reason for someone to be found unfit for duty. The abuse can come in many forms, such as legal and illegal drugs, alcohol and ordinary chemicals. Such abuse often results in increased absence, on-the-job errors, doctor visits, accidents and worker compensation claims. Those who are abusing substances often have differing perceptions from the norm, have slower reflexes, impaired vision, slurred speech, exhibit confusion or become loud and aggressive in their behavior.

Employees who are unfit for duty may also be suffering from chronic stress, excessive fatigue or some sort of illness. Stress is common in everyday life, and some research suggests that an amount of stress can actually be beneficial. However, if the stress builds and occurs over a prolonged period, then it can become a chronic disorder. This can lead to depression, irritability, fatigue, illness and even substance abuse. As a normal part of life, employees are going to be ill. Sickness can be at many levels from a common cold to something more serious. When employees are ill, their work is affected and they are less productive, not only because of their illness, but also any medication they are taking. Serious illness or medications may make an employee unfit for duty for reasons of safety. The problem of fatigue can also lead to fitness for duty issues. Like stress, fatigue is common, but can have a cumulative effect over time leading to chronic issues. Chronic fatigue can lead to a general lack of energy, apathy, joint and muscle pain, sleepiness, difficulty in performing assigned tasks, memory issues and increased errors in judgment and tasks.

To identify employees who may be at risk, or to identify issues that can lead to fitness for duty issues, whether in permanent or non-permanent employees, managers must be trained to identify the characteristics leading to substance abuse, stress, illness and fatigue. By identifying those issues early on, steps can be taken to minimize the risks associated with them and assist employees to overcome them. In the USA, nuclear power plant sites use psychological tests (e.g. the Minnesota Multiphasic Personality Inventory (MMPI)) as a part of the FFD testing in addition to drug and alcohol screening.

3.3.5 Human performance training

Human performance training provides permanent and non-permanent personnel with information on how they can maintain and improve the overall performance at a nuclear station by enhancing the performance of station personnel. Although a good deal of attention has been given to the hard skills necessary for competency, considerably less focus has been provided in soft skill areas such as:

- Communication.
- Resolving problems.
- The importance of teamwork.
- Safety-conscious work environment.
- Leadership training.
- Adaptability to changing situations.
- Professionalism in the workplace.

These soft skills not only are necessary for successful management, but also are important for individuals at all levels at the site. Soft skill training can greatly assist in improving performance.

One of the most important aspects of human performance improvement is to eliminate unusual incidents and or events in the workplace that result from human performance errors. Through training, these errors can be minimized with the resultant reduction of costs and risks to plant safety. There are several causes for a need to improve human performance, one of which is changes in the environment, both internal and external to the organization. However, the most likely cause is the identification of deficiencies in human performance. Common today is the use of the Human Performance Toolbox, which consists of a variety of 'tools' that individuals may use to maintain focus. The following are 14 tools common in the Human Performance Toolbox:

- Pre-Job Briefing.
- Two Minute Rule.
- Three Way Communication.
- Phonetic Alphabet.
- Procedure Use and Adherence.
- Place Keeping.
- Flagging/Operational Barriers.
- Touch STAR.
- Independent Verification.
- Concurrent Verification.
- First Check.
- STOP When Unsure.
- Peer Check.
- Post-Job Review.
  (see http://multi.tva.gov/contractor/instructors/ATIS00076300/HU_Tools_Student_Handout.pdf).

When weaknesses in human performance occur, the deficiencies are often identified through observation, by conducting a root cause analysis or a self-assessment. Organizations today usually have processes in place to identify human performance deficiencies as part of their investigation into unusual events that occur at the station.

To improve human performance, training needs to be focused on several areas:

- *Communication*. Effective, clear communications must be established between managers and between co-workers and other peers and working partners.
- *Management*. Management must become involved in the working process.
- *Management by walking around (MBWA)*. Being out observing the workforce.
- *Procedures*. Procedures must be formalized, documented and understood by participating members.
- *Documentation*. Documentation must be current and strictly adhered to.

- *Human resources*. Need to be very selective in those recruited and hired and there needs to be a careful review of individual performance evaluations.
- *STAR*. The STAR – Stop, Think, Ask, Review – process must be adhered to on-the-job.
- *Change of culture*. A culture that insists on doing the job right the first time, rather than just getting the job done, should be embedded in the organization.
- *Evaluation of human performance*. This must take place systematically.

There must be a sincere commitment of personnel at all levels to implement the measures taken to improve human performance. This commitment must be led from senior management down through to first line supervision. A systematic approach to human performance improvements should be utilized to identify deficiencies. Training can only be effective when it is an integral part of an overall system, at all levels of the station to improve human performance.

3.4 Specialized technical training

Recall that what is referred to by training encompasses not only the activities which prepare site personnel for the jobs they are to perform but also those which govern monitoring of that job performance and those which ensure that adjustments to the training programs are made to improve that performance. This is all part of the systematic approach to training. This includes the specific technical training activities, as well as value-based compliance training.

Each area of the system needs specific attention to function properly. Specialized training needs to be developed for technical aspects to ensure that procedures are followed and proper attention is given to areas where technical expertise is essential. Proper training on site procedures, safety and particularly radiation safety is necessary to reduce the likelihood of incidents occurring. By aiming training at specific areas and targeting them for intense training, the performance of all workers can be markedly improved.

With widespread use by nuclear facilities of supplemental workers for radiological (primarily radiation protection) and trades (mechanical, electrical and instrumentation) activities, the need for targeted training on proper use of and adherence to station procedures, particularly during outages, is imperative.

3.4.1 Technical training

Nuclear power plants, by their very nature, are highly complex and technically challenging. To operate these complex mechanisms requires the skills of individuals who are highly technically versed and fully understand the intricacies of nuclear power plant operations. Engineering personnel are those individuals who are given that responsibility.

Engineers are highly educated individuals, many of whom have advanced degrees in their respective fields. Some of those fields are electrical, mechanical, chemical and, of course, nuclear engineering. At a nuclear facility, those engineers pool their talents to plan, operate and maintain the station in a safe and efficient manner.

When entering the nuclear environment, engineers undergo further training that acquaints them with the special responsibilities inherent at a nuclear station. They take training that is specific to their particular engineering position within the plant. Once established, they will quickly see the interaction of the differing fields as they contribute their specialized expertise towards the common goal. The training they receive is developed using SAT and is site-specific. Individual engineering fields – mechanical, electrical, nuclear, chemical – work together as one engineering component to solve problems and at the same time interact with other groups such as operations, radiation protection, maintenance, etc., to complete the task assigned to the site as a whole.

3.4.2 Site procedures

At nuclear stations, the importance of procedures and following them religiously is of vital importance. Nuclear stations are complex, highly technical installations where deviations from accepted norms can result in equipment failure, reactor shutdown, safety issues and loss of revenue. If procedures are followed to the letter, the danger of such events happening will be minimized.

To help ensure that procedures are followed, procedures must first be written in a manner that is exacting and understandable by everyone who will utilize those procedures in future work. This requires the expertise of a skilled nuclear procedures writer. Many such writers are frequently licensed Senior Reactor Operators (SROs), well versed in operations, who possess exceptional knowledge of established procedures. Written procedures are fundamental for the success and safety of a nuclear station. They are step-by-step instructions that workers must follow to ensure that the tasks being performed are done correctly. Procedures and revisions incorporate the documentation trail that has been established by previous work and are fully in accordance with the site operations/procedure writer's manual and other supporting documentation. When written, procedures are thoroughly reviewed, as are all related documentation and data used in their preparation. Particular attention should be given to operations and emergency operating procedures. Before implementation, the completed procedure should be submitted to engineering experts and senior operations personnel for review and cross checking. Finally, the procedure should be reviewed where possible to ensure there are no conflicts and all processes are in order. Procedures are perhaps the most important aspect in the operation of a nuclear station. Without them and their proper usage, the site would cease to function properly, and the safety and effectiveness of the plant would be in jeopardy.

3.4.3 Operator training

Reactor operators are responsible for operating the reactor controls from the control room. Their activity provides for the safe generation of electric power via nuclear reaction. They monitor gauges, manipulate switches and controls, and possess an in-depth working knowledge of all the systems which they control.

Significant changes to the training of licensed reactor operators have come about as a result of the Three Mile Island (TMI) incident of 1979. Post TMI, strict regulations governing the licensing of operators went into effect in the USA as per regulations from the Nuclear Regulatory Commission (NRC).

Operators generally rise from the ranks and ascend the operations ladder. They often begin as non-licensed operators under the supervision of those that are licensed. They must meet education and power plant experience requirements before they are selected for additional training as a Reactor Operator (RO), and then a SRO. In the USA, many operators joined the private sector after serving time in the military service, primarily the US nuclear navy.

If they meet the qualifications and are selected for training, they then begin an intense on-site training program that covers every aspect of nuclear generation, from basic fundamentals of reactor operation to plant systems and transient and accident analysis. On completion of their training, they undergo rigorous testing, the outcome of which determines their election as licensed ROs.

ROs hold a great responsibility in their hands, but they are well trained and highly qualified to assume their positions of trust.

3.4.4 Industrial safety

Although nuclear stations have inherent safety issues because of the nature of their activities, they are also large industrial facilities with all the safety hazards found in any industrial setting. There are large moving objects, hot steam lines, cables on floors, electrical hazards, dangerous heights, high noise levels and a myriad other issues. As such, workers must be trained to function safely in the industrial environment. Training for new workers should include personal safety which includes:

- Head protection – properly fitted hard hats.
- Eye protection – goggles.
- Hearing protection – ear plugs or ear muffs as required by noise level.
- Foot protection – work boots or hard toe shoes.

Workers also need to be trained to recognize both safe and unsafe working conditions and report near misses, unsafe conditions and injuries. Training should be given to recognize signage, safety barriers, radiation notices and barriers, confined spaces, no smoking, fire escape routes, safety tags and no admission areas. In the industrial setting there are numerous hazards to which workers must be alerted:

- Moving objects.
- High noise area.
- Tripping hazards.
- Chemical hazards.
- Confined spaces.
- Steam leaks.
- High heat areas.
- Electrical hazards.
- Slippery areas.
- Eye hazards.

Training should not only alert workers to potential dangers, but also make them aware of how to work in the presence of potential dangers.

Industrial settings are inherently dangerous places in which to work. Safety standards for all industrial environments in the USA are set by the Occupational Safety and Health Administration (OSHA). Following OSHA guidelines and regulations will keep workers safe, reduce time lost as a result of injuries and result in a better performing station.

3.4.5 Radworker training

Training for workers who function in close proximity to radiation sources includes increased training in radiation safety and awareness. The training covers a wide array of topics, with emphasis on the sources and various types of radiation, how to measure the dose that workers may receive, and the effects of limited and prolonged exposure.

Naturally, at a nuclear station there are numerous sources of radiation. They include not only the reactor fuel, but also the coolant which migrates through various filters, pipes and valves in the system. Knowing what equipment is potentially radioactive is essential knowledge to have when working in the plant environment. Workers also need to be aware of the types of radiation to which they are being exposed. On a daily basis, everyone everywhere is exposed to some amount of radiation from background radiation from consumer products. In the plant environment, the workers who will need to work in a radiation environment at the site are classified as Radiation Workers. Radiation dose limits and guidelines for such workers are set by regulatory agencies.

3.4.6 Maintenance training (trades staff)

The maintenance department at nuclear stations serves a very important function at the station. The department's main purpose is to perform scheduled maintenance of plant equipment that lessens the possibility of that equipment failing prior to its life expectancy. Aside from servicing and maintaining existing equipment, maintenance workers are also called on to replace worn out equipment. This is an ongoing process that continues throughout the life of the plant; as equipment grows old, it is replaced and or upgraded before it fails and causes an unscheduled event to occur. The maintenance department also ensures that testing of the equipment is conducted at intervals specified by the regulatory agencies or in the licensing conditions.

Maintenance departments do not work in a vacuum, and the various departments within maintenance known as the trades – electrical, mechanical and instrument and control (I&C) – work in conjunction with other departments such as operations, chemistry and radiation protection. Scheduled tasks are correlated with these departments to ensure that procedures are followed and there is compliance with all safety standards. This sees to the efficiency of the plant and the safety of the employees.

Maintenance personnel are well trained and highly skilled employees of the station. They have gone through extensive initial training programs that train new employees, and enhance the skills of experienced members through continuing training to keep them current on new procedures, equipment, tools and processes.

These personnel are led by trained managers and first line supervisors who have spent extensive time in the plant. These managers are well versed in the tasks that need to be accomplished, and assign and brief personnel on those tasks. They also see that procedures are followed, resources are available and assigned tasks are supervised. Maintenance leadership sets high standards for those they supervise, models ethical behavior, evaluates performance and establishes continuing training to upgrade the skills of those they lead.

Working collaboratively with other departments at the station, the maintenance department's role is to keep the station running at maximum efficiency through equipment and systems monitoring, repair and modification.

3.5 Training for site specialists

The need for site specialists to understand the processes used at the site is inherent in site procedures and emphasized through specific training for each job position. The vast majority of training provided at nuclear power stations is designed and developed to prepare site personnel to perform job/position-specific tasks or activities. What should be remembered is that plant personnel do not work in isolation from other personnel. In many ways, plant processes intersect and are interrelated in ways that are not always adequately described in job/position-specific training. Managers need to understand, through proper training, that the systems at a plant are interrelated and should be treated with a holistic approach when considering change initiatives.

3.5.1 Systems engineers

A typical systems engineer may manage one or more systems at a nuclear facility. Systems engineers are responsible to monitor systems within the plant – they monitor system performance, identify system problems and develop problem solutions, maintain applicable system operating procedures, identify necessary testing and provide technical problem solving to support plant operation. Systems engineers must possess in-depth technical knowledge to allow them to develop, manage and implement analysis and management of engineering issues related to the identified system. They must possess the functional discipline expertise for practical application and have the ability to apply detailed knowledge of pertinent industry codes and regulations. This knowledge allows them to ensure that standard design criteria, practices and procedures and codes are used, as well to recommend new equipment and techniques to improve performance, reduce costs, maintain configuration management, and perform independent reviews and analysis. The systems engineer is capable of developing troubleshooting plans, improving performance of relevant plant systems, monitoring equipment performance and providing recommendations for improvement. Generally, systems engineers come with a background in electrical, mechanical, chemical or nuclear engineering, and knowledge of regulatory requirements and industry codes and standards.

3.5.2 Shift Supervisor or Shift Manager

The Shift Supervisor or Manager at a nuclear station serves much the same function as the captain of a ship at sea. At a nuclear station, the Shift Manager is considered the most highly qualified person on-site and is responsible not only for the safe operation of the reactor, but is generally considered to be in command of the entire station during his or her shift. They are most likely to be licensed SROs with years of experience in the control room during normal operations as well as during refueling outages. They are highly professional and well vested in the operations of the station.

Shift Managers are chosen by their organization not only for their experience, but also their integrity, leadership, good judgment, in-depth technical knowledge, ability to coordinate the activities of their team and strong analytical skills.

Once selected, Shift Managers continue to receive training that seeks to enhance their already solid skill sets through regular and continuing operations training, seminars, readings, visits to other plants and membership of professional organizations. They are also encouraged to take formal training courses.

3.5.3 Subject matter experts

Subject matter experts (SMEs) are generally individuals with specialized technical expertise. Because the SMEs are technically qualified, they are able to provide focused training when requested by line or training supervision, are able to assist training personnel with in training activities such as needs, job and task analysis, performance analysis, lesson plan and materials development, and implementation of the training, as well as review of training materials. They are also able to provide on-the-job training and on-the-job evaluation. Because they have strong technical credibility, trainees are prone to paying particular attention to their presentations. In the field when conducting on-the-job training, they are seen as having first-hand knowledge in their area of expertise. This ability to promote strong alignment with day-to-day work activities has made SMEs desirable in many training settings. Although SMEs may do varying levels of development work or presentation, they provide the technical expertise. The trainer is responsible to put that information into the training realm. However, because the SME is working within that realm, the time spent to provide a level of training to them on the SAT process is time well spent. A SME qualification process on SAT can be easily developed; however, it will provide the SME the level of skills needed not only to be a technical expert but also possess the basics of presenting, knowledge of the techniques for conducting on-the-job training and evaluation, and be able to function effectively while performing SME duties within the training realm. Although they are not qualified to the level of a trainer on the SAT process, without a level of SAT knowledge, it will be much more difficult for both the trainer and the SME to work together.

Some of the basic skills needed for a SME to assist in training are a desire to teach, good communication and organizational skills, knowledge of questioning techniques, leadership abilities, conflict management skills and a positive attitude.

3.6 Challenges and lessons learned

Training departments at nuclear plant sites generally have done a very good job in ensuring that managers and employees are well trained, responsive and acutely aware of their roles and responsibilities. Experience has shown that incidents of human performance errors have been reduced significantly.

However, the nuclear industry and its related training departments have faced numerous challenges, many in the form of unforeseen occurrences from which lessons have been learned over the decades.

Although every effort is made to minimize the possibility of errors by having properly trained workers, they may still occur. Those occurrences can, should and do serve as learning experiences to nuclear training departments across the industry. By openly sharing the circumstances that led to the errors, and what measures were taken to eliminate the possibility of them happening again, training departments and the industry as a whole will greatly benefit.

Some examples include:

- Where high failure rates in licensing classes were caused by insufficient initial license training, it was discovered that individuals had been inadequately tested early on and were not sufficiently prepared for advanced work. A self-assessment revealed that the training staff needed further preparation.

- In one instance work was performed by an unqualified individual who had failed an exam and was remediated, retested and returned to the job. Unfortunately, some of the test questions in the second exam were identical to the first exam and during reevaluation it was determined that the worker was still not fully qualified. A determination was made that the instructor did not use due diligence in administering the second test and that testing procedures needed to be reevaluated.
- Exams were not ready for an operations training class because instructors had not produced the exam in a timely manner. An evaluation of the problem revealed that the instructors had been drawing from several test banks but failed to meet the time constraints.
- When unqualified supplemental workers performed a task and new procedures were to have been in place that assured supplemental workers would be qualified, it was discovered that implementation of the new policy was not adhered to. The process was reevaluated.
- Where training was not completed in a timely manner, and training classes were repeatedly cancelled or delayed because of lack of resources, instructors and other site commitments that took priority, evaluation revealed that because of poor planning, managers had not dedicated enough time and plant resources for the training to be completed on time.
- Examples such as these indicate that incidents do indeed occur over time, often because of oversights and human performance errors. Training departments constantly work to lessen such errors by benchmarking with other plants, evaluating training procedures and updating software programs and recordkeeping. Much is learned from errors, and by sharing information with other plants, much can be gained and, as a result, the likelihood of the same errors being repeated is diminished.

3.7 Future trends

The future of nuclear training looks to be both exciting and challenging. To be sure, much needs doing in a relatively short period of time. The nuclear renaissance and changing demographics require a large supply of highly trained personnel within a short time span. According to the Nuclear Energy Institute, over 30% of the current workforce will be eligible for retirement in just a few years. (NEI Fact Sheet, 2008) The retirement of veteran personnel coupled with the need for additional people to staff new plants will certainly require new methods of training and the broad cooperation of all the stakeholders in the industry.

The path for new employees needs to be prepared early in their education. Talented grade and middle school students with the potential to be nuclear employees need to be groomed and guided onto the path, and any obstacles to their continuing education reduced. College and utility partnership programs should be developed or existing ones streamlined and enhanced to facilitate nuclear-related programs. In education and training, leadership programs that upgrade the skills of existing and future leaders have to be planned and implemented. With new generations will come a need for new leadership techniques and new training methods. With actions such as these, the industry can be assured of an adequate pipeline of well-trained and educated employees and leaders.

Emphasis must be placed on new and improved training methods. Advances in technology will certainly play a significant role in improved training. Computer-based training (CBT) is already used in the industry, but its use and advantages have only begun to be fully realized. Advanced simulations, 3-D virtual imaging, digital animation and advanced software combined with high-speed computers, will provide great opportunities for efficient and effective training approaches. With these advances, the need for face-to-face training classes for trainees may be greatly reduced. Learning and training will be facilitated by instructors who will guide the learners along the way. Such training will reduce costs, offer flexibility and offer individualized instruction as needed.

Finally, the industry and all stakeholders must come together and work with a synergetic to move the industry forward. Dea Holman (CONTE 2011) notes ‘A Community of Practice (CoP) for instructors and instructional technologists in the nuclear industry will provide benefits in knowledge management, benchmarking, resource sharing, professional networking, problem solving, and idea generation’.

As the future unfolds before us, such a community must be all encompassing and involve universities, utilities, government agencies from across the globe, private organizations and regulatory bodies in the USA and abroad. Working together and sharing their training experiences and insights, the nuclear industry of the near future will become a vast ‘learning organization’ for the benefit of all.

3.8 Sources of further information

Human Performance Tools. Retrieved from: http://multi.tva.gov/contractor/instructors/ATIS00076300/HU_Tools_Student_Handout.pdf.

IAEA-Nuclear Energy Series No. NG-G-2.1. (2009). Managing Human Resources in the Field of Nuclear Energy.

IAEA-TECDOC-1204. (2001). A systematic approach to human performance improvement in nuclear power plants: Training solutions.

IAEA-TECHDOC-1232. (2001). Assuring the competence of nuclear power plant contractor personnel.

IAEA-TECDOC-1358. (2003). Means of evaluating and improving the effectiveness of training of nuclear power plant personnel.

IAEA-TECDOC-1411 (2004). Use of Control Room Simulators for Training of Nuclear Power Plant Personnel.

INSAG-16. (2003). Maintaining Knowledge, Training and Infrastructure for Research and Development in Nuclear Safety.

Instrumentation and Control Technologies, IAEA.org.

Nuclear Energy Institute: NEI 09-12, Revision 0. (February 2010). Guideline for Establishing a Safety-Conscious Work Environment for New Nuclear Power Plant Construction Sites.

Nuclear Power Reactor Fuel Engineering. IAEA.org.

NUMARC 93-01, Revision 4A. (April 2011). Industry Guideline for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants.

NUREG/CR-6751. (March 2002). The Human Performance Evaluation Process: A Resource for Reviewing the Identification and Resolution of Human Performance Problems. US Nuclear Regulatory Commission.

NUREG/CR-6775. (September 2002). Human Performance Characterization in the Reactor Oversight Process. US Nuclear Regulatory Commission and Idaho National Engineering and Environmental Laboratory.

Skornik K. (1994). Education and training in radiation protection and nuclear safety: Bridging the gaps.

Training a New Generation of Nuclear Specialists. IAEA.org.

3.9 References

Anderson, E. (2007). What is the Purpose of Documentation? Retrieved from: http://www.cmswire.com/cms/enterprise-20/what-is-the-purpose-of-documentation-001991.php.

Deitrich, L. W. (2006). IAEA Safety Standards for management Systems. Retrieved from: http://www.ansn.org/ansn.org/Common/Documents/apmd/asia251p9.pdf.

Exelon Nuclear Unescorted Access Requirements. Retrieved from: http://www.nukework.com/files/FAQ%20In-Processing%20Final%20060607.pdf.

Fukushima Nuclear Accident Update Log. (June 2011). Retrieved from: http://www.iaea.org/newscenter/news/tsunamiupdate01.html.

Holman, D. (2011). Benefits of a Community of Practice for Instructors and Instructional Technologists in the Nuclear Industry. Conference on Nuclear Training and Education (CONTE).

Human Performance Tools. Retrieved from: http://multi.tva.gov/contractor/instructors/ATIS00076300/HU_Tools_Student_Handout.pdf.

IAEA and ICTP Open Nuclear Energy Management School: Training a New Generation of Nuclear Energy Leaders. Retrieved from: http://www.iaea.org/newscenter/news/2010/nemschool.html.

IAEA Safety standard series: No. GS-R-2. (2002). Preparedness and Response for a Nuclear or Radiological Emergency. Retrieved from: http://www-pub.iaea.org/MTCD/publications/PDF/Pub1133_scr.pdf.

IAEA Safety standards series: No. GS-R-3. (2006). The Management System for facilities and Activities. Retrieved from: http://www-pub.iaea.org/MTCD/publications/PDF/Pub1252_web.pdf.

IAEA Safety standards series: Safety Fundamentals: No. SF-1. (2006). Fundamental Safety Principles. Retrieved from: http://www-pub.iaea.org/MTCD/publications/PDF/Pub1273_web.pdf.

IAEA Safety standards series: No. DS325. (2006). The Operating Organization and the Recruitment, Training and Qualification of Personnel for Research Reactors for Protecting People and the Environment. Retrieved from: http://www.caea.gov.cn/n16/n1115/n44542.files/n44543.pdf.

IAEA Safety standards series: No. NS-G-2.14. (2008). Conduct of Operations at Nuclear Power Plants. Retrieved from: http://www-pub.iaea.org/MTCD/publications/PDF/Pub1339_web.pdf.

IAEA-TECDOC-1204. (2001). A systematic approach to human performance improvement in nuclear power plants: Training solutions. Retrieved from: http://www-pub.iaea.org/MTCD/publications/PDF/te_1204_prn.pdf.

IAEA-TECDOC-1232. Assuring the competence of nuclear power plant contractor personnel. Retrieved from: http://www-pub.iaea.org/MTCD/publications/PDF/te_1232_prn.pdf.

IAEA-TECDOC-1590. (2007). Application of Reliability Centered Maintenance to Optimize Operation and Maintenance in Nuclear Power Plants. Retrieved from: http://www-pub.iaea.org/MTCD/publications/PDF/te_1590_web.pdf.

Licensee use of contractors and intelligent customer capability. (2009). Retrieved from: http://www.hse.gov.uk/nuclear/operational/tech_asst_guides/tast049.pdf.

NEI Fact Sheet: Nuclear Industry's Comprehensive Approach Develops Skilled Work Force for the Future. (April 2008). Retrieved from: http://www.nei.org/resourcesandstats/Documentlibrary/New-Plants/factsheet/nuclearindustrydevelopsworkforce.

NRC Event notification reports. Retrieved from: http://www.nrc.gov/about-nrc/regulatory/enforcement/safety-culture.html.

Nuclear Fuel Cycle and Materials: Nuclear Power Reactor Fuel Engineering. Retrieved from: http://www.iaea.org/OurWork/ST/NE/NEFW/Technical_Areas/NFC/nuclear-fuel-engineering.html.

Nuclear Operations Plant Instructor – Plant Vogtle. Retrieved from: http://www.linkedin.com/jobs/jobs-Nuclear-Operations-Plant-2574520.

PDRP-5. Regulatory control of the use of contractors by operating organizations. (2000). Retrieved from: http://www-pub.iaea.org/MTCD/publications/PDF/pdrp_005_prn.pdf.

Power to the People; The World Outlook for Electricity Investment. Retrieved from: http://www.iaea.org/Publications/Magazines/Bulletin/Bull461/power_to_the_people.html.

USNRC. (2011). North Anna Power Station Restart Readiness. Retrieved from: http://www.nrc.gov/info-finder/reactor/na/dominion-slides-11-01-2011-meeting.pdf.

4

Managing complex projects and facilities: practices at the United States Department of Energy's Office of Environmental Management

M. RAWLINGS and A. SZILAGYI,
Office of Environmental Management, U.S. DOE, USA

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Abstract: The Office of Environmental Management (EM), within the United States Department of Energy, manages numerous, multi-billion dollar projects and facilities. Managing these large projects presents a number of unique challenges that must be overcome, and EM has gained a wealth of experience in this area. This chapter outlines how EM manages large projects and the fundamental issues and challenges that EM has faced, along with the root causes and corrective measures taken.

Key words: Environmental Management, project management, nuclear cleanup, Hanford, Waste Treatment Plant, DOE Order 413.3B.

4.1 Introduction

The Office of Environmental Management (EM), within the United States Department of Energy (DOE), manages numerous, multi-billion dollar projects and facilities. Managing these large projects presents a number of unique challenges that must be overcome, and EM has gained a wealth of experience in this area.

Fifty years of nuclear weapons development and production and nuclear energy research in the USA has generated millions of gallons of liquid radioactive waste, millions of cubic meters of solid radioactive wastes, thousands of tons of spent nuclear fuel and special nuclear material, along with huge quantities of contaminated soil and water. The EM program was established in 1989 to achieve the successful cleanup of this waste. This cleanup effort, which deals with some of the most dangerous materials known to man, is the largest in the world, originally involving 2 million acres at 107 sites in the USA.

A lot of progress has been made since the EM program began in 1989. By the end of Fiscal Year (FY) 2011, cleanup activities have been completed at 90 sites. The remaining 17 sites present a difficult challenge with a goal of EM to complete the cleanup in approximately six decades within an estimated life-cycle cost of approximately $300 billion.

EM is pursuing its cleanup objectives within a framework of regulatory compliance commitments and best business practices. The rationale for cleanup prioritization is based on achieving the highest risk reduction benefit per radioactive content (wastes that contain the highest concentrations of radionuclides). EM has prioritized its cleanup activities:

- Activities to maintain a safe, secure and compliant posture in the EM complex.
- Radioactive tank waste stabilization, treatment and disposal.
- Spent nuclear fuel storage, receipt and disposition.
- Special nuclear material consolidation, stabilization and disposition.
- High-risk soil and groundwater remediation.
- Transuranic and mixed/low-level waste disposition.
- Soil and groundwater remediation.
- Excess facilities deactivation and decommissioning.

In addition to these priorities, supplemental strategies are integrated into cleanup activities that are important to the achievement of EM cleanup progress as well as to the stakeholders and states where cleanup sites are located. Most importantly, EM continues to discharge its responsibilities by conducting cleanup within a ‘safety first’ culture that integrates environmental, safety and health requirements and controls into all work activities. This ensures protection to the workers, public and the environment.

The current FY 2012 budget for EM is approximately $5.7 billion, over half of which goes to the three largest sites: $1.0 billion at the Richland Site, $1.2 billion at the Office of River Protection and $1.3 billion at the Savannah River Site. These sites also have the largest estimated life-cycle costs: $56–59 billion for the Richland Site, $67–74 billion for the Office of River Protection and $49–54 billion for the Savannah River Site. Sites are further broken down into five to ten ‘Project Baseline Summaries’ (PBSs), which group like types of work.

PBSs are further broken down into Capital Projects or Operating Activities. Some of the EM Capital Projects are still very large and take many years to complete. One of the largest projects in EM, which will be discussed in more detail later in this chapter, is the Waste Treatment Plant construction within the Office of River Protection, at approximately $12 billion.

In EM, the management of projects, from the initial decision that a project is needed through completion and project closeout, is guided by a series of DOE Orders, Manuals, and requirements. However, to effectively manage projects this large, a number of unique challenges must be overcome, including technical challenges, cost estimating and budget challenges, contracting challenges and identifying relevant risks.

EM has gained a lot of experience and refined its project management practices over the years related to managing large, complex cleanup and construction projects.

4.2 Fundamental issues for managing complex projects and facilities

The EM portfolio of projects is large, complex and technically challenging. Many are unique, one-of-a-kind initiatives that involve cutting-edge technology. Few other government or private sector organizations are challenged by projects of a similar magnitude, diversity and complexity. To complete these complex projects on schedule and within budget, it is necessary for EM to have highly developed project management capabilities, processes and procedures. Although EM has had many project successes over the years, some projects have suffered significant cost and schedule overruns. A detailed analysis of the various projects that had cost and schedule overruns resulted in a number of fundamental issues that, if corrected, would result in improved project performance. These fundamental issues, along with the root causes of the issue and EM's corrective action, are as follows.

Issue: EM often did not complete front-end planning to an appropriate level before establishing project performance baselines.

Root cause:

- Insufficient number of personnel.
- Lack of personnel with the appropriate skills.
- Inadequate time dedicated to front-end planning.
- Over reliance on the M&O contractor.
- Lack of defined benchmarks.
- Lack of effective interdepartmental integration.
- Insufficient planning budget resources.

EM's corrective measure:

- Establish and implement measures to ensure adequate project requirements definition is accomplished before a project performance baseline is established. This includes defining planning benchmarks, ensuring adequate resource allocation, and conducting third-party reviews prior to project approval, additional funding authorization and project execution.

Issue: EM did not have an adequate number of federal contracting and project management personnel with the appropriate skills (e.g. cost estimating, scheduling, risk management, and technical) to plan, direct and oversee project execution.

Root cause:

- Insufficient budget resources.
- Conflicting and competing priorities.
- Inferior federal government compensation compared with the private sector.
- Inadequate roles and responsibilities definition.
- Inadequate training.

EM’s corrective measure:

- Develop and implement a comprehensive federal staffing plan, with an associated resource plan, to recruit, develop and retain the optimum contract and project management federal workforce.

Issue: Risks associated with projects were not objectively identified, assessed, communicated and managed through all phases of planning and execution.

Root cause:

- Insufficient number of personnel.
- Inadequate training.
- Lack of management emphasis and direction.
- Lack of recognition of required number and skills of personnel needed.

EM’s corrective measure:

- Establish objective, uniform methods for assessing, communicating and managing project risks and uncertainties. This would include the development of realistic budgets and schedules, and the consistent definition, development and use of management reserve and contingency.

Issue: Failure to request and obtain full funding or planned incremental funding results in increased risk of project failure.

Root cause:

- Ineffective project and program prioritization.
- Inadequate resource allocation.

EM’s corrective measure:

- Improve the alignment and integration of cost baselines with budget funding profiles to account for federal budget fiscal realities and to ensure uninterrupted project execution. Enhance project and program prioritization and associated resource allocation to minimize negative impacts to the performance baseline.

Issue: Contracts for projects were often awarded prior to the development of an adequate independent government cost estimate.

Root cause:

- Lack of policy or standards.
- Lack of personnel with the appropriate skills.
- Lack of databases with current or historical cost information.

EM’s corrective measure:

- Establish and implement a federal independent government cost estimating capability, including the development of appropriate policy and standards, allocation of required resources, and compilation of unit cost labor and material databases.

Issue: EM's acquisition strategies and plans were often ineffective and were not developed and driven by federal personnel. EM did not begin acquisition planning early enough in the process or devote the time and resources to do it well.

Root cause:

- Lack of personnel with the appropriate skills.
- Competing priorities.
- Personnel resource conflicts and budget limitations.
- Lack of effective field and headquarters integration.
- Lack of lessons learned.
- Inadequate roles and responsibilities definition.

EM's corrective measure:

- Strengthen the commitment to federal ownership by aligning and integrating acquisition strategies and acquisition plans, and project plans; clearly define roles and responsibilities, enhance integrated project team participation, and ensure accountability for ownership and integration.

Issue: EM's organizational structure was not optimized for managing projects.

Root cause:

- Competing priorities.
- Lack of prioritization on project management.
- Lack of alignment in authority, accountability and responsibility.
- Attributes of optimized organizational structure are not understood.

EM's corrective measure:

- Identify and implement opportunities to improve the management and oversight of projects; clarify federal project management roles, responsibilities and authorities, including field and headquarters integration; establish a project oversight benchmark; and align the program and project organizational structures.

Issue: EM had not ensured that its project management requirements were consistently followed. In some instances projects were initiated or carried out without fully complying with the processes and controls contained in EM policy and guidance.

Root cause:

- Conflicting guidance and priorities.

- Lack of adequate personnel resources.
- Inadequate training.
- Lack of failed project reviews.

EM's corrective measure:

- Re-evaluate program and project management policy, guidance and standards for alignment and consistency. Establish measures and procedures to ensure that all project management requirements are clearly documented and followed and responsible personnel are held accountable.

4.3 Project management at EM

4.3.1 EM's contract and project management improvement timeline

In 1997, EM established a PBS for each major mission category of activity to establish a consistent structuring of work and performance reporting. For example, at the Richland Site, there are eight PBSs in the following work areas:

- Nuclear Material Stabilization and Disposition.
- Spent Nuclear Fuel Stabilization and Disposition.
- Soil and Water Remediation.
- Solid Waste Stabilization and Disposition.
- Nuclear Facility D&D – River Corridor Project.
- Nuclear Facility D&D – Remainder of Hanford.
- Fast Flux Test Reactor D&D.
- Richland Community and Regulatory Support.

In 2003, EM began to 'projectize' most of the PBSs by establishing them as single projects. Cost and schedule baselines were developed and approved for each of the PBSs. The result of this was very large projects (with many over $1 billion) that consisted of a mixture of construction projects, cleanup projects and operations activities, with various completion dates.

This approach aided EM in defining and controlling the technical scope, costs, schedules and risks, and helped improve the overall project performance. However, it became apparent that the approach had limitations, including: (1) some PBSs were very large and hard to track, (2) annual budgets were unpredictable and often subject to competing priorities, (3) some PBSs included work that spanned several decades and (4) capital asset work and operations activities were often part of the same PBS, making earned value measurement difficult to apply and report.

In 2006, the National Academy of Public Administration (NAPA) began a study of EM, and published a final report in December 2007. The NAPA Panel recommended various improvements, including standardization and integration of project performance management tools across the complex, implementation of 'Best-In-Class' project and contract management standards, use of project-specific success metrics, evaluation of the existing project contingency policy and use of case studies as a training tool. All of the NAPA recommendations complimented the ongoing changes and EM continued making improvements.

As part of an effort to translate the project and contract management reforms to the overall departmental level, a detailed analysis of the root causes contributing to less than satisfactory project performance was conducted. DOE started the Root Cause Analysis in late 2007, completed the Root Cause Analysis Report in April 2008 and issued a Corrective Action Plan in July 2008. In 2009, EM began implementing additional measures targeted at project and contractor performance, including monthly senior management reviews for projects at risk, evaluation of contractor construction project management and technical capabilities, comprehensive construction project status reviews and deployment of a new project management information system for analysis of project performance. In February 2011, EM issued a Closure Report for the Root Cause Analysis and Corrective Action Plan. Currently, EM is focusing on continuous improvement with respect to project management.

4.3.2 How EM manages projects

Management of projects in EM is governed by a series of orders, manuals and requirements, with the goal of delivering projects on schedule and within budget. One of the primary orders that provides direction for management of projects in EM is DOE Order 413.3B, 'Program and Project Management for the Acquisition of Capital Assets'. The guiding principles in DOE Order 413.3B for successful execution of projects include the following:

- Line management accountability.
- Sound, disciplined, up-front project planning.
- Well-defined and documented project requirements.
- Development and implementation of sound acquisition strategies that incorporate effective risk handling mechanisms.
- Well-defined and managed project scope and risk-based performance baselines and stable funding profiles that support original cost baseline execution.
- Development of reliable and accurate cost estimates using appropriate cost methodologies and databases.
- Properly resourced and appropriately skilled project staffs.
- Effective implementation of all management systems supporting the project (e.g. quality assurance, integrated safety management, risk management, change control, performance management and contract management).
- Early integration of safety into the design process.
- Effective communication among all project stakeholders.
- Utilization of peer reviews throughout the life of a project to appropriately assess and make course corrections.

- Process to achieve operational readiness is defined early in the project for nuclear facilities.

Within DOE, projects typically progress through five Critical Decisions (CDs), which serve as major milestones approved by a high-level Acquisition Executive. Each CD marks an authorization to increase the commitment of resources by DOE and requires successful completion of the preceding phase or CD. The amount of time between decisions will vary. The CDs are:

- CD-0, Approve Mission Need. The initial phase of a project begins with the identification of a mission-related need. A Program Office will identify a credible performance gap between its current capabilities and capacities and those required to achieve the goals articulated in its strategic plan. The Mission Need Statement is the translation of this gap into functional requirements that cannot be met other than through material means. It describes the general parameters of the solution and why it is critical to the overall accomplishment of the department's mission, including the benefits to be realized. The mission need is independent of a particular solution, and should not be defined by equipment, facility, technological solution or physical end-item. This approach allows the Program Office the flexibility to explore a variety of solutions and not limit potential solutions. The cost range provided at CD-0 should be Rough-Order of Magnitude.
- CD-1, Approve Alternative Selection and Cost Range. CD-1 approval marks the completion of the project definition phase and the conceptual design. This is an iterative process to define, analyze, and refine project concepts and alternatives. This process uses a systems engineering methodology that integrates requirements analysis, risk identification and analysis, acquisition strategies and concept exploration in order to evolve a cost-effective, preferred solution to meet a mission. The recommended alternative should provide the essential functions and capabilities at an optimum life-cycle cost, consistent with required cost, scope, schedule, performance and risk considerations. It should be reflected in the site's long-range planning documents as well. Approval of CD-1 provides the authorization to begin the project Execution Phase. The cost range provided at CD-1 is the preliminary estimate for the selected alternative. As CD-1 progresses to CD-2, the total project cost will be refined. The performance baseline against which project success is measured will be established at CD-2.
- CD-2, Approve Performance Baseline. At CD-2, the definitive scope, schedule and cost baselines have been developed. Completion of preliminary design is the first major milestone in the project Execution Phase. The design must be sufficiently mature at the time of CD-2 approval to provide reasonable assurance that the design will be implementable within the approved performance baseline. The approval document signed at CD-2 must clearly specify the project's approved performance baseline, which includes the total project cost, CD-4 date, scope and minimum Key Performance Parameters (KPPs) that must be achieved at CD-4.

- CD-3, Approve Start of Construction/Execution. At CD-3, the project is ready for implementation and continues with the execution phase. The project is ready to complete all construction, implementation, procurement, fabrication, acceptance and turnover activities. It may be necessary to obtain CD-3 approval early, namely CD-3A, for long-lead item procurement. When exercising long-lead procurement, the Federal Project Director must consider design maturity and the associated project risk. If the long-lead item is nuclear safety-related or nuclear safety-related equipment, safety document maturity must also be considered. Activities such as site preparation work, site characterization, limited access, safety and security issues (i.e. fences) are often necessary prior to CD-3, and may be pursued as long as funding approvals are in place. The default CD-2 performance baseline is the upper limit of the CD-1 cost range. This represents that project execution has started, but only for the procurement of specified long-lead items.
- CD-4, Approve Start of Operations or Project Completion. At CD-4, the project is ready for turnover or transition to operations. CD-4 is the achievement of the project completion criteria, the approval of transition to operations, and it marks the completion of the execution phase. The approval of CD-4 is predicated on the readiness to operate and/or maintain the system, facility, or capability. Transition and turnover does not necessarily terminate all project activity. The Acquisition Executive approves CD-4 on notification from the project team that all project completion criteria have been met.

4.3.3 Considerations for successful project management at EM

The following topical areas discussed in DOE Order 413.3B are important considerations for successfully managing EM projects.

Federal Project Director

Successful performance of EM projects depends on professional and effective project management by the Federal Project Director (FPD). The FPD is accountable to the Acquisition Executive for the successful execution of the project. The FPD's assigned project must meet cost, schedule and performance targets unless circumstances beyond the control of the project directly result in cost overruns and/or delays. FPDs must demonstrate initiative in incorporating and managing an appropriate level of risk to ensure best value for the government. In cases where significant cost overruns and/or delays may occur, the FPD must alert senior management in a timely manner and take appropriate steps to mitigate them. Roles and responsibilities of the FPD's team must be clearly defined relative to the contractor management team.

Integrated Project Team

The Integrated Project Team (IPT) is an essential element in EM's acquisition process and is involved in all phases of a project. The FPD organizes and leads the IPT. This team consists of professionals representing diverse disciplines with the specific knowledge, skills and abilities to support the FPD in successfully executing a project. The team size and membership may change as a project progresses from CD-0 to CD-4 to ensure that the necessary skills are always represented to meet project needs. Team membership may be full or part time, depending on the scope and complexity of a project and the activities under way. However, the identified personnel must be available to dedicate an amount of time sufficient to contribute to the IPT's success. Qualified staff (including contractors) must be available in sufficient numbers to accomplish all contract and project management functions. Project staffing requirements should be based on a variety of factors, including project size and complexity, as well as the management experience and expertise of the project staff.

Project Execution Plan

The core document for the management of a project is the Project Execution Plan. It establishes the policies and procedures to be followed in order to manage and control project planning, initiation, definition, execution and transition/closeout, and uses the outcomes and outputs from all project planning processes, integrating them into a formally approved document. It includes an accurate reflection of how the project is to be accomplished, the minimum Key Performance Parameters, resource requirements, technical considerations, risk management, configuration management, and roles and responsibilities. Generally, a preliminary Project Execution Plan is required to support CD-1. The Project Execution Plan continues to be refined throughout the duration of a project and revisions are documented through the configuration management process.

Performance Baseline

The Performance Baseline, as established in the Project Execution Plan, defines the total project cost, CD-4 completion date, performance and scope commitment to which EM must execute a project and is based on an approved funding profile. The Performance Baseline includes the entire project budget, including contingency, and represents EM's commitment to congress. The approved Performance Baseline must be controlled, tracked and reported from the beginning to the end of a project.

Change control

Change control, which is defined in the Project Execution Plan, ensures that project changes are identified, evaluated, coordinated, controlled, reviewed, approved/

disapproved and documented in a manner that best serves the project. One key goal of change control is to ensure that baseline thresholds are not exceeded. Approval authority for changes depends on the estimated impacts of the change.

Key Performance Parameters

A Key Performance Parameter is a characteristic, function, requirement or design basis that if changed would have a major impact on the system or facility performance, schedule, cost and/or risk. In some cases, minimum Key Performance Parameters or threshold value should be highlighted for CD-4 (project completion), realizing that in many instances full operational capabilities may take years to achieve. The minimum Key Performance Parameters and facility mission must stay intact for the duration of the project as they represent a foundational element within the original baseline.

Project progress reviews

Quarterly or monthly progress reviews must be conducted with the applicable Acquisition Executive. Project performance assessments, determined through quantitative and qualitative methods, are discussed at the meetings, along with any project issues. Additional elements that are discussed are the Earned Value Management System (EVMS) data, contractor's monthly reports, acquisition management practices, risk management status, peer reviews, site visits, staffing assessments and budget submittals.

Independent Cost Review

For major projects, an Independent Cost Review is conducted. This review validates the basis of the rough order of magnitude cost range and provides an assessment of whether the range reasonably bounds the alternatives to be analyzed in the next project phase.

Performance Baseline Validation Review

A Performance Baseline Validation Review is required to provide reasonable assurance that the project can be successfully executed and to validate the performance baseline. Findings resulting from project reviews must be addressed by the Integrated Project Team.

Risk Management

Risk Management is an essential element of every project and must be analytical, forward looking, structured and continuous. Risk assessments are started as early in the project life-cycle as possible and should identify critical technical, performance, schedule and cost risks. Once risks are identified and prioritized, sound risk mitigation strategies and actions are developed and documented in a risk register. Post CD-1, the risk register (including new risks) is regularly evaluated. Risks and their associated confidence levels are dependent on multiple factors such as complexity and technology readiness. Risks for all capital asset projects are analyzed using a range of 70–90% confidence level on baselining at CD-2, and are reflected in funded contingency, budgetary requests and funding profiles.

EVMS

An EVMS is required for all projects with a total project cost greater than or equal to $20 million. The contractor's EVMS must be certified by EM and is subject to regular surveillances to ensure that the system remains in full compliance.

Integrated Safety Management System

An Integrated Safety Management System (ISMS) must be in place to ensure that potential hazards are identified and appropriately addressed throughout the project. It will be used to systematically integrate safety into management and work processes at all levels.

Lessons Learned process

Lessons Learned and best practices should be captured and reported throughout the continuum of a project. Lessons Learned reporting allows the exchange of information among DOE users in the context of project management.

Tailoring strategy

The tailoring strategy for a project is a reasonable adjustment of requirements considering the risk, complexity, visibility, cost, safety, security and schedule of the project. Tailoring does not imply the omission of essential elements in the acquisition process or other processes that are appropriate to a specific project's requirements or conditions. The tailoring strategy is generally described in the Project Execution Plan. The tailoring strategy may involve consolidation or phasing of Critical Decisions, substituting equivalent documents, graded approach to document development and content, or concurrency of processes. Tailoring may also include adjusting the scope of various project reviews, delegation of acquisition authority and other elements.

4.4 Case study of Waste Treatment Plant management by the Office of River Protection

The Waste Treatment Plant, managed by the Office of River Protection, is EM's most costly and complex capital asset project. The current cost estimate for the

Waste Treatment Plant is $12.3 billion, with a scheduled startup in 2019. As of March 2012, the design is approximately 86% complete, procurement approximately 65% complete, and construction is approximately 61% complete.

The Waste Treatment Plant has had large cost increases and schedule delays – the initial cost estimate (for a smaller scope project) was $4.3 billion with a projected startup date in 2011. The fundamental issues that have impacted the project include:

- Inadequate front-end planning.
- Failure to obtain planned funding.
- Poor independent government cost estimates.
- Problems with assessment, communication and management of risks.

Specific issues/challenges will be discussed at the end of this section, along with various things that have worked well.

4.4.1 Project overview

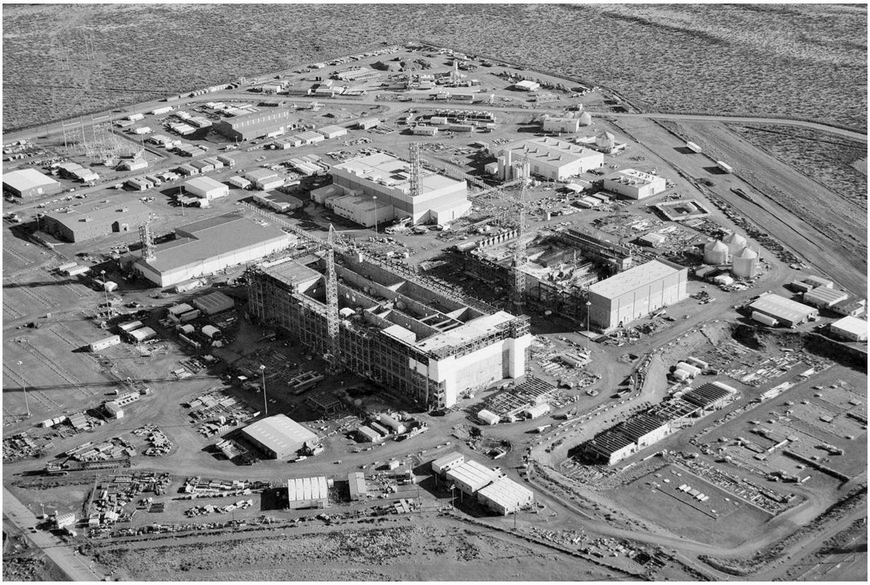
The Hanford Site, located in southeastern Washington State, was the largest of three defense production sites in the USA. Over the span of 40 years, it was used to produce 64 metric tons of plutonium, helping to end World War II and playing a major role in military defense efforts during the Cold War. As a result, 56 million gallons of radioactive and chemical wastes are now stored in 177 underground tanks on the Hanford Site.

To address this challenge, the US Department of Energy contracted with Bechtel National, Inc., to design and build the world's largest radioactive waste treatment plant. The Waste Treatment Plant (see Fig. 4.1) will use vitrification to immobilize most of Hanford's dangerous tank waste. Vitrification involves blending the waste with molten glass, heating it to high temperatures, and then pouring it into stainless steel canisters. In this glass form, the waste is stable and impervious to the environment, and its radioactivity will dissipate over hundreds to thousands of years.

The Waste Treatment Plant will cover 65 acres with four main nuclear facilities (discussed below) – Pretreatment, Low-Activity Waste Vitrification, High-Level Waste Vitrification and an Analytical Laboratory – as well as operations and maintenance of buildings, utilities and office space. Site preparation began in October 2001, and the concrete for the first nuclear facility's foundation was placed in July 2002. The Waste Treatment Plant is scheduled to reach commissioning in 2019 and full operations in 2022.

Pretreatment

The first treatment step in the waste treatment process is pumping the waste from the underground storage tanks through a buried pipeline to the Pretreatment Facility. Pretreatment separates the low-activity radioactive waste from the high-level radioactive waste. Low-activity waste is the liquid portion of the tank waste. It



4.1 Waste Treatment Plant under construction, Hanford, Washington, 2012.

contains a relatively small amount of radioactivity in a large volume of material. High-level waste is primarily in the solids of the tank waste. It contains most of the radioactivity in a relatively small volume of material. During pretreatment, the waste is concentrated by removing water in an evaporator. Solids are filtered out, and remaining soluble highly radioactive isotopes are removed by ion exchange units.

Low-Activity Waste Vitrification

The pretreated wastes go to separate Low-Activity Waste and High-Level Waste Vitrification Facilities. Handling the wastes separately speeds treatment because high volumes of low-activity waste can be processed faster than the high-level waste. The waste goes into a melter preparation vessel where silica and other glass-forming materials are added and the mixture is fed into one of two melters. The mixture is heated to 2100°F by passing electricity through it, a process known as joule heating. The molten mixture is then poured into large stainless steel containers. The filled low-activity waste containers are 4 feet in diameter, 7 feet tall and weigh more than 7 tons. The containers will be stored at Hanford in permitted trenches covered with soil.

High-Level Waste Vitrification

High-level waste from the Pretreatment Facility is mixed with glass-forming materials and vitrified in two melters of similar design to the low-activity waste melters. High-level vitrified waste is poured into stainless steel canisters that are 2 feet in diameter and about 15 feet tall. The filled high-level waste canisters, each weighing more than 4 tons, will be temporarily stored at Hanford. Eventually, the high-level waste containers will be shipped to a federal geological repository deep underground for permanent disposal.

Analytical Laboratory

The Analytical Laboratory, also known as the Lab, will serve as a process link between the Pretreatment, High-Level Waste Vitrification and Low-Activity Waste Vitrification Facilities. The Lab's key function is to ensure that all glass produced by the Low-Activity and High-Level Waste Vitrification Facilities meets all regulatory requirements and standards. Each year, when the Waste Treatment Plant is operational, the Lab will analyze approximately 10 000 waste samples.

4.4.2 Waste Treatment Plant issues and challenges

Some specific issues/challenges that EM faced with the Waste Treatment Plant, and the corrective measures instituted, are as follows.

Issue/Challenge: Difficulties establishing a credible cost and schedule baseline:

- Initial baseline established with less than 15% design.
- Project contingency level set at 16% of to-go cost.
- Only $100 M of technical/programmatic risk contingency originally identified.
- No comprehensive review conducted to validate early estimates.
- Contract lacked clear definition of mission and performance specifications.
- Contract incentive structure was not optimal.

Corrective measures:

- Bottoms-up estimate developed with nearly 70% design.
- Developed project-specific escalation rates.
- Use 'post-Three Mile Island' and 'DOE first-of-a-kind' unit rates.
- Total project contingency established at 44% of to-go cost.
- Active risk management and quantification program in place.
- Conducted external reviews.
- Contract and incentive structure significantly modified to allow EM to better manage performance.

Issue/Challenge: Earlier assessment of process technology maturity was needed.

- No method to gauge technology maturity before CD-2.
- Inadequate scaled and prototypic testing.

Corrective measures:

- Used process that supports the objectives of DOE-STD-1189, Integration of Safety into the Design Process.
- Used Technology Readiness Assessment (TRA) process.
- Identified where additional R&D and design efforts were needed.
- Tool to gauge design advancement.
- Tool to supplement project's risk management program.
- FPD should seek advanced project funding to conduct TRA and scaled/prototypic testing.

Issue/Challenge: Needed to rely sooner and more often on industry experts.

- Relied too heavily on contractor's in-house expertise.
- Insufficient federal staff or skill sets to oversee all elements of design and construction.

Corrective measures:

- Established Structural Peer Review Team.
- Used team of design and baseline reviewers.
- Continued reliance on industry and academic experts.
- Engaged with national labs to assure independence.
- Mandatory reliance on scaled and prototypic testing to resolve residual technical issues.

Issue/Challenge: Needed to rely on conventional management tools and oversight.

- Relied on EM's role as 'Contract Manager' vs. 'Management of the Contractor'.
- Late implementation of comprehensive EVMS.
- Insufficient federal staffing.

Corrective measures:

- Active management of the contractor in all areas.
- Certification of the contractor's EVMS.
- Invested in training of staff.
- Developed routine surveillance of system to assure integrity.
- Added DOE Project Management directives to the contract.
- Actively managed all project contingency.

Issue/Challenge: Needed to establish site-specific seismic design criteria.

- Relied on Hanford Site generic seismic criteria.
- Geomorphology and physical characteristics vary.
- Used non-conservative criteria.
- Late decision to conduct site-specific analysis.

Corrective measures:

- Develop site-specific criteria during CD-1.
- Prudent to factor in additional margin beyond just code-allowable design margins.

4.4.3 Project management successes

Although there have been a number of issues and challenges with the Waste Treatment Plant, there have also been a number of things that have worked well, including:

- Well-established relationship with state regulators.
- Cost and schedule reviews by recognized experts from DOE, industry and academia.
- Strong community and stakeholder support.
- Limited number of employees empowered to give contractual direction.
- Building a well-qualified and experienced staff.
- Positive relationships between management and labor.
- Engagement from senior headquarters staff as a project advocate.
- Conducted regular Construction Project Reviews.

4.5 Summary of challenges and lessons learned

Specific key accomplishments to improve management of complex facilities in EM include the following:

- Improved front-end planning by requiring sufficient design maturity prior to establishing performance baselines; using industry standard practices such as Technology Readiness Assessment and Project Definition Rating Index tools to determine projects readiness for baselining; and dividing large programs/projects into smaller, stand alone projects, as appropriate.
- Developed a departmental project team staffing guide to help determine and assess project staff size and required skill set across the life of each capital asset project.
- Established project funding stability by: fully funding capital asset projects with a total project cost less than $50 million; approving funding profiles at Critical Decision 2 and Acquisition Executive approval of any subsequent changes to the profile; and ensuring affordability and adherence to baseline funding profiles for incrementally funded projects in annual budget requests.
- Enhanced senior EM management dedication and commitment to improving contract and project management.
- Conducted numerous Deputy Secretary-led in-depth reviews on EM capital asset projects and contracts.

- Improved the Project Assessment and Reporting System (PARS II) to maintain leadership awareness of project status and to effect appropriate corrective actions in a timely manner.
- Strengthened project management procedures by revising DOE Order 413.3A, Program and Project Management for the Acquisition of Capital Assets, and providing new cost estimating requirements in the order, along with revisions to, or development of, associated supporting guides, including risk management and change control.
- Enhanced the Project Management Career Development Program and the Acquisition Career Development Program to improve the training and qualifications of contract and project management personnel.
- Achieved Project Management Professional certifications for EM personnel.
- Implemented Project Peer Reviews across the complex to better monitor project development and execution by leveraging the successful best practices employed by other Department of Energy offices.
- Expanded the breadth and depth in scope of External Independent Reviews by expanding existing lines of inquiry and adding lines of inquiry.
- Enhanced the use of project management tools and techniques, including Technology Readiness Assessments, the Project Definition Rating Index, Risk Registers and Monte Carlo risk analyses, and Earned Value Measurement, for improved management decision making.

4.6 Continuous project management improvement

EM has had many accomplishments and made numerous improvements in its management of complex projects and facilities; however, continuous improvement is necessary to ensure that all of the developed and implemented solutions addressing the fundamental issues are maintained and strengthened. EM is formally committed to continuous project management improvement, and has been directed to incorporate the following policy statements into its processes for planning and executing projects. These policies will also be included in the planned revisions to contracts and project management directives.

4.6.1 Project management policy statements

Design maturity

Advancing design maturity to a sufficient level prior to establishing the performance baseline is essential to project management success. The project design will be considered sufficiently mature when the program has developed a cost estimate and all relevant organizations have a high degree of confidence that it will endure to project completion. In determining the ‘sufficiency’ of the design level, factors such as project size, duration and complexity will be considered. For basic facilities, such as administrative buildings, general purpose laboratories and utilities, the design does not have to be as mature as for a complex chemical or nuclear processing facility, which may necessitate the design being complete before work begins. Construction should not be allowed to proceed until the design is sufficiently mature to limit change orders to a minimum. The sufficiency of the project's design maturity will be evaluated during External Independent Reviews. This analysis will serve as a key evaluation factor in formulating a recommendation to validate a project performance baseline.

Project size and structure

Projects should be configured to fulfill mission need and facilitate the most effective management of cost, scope, schedule and risk. Smaller projects are often easier to manage than larger projects and can be completed in less time with reduced risk. Therefore, EM should consider breaking larger projects into multiple, smaller, more discrete and usable projects that collectively meet the mission need. Although dividing a large, high-risk project into smaller projects can provide the opportunity for better oversight, the benefits of improved management and risk exposure should be balanced with the potential for increased overhead costs. Each project, regardless of size, must be led by a certified Federal Project Director. Depending on the project size, a Federal Project Director can be assigned to direct one large project and/or multiple small projects. Each project should stand on its own and will be subject to appropriate departmental directives.

Project staffing

Sufficient qualified staff (including contractors) must be available to accomplish all contract and project management functions. Project staffing requirements should be based on a variety of factors, including project size and complexity, taking into account the management experience of the project staff. Programs must use a validated methodology to determine the appropriate project team size and required skill sets. Once the appropriate staff size has been determined, programs should plan and budget accordingly.

Funding stability

Improved project and financial management integration strengthens project stability and reduces risk. In approving the funding profile for the life-cycle of the project, Acquisition Executives must determine that the proposed funding stream is affordable and executable within the program's capital and operations budget portfolio. Any changes to the approved funding profile must be endorsed by the project's Acquisition Executive. In addition, line item capital asset projects with a total project cost less than $50 M should be fully funded in a single budget request.

Project peer reviews

Numerous studies have demonstrated the benefit of cross-functional Project Peer Reviews. These focused, in-depth reviews are conducted by non-advocates (federal or contractor experts) and support the design and development of a project. Project Peer Reviews should be conducted at least once a year for large or high-visibility projects, and more frequently for the most complex projects or those experiencing performance challenges. These Project Peer Reviews may supplement or replace applicable Independent Project Reviews at the discretion of the Program Office.

Project management information

To be of value, project information must be timely, accurate, consistently reported and auditable. DOE's Project Assessment and Reporting System will be the central repository for key departmental-level project information. Program Offices will support the Project Assessment and Reporting System as the department's project management system and provide sufficient resources. Programs and their Federal Project Directors will ensure that project data is uploaded into the system each month, including monthly EVMS data provided directly from contractors' systems.

Improving cost estimates

DOE's pending cost estimating order will require independent cost estimates for major projects prior to approval of Alternative Selection and Performance Baseline (CD-1 and CD-2). These independent cost estimates will be consistent with the project phase. For CD-1, the department will identify a cost range using parametric cost methods (or extrapolation from actual costs for similar projects when available). For CD-3, start of construction, DOE will conduct an independent cost estimate if warranted by risk and performance indicators or required by senior officials. Another important element in improving cost estimates is the development of a DOE Cost Database. All programs will support the development of the DOE Cost Database with historical and actual costs.

4.6.2 Addressing continuing challenges

In addition, EM will continue to keep management attention focused on challenges that require further improvement. These challenges include:

- Project and Contract Alignment and Change Control.
- Contract Administration, including Surveillance, Monitoring and Oversight.
- Program/Project Prioritization and Funding Alignment.
- Roles and Responsibilities – Contracting Officers and Contracting Officer Representatives.

- Accountability – Aligning Incentives.
- Adequate Project and Contract Management Staffing.

Continuous improvements identified in each of these areas will be established and implemented in EM. EM understands the principles fundamental to effective project management, including leadership commitment, appropriate management and technical expertise, and disciplined and rigorous implementation of contract and project management policies. These principles have been and will continue to be aggressively pursued by EM to ensure contract and project management requirements are consistently followed, federal oversight of contractors continues to improve and accountability for performance is strengthened. Ultimately, EM's effectiveness and success will be measured and validated by improved cost and schedule performance.

4.7 Sources of further information

Department of Energy Office of Environmental Management, http://www.em.doe.gov.
Department of Energy – Hanford Site, http://www.hanford.gov/.
Department of Energy – Directives, Orders, and Guides, https://www.directives.doe.gov.

4.8 References

Department of Energy Order 413.3B, Program and Project Management for the Acquisition of Capital Assets, November 2010.
High-Risk Series: An Update. GAO-11–278. Washington, D.C.: February 2011.
High-Risk Series: An Update. GAO-09–271. Washington, D.C.: January 2009.
Root Cause Analysis – Contract and Project Management, Department of Energy, April 2008.
Root Cause Analysis – Corrective Action Plan, Department of Energy, July 2008.
Root Cause Analysis and Corrective Action Plan Closeout Report, Department of Energy, February 2011.

5

Managing nuclear research reactor construction projects and operation

J. P. ORDONEZ and N. DE LORENZO,
INVAP and Balseiro Institute, Argentina

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Abstract: This chapter addresses the specificities of management of nuclear research reactor projects and nuclear research reactor operation. A short description of the differences between research reactors and nuclear power plants is presented first, followed by a classification of research reactors into different types, describing their characteristics. The particular issues in managing research reactor projects and operations are described. The significant differences between the licensing approach for research reactors, usually one-of-a-kind facilities, and for nuclear power plants are also highlighted.

Key words: research reactor management, research reactor licensing, neutron scattering research, radioisotope production, material irradiation reactors.

5.1 Introduction

This chapter addresses the specificities of management of nuclear research reactor projects and nuclear research reactor operation, highlighting the differences between research reactors and nuclear power plants, classification of research reactors into types and differences between management of a research reactor construction project and management of nuclear power plant projects.

There are over 200 research reactors in operation around the world. Managing the operation of these facilities is an interesting issue in nuclear management so the remaining sections of the chapter are devoted to describing the specifics of operation management.

5.2 Types of research reactors

The term 'research reactors' generally refers to nuclear reactors that are not used for production of electricity. Whereas nuclear power plants are all used for the same purpose, that is production of electricity, the only characteristic shared by research reactors is what they do not do: they do not produce electricity. Thus, the variability of designs in research reactors is far greater than in nuclear power plants. In fact, most research reactors are one-of-a-kind facilities, designed for a given client and for a given set of specifications. Any categorisation of these facilities is then arbitrary. However, the most important parameter of a research reactor is its power, which strongly determines the neutron fluxes available for applications. Thus, the categorisation that makes most sense is to classify research reactors in accordance to their power.

It is possible to distinguish, going from lowest power to highest power, with some allowance for overlap of the different categories, the following types of research reactors:

- Critical facilities.
- Training reactors.
- Radioisotope production reactors.
- Neutron research reactors (beam reactors).
- Multipurpose reactors.
- Irradiation reactors.

5.2.1 Critical facilities

These reactors are also known as ‘zero power reactors’ because their power can be from a few miliwatts up to a few kilowatts. These reactors are primarily used for validating computer codes used for neutron calculations. Neutron fluxes in different positions are measured and compared with the predictions of the computer codes. Models of the codes are then improved and tuned as required, so that they can reproduce the experimental results. Then, these adjusted codes are used for neutron calculations for reactors of higher power.

Many critical facilities are built in order to obtain experimental data to develop nuclear power plant core designs. These facilities operate in campaigns separated by extended shutdowns aiming to introduce major modifications to accommodate new experimental programmes including different fuels or core geometries.

5.2.2 Training reactors

Research reactors are very useful tools for training nuclear engineers, technicians and operators. Most universities that include nuclear courses have a research reactor to allow students and trainees direct contact with the technology. These reactors are thus also known as ‘university type’ reactors.

This type of reactor is chosen by some countries as the initial facility to introduce nuclear energy into their economies and society, pursuing establishment of a human resource centre and initiating a group of industries with ‘nuclear capabilities’ at an affordable budget.

The power of a training reactor can go from a few watts up to several megawatts. They rarely have a power above 10 MW.

5.2.3 Radioisotope production reactors

Radioisotopes are isotopes of natural chemical elements that have been made radioactive by irradiation in a reactor. Radioisotopes are used for medical diagnosis and treatment, and for industrial applications. They are produced in research reactors.

Continuous supply of radioisotopes to patients locally, regionally and internationally requires a demanding operating programme, a high availability facility and a business group acquainted with freight logistics.

Research reactors used for this purpose usually have power from a few megawatts up to tens of megawatts. Radioisotope production is discussed in more detail in Chapter 7 of this book.

5.2.4 Neutron research reactors (beam reactors)

Neutrons are useful probes for exploring the structure of materials. Neutron beams are focused on samples, and information on the structure and other features of the sample can be obtained from the way in which the sample scatters the neutrons.

Special narrow neutron beams have been developed for the cancer treatment known as boron neutron capture therapy (BNCT). This combines administration of a neutron absorber to the malignant tissue and subsequent irradiation of the patient using the neutron beam. Neutron beams for this purpose are produced in research reactors from a few megawatts up to tens of megawatts of power.

5.2.5 Multipurpose reactors

Radioisotope production, irradiation and research with neutron beams can be combined in multipurpose reactors. There are reactors that combine radioisotope production with irradiation, and others that combine radioisotope production with neutron beam research. There are a few that can combine all three purposes in a single facility.

Multipurpose research reactors have powers of tens of megawatts.

5.2.6 Irradiation reactors

Irradiation of materials in strong neutron fields is frequently used for assessing how these materials will behave in nuclear power plants. To accelerate the effect of the radiation on the properties of the materials, neutron and gamma fluxes one order of magnitude larger than the fluxes in nuclear power plants are needed.

Some experimental devices, sometimes as complex as the reactor itself, provide demanding irradiation conditions such as steep power ramps, strong stresses or aggressive environment for the samples being analysed.

Research reactors used for this purpose are called irradiation reactors and have powers of several tens of megawatts. A few of them have powers higher than 100 MW.

5.3 Managing research reactor construction projects

Research reactors Design and Construction (D&C) have the same characteristics as other nuclear projects. However, there are certain features of research reactors, which are specific to these projects. These features are analysed in the following paragraphs.

5.3.1 Differences in project scope, cost and duration

Even large research reactors rarely have a thermal power above 100 MW, whereas a small nuclear power plant has a thermal power of more than 1000 MW. The power of most research reactors is more than 100 times smaller than that of standard nuclear power plants.

However, the difference in power does not translate into a comparable difference in project scope. Whereas nuclear power plants are usually standardised designs, leading to several very similar or identical nuclear power plants being built (the most successful projects may reach tens of identical plants), that is not the case for research reactors.

Research reactors are usually designed in accordance to client specifications. Each client has different requirements and the supplier has to design the reactor in order to comply with these requirements. Although modern research reactors share similar design features, the different requirements lead to different designs and, thus, different facilities. Moreover, clients usually require improved performance with respect to what has been previously achieved.

As a result, whereas in power terms regular research reactors may be 100 times smaller than standard nuclear power plants, in terms of capital cost a large modern research reactor may be just ten times less expensive than a nuclear power plant. In terms of complexity, a large, innovative research reactor project might require stronger management skills than a replicate nuclear power plant. The average project duration is similar in both cases: around ten years, including the pre- and post-project phases.

5.3.2 One-of-a-kind facilities

As discussed in the previous sections, research reactors are usually one-of-a-kind facilities.

Nuclear power plants are usually designed to be built in series. A very large front end Research and Development (R&D) effort is then assumed to be recoverable through the sale of several units. No construction effort is started until

R&D, and, frequently, the detail engineering are finished. The first unit is the prototype for the series. The prototype might even be considered as part of the R&D effort and no recovery of the investment might be required for this first unit.

Having been designed to custom specifications, each research reactor is a prototype. Although previous knowledge and proven technology are used to the largest possible extent, R&D, detail engineering and construction are concurrent tasks.

This fact increases the project risks: sound management of the project risks, and in particular of the technical risks, is fundamental for the success of the project. Some good practices in managing the R&D risks are:

- R&D requirements should be kept to a minimum, through the use of previous experience and proven technology.
- The R&D effort should be launched as early as possible.
- Abundant resources should be allocated to the R&D tasks: they are not usually significant cost drivers for the project, but they will probably have an impact on the project schedule, thus each dollar spent ensuring that the development tasks stay within the program will save many dollars in delay costs.
- Contingency plans for unexpected results of R&D efforts have to be drafted during the early planning phase.

The engineering process has to be flexible enough to allow changes to the specification of structures, systems or components at a late stage of the process. However, keeping the engineering flexible breeds temptation to continuously improve the requirements, thus creating the risk of never having a frozen design specification. A balancing act is then required from the project management, fighting the creep of the design specifications while still making room for incorporation of changes mandated by the results of the R&D effort.

5.3.3 Licensing a research reactor

Licensing differs between countries; however, in general, two main licensing systems have evolved for licensing nuclear power plants: one step licensing and two step licensing.

In the one step licensing process, the operation licence is approved at the same time as the construction licence is granted, with the proviso that the project complies with every detail of the engineering as approved for construction. This approach requires a significant front end engineering effort and is only valid when a company is planning to build several identical plants and thus recovery of the front end effort can be spread over several units.

In the two step licensing process, a construction licence is granted based on the preliminary engineering of the facility, and an operating licence is granted only after the plant is completely built and tested or ready for testing. This process results in great uncertainty for the owner of the plant, as, having invested a significant amount of resources in the project, the owner faces the possibility of not receiving an operation permit.

Being one-of-a-kind facilities, research reactors are not suitable for the one step licensing project, and the uncertainty of the two step licensing process is even larger for research reactors, as they normally cannot benefit from having a reference facility, successfully licensed in other instances. An alternative to the classic licensing process, which has been successfully used, is the multistep licensing process. In this process a construction licence is granted with the submission of the Preliminary Safety Assessment Report (document that corresponds to a preliminary engineering level) and specific construction licences are granted for the construction of each component relevant for the safety of the reactor only after the detail engineering of the component has been submitted to, and reviewed and approved by the regulatory body. This process ensures that the licensing process progresses along the project without a huge front end effort, while at the same time reducing the uncertainty of not having any feedback or early warning from the regulatory body concerning the detail engineering.

The appropriate licensing process for a given research reactor is a matter that should be agreed to by the owner and the regulatory body of the corresponding country. Frequent, periodic, open and candid communication between the owner, the reactor supplier and the regulatory body throughout the project is essential for the success of the project.

Managing licensing risks is one of the most important tasks of the project group. The project organisation should recognise this fact by assigning an experienced officer with strong management and technical capabilities to the licensing management.

5.4 Managing the operation of research reactors

The variety of research reactor (RR) designs is large, and the range of institutions or organisations managing utilisation is even larger. However, common characteristics and strategies implemented by operating organisations (OOs) can be recognised around the world and will be outlined in this section.

These descriptions will be organised into three categories according to the reactor type as follows:

- Small, university type research reactors.
- Research reactors for training and R&D.
- Production research reactors.

From an operating point of view, critical facilities are similar to university type reactors, whereas radioisotope production reactors, large neutron beam research centres, multipurpose reactors and irradiation reactors can be merged, from an operating point of view, in one category, which we have called production research reactors.

5.4.1 Operating small, university type research reactors

Characteristics

In OOs commonly associated with small RRs, running costs are usually dominated by the payroll. The budget for operating the reactor is a small portion of the budget of the OO and completely independent of the performance of the facility.

The OO shares human resources with the reactor, generally providing qualified professionals, technicians and even students to run the facility.

The Reactor Manager is part of the OO and generally has an Advisory Committee both on Safety and Operational issues.

Applications

The limited power of the associated facilities reduces the range of potential applications. Limited isotope production activities may be run if the power is in the order of some kilowatts but, in any case, a profitable business case may be developed based on these applications. But, material studies are out of reach as the achievable integrated neutron flux is limited. There are, however, important niches such as the Neutron Activation Analysis (NAA) and Training to be exploited.

The limited applications of these facilities may be overcome by many technical advantages such as:

- Core flexibility.
- Core accessibility.
- Negligible fuel costs.
- Simple maintenance.

Another important asset is the human resource available in the staff. As education is one of the activities of the OO, it is quite common to find professionals on the staff who are acquainted with nuclear applications and reactor operations. These members constitute valuable capital, available to develop the activities of the facility as explained further in this section.

Development strategies

These institutions are usually highly respected and appreciated by local communities, and this is an important aspect to be fostered and enhanced. Therefore, considering that operating costs are small and the human resources may be, sometimes, underutilised, some activities may be delivered for free to the general community. Some examples of potential services that could be offered are:

- Advice on shielding calculations and implementation for medical apparatus (RX, accelerators, imaging devices, etc.).

- Radiation field measurements for institutions running medical apparatus.
- Providing support in waste handling and management to institutions delivering radioisotopes for medical purposes.
- Instrument calibration services for detectors used in nuclear medicine.
- General clarification talks on nuclear issues concerning the community.
- Support in handling decommissioned radioactive sources (some devices used in industrial or medical applications (welding radiography and cobalt-therapy for instance) have embedded sources that should be appropriately handled when decommissioned).
- Provision of personal dosimetry services: dosimeters used in the facility may be assigned to support local hospitals after appropriate calibration.
- Free services of NAA to supplement assessments on water or air quality run by public organisations.
- Advice on sampling methodologies or strategies on soil, air and water quality for environmental analysis.

These are a few examples of the range of activities supporting the general community that may be delivered by small educational organisations. It is the responsibility of the Reactor Manager and the staff in general to explore partnerships with the rest of the OO and the local community to foster utilisation of the facility.

5.4.2 Operating research reactors for R&D

Characteristics

Research reactors under the management of research organisations usually are of higher power than university type reactors. As a result, the range of applications is wider, and the budget associated with the operation of the reactor is important compared with the whole OO.

The staffing level in this medium range RR is important and staff generally cannot be shared with the rest of the OO, requiring personnel strategies to be implemented such as:

- Career plan.
- Induction and training programmes (including evaluation and licensing stages).
- Roster organisation.

The Reactor Manager should assemble an Advisory Group aiming to assess the feasibility and safety of reactor modifications or implementation of new practices.

Applications

In addition to the applications listed in Section 5.4.1, the higher power range enables production of some radioisotopes on a small commercial scale. Neutron transmutation of silicon ingots is also feasible, requiring simple devices to handle the targets.

Neutron radiography is a field that may produce a significant income, if adequate equipment is procured. Both static and dynamic analyses are being used in several areas such as steel metallography or fluid dynamics.

Many of these medium power reactors feature strongly underutilised irradiation beams. Applications of these beams in prompt gamma analyses or boron neutron capture therapy have been reported in many reactors around the world with relative success. Reactor Managers may consider the implementation of these applications as a scientific activity rather than a business case.

Continuous screening of new application areas should be implemented in the facility, also aiming to identify local customers that could fund the required modifications.

Development strategies

Reactor Managers for these facilities are in the uncomfortable position of requiring a substantial running budget while not having enough opportunities to develop a self-sustained business activity. The development of a framework for Strategic Alliances between facilities both at a regional and global scale might help to alleviate this problem. In these alliances, the versatility of Research Organisations might be paired with smaller or bigger reactors (i.e. Educational or Production Organisations) fostering utilisation of both facilities.

Some points to explore in alliances with smaller reactors:

- Is the Educational Organisation running the small reactor in a condition to train our staff?
- Can we supplement the services provided by the Educational Organisation (for instance a wider range of NAA assessment)?
- Could a cross QA auditing system be established, thus reducing certification costs?

Interaction with large production reactors may explore the following items:

- Could we undertake development of new applications in our facility, thus minimising the impact on the availability of the production reactors?
- Are applications being refused by the production facilities (as these facilities are generally overbooked) that could be performed in our facility?
- Could our facility undertake a portion of the production in case of disruptions in the operating programme of the production reactor?
- Can we provide qualified personnel if required by the production schedule of our partner?

The previous sets of questions are starting points for exploration of collaboration programmes aiming to promote utilisation of these medium power facilities. In addition, programmes supporting national initiatives should be screened to obtain funding for new applications or research programmes.

5.4.3 Operating production research reactors

Characteristics

Production organisations are generally running reactors with powers in the tens of megawatts for radioisotope production, material irradiation and testing and neutron beam research. The running costs may be covered by the production of radioisotopes and transmuted silicon ingots in large quantities.

The operating experience in multipurpose reactors has demonstrated that production and research activities may be blended in the same organisation. A recent example is the OPAL reactor in operation in Sydney, Australia, providing radioisotopes for medical and industrial application, silicon ingots and, at the same time, supporting basic research by the outstanding utilisation of the several neutron beams available.

Reactor Managers of these facilities should be acquainted with administrative and managerial techniques. Running a research reactor of this type requires the same skills as running a commercial company, as the management staff has to deal with several issues such as:

- Ensuring that the reactor achieves its availability goals.
- Setting priorities for reactor use and managing relationships with the diverse users and stakeholders.
- Managing a sizable budgeting and operating staff, which could be larger than 100 persons.
- Ensuring production handling and commercialisation.
- Procuring fresh fuel and managing the spent fuel handling.
- Recruiting, training and evaluating the reactor staff.
- Ensuring the availability of spare parts and consumables.
- Putting in place a sound maintenance programme including in-service inspections and ageing handling programmes.
- Managing the relationship with the local community.

As the availability and reliability of these facilities are vital for reliable delivery of radioisotopes, maintenance activities play a fundamental role in the organisation. Many production reactors are very old and require intensive surveillance programmes aiming to minimise possible disruptions to the operating programme.

Applications

Reactors in this category usually have the following features:

- Large irradiation volumes with very high neutron fluxes.
- Enough power to drive cold/hot neutron sources.

- Underwater space to implement irradiation loops (including special coolants, pressure control, etc.).
- Pool space to accommodate ramping, underwater neutron radiography and other research devices.

Radioisotope production is the prominent application of these facilities. Some of the radioisotopes produced are:

- Medical radioisotopes, generally dominated by the molybdenum-99 produced by fission, but with other products obtained by activation of stable targets.
- Industrial radioisotopes, as there is an interesting demand for iridium sources for gammagraphy in countries developing the oil and gas pipelines. (Cobalt sources for industrial applications are generally supplied by CANDU types NPPs.)
- Tracers and other radioisotopes are of minor relevance.

Silicon ingots of different diameters are required by the power electronic industries. Homogeneity in the transmutation pattern, directly related with the neutron flux distribution, strongly influences the acceptability and price of production. Therefore, efforts should be made to obtain the best possible results using flux flatteners, rotational devices or a combination.

Research applications include those mentioned in Sections 5.4.1 and 5.4.2, plus those allowed by the higher neutron fluxes such as:

- Research on material properties.
- Development of innovative nuclear fuels.
- Research based on neutron scattering.

Development strategies

These OO usually have a sustainable business case. The main challenge for these facilities is to keep developing new activities and responding to changes in the industry and research environment, as stringent schedules to deliver the production on time as well as high reliability requirements preclude exploration of new areas. In addition, the complex processes required to modify the facilities in order to accommodate new activities, reduce the possibility of a prompt answer to new demands.

As stated in the previous section, a good strategy is to establish an association with Research Organisations capable of running development activities as soon as the need is detected without disturbing a production programme. These associations with medium range reactors may be applied from the identification of the potential market up to the engineering (including licensing studies) of new devices.

Fuel costs are a relevant expenditure for these facilities, so the Reactor Manager should continuously reassess the production processes and identify modifications aiming to reduce the fuel consumption, taking into consideration that:

- Neutron fluxes are related to the reactor power but also to the core geometry.
- Fuel discharge burn-up must be maximised, working on refuelling strategies, cycle length and reactivity control strategies.
- Some conservative assumptions in the safety analysis may be reviewed in the light of new information available or using better calculation tools, allowing optimisation of the refuelling strategy.
- Irradiation devices may be reengineered using alternative materials, geometries or technologies, thus improving the neutron economy.
- Fuel manufacturers may improve the performance of nuclear fuels by modifying parameters such as the uranium content and density, or using burnable neutron poisons.

Except for a few facilities, many of the high power research reactors are coming to the end of their design lifetime. Refurbishment and upgrading programmes should be developed and implemented in order to maintain the customer portfolio and the OO structure. These programmes should ensure that the facility may continue its current production activities with enough flexibility to accommodate new applications.

In conclusion, although these facilities may have a sustainable business case, continuous screening of alternatives is required to ensure a proper reaction to new requirements.

5.5 Scheduling research reactor operation

Considering the range of RRs and OOs described in this chapter, different strategies may be implemented to manage the reactor schedule efficiently. Whereas in small reactors the operating flexibility is very large, thus allowing proper handling of all activities, in production reactors the schedule should be defined well in advance to coordinate the delivery of the products to the final users and customers.

The medium size facilities are in an intermediate position, considering that research activities have more flexible schedules than production ones; however, a commitment to deadlines is required.

Therefore, this section will describe general approaches for those reactors requiring a yearly organisation of activities to a programme driven by production. Activities are grouped in four sections and they include normal expected operations: management of abnormal conditions has not been taken into consideration in this chapter.

5.5.1 Operating cycle

These reactors might achieve more than 300 full power days per year while satisfying all the required objectives and requisites. The operating cycle of a reactor is closely related to the fuel strategy implemented to minimise operating costs. It is common practice to define cycle lengths (including shutdown time) of a certain number of weeks, and to start each cycle on a particular day of the week at a predefined time.

For instance, cycles at a given reactor might always be started on Fridays at 8:00 AM and last for 28 days including starting up, running, shutting down, refuelling and production handling time. This type of predefined schedule allows:

- Delivery of products to customers on a fixed day of the week thus facilitating, for example, the distribution of radiopharmaceutical products.
- Arrangement of special staffing levels for demanding shifts such as the start-up shift and refuelling shift as these activities will be scheduled in advance.
- Arrangement of periodic maintenance activities with external services/suppliers. For instance, delivery of chemical additives for the cooling towers or diesel fuel or refilling special gases.
- Definition of appropriate time windows for inspections from regulatory agencies.

5.5.2 Refuelling downtime

Between operating cycles, the fuel assemblies of the core are rearranged or replaced by fresh fuel after achieving their operating lifetime. These manoeuvres require highly skilled operators and involve handling highly radioactive components and addressing safeguards and safety requirements.

It is a normal practice to assign these refuelling activities to a single shift some time after the reactor was shut down (thus minimising radiation fields).

The refuelling downtime should be also used to prepare the irradiation facilities, to load target holders, to position loops and to carry out other activities that cannot be performed with the reactor at power. It is also the proper time to undertake those maintenance activities requiring the facility to be in a ‘cold state’.

Proper programming and preparation are required to ensure efficient use of the downtime, which generally lasts from a couple of days up to a week.

5.5.3 Maintenance requirements

Major efforts should be made to run maintenance activities while the reactor is at power thus minimising the workload during shutdown periods, and levelling the manning requirements. Maintenance which cannot be carried out at power should be scheduled if possible during the refuelling downtime, as explained in the previous section. Nevertheless, some activities are only possible after a certain cooling time or require shutdown times longer than the refuelling downtime, so demanding longer shutdown periods. Typical schedules include two to four weeks’ shutdown per year (in addition to the refuelling shutdowns) for these activities.

Strategies aiming to minimise the number of activities requiring extended shutdown times should be considered. For instance:

- Designing additional shields to minimise radiation fields in areas where maintenance activities are performed.
- Applying predictive maintenance techniques, thus reducing corrective maintenance activities.
- Developing remote operation tools, thus allowing maintenance tasks to be carried out with the reactor at power and also minimising doses to staff.

5.5.4 Training, drills and other administrative activities

Modern reactors and refurbished facilities are easy to operate as a result of state of the art control and monitoring systems. Simplicity in operation results in very small operation teams, generally including five shifts of three operators each.

However, Regulatory Authorities around the world enforce extensive training programmes for staff, which may demand several weeks of theoretical lectures and drills, sometimes involving training in simulators, other times in the facility itself.

These activities require both a diversion of the staff from operation work and the availability of the reactor for drills (e.g. the facility evacuation drill should be run with the reactor in shutdown state). It is good practice to programme training of the operating personnel and extensive drills during the time set aside for extended maintenance shutdown.

In addition, some administrative activities such as the safeguards inspections require the reactor to be in a defined operating condition (e.g. shutdown or low power). These activities should be arranged well in advance with any external organisations involved (the regulatory authorities) and accommodated, if possible, during the refuelling downtime.

5.6 Managing ageing, repair and maintenance of research reactors

At present, ageing management and life extension are significant issues for a large number of research reactors, as they are near the end of their design lifetime.

As reactors age, damage to materials, obsolescence of components, components reaching design lifetime and other factors require the OO to put in place strategies to manage these issues. Large refurbishment projects might be required to solve ageing problems or to update the reactor to new requirements.

The more stringent regulatory requirements being enforced nowadays could be a significant issue for ageing reactors. In some cases, the only way to comply with the new safety requirements (which might include extra redundancies, diversity of safety systems, reinforced seismic design, upgraded electrical feed) is a complete retrofit of the facility.

Another source of refurbishment could be uranium enrichment reduction programmes developed worldwide in recent decades, requiring extensive core redesign to reduce the enrichment without significantly impairing the reactor performance.

Availability of spare parts is also a key issue generating onerous and complex maintenance programmes to ensure a reliable operating schedule. Refurbishment plans are to be considered as an alternative to strategies requiring large stocks of insurance spare parts and tedious mending of obsolete components.

Maintenance costs could increase year on year, not only from a monetary perspective but also considering the staff collective dose, as activation of components, longer repair times, corrosion products and other factors may cause increases in doses to the maintenance staff.

Inspections and assessments aiming to evaluate the lifetime extension possibilities or requirements for major refurbishment and upgrading programmes are being implemented or considered in these facilities.

5.6.1 Inspections, data gathering strategies and assessments

The implementation of inspection programmes requires identification of the items to be inspected. The preliminary list should include at least the following items:

- Components receiving high integrated neutron fluxes (especially fast neutrons).
- Components immersed in high velocity coolant flows.
- Components suffering relevant pressure or temperature changes between cold and hot states.
- Components found defective during the lifetime of the facility or other similar reactors.
- Components in corrosive environments.
- Moving parts of the core related structures (e.g. control rods).
- Metallic components in electrochemically corrosive environments (e.g. steel–aluminium joints, steel–concrete interaction).
- Welds, flanges, threaded unions and spools.

This list may be added to based on operating experience accumulated in the facility or the international information available, but completeness should be guaranteed before structuring an inspection programme.

It is also important to consider other ‘non-nuclear’ components such as heat exchangers or diesel fuel tanks whose inspection programmes may be merged with the ones to be implemented over the listed components.

Having determined the items to be included in the inspection programme, the characteristic (parameter) to be surveyed should be defined together with the appropriate technique. A minimum set of techniques should be stated in order to save cost and implementation time.

Currently, many companies provide worldwide services to nuclear power plants including inspection of highly activated components located underwater and with poor lighting and access conditions. These services may be utilised in research reactors (if the budget allows it). Some less expensive alternatives are available, for example the utilisation of metallic mirrors and low cost webcams for underwater surveillance.

The next step is the identification of any tests that require the reactor to be in cold condition and the time needed to make the initial 'mapping' and the follow up screenings.

Those tests that can be run with the reactor at power are not disruptive but the rest should be adequately scheduled to preserve the facility utilisation schedule.

In addition to the inspection results, the availability of the original design information and information on the operating history is a key factor to successful implementation of a strategy for ageing management. Information may be obtained from:

- Original design documentation including photographic records, sometimes filed in a library.
- Facility log books (operation and maintenance).
- Information from retired operators (always willing to retell 'ancient stories').
- Material samples, coupons, testing probes (welds) from construction time.
- Information from similar facilities.

5.6.2 Strategies to handle ageing issues

Having gathered information using the approach described above, a global strategy to handle the progressive ageing of the facility should be defined encompassing several aspects such as:

- Scope of the activities to be undertaken, for instance:
    - Core redesign: including fuel assemblies, core structures and control rods.
    - Coolant systems update: integrating high efficiency pumps, plate type heat exchangers or compact cooling towers. Replacement of piping sections embedded into shielding bodies or affected by aggressive environments.
    - Nuclear and conventional instrumentation upgrade, and conversion towards digital instrumentation and modern control and monitoring systems.
    - Human–machine interface redesign, aiming to minimise staffing levels and training requirements.
    - Upgrade of support systems such as diesel generators, security arrangements and general housekeeping.
- Time frame and opportunity to undertake the activities with minimum disruption over the services provided by the facility.

- Resources required (capital and human) for undertaking the activities.
- Quantification of active waste generated that requires special handling.
- Possible involvement of other institutions to provide temporary support during the development of the activities.

A full assessment of the elements mentioned above provides the grounds to develop a plan commensurable with the facility and the scope of the possible refurbishment or upgrade identified. An assessment of the feasible alternatives should finally be undertaken and the preparation initiated well in advance considering the estimated opportunity window.

5.6.3 Managing the refurbished facility

After a refurbishment, major repair or modification, actions should be implemented to resume the routine operation schedule. If the works were performed properly, the facility should be in condition to:

- Provide a wider range of services in a reliable manner.
- Minimise the operating costs through the reduction of:
  - Nuclear fuel cost at similar or higher performance.
  - Staffing levels.
  - Spare parts consumption and stocking levels.
  - Electric power consumption.
  - Waste.
- Minimise doses to the staff.
- Reduce the scope of inspection programmes.

All these advantages should be capitalised in the shortest possible term after the overhaul in order to maintain and enlarge the previous portfolio of the facility. Actions for attracting new users might include:

- Screening of services required by local or regional customers able to be developed in the facility.
- Purchasing of additional equipment required to support these services.
- Training of the required human resources.
- Liaising with potential customers.
- Analysing the potential licensing actions and permits required.
- Establishing the commercial structure required to profit from the new services.

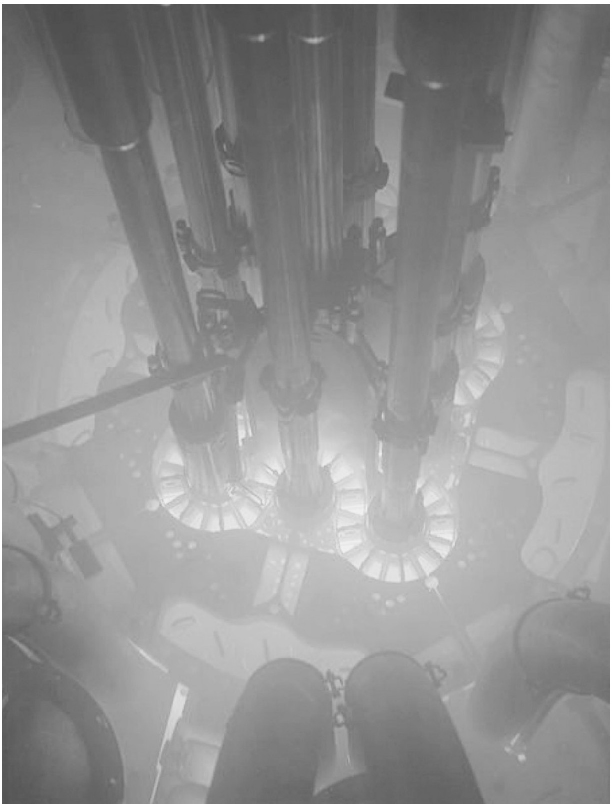
5.7 Research reactors: selected examples

There are 687 research reactors in the world. Four hundred and forty-eight of these are shut down, 232 are in operation and seven are planned or under construction.

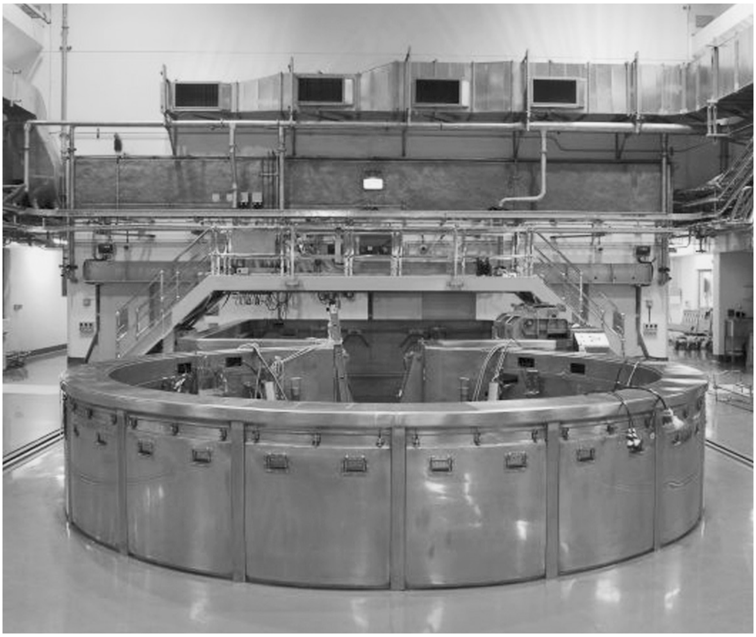
The International Atomic Energy Agency has a data base listing all research reactors (http://nucleus.iaea.org/RRDB/RR/ReactorSearch.aspx). The data base can be searched for different categories, such as location, power, type or status. There is a short description of each research reactor, featuring its main characteristics.

The research reactor of highest power presently in operation is the Advanced Test Reactor (ATR). The ATR is located at the Idaho National Laboratory and is mainly used for testing materials. It can operate at a maximum power of 250 MW and has a 'Four-Leaf Clover' design that allows for a variety of testing locations (Fig. 5.1). Further details on the ATR can be found at http://atrnsuf.inl.gov/.

One of the most recent reactors is the Open Pool Australian Lightwater (OPAL) reactor (Fig. 5.2). The OPAL is a 20 MW pool type reactor, with a compact core using low enriched uranium.



5.1 The Four-Leaf Clover Core of the ATR reactor.



5.2 Reactor hall of the OPAL reactor (author's photograph).

The main reactor uses are:

- Irradiation of target materials to produce radioisotopes for medical and industrial applications.
- Research in the field of material science using neutron beams.
- Analysis of minerals and samples using the neutron activation technique and the delay neutron activation technique.
- Irradiation of silicon ingots in order to dope them with phosphorus and produce the basic material used in the manufacturing of semiconductor devices.

During 2010 OPAL ran a total of 286 days at power, which makes it a worldwide leader in terms of availability. Further details on OPAL can be found at http://www.ansto.gov.au/discovering_ansto/anstos_research_reactor.

Another reactor that was started less than ten years ago is the Forschungs-Neutronenquelle Heinz Maier-Leibnitz (FRM II) reactor (Fig. 5.3). The FRM II is a 20 MW, tank-in-pool reactor used mainly for neutron research, so it is a beam type reactor. Information on the FRM II can be found at http://www.frm2.tum.de/.

A very interesting reactor presently under construction is the Jules Horowitz Reactor in France. This 100 MW reactor is intended to be a material testing reactor. It will mainly be used for research and development of nuclear fuels, for

5.3 FRM II reactor.

testing materials' behaviour under irradiation, and for the production of radioisotopes. More information on the Jules Horowitz Reactor can be found at http://www.cad.cea.fr/rjh/index.html.

Argentina and Brazil are presently designing two research reactors. These reactors will be very similar to each other and both based on the design of the OPAL reactor in Australia. They will be multipurpose reactors, capable of producing radioisotope, irradiating materials and generating neutron beams for research.

5.8 Emerging techniques and future trends

The golden age for construction of research reactors is in the past. Nowadays, there are few new research reactor projects worldwide: to put this in perspective, the whole foreseeable market for research reactors, including all projects planned for the next two decades, amounts to the dollar value of just one large nuclear power plant.

The main drivers for new research reactors are the following:

- Replacement research reactors: Many research reactors are reaching the end of their lives, and, having been valuable contributors to the development of nuclear activities in their countries and having given valuable services to different industries, they are being replaced by new facilities.

- Molybdenum-99 production: Molybdenum-99 is used by physicians in a diagnostic radioactive imaging technique. The reactors in which Molybdenum-99 is produced are very old, and demand for the radioisotope is growing, so there is a real need for new reactors that produce this and other radioisotopes.
- Silicon doping: Neutron transmutation doping in a research reactor is one of the most popular techniques used for producing the raw material for manufacturing semiconductors. Demand for these services is increasing worldwide.
- Research with neutrons: Neutrons have been shown to be very useful particles for probing samples so they have found extensive uses in materials and biology research. Demand for neutron beams exceeds present availability, so there is a need for new neutron sources based in research reactors.
- As additional countries plan to use nuclear energy, they need to identify the human resources required to carry out a nuclear power plan. A research reactor is normally the focal point of this training effort, serving as the core of a centre for the development of nuclear technologies.

Other trends affect the operating research reactors:

- The Global Thread Reduction Initiative is expediting the migration of old facilities towards low enriched uranium cores.
- The optimisation of operating costs (including staff) is leading to the modernisation and refurbishment of facilities in operation.
- Whereas mechanical, electric and process equipment last several decades and may be replaced item by item, instrumentation and control systems have shorter lifetimes and normally need to be replaced as a system, requiring a major upgrade of a facility. Many research reactors have undergone this type of refurbishment in the past and there are several projects at the planning stage.
- A few research reactors are closed every year, as they reach the end of their useful life.

These trends imply that the total number of operating research reactors is decreasing every year, as more research reactors are permanently shut down than new reactors are started up. As usual in these consolidation processes, the reactors that remain in operation and the new facilities have larger factors of utilisation than what was previously standard.

This consolidation in utilisation of research reactors has led to a mirror consolidation of the research reactor design and construction industry, only a handful of companies are active in the field.

5.9 Sources of further information

The IAEA's Research Reactor Section (RRS) is working continuously in developing useful and detailed information for every step of the research reactor lifetime. This includes activities from the initial decision to build a research reactor, the further utilisation, operation and maintenance, up to the final decommissioning and disposal of spent nuclear fuel.

Recent agency publications are chronologically listed in Section 5.9.1, separated by area of interest. Section 5.9.2 identifies useful links providing updated information on research reactors.

IAEA documents

Safety, licensing and regulation

- IAEA, Safety Standards Series No. NS-G-4.6, 'Radiation Protection and Radioactive Waste Management in the Design and Operation of Research Reactors', Vienna (2009).
- IAEA, Safety Reports Series No. 55, 'Safety Analysis for Research Reactors', Vienna (2008).
- IAEA, 'Code of Conduct on the Safety of Research Reactors', Vienna (2006).
- IAEA, Safety Standards Series No. NS-R-4, 'Safety of Research Reactors – Safety Requirements', Vienna (2005).
- IAEA, Safety Reports Series No. 41, 'Safety of New and Existing Research Reactor Facilities in Relation to External Events', Vienna (2005).

Utilisation

- IAEA, IAEA TECDOC Series No. 1659, 'Research Reactor Application for Materials under High Neutron Fluence', Vienna (2011).
- IAEA, Technical Report Series No. 455, 'Utilization Related Design Features of Research Reactors: A Compendium', Vienna (2007).
- IAEA, IAEA TECDOC Series No. 1545, 'Characterization and Testing of Materials for Nuclear Reactors Proceedings of a Technical Meeting held in Vienna, 29 May–2 June 2006', Vienna (2007).
- IAEA, IAEA TECDOC Series No. 1340, 'Manual for Reactor Produced Radioisotopes', Vienna (2003).
- IAEA, IAEA TECDOC Series No. 1234, 'The Applications of Research Reactors', Vienna (2001).
- IAEA, IAEA TECDOC Series No. 1215, 'Use of Research Reactors for Neutron Activation Analysis', Vienna (2001).

Planning, infrastructure and innovation

- IAEA, IAEA TECDOC Series No. 1601, 'Homogeneous Aqueous Solution Nuclear Reactors for the Production of Mo-99 and other Short Lived Radioisotopes', Vienna (2008).
- IAEA, Safety Standards Series No. NS-G-4.1, 'Commissioning of Research Reactors – Safety Guide', Vienna (2006).
- IAEA, IAEA TECDOC Series No. 1212, 'Strategic Planning for Research Reactors', Vienna (2001).

Fuel cycle

- IAEA, IAEA TECDOC Series No. 1637, ‘Cost Aspects of the Research Reactor Fuel Cycle’, Vienna (2010).
- IAEA, IAEA TECDOC Series No. 1637, ‘Corrosion of Research Reactor Aluminium Clad Spent Fuel in Water’, Vienna (2010).
- IAEA, IAEA Nuclear Energy Series No. NF-T-5.2, ‘Good Practices for Qualification of High Density Low Enriched Uranium Research Reactor Fuels’, Vienna (2009).
- IAEA, IAEA TECDOC Series No. 1593, ‘Return of Research Reactor Spent Fuel to the Country of Origin: Requirements for Technical and Administrative Preparations and National Experiences: Proceedings of a Technical Meeting held in Vienna, 28–31 August 2006’, Vienna (2008).
- IAEA, Safety Standards Series No. NS-G-4.3, ‘Core Management and Fuel Handling for Research Reactors – Safety Guide’, Vienna (2008).
- IAEA, IAEA TECDOC Series No. 1508, ‘Spent Fuel Management Options for Research Reactors in Latin America’, Vienna (2006).
- IAEA, IAEA TECDOC Series No. 1452, ‘Management of High Enriched Uranium for Peaceful Purposes: Status and Trends’, Vienna (2005).
- IAEA, IAEA TECDOC Series No. 1374, ‘Development Status of Metallic, Dispersion and Non-oxide Advanced and Alternative Fuels for Power and Research Reactors’, Vienna (2003).

Operation and maintenance issues

- IAEA, IAEA Safety Standards Series No. SSG-10, ‘Ageing Management for Research Reactors’, Vienna (2010).
- IAEA, IAEA TECDOC Series No. 1625, ‘Research Reactor Modernization and Refurbishment’, Vienna (2009).
- IAEA, IAEA Nuclear Energy Series No. NP-T-5.4, ‘Optimization of Research Reactor Availability and Reliability: Recommended Practices’, Vienna (2008).
- IAEA, Safety Standards Series No. NS-G-4.5, ‘The Operating Organization and the Recruitment, Training and Qualification of Personnel for Research Reactors – Safety Guide’, Vienna (2008).
- IAEA, Safety Standards Series No. NS-G-4.4, ‘Operational Limits and Conditions and Operating Procedures for Research Reactors – Safety Guide’, Vienna (2008).
- IAEA, Safety Standards Series No. NS-G-4.2, ‘Maintenance, Periodic Testing and Inspection of Research Reactors – Safety Guide’, Vienna (2007).

Decommissioning

- IAEA, Technical Reports Series No. 463, ‘Decommissioning of Research Reactors and Other Small Facilities by Making Optimal Use of Available Resources’, Vienna (2008).

- IAEA, IAEA Proceedings Series, 'Lessons Learned from the Decommissioning of Nuclear Facilities and the Safe Termination of Nuclear Activities: Proceedings of an International Conference held in Athens, 11–15 December 2006', Vienna (2007).
- IAEA, Technical Reports Series No. 446, 'Decommissioning of Research Reactors: Evolution, State of the Art, Open Issues', Vienna (2006).
- IAEA, 'Status of the Decommissioning of Nuclear Facilities around the World', Vienna (2004).
- IAEA, IAEA TECDOC Series No. 1273, 'Decommissioning Techniques for Research Reactors', Vienna (2002).

Web resources

In addition to the activities organised within the IAEA framework, different working groups organise periodic meetings publishing the proceedings in their respective webpages. Three of the main sources of information are the papers and proceedings published by:

- The National Organization of Test, Research, and Training Reactors (http://www.trtr.org/).
- The International Group on Research Reactors (http://www.igorr.com/home/index.htm).
- The Reduced Enrichment for Research and Test Reactors (RERTR) Program (http://www.rertr.anl.gov/index.html).

6

Managing modifications, power uprates and outages at operating nuclear power plants

J. DEVGUN, Senior Consultant, USA

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Abstract: This chapter covers three important areas related to operating nuclear power plants: modifications, power uprates and outage management. The discussion in this chapter is primarily based on the US regulatory environment and the US power industry experience. The discussion is oriented from the perspective of a manager with emphasis on the process, requirements, lessons learned and key attributes necessary for managing such projects. Future trends in the nuclear industry relevant to these areas are also discussed.

Key words: nuclear power reactor, managing modifications, power uprates, managing uprates, reactor outage, outage management.

6.1 Introduction

This chapter covers three topic areas related to operating nuclear power plants. These areas are modifications, power uprates and outage management. As with all aspects of nuclear power plant operation, activities in these areas are highly regulated. Regulatory requirements vary from country to country and the discussion in this chapter is primarily based on the US regulatory environment and the US power industry experience. The discussion is also focused from the perspective of a manager with emphasis on the process, requirements, lessons learned and key attributes necessary for managing such projects.

6.2 Managing modifications

During the operating period of a nuclear power plant, which may span several decades, it is necessary to ensure that it continues to operate safely and that it complies with applicable regulations, licensing conditions and standards. Throughout its operational lifetime, a plant is regularly inspected and its systems and components are maintained by the operating organization. The plant is also under regulatory watch, and inspections are frequently conducted by regulatory agency inspectors.

6.2.1 Necessity to modify structures, systems or components and regulatory aspects

The necessity to modify structures, systems or components (SSCs) may originate from various reasons such as the following:

- To address findings and potential safety issues brought to attention by an inspection.
- To address performance degradation in systems or components.
- Ageing of components.
- Enhancements in technology and to improve performance.
- Operational experience from industry.
- Generic issues identified by the regulator for specific reactor design or applicable to all reactor designs.
- To make changes to the original design basis for other reasons such as power uprates.

Safety classification of modifications is the first important parameter. Safety-related modifications must go through a screening or assessment and, in many cases, must be submitted for review and approval by the regulatory agency prior to initiation of any installation work. The plant's ability to be operated safely under the existing design basis is the key requirement. Non-safety-related modifications can generally be processed under the site's applicable procedures.

In the USA, a process for screening of the modification (or for that matter other major activities such as the design basis calculations) is applied under the site procedures and guidance. Applicability determination is first made of whether the 10 CFR 50.59 process is applicable or that the activity is controlled under another process or procedure. If the activity falls under the 50.59 process, then a 50.59 Screening is prepared. If this screening results in a conclusion that a formal 50.59 Evaluation is necessary, then such an evaluation is prepared and documented. This formal evaluation determines if prior approval is required from the Nuclear Regulatory Commission (NRC).

6.2.2 Modification preparation and process

The modification process involves several key steps and, in many cases, larger modifications can take several months (or even a year or longer) for preparation. It should also be noted that installation of many modifications is also tied to the outage schedule of the reactor, that is the modifications are installed when the reactor is down for refueling outage once every 18 or 24 months for the Pressurized Water Reactors (PWRs) and Boling Water Reactors (BWRs).

The process steps for modifications include the following:

- Defining the scope of the modification and getting financial and management approvals for the project.

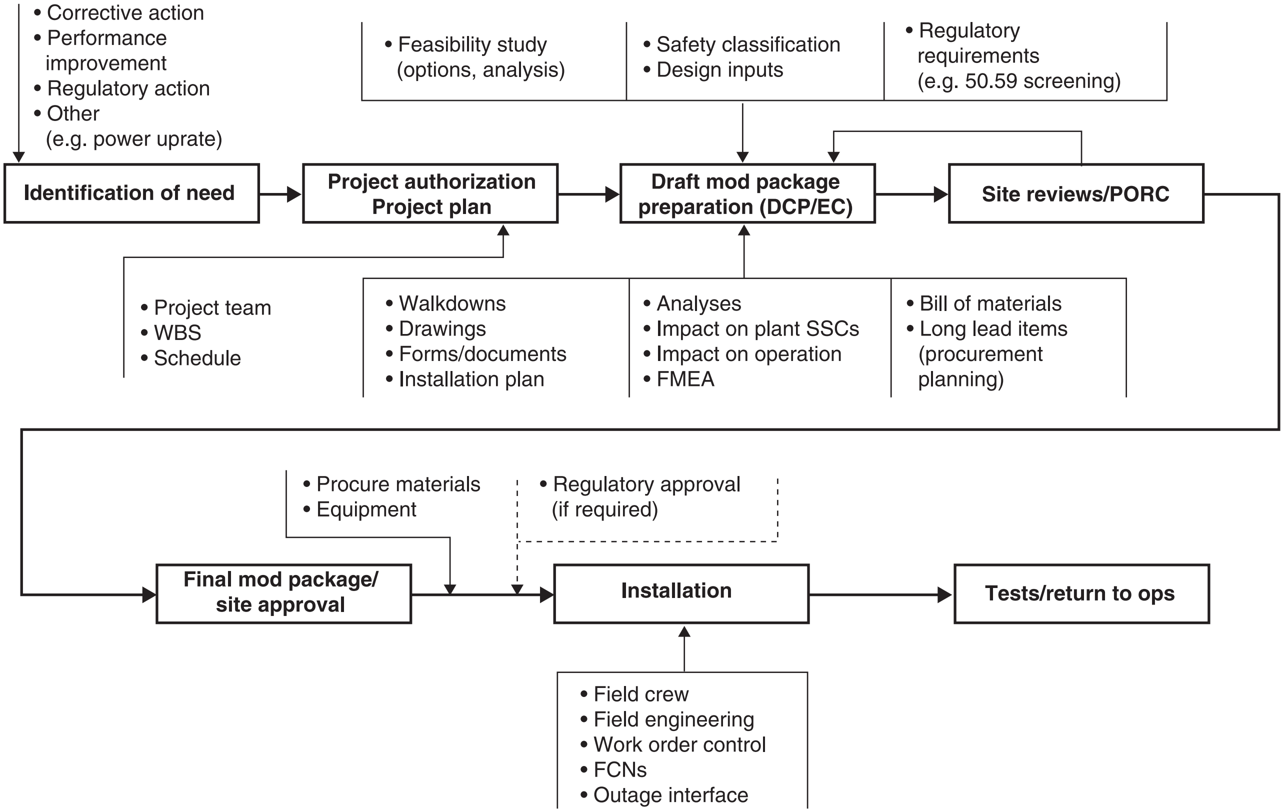
- Decisions on in-house or contractor services to prepare the Design Change Package (DCP) or Engineering Change (EC).
- Collecting design inputs, conducting analyses and preparing the DCP or EC.
- Procurement actions for components and services.
- Implementation of the modification:
    - Installation schedule (tied to outage schedule).
    - Installation mock up or dry run (if necessary).
    - Field installation.

Figure 6.1 depicts a generic flow of activities and steps for a modification including identification of the need, project approval, preparation of the design change package, reviews, plant approval (and regulatory approval, if required) and installation. Note that each plant site has specific procedures, guidelines and requirements that will be applicable to the modifications prepared and installed at that site. Thus, Fig. 6.1 is a simplified flow of work activities meant for illustrating the process.

Key elements of a Modification Package

Key elements of a Modification Package are:

- Description of the change
    - Purpose of the modification
      This section discusses the purpose of the modification including resolution of any regulatory issues and background of the issue(s) being resolved by the modification.
    - Modification description
      This section discusses the modification scope, changes to SSCs being made and the equipment being installed. In complex medications, where a number of smaller modifications (changes) are a part of the overall scope, a detailed description of each is provided.
    - Interfacing modifications
      As most modifications are installed during plant refueling outages, it is necessary to review and list other modification/maintenance actions that are planned for the same outage and that have potential interfaces with the modification under development. This is especially important for modifications and physical work activities inside the containment.
    - Impacted programs
      This section discusses the programs that are impacted by the modification. An Engineering Review and Scoping Screen (ERSS) worksheet may be used by the Lead Engineer to screen the various programs for impact.
    - Safety classification
      This section discusses whether the modification is considered safety-related or non-safety-related, and the reasons for that classification.



6.1 Generic flow of activities and steps for modifications.

- Design inputs
  Design inputs consist of many considerations and parameters and detailed discussion and documentation of each is essential to develop and support the modification. These are briefly summarized below (several are self-explanatory).
    - Structure, system or component functions
      Functions/requirements of each SSC relevant to the modification are discussed.
    - Performance requirements
      Performance requirements and criteria are discussed for key equipment being installed for the modification or the changes being made to SSCs.
    - Regulatory requirements.
    - Codes and standards for equipment and SSCs.
    - Design conditions
      Design conditions and qualifications of equipment/system are discussed with respect to hydraulic, seismic, temperature, pressure, environmental qualification and other parameters as relevant.
    - Loading under maximum applicable conditions.
    - Mechanical analysis.
    - Structural/seismic analysis.
    - Electrical analysis.
    - Instrument & Controls (I&C) requirements.
    - Testing requirements.
    - Accessibility, maintenance, repair.
    - In-Service Inspection (ISI) and In-Service Test (IST) requirements.
    - Personnel and training requirements.
    - Environmental conditions.
    - Interface requirements.
    - Materials requirements or materials restrictions
      For example, type of steel required for the modification. Certain materials may be restricted, such as use of aluminum in the containment unless specifically approved.
    - Layout and space envelope.
    - Handling, storage and shipping requirements.
    - Fire protection or fire resistance requirements.
    - Modification testing requirements.
    - Other requirements (such as redundancy, separation between components).
    - Operating Experience (OE) reviews.

- Design analysis
  The design analysis section is a comprehensive section analyzing all relevant aspects of the modification including topics and requirements discussed in the design inputs section. A detailed analysis is provided (as relevant) of the

hydraulic performance, code compliance, load analysis, anchoring details, impacts on safety analyses, radiation dose assessment and other aspects. In addition, the following may be required: assessment of the single failure requirements, evaluation of piping changes and evaluation of environmental/waste management aspects.

- Implementation
  This section discusses all work planned as a part of the modification installation and how it will be executed in accordance with the site procedures. Specific instructions are provided for installation of the equipment and piping. Main installation instructions are also provided on the drawings. General notes may be provided for the work by discipline such as mechanical, electrical and I&C. It should also be noted that the Sites' Foreign Materials Exclusion (FME) program for the containments should be followed so that materials are not left in the containment inadvertently.

Other items in the Modification Package

A typical Engineering Change Package will include the 'body' of the package containing the key items discussed above. Many sites use specific forms that must be completed as per site guidelines. Signatures from various plant discipline representatives and/or cognizant engineers are required on the package before it is approved by the site. Safety-related modifications require acceptance from the Plant Operations Review Committee (PORC) before they are approved by the Plant Manager. In addition to the 'body' of the package discussed in the earlier section, the Engineering Change Package or the Design Change Package may contain many attachments such as the following.

- Open Items/Constraints (OICs) List.
- Impact Evaluation Worksheet.
- Worksheet for ERSS
  This is used by the Lead Engineer/Responsible Engineer to quickly screen a variety of programs or topics whether they are relevant to the modification or not. This is done early in the modification development process to plan for and gain input from a variety of plant departments, disciplines and programs.
- 10 CFR 50.59 Screen (as required in the USA by the NRC).
- Interim Drawing List.
- Bill of Materials (i.e. materials and equipment that will be required).
- Design Change risk analysis.
- Document Review Worksheet.
- ALARA Review Checklist.
- Fire Protection Impact Screen.
- Human Factors Review.

- Failure Modes and Effects Analysis.
- Design Basis Document (DBD) or System Description (SD) changes.
- Safety Analysis Report (SAR) or Updated Safety Analysis Report (USAR) changes.
- Design Inputs List.
- Review Documentation.
- Design Review Board and PORC Documentation.
- Installation Instructions.
- Modification Test Plan.
- Operating Experience Review.
- Plant walkdown record.
- Drawings.
- Vendor technical manuals.
- Equipment labeling request.
- Project reference documentation.

It should be noted that Failure Modes and Effects Analysis (FMEA) is a standard industry practice in which component functions and failure mechanisms are analyzed. For the relevant components in the modification, a detailed FMEA is prepared and attached to the package. The analysis will document the likelihood of a potential failure mode, its analysis and the results. For the modification purpose, if the results show that the likelihood of a potential failure mode is negligible or the effect is negligible and no new failure modes arise from the design change, the modification is acceptable without further detailed analyses or mitigation.

Finally, it should be recognized that even though the plant walkdowns and other means (such as review of plant data, drawings and plant laser scans of the containment) are used to develop the modifications, in some cases it will be necessary to adjust the modification installation layout in the field. This is true for a significant portion of the work inside the containment because it is not feasible to do the walkdowns in the containment when the plant is running. In such cases, adaptations to designs are made by collecting walkdown data soon after the plant shuts down for outage. Nevertheless, some changes may be necessary when installation work begins. Thus, the modification packages should assess the need for and include planned Field Change Notices (FCNs) that are thought to be necessary.

6.2.3 Manager's role and other aspects

The manager responsible has to ensure that the draft modification packages prepared are complete, designs are complete, required analyses are complete, PORC reviews and other site reviews are planned for, and that the final modification package can be delivered to the plant manager (site management) on schedule.

Thus, adequate planning of resources, both funds and the staff, is a key consideration. This needs to be determined early and commitment obtained from senior management at the time of the project authorization. As a matter of advice for the manager, some key points are noted below.

- Learn from past experience and the 'lessons learned' on modifications at the site and in the industry in general.
- Engineering work must be planned in detail. Work should be tightly controlled with respect to scope, budget and schedule. If contractors are used to prepare the modification package, contracts should be clear on these aspects and a formal contract change process must be in place.
- Schedule must reflect a tie to the refuelling outage if the modification is planned for installation during the outage.
- Interface with site departments and programs is necessary.
- Safety procedures, walkdown procedures and site work procedures must be adhered to.
- Ensure that the modification package is prepared according to site procedures and guidance, and that the regulatory requirements are met.
- Regular status meetings should be held so that corrective actions can be taken in a timely fashion if necessary.
- Ensure that equipment which requires long lead time is planned for procurement.
- Changes to scope must be addressed in a timely and effective manner, and documented per site procedures.
- Installation packages (or installation instructions) must be detailed enough for the field crew to understand clearly and detailed installation drawings must be included.
- Modifications that make changes to key plant parameters (e.g. the parameters displayed at reactor operator panels) should include what parallel changes to simulators are necessary and what specific operator training is necessary in this regard.

6.3 Managing power uprates

Power uprating is the process of gaining an increase in the maximum thermal power level of a reactor (therefore, also the electrical output) through regulatory approval, supported by analyses, safety system reviews, system modifications and other actions that may be necessary.

6.3.1 Background

Commercial power reactors are licensed to operate at a maximum thermal power level set by the regulatory authorities and any changes to this level are only feasible if an application for power uprate is approved by the regulatory agency. Thus, impact of the new power level on SSCs, design margins and the licensing basis analyses must be evaluated in support of the application. A feasibility study can form the first step in the process to plan for an uprate.

To increase the power level, it may be necessary to implement changes on the Nuclear Steam Supply Systems (NSSS) side of the plant, for example higher enriched fuel or more fuel. However, power uprates generally require substantial changes to the secondary side, that is the Balance of Plant (BOP) side of the plant. As the overall electric output from the reactor is dependent on the turbine operation and the steam flow to the turbine, increased thermal power will directly impact these systems. Power uprates involve higher steam and water flows through the plant systems and the capability of the systems must be assessed to handle these increased flows. A large portion of the power uprate project consists of an engineering analysis effort and demonstrating that all SSCs are capable of performing their functions under the proposed new power level for the reactor.

Power uprates are especially challenging for older plants where complete design information may not be available because, in many cases, past documentation requirements were not as stringent as they are today.

The degree to which power uprates are desired and can possibly be done depends on a number of factors. It should be noted that the ability of the reactor to safely shut down under postulated accident conditions is the overriding factor.

6.3.2 Types of uprates and guidance

In the USA, the NRC defines three types of power uprates.

- Measurement Uncertainty Recapture (MUR) power uprates consist of a less than 2% increase in thermal power, and are generally achieved by reducing the degree of uncertainty in the power levels through precise measurements of certain parameters.
- Stretch power uprates are typically an increase of up to 7%, but the actual value is plant-specific depending on the design margins available for the systems and the feasibility of changing instrument setpoints (based on analysis) without impacting the safe operation of the plant.
- Extended power uprates can range to as high as a 20% increase in thermal power.

Starting with the first uprate in September 1977, by July 2012, about 20 000 MWt in total had been approved by the NRC for the US fleet of commercial reactors. Uprates for individual reactors have ranged from 1% at the low end to 20% at the high end. In total, the approved uprates have added about 6700 MWe to the electric generation capacity. Both PWR and BWR reactors have been uprated. As of September 2012, applications were pending with NRC for an additional total of approximately 2600 MWt, that is approximately 860 MWe. The implementation of all this combined capacity gained through power uprates of existing reactors leads to an increase in electricity generation output similar to the output from seven new reactors of 1000 MWe size. This is the key advantage of power uprate implementation. Power uprates have also been done for PWR and BWR reactors in Europe, although on a smaller scale.

The RS-001 'Review Standard for Extended Power Uprates' (NRC 2003) provides guidance for NRC staff on the technical review of applications for uprate and the processing of such applications. It is also indispensable guidance for managers handling power uprates in terms of NRC's expectations in this regard.

The review process itself involves initial screening of the application by the NRC for completeness and acceptability with respect to the minimum documentation requirements under the applicable regulations. The acceptance review (note that it is not a detailed technical review that occurs at a later stage and it does not represent approval of the EPU) involves review of the EPU application to ensure that it adequately identifies the design basis of the plant for the items in the 'Areas of Review' column in the matrices in the guidance provided in RS-001.

The next step is the detailed technical review. This is a review of the technical information in the application in 13 matrices in the following areas: Materials and Chemical Engineering; Mechanical and Civil Engineering; Electrical Engineering; Instrumentation and Controls; Plant Systems; Containment Review Considerations; Habitability, Filtration, and Ventilation; Reactor Systems; Source Terms and Radiological Consequences Analyses; Health Physics; Human Performance; Power Ascension and Testing Plan; and Risk Evaluation.

During this review, the NRC can formally issue Requests for Additional Information (RAIs). It is not unusual to have RAIs nearing 100 or more for Extended power uprates. These must be addressed by the utility (reactor licensee) to the satisfaction of NRC, with responses provided in a timely fashion.

6.3.3 Analyses and modifications for power uprates

Planning for power uprates will include analyses of the key systems on the NSSS and BOP sides. The analyses may also lead to planning for modifications, in most cases on the BOP side but may also include some modification work on the NSSS side.

Heat balance analyses for the plant are done using codes such as PEPSE™ and a benchmark model is created specific to the plant using the plant parameters and the plant operating data. Actual operating data may be taken from the screen shots of the Emergency Response Computer System (ERCS) data displays. The EPU cases are then run with the NSSS data provided by the NSSS vendor including the Steam Generator parameters. The analyses conducted for EPU document expected changes in plant operating parameters, such as pressures, temperatures and flowrates under the EPU conditions.

Many plants that have implemented the MUR uprate have installed Leading Edge Flow Meters (LEFM) for accurate measurements of feedwater flow and temperature. The LEFM-based reduced power measurement uncertainty allows an increase in the rated thermal power (RTP) of the plant. The more accurate data from LEFM is also input to the heat balance analyses and the hydraulic analysis for the Extended power uprate. The hydraulic analyses of the power train systems are performed using codes such as Fathom™.

The analyses on the NSSS side may include: NSSS design transients, reactor pressure vessel (RPV) integrity, RPV supports, bottom mounted instrumentation (BMI) nozzles, core support block, head penetrations, primary nozzles and the reactor coolant loop piping. The containment analysis must confirm that the pressure and temperature under power uprated conditions would remain below the design limits.

The analyses on the BOP side generally include: main steam system, feedwater system, feedwater heaters, circulating water system, cooling water system, cooling towers, component cooling water system, condensate system, heater drain system, drain control valves, overpressure protection, BOP piping, reactor coolant system (RCS) attached piping, steam extraction system, condenser and air removal system, heating ventilation and air conditioning (HVAC) system, steam generator blowdown system, spent fuel pool cooling, power conversion (turbine generator), on-site electrical power, emergency off-site electrical power, BOP instrumentation and controls, high energy line break (HELB) and environmental qualification (EQ) of equipment.

In addition to the above, many of the existing plant programs may be impacted by an uprate. Thus, an evaluation of such impacts is necessary. On the BOP side, the program review (in the USA) generally includes the following: Check Valve Program; Appendix J Containment Leakage, In-service Inspection and In-service Testing Programs; RCS Leakage; Internal Missile Program; Simulator; Appendix R Safe Shutdown/Fire protection; Generic Letter 89-13 Program (Safety-Related Heat Exchanger); Coatings Program (part of GSI-191); AOV Program; MOV Program; Generic Letter 96-06 Program (in the USA related to containment response following a loss of coolant accident (LOCA) or main steam line break (MSLB)); Flow Accelerated Corrosion (FAC) Program; Vibration Monitoring Program; Environmental Qualification (EQ) Program; and the Station Blackout (SBO) Program.

Margin management requires special attention and all changes to equipment must be assessed in this regard. The regulatory margin is maintained between the design/safety limit and the operating limit, which is below the design/safety limit. The operating margin is provided by the difference between the operating limit and the operating level, which is set below the operating limit. Power uprate changes may have the potential to erode these margins.

Although it will vary from plant to plant, from past experience, some of the main EPU-related modifications on the BOP side include one or more of the following:

- Auxiliary feedwater system modifications/upgrades.
- Feedwater modifications (piping, valves, and instrumentation).
- Modifications in the main steam system.
- Modification of high pressure turbine.
- Upgrades/replacements of pumps and motors.
- Steam dryer modifications.
- Heater modifications.
- Upgrades of monitoring instrumentation and setpoint changes.

Because of the increased mass steam flow, the main turbine generator may require modifications which include widening of the high-pressure turbine inlet nozzles or major modifications requiring replacement of the entire high-pressure turbine rotor/blades.

Data from recent power uprate-related events/issues point to causes that include inadequate analysis, inadequate design or implementation issues during the power uprates. Several of the significant events have been related to vibration issues for various components, which could cause damage to components or lead to loosening of the parts. Thus, vibration analyses are a significant portion of the work because of increased system flows.

Instrument calibration problems and containment analyses are other areas that need attention. Past experience also points to issues related to operational procedure deficiencies. Other areas of concern that need analyses or modifications include: accelerated wear and degradation in valves and piping; flow accelerated corrosion of heaters and system components, pump seals and thermowells; off gas condenser and gland seal valves; air operated and motor operated valves; and turbine control valves.

It is worth noting that NRC in its Inspection Guidance for its staff advises staff to select risk significant plant modifications from those implemented for the power uprate. These consist of: modifications which impact Emergency Core Cooling System initiation, or the ability of the system to mitigate an event; modifications which could contribute to the initiation of an event following installation; modifications which implement new equipment setpoints on risk significant equipment; and modifications which caused unexpected problems when installed at another plant.

Grid interface is an important area that needs to be evaluated to determine if modifications or upgrades are required to the equipment in the electrical switchyard, such as transformers. A power uprate will increase the power input to the grid from the station. Thus, local grid voltage regulation is necessary to avoid transmission system overloads. In the USA, regional power transmission system organizations are responsible for the grid operation. Interface with the regional organization should begin from the planning stages of the uprate. The local grid and the equipment must be capable of handling the increased power output or the capability must be upgraded.

6.3.4 Regulatory approval

Implementation of power uprate for a commercial nuclear power plant requires regulatory approval and this process varies from country to country.

In the USA, the NRC requires submission of a request to amend the commercial nuclear power plant license and the technical specifications related to the power uprate pursuant to 10 CFR 50.90. A minimum, the license amendment request fulfils the information requirements of RS-001. Technical information related to the guidance in RS-001 is provided in an EPU Licensing Report. In addition to the Licensing Report, various other attachments to the application may consist of technical justifications for the proposed License Amendment and Technical Specification changes and their bases, and description of changes to the Updated Safety Analysis Report. Note that some parts of the Licensing Report may be proprietary and the application may contain a request for withholding the proprietary information. In such cases, a non-proprietary version of the EPU Licensing Report is publicly available. Note that the Licensing Report is generally supported by numerous individual calculations, assessments and task reports, which may not be submitted to the NRC (unless requested) but form the basis of the conclusion reached in the individual sections of the Licensing Report.

As the application is reviewed, RAIs on the power uprate application are issued by the NRC and the applicant must provide the information in a timely fashion.

The NRC review consists of a thorough technical review of the application, any public comments, as well as any requests for hearings received from the public. NRC's findings are issued in a Safety Evaluation Report (SER) and NRC notifies the public in a Federal Register notice regarding its decision related to the application, approving it or denying it.

Licensing application preparation and technical analyses for Extended power uprate are a complex undertaking requiring substantial efforts, in many cases stretching over two or more years and it is not unusual for a Licensing Report to be over 1000 pages. The NRC may take one or two years for the application review before a decision is reached.

6.3.5 Manager's role and other aspects

In a project of large size and complexity such as the Extended Power Uprate, the utility (holder of the license for the nuclear power station) will generally retain a specialized contractor to conduct and coordinate the technical analyses and prepare the Licensing Report. The utility retains the ownership of the project and is responsible for submitting the License Amendment application for the uprate. Thus, the management team consists of the utility as well as the other organizations supporting the effort.

From a manager's perspective a few key points can be summarized:

- Power uprates are a complex activity and a manager well-versed in project management practices and with substantial experience in managing large projects will be best suited to managing an uprate project.
- Coordination of parallel activities being conducted at various organizations and integration of resources is a challenge.
- Schedules, scope, budget and risk priorities need constant attention and updates.
- Consideration should always be towards maintaining or improving safety margins and equipment reliability.
- Use industry experience from prior uprate applications and RAIs that followed from the regulatory agency.
- Minimize impact on plant operations as the work related to uprate application is conducted, for example walkdowns of the plant systems and components.
- Be cognizant of plant schedule, interface requirements for outage schedule, preparation and planned submission date to the regulatory agency, and eventual implementation after approval.
- Have a Recovery Plan and be prepared for recovery measures for design outputs that may be incomplete or late on schedule delivery.
- Consider License Renewal application by the plant (if such an application is also being submitted to the regulatory agency) and coordinate as necessary.
- Maintain interface with the regulatory agency on the application for the uprate.
- Ensure early interface and continual interface with the regional grid organization.

In the end, implementation of an uprate is a business decision where the senior management has to decide whether the benefits in the form of increased revenue from added MWe justify the expense of the preparation of the application and the eventual modifications to the systems or components required to implement the uprate. There are instances in the industry where the decisions have led to postponing of the uprate application after the technical work has been completed because of concerns related to the costs of the eventual implementation or the possibility of a prolonged process involving additional regulatory requirements.

6.3.6 Uprate implementation

When approval from the regulatory agency has been received, and a decision has been made on moving forward with the implementation, the plants may implement the modifications and changes over one or more refueling outages. The Extended power uprates may require capital intensive equipment for procurement and installation. The plant site will have specific plans and procedures covering the uprate implementation which should be followed.

A formal Uprate Startup Test Plan will generally be prepared and it will include details of the planned power ascension testing. Measurements may be made at selected power levels. The tests may include main steam and feedwater piping vibration, core performance (and measurement of reactor parameters as power is increased in incremental steps), calibration of the instrumentation, steam dryer/separator performance, chemical system measurements, as well as routine measurements of the power-dependent parameters for systems and components affected by the uprate.

The plant may be required to monitor specific measurements (such as vibration measurements) and equipment (such as steam dryer stress levels) during power ascension as a part of the regulatory approval decision. Because of increased emphasis on vibration issues in the past several years, requirements for vibration monitoring have generally been included in the approval process.

Testing related to the modifications themselves is performed in accordance with the site's modification program and the requirements of each modification.

From management perspective, site management has to recognize the impact of the power uprate on the plant systems and specific attention must be paid to managing risk, margin management and the grid interface requirements.

6.4 Outage management

The refuelling outage for a light water reactor occurs once every 18 months to 24 months when approximately one-third of the reactor fuel is typically replaced. Tremendous improvements have been made in the outage management and the time span of the outages on the average has dramatically improved. In the USA, refuelling outages during 1990 and 1992 were over 100 days. By the latter half of the 1990s, the average was about 60 days, and by 2010, it was approximately 40 days. A few of the reactors have achieved the shortest refuelling outage at 15 days.

In addition to the refuelling outage, the plant may schedule outages for inspection and maintenance purposes.

6.4.1 Planning and coordination

Lack of adequate planning can lead to outage extension and declining plant performance. Every day the reactor is down with unplanned extension of the outage, it costs the plant significant revenue from lost production.

Pre-outage planning is the key. As discussed in Section 6.2, many modifications are installed during the reactor outage. Thus, there is a significant potential for modification work delaying the outage completion. Reactor refueling may be complete but the reactor startup is held back by pending completion of the modification work. It is critical that along with the engineering design of the modification, the procurement of the components be complete prior to start of the outage and all materials needed for the modification be available on-site.

The refueling part of the outage is well optimized with lessons learned over the past few decades. As far as the outage duration is concerned, most outages depend on the scope and complexity of the modifications that are planned to be installed during the outage. For larger modifications such as steam generator replacement or turbine upgrade, an outage may run over 50 days. For modifications such as the reactor head replacement, the outage may be even longer. For smaller modifications, the outage duration may be closer to the regular refueling outages.

It is also important that the appropriate manpower is assembled, such as the trades personnel. Another important aspect for complex installations is a mockup of the installation (and rehearsal of actions) that should be done prior to the outage to train the field crew on the actions and sequence of actions. It should also be recognized that things can happen in the field that may require corrective action on an expedited basis. In many cases these end up being adjustments or changes made to the design. The engineering team supporting the installation must be quick to develop solutions. Changes to design during installation are usually accomplished with the FCNs. These need to be done in a matter of hours, not days, because the field crew is on hold in their activities during this time. The outage teams work 24/7, with the outgoing team turning over the activities to the incoming team and the process is repeated after eight- or ten-hour shifts. Thus, all outage team staff must be up-to-date on the progress of activities.

Testing of the installed equipment and turning over the system to the operations organization should be on schedule.

Another important aspect is coordination between several modifications that may be installed during the outage. This impacts the implementing staff, supporting staff and, more importantly, it impacts the work flow control. For modifications being installed inside the containment, the relatively crowded space makes the work planning and work control activities difficult. Similarly, the support staff, such the Radiation Protection (RP) department may be challenged in providing RP technical support to all ongoing activities.

A refueling outage when refueling is the only activity is more straightforward. However, typically, outage is a period of intense and multiple activities, with millions of dollars worth of modification work going on along with the refueling. Pre-outage work planning should consider the work control process, i.e. how the work orders will be prepared, scheduled and implemented for multiple projects.

Stations use Outage Management or an Outage Control Center and the position of an Outage Director or Outage Manager to ensure that activities are coordinated and that schedule milestones can be achieved. The outage organization must have representatives from all key departments such as Operations, Maintenance, System Engineering, Design Engineering, Radiological Protection/Health Physics and Plant Chemistry.

Outage goals and objectives must be defined at the beginning of the planning process. Focus should be maintained on nuclear safety, plant safety and worker safety.

Plant walkdowns for each major field work should be completed in advance, where possible. In those cases where this is not feasible when the plant is operating, such as the modifications inside the containment, modification design should leave some flexibility in the form of planned FCNs (as an example, tolerances to which the equipment can be installed in a specific location may have to be adjusted in the field).

6.4.2 Key points for outage management

Some key points for the managers are summarized below:

- Senior management needs to set up the outage implementing organization early so that outage planning can begin and interfaces with other plant organizations can be established.
- Management must clearly communicate the expectations for the outage and provide adequate resources to the teams in the field.
- ‘Lessons learned’ from prior outage experience at that specific plant and at other plants must be applied.
- Management must establish 24/7 (24 hours every day of the week) coverage for the work and establish proper turnovers from one shift to another.
- It should be ensured that the workers have the necessary skills and training.
- It should be ensured that engineering and other skilled staff from outside organizations coming to the site to support the outage are properly integrated into the site organizations. Site staff responsible for providing access and badging services must be ready to process an influx of individuals in a short time. Contractor workers to support larger outages may number in the hundreds. This must be pre-planned because security clearance and access requirements may require several weeks of lead time.
- It should be ensured that procedures are up-to-date and that everyone follows the procedures.
- Safety comes first; this includes nuclear safety, radiological safety and industrial safety.
- Special attention must be paid to critical path items.
- It should be ensured that quality control is maintained even though the schedules are very tight during the outage period.
- It should be ensured that contingencies can be handled by the appropriate organizations.

Some key points for the Work Supervisors and Task Leads are as follows:

- It should be ensured that the workers fully understand the tasks, their sequence and their duration.
- It should be ensured that workers are briefed on the scope of the job as well as the hazards associated with the job.

- Some craft workers may be brought on-site for their skills (e.g. welding) but may be new to the nuclear work. It should be ensured that they get training and understand the radiological, quality and regulatory implications of their work at the nuclear station.
- Schedules and schedule changes must be communicated promptly to the field crew.
- A mechanism must exist for prompt notification for supervision and other organizations such as design engineering if installation in the field requires changes to the design.
- It should be ensured that Health Physics support is provided where needed.
- It should be ensured that temporary shielding is available when required.
- It should be ensured that adequate resources are lined up for the activities to be performed.
- It should be ensured that scaffolding and rigging equipment is available.
- It should be ensured that lighting is available in the work area.
- Equipment tagout and lockout must be in place where required.
- It should be ensured that sufficient hand tools, special tools and other items needed are available.
- It should be ensured that the equipment and components that will be installed as a part of the modification work are available in the inventory.
- Inventory control for special equipment is key, and a chain-of-custody should be used to ensure that equipment is not misplaced or lost and is available when needed for installation.

6.4.3 Plant risk and safety

All worker safety policies and procedures apply during the conduct of the outage. From a system/plant perspective, control of the Residual Heat Removal (RHR) system, especially during the early stages of the outage (soon after the plant is shut down for outage) is important along with the reactivity control and containment controls. Another important aspect is maintaining the cooling of the spent fuel pool.

A large number of activities are conducted in a relatively short period during an outage. Many of the activities may be related to changes to systems that have safety function or support a safety function. Control of these activities and other risk significant activities is generally provided by the PORC, which advises the Plant Manager on all matters related to safety and recommends approval or disapproval of all items reviewed. PORC also assesses the 10 CFR 50.59 Screening and Evaluations prepared for specific activities and modifications and determines if the reviewed items require NRC approval (prior to implementation of any changes) in accordance with 10 CFR 50.59.

6.4.4 Forced outages

Forced outages are relatively rare and from a management perspective the main difference between a scheduled outage and a forced outage is that there is no time available for pre-planning for such an outage. Discovery of a malfunction of a key component or system or a degraded safety equipment condition may lead to forced outage by the plant management or regulatory inspection may lead to forced outage if serious safety issues are present.

The US NRC defines forced outage as follows:

> The shutdown of a generating unit, transmission line, or other facility for emergency reasons, or a condition in which the equipment is unavailable as a result of an unanticipated breakdown. An outage (whether full, partial, or attributable to a failed start) is considered 'forced' if it could not reasonably be delayed beyond 48 hours from identification of the problem, if there had been a strong commercial desire to do so.

Some examples of events that lead to forced outage are provided. This is meant to be for illustration purposes only and the examples are neither meant to be comprehensive nor as a comment on the potential vulnerability of a system or component. Examples include:

- Reactor Coolant Pump leaks.
- Inoperable Auxiliary Feedwater Containment Isolation Valves.
- Failure of Control Rod Drive System indicator.
- Main Steam Isolation Valves (MSIV) problems.
- Reactor Coolant Pump Oil System leaks.
- Extraction Steam Expansion Bellows failure.
- Pressurizer Safety Valve leakage.

Even for forced outages, the outage process must be followed. The organizational and response aspects must be optimized for work execution and the strategy should be to respond quickly to the problems that caused the outage. Comprehensive planning in a very limited time is the key. The objective is that the plant can be safely brought on-line as soon as possible after the conditions causing the outage are resolved.

The type of malfunction or deficiency will determine how long the forced outage period extends. Organizations can learn from such past events at the plant (if any) and the industry wide experience in general. Some degree of contingency planning can also be in place, for example establishment of an organization to respond to such potential events. In extremely rare cases (e.g. major equipment failure in the turbine generator), there have been cases in the industry where forced outage has lasted a year with substantial expense and lost revenue. In some cases, if the forced outage happens to occur close to a scheduled outage, then consideration should be given to the coordination of all aspects of the scheduled outage and the forced outage.

6.4.5 Other aspects

Other aspects that the outage organization needs to consider include: power availability during the outage, in-service inspections and tests that are scheduled for the outage, and coordination of the inspections with maintenance work. Many programs such as the air operated valves, motor operated valves, flow accelerated corrosion may also have scheduled activities during the outage.

Contingency plans should be developed for potential failures of the snubbers, valves and piping/welds. Required material should be planned for.

A successful outage would meet the schedule and budget performance, experience no loss of reactor decay heat removal, experience no significant events (plant events or significant health and safety or radiation issues) and meet the goal of returning the plant to on-line status in an efficient manner.

6.5 Challenges and future trends

In the modifications area, the near term future activities in the nuclear power industry are focused on actions resulting from the Fukushima Daiichi accident.

The accident at Fukushima Daiichi station (a six-unit site) occurred on 11 March 2011 as a result of the magnitude 9.0 earthquake and the tsunami that followed. Fukushima Daiichi has led to re-examination of the plant design both by the regulatory bodies and the industry. In the USA, the NRC established a Near-Term Task Force which issued its report on 12 July 2011 (NRC 2011). Among others, the recommendations included the following areas: seismic and flooding protection, prolonged loss of AC power, containment venting, spent fuel pool cooling, severe accident procedures, emergency preparedness, seismically induced fires and flooding, hydrogen control mitigation insider buildings and regulatory framework for low probability high consequence events.

As a part of the implementation activities, the NRC has issued Orders and RAIs that require plant specific actions by the licensees. Orders issued in 2012 are related to: mitigation strategies to respond to extreme natural events resulting in loss of power at the plant; ensuring reliable hardened containment vents (which actually applies to Mark I and Mark II BWR designs as the subsequent BWR designs and PWRs do not have this issue); and enhancing spent fuel pool instrumentation for monitoring water levels. Other areas for RAIs include seismic and flooding re-evaluations, emergency communications systems and staffing levels.

The industry has been analyzing plant response to external events and implementing modifications to plant designs as appropriate. Some areas of note are upgrades to the SSCs for external events such as earthquakes and flooding. The scale of these events considered in the original design basis has changed since the Fukushima event.

Emergency backup power is another area of re-examination and the availability of Emergency Diesel Generators and backup power is being ensured under earthquake conditions (and tsunami in coastal areas) through a variety of modifications. Another area for consideration is the hydrogen control in the reactor building.

In the area of power uprates, the impetus to uprate has slowed somewhat following the Fukushima accident and more rigorous regulatory reviews are expected in the future. Technically, one of the more important areas for additional effort is the potential for induced vibrations in components and piping because of the increased flow under uprate conditions.

In the area of outage control, more emphasis is being placed on optimization so that refueling outage periods remain at or close to the planned interval. Coordination of multiple projects during an outage involving major modification work presents significant challenges.

6.6 Sources of further information

IAEA (2004) Implications of power uprates on safety margins of nuclear power plants, IAEA-TECDOC-1418, September 2004.

IAEA (2004) Nuclear power plant outage optimization strategy, IAEA-TECDOC-1315, Vienna, 2002.

IAEA (2011) Power Uprate in Nuclear Power Plants: Guidelines and Experience, IAEA Nuclear Energy Series, NP-T-3.9, Vienna, 2011.

Web-based resources (various organizations)

International Atomic Energy Agency, www.iaea.org.

Organisation for Economic Co-operation and Development /Nuclear Energy Agency, OECD/NEA, www.oecd-nea.org/.

World Nuclear Association, www.world-nuclear.org.

Nuclear Energy Institute, www.nei.org/.

US Nuclear Regulatory Commission, www.nrc.gov.

6.7 References

NRC (2003) Office of Nuclear Regulation, Review Standard for Extended Power Uprates, RS-001, Rev. 0, December 2003.

NRC (2011) Recommendations for Enhancing Reactor Safety in the 21st Century, The Near Term Task Force Review of Insights from the Fukushima Dai-ichi Accident, Enclosure to SECY-11-0093, July 2011.

7

Managing medical radioisotope production facilities

C. ALLEN and L. MANSON III,
University of Missouri Research Reactor, USA

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Abstract: This chapter discusses the production of the medical radioisotope molybdenum-99 (^{99}Mo). This radioisotope is commonly referred to as the 'workhorse' of the global nuclear medicine community. Foreign heads of state support of the United States' nuclear non-proliferation objectives has had a significant economic impact on the way ^{99}Mo/ technetium-99m (^{99m}Tc) is produced. Reactor facilities must convert from using highly enriched uranium (HEU) to low enriched uranium (LEU) as the source material (i.e., target) used to produce fission product ^{99}Mo, the parent nuclide of ^{99m}Tc. The technical challenges that must be overcome are summarized in this chapter. The research and development of alternate technologies that do not use uranium to produce ^{99}Mo are also presented.

Key words: accelerator, fission, molybdenum, radioisotope, reactor, technetium, uranium

7.1 Introduction

Commercial production of radioisotopes concentrates on two main areas: medicine and industrial applications. Radioisotopes for medical purposes, such as ^{99}Mo, ^{125}I and ^{131}I, ^{133}Xe and ^{89}Sr, are better known than those for industrial purposes, such as ^{75}Se, ^{192}Ir, ^{169}Yb and ^{60}Co. Production is dominated by ^{99}Mo in medicine and by ^{60}Co in industry. Whereas ^{60}Co, applied in large quantities in food product gamma irradiation and medical instrument sterilization facilities, is primarily produced in nuclear power plants, ^{99}Mo is produced in medium to high power research reactors. Molybdenum-99 (^{99}Mo) is often referred to as the 'workhorse' of the nuclear medicine community. This chapter focuses on ^{99}Mo production. However, much of the information presented is applicable to medical radioisotope production in general.

7.2 Radioisotope production technologies and current supply chain

The fission-based production of ^{99}Mo in a nuclear reactor involves the irradiation of a uranium target. As the target is irradiated, ^{235}U atoms within the target undergo fission. ^{99}Mo is a fission product that is yielded directly from ^{235}U fission. Following irradiation in the reactor, typically 120 hours or more, the targets are removed and chemically processed to recover the ^{99}Mo. ^{99}Mo radioactively decays to the nuclear medicine radioisotope technetium-99m (^{99m}Tc).

^{99m}Tc is medically useful because it emits 140 keV gamma rays that are easily detectable using a gamma camera. Because of its relatively short half-life, approximately six hours, greater than 90% of the radiotoxicity in a patient is eliminated (by radioactive decay) in less than one day. More than 30 common nuclear radiopharmaceuticals are formulated using ^{99m}Tc allowing precision imaging of the heart, brain, thyroid, liver, lungs, gallbladder, kidneys and some types of tumors.

In the field of nuclear medicine, a ^{99}Mo/^{99m}Tc generator (see Fig. 7.1), or colloquially a ‘technetium cow’ or ‘moly cow’, is a device used to extract the metastable isotope of technetium (^{99m}Tc) produced as the result of the radioactive of decay of ^{99}Mo. ^{99}Mo has a half-life of approximately 66 hours. As such, it can be easily transported over long distances to radiopharmacies where its decay product ^{99m}Tc (half-life of about six hours) is extracted from the generator by normal saline elution. The half-life of the parent nuclide (^{99}Mo) is about ten times longer than that of the daughter nuclide (^{99m}Tc). Therefore, eluting the daughter nuclide from the generator, using a normal saline solution, can be performed repeatedly to obtain patient-dose quantities as often as every six hours at a radiopharmacy. A ^{99}Mo/^{99m}Tc generator is typically used for a period of one week. ^{99m}Tc is used in approximately

(a) (b)

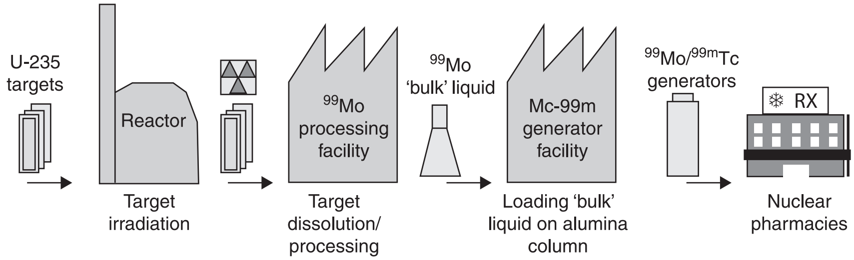
7.1 External (a) and cutaway (b) views of Lantheus Medical Imaging’s TechneLite® ^{99}Mo/^{99m}Tc generator. (Photos provided courtesy of Lantheus Medical Imaging, Inc. TechneLite is a registered trademark of Lantheus Medical Imaging, Inc. © 2013 Lantheus Medical Imaging, Inc. All rights reserved).

90% of all nuclear medicine diagnostic imaging procedures performed worldwide every year. This equates to an estimated 30 million diagnostic medical procedures per year worldwide. Other medical radioisotopes such as iodine-131 (^{131}I) and xenon-133 (^{133}Xe) are byproducts of the fission product ^{99}Mo production process. The most commonly used alternative method for producing ^{99}Mo involves neutron capture on a molybdenum-98 (^{98}Mo) target. However, the ^{99}Mo produced by this process has a very low specific activity because most of the Mo in the product is ^{98}Mo. 'Specific activity' is the radioactivity of the ^{99}Mo in a sample expressed in Curies (Ci) divided by the total mass, expressed in grams, of the molybdenum isotopes (^{97}Mo, ^{98}Mo, ^{99}Mo and ^{100}Mo) in the sample at a specified reference calibration date and time. The ^{99}Mo activity (Ci) is measured by the method of gamma spectroscopy. The total mass of molybdenum is typically determined by the method of mass spectrometry. The specific activity for fission produced ^{99}Mo is two to four orders of magnitude higher than from the neutron capture process.

Currently, the global demand for ^{99m}Tc is met primarily by producing ^{99}Mo by nuclear fission of uranium. An estimated 80% of this medical radioisotope is produced by only eight material test reactors (see Fig. 7.2). The geographical locations of these reactors are Canada, Eastern Europe, South Africa and Australia. No fission product ^{99}Mo is currently produced in the USA. The fission produced ^{99}Mo is extracted, purified and packaged in five commercial facilities and supplied to manufacturers of ^{99}Mo/^{99m}Tc generators around the world (see Fig. 7.2). Demographic and medical trends suggest that in the near future the global demand for ^{99m}Tc will grow at an average rate between 3% and 8% per year as new markets (primarily in Asia) develop as a consequence of those countries who plan to expand their nuclear medicine technology infrastructure.[1] The 2012 worldwide demand of ^{99}Mo is estimated to be about 15 000 six-day Ci per week.

Six of the eight material test reactors that produce fission product ^{99}Mo on a large scale are more than 40 years old. Several recent interruptions in the supply of ^{99}Mo/^{99m}Tc prompted international agencies and several government agencies to accelerate their efforts to establish both short-term and long-term solutions to prevent the recurrence of future shortages of this vital medical radioisotope.

In addition, the worldwide support of the US Global Threat Reduction Initiative (GTRI) program objectives has had a direct impact on those isotope production



7.2 Schematic of ^{99}Mo/^{99m}Tc production/supply chain.

facilities that currently use highly enriched uranium (HEU) targets to produce fission product radioisotopes. Its impact is significant for those facilities that produce ^{99}Mo/^{99m}Tc.

7.3 Conversion from highly enriched uranium to low enriched uranium

The U.S. Department of Energy (DOE) National Nuclear Security Administration (NNSA) manages the Global Threat Reduction Initiative (GTRI) Reactor Conversion Program, a continuation of the Reduced Enrichment for Research and Test Reactors (RERTR) Program. This program was established by the DOE in 1978. The GTRI implements the long-standing U.S. policy to minimize and eliminate the use of highly enriched uranium (HEU) in civilian applications by working to convert research reactors and isotope production facilities to the use of low enriched uranium (LEU).

Production of ^{99}Mo using LEU instead of HEU eliminates concerns over nuclear proliferation, criticality and the transportation of weapons-grade material. However, the substitution of LEU for HEU also poses a technical challenge. To yield the equivalent quantity of ^{99}Mo, the use of LEU requires approximately five times more uranium than HEU. Consequently, substituting LEU for HEU requires changes to the chemical process to efficiently separate the ^{99}Mo from high concentrations of uranium while obtaining a finished product of equal purity. Another challenge is to modify the existing HEU-based radiochemical processes as little as possible so as to limit the economic disadvantage of using LEU.

Production of ^{99}Mo using LEU targets is almost identical to the present ‘gold’ standard process for producing ^{99}Mo using HEU targets, and chemical processing is, in many cases, almost identical. In some cases, however, chemical processing might need to be modified to accommodate the larger mass of LEU target material. The LEU-based production process and products must be validated and approved by regulatory bodies, but past experience suggests that this will be a straightforward process when carried out in close coordination with regulators.

US Senate Bill S. 99, ‘American Medical Isotopes Production Act of 2011’ authorizes a new DOE program to support production of ^{99}Mo in the USA. The objective of this act is to phase out the DOE’s exportation of nuclear proliferation-sensitive HEU to foreign reactors that use this material as irradiation targets to produce this radioisotope. Senate Bill S. 99 requires that the DOE ‘provide assistance for . . . the development of fuels, targets, and processes for domestic molybdenum-99 production that do not use highly enriched uranium’ and commercial operations using these fuels, targets and processes. The DOE program is required to be technology-neutral in the evaluation of an isotope production process that is to be judged on timeliness, production capacity and cost. Senate Bill S.99 authorizes $150 million in appropriations for this program in Fiscal Years 2012 through 2016. The bill was officially enacted by the president in January 2013.

Six of the major production reactors irradiate HEU targets with the isotope ^{235}U enriched to as much as 93% to produce ^{99}Mo. As mandated by the US Congress, the US National Academies examined the feasibility of ^{99}Mo production without using HEU. The report concluded that elimination of HEU is technically and economically feasible.[2] In South Africa, plans for conversion to LEU achieved a major milestone in 2010 when ^{99}Mo produced from LEU was imported into the USA for patient use for the first time. ANSTO, in Australia, routinely produces ^{99}Mo from LEU targets irradiated in the OPAL reactor.

In addition, there is a need for diversity and redundancy in all aspects of the isotope supply chain. Well-distributed and smaller-scale production facilities are important supplements (for domestic and regional use) that will increase the reliability of supply.

Several alternative/supplementary technologies for producing ^{99}Mo/^{99m}Tc have been proposed. Some are not yet commercially proven or still require further development. International exchanges of information and coordination of individual efforts in developing technically and economically viable technologies may provide the essential thrust to prepare them for deployment. Various projects are underway worldwide to implement the conversion of fission product ^{99}Mo targets from HEU to LEU.

7.4 New production facilities and decommissioning

New research reactors for future production of medical radioisotopes are now in the planning stage or under construction. A brief summary of these projects is presented later in this section. These reactors are often referred to as 'multi-purpose' because they are used for purposes other than just the production of radioisotopes. For example, enhancing the quality of semiconductor materials by neutron transmutation doping (NTD).

NTD is the process of creating non-radioactive impurity isotopes, also known as dopants, from the host atoms of semiconductor materials (usually silicon) by irradiation with thermal neutrons and subsequent radioactive decay. The purpose of adding dopants, either by NTD or alternative chemical means, is to decrease the resistivity of the semiconductor material to produce the desired electrical characteristics in the fabrication of semiconductor components. Significant commercial use of semiconductors began in the 1970s. NTD is a technically superb and cost-effective method for adding small amounts of dopants to semiconductor materials in order to achieve low resistivity in conjunction with high spatial uniformity of the dopant.

NTD is the preferred method over conventional, chemical means for introducing dopants in semiconductors, in the manufacture of small, discrete low power devices and especially in the manufacture of power electronics that need to operate at high temperatures, voltages and currents. Nuclear research reactors are the ideal source for performing the doping process.

7.3 ^{99}Mo production hot cell train (photo courtesy of NRG-Petten).

The growing demand for such semiconductor materials, therefore, presents opportunities and challenges for existing research reactor facilities desiring to operate in a commercial, high throughput service for fee operation. For new research reactor facilities in the design or planning stages, the demand for such semiconductor materials presents an opportunity to design the reactor and ancillary facilities from the ground up in order to achieve the high-quality doped semiconductor material desired and the production throughput required. This is necessary to ensure facility operation profitability.

Mallinckrodt, Inc., now Covidien, completed construction of a 500 m^2 manufacturing facility dedicated to ^{99}Mo production in 1996. This facility is located on the Petten reactor site in the Netherlands. It is a standalone manufacturing building that is not annexed to the reactor building where the ^{99}Mo production targets are irradiated. The irradiated targets must be transported in a heavily shielded transport cask and moved to the manufacturing facility where they are chemically processed to produce ^{99}Mo. The chemical processing of the irradiated targets is performed in the hot cell train, as shown in Fig. 7.3. The facility consists of two separate hot cell trains in order to accommodate the maintenance of a production train without interrupting the weekly batch production of ^{99}Mo. Covidien ships its ^{99}Mo worldwide.

7.4.1 Projects under construction

The Jules Horowitz Reactor Collaborative Project (JHR-CP) organizes and implements the design and construction of the Jules Horowitz Reactor. This reactor represents a new research infrastructure of pan-European interest.

This reactor, located at CEA Cadarache Research Center, is tentatively scheduled to start full-power commercial operation in 2017 (see Fig. 7.4). This

7.4 Reactor containment building under construction, February 2012 (photo courtesy of CEA).

multi-purpose reactor will support the European scientific community in the area of nuclear energy technology development for several decades. It will also be used to produce ^{99}Mo and other radioisotopes, and high performance silicon used in electronic devices, such as those used in electric and hybrid vehicles, computer systems or energy control systems.

Because the JHR is a key research infrastructure of pan-European interest and is open to international cooperation, 20% of the JHR-CP cost is provided by European and international partners. Several European research institutes and utilities have joined the JHR-CP in order to have long-term access to a 'state-of-the-art' research facility and infrastructure.

The nuclear unit is composed of only one civil engineered structure supporting two zones with different containments: the reactor building (RB) and the nuclear auxiliary building (NAB). The objective of this single structure is to contain all the radioactive materials in one place. The reactor is a pool type reactor that has a maximum power of 100 MW_{th}. The primary cooling circuit and experimental rigs are completely enclosed in the RB. The reactor pool is connected to several storage pool and hot cells located in the NAB through a water-filled transfer canal.

7.4.2 Projects under development

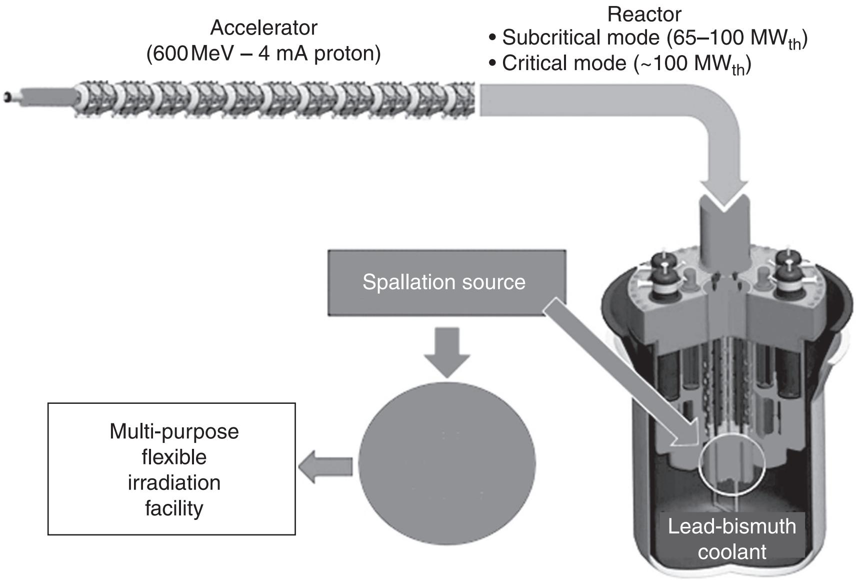
Babcock & Wilcox Technical Services Group, Inc. has developed a conceptual design for a 200 kW aqueous homogeneous reactor and recovery system to produce ^{99}Mo. This production technology is referred to as the Medical Isotope Production System (MIPS). The reactor fuel solution in the form of an LEU-based nitrate salt dissolved in water and acid is also the target material for ^{99}Mo production. The reactor would be operated in batch mode to produce ^{99}Mo. In essence, the reactor would be operated for the time required for the build-up of ^{99}Mo in the fuel solution. Following significant build-up of the ^{99}Mo, the reactor is shut down and the fuel solution pumped through a recovery column that preferentially sorbs molybdenum. The ^{99}Mo is then recovered by stripping (i.e. eluting) the recovery column and subsequently conditioned by one or more purification steps. It is estimated that a 200 kW MIPS is capable of producing about 10 000 Ci of ^{99}Mo at the end-of-bombardment (five day irradiation). A comprehensive description of the MIPS concept is presented by the International Atomic Energy Agency.[8]

SCK•CEN, the Belgian Nuclear Research Centre in Mol, has been working for several years on the design of a multi-purpose irradiation facility in order to replace their aging BR2 reactor, a multi-functional materials testing reactor (MTR), that has been in operation since 1962. BR2 currently irradiates ^{99}Mo production targets. The irradiated targets are transported to the Institut National des Radioéléments (IRE) located in Fleurus, Belgium where they are processed into the finished product form of sodium molybdate.

MYRRHA, a flexible fast spectrum research reactor (65–100 $\mathrm{MW_{th}}$) is conceived as an accelerator driven system (ADS), that is designed to operate in both subcritical and critical modes (see Fig. 7.5). It will consist of a 600 MeV proton accelerator, a spallation target for producing fast neutrons and a mixed-oxide (MOX) fueled reactor core. Heat removal from the reactor will be accomplished by a liquid lead-bismuth (Pb-Bi) coolant loop. Full power operation of MYRRHA is tentatively scheduled for around 2023. The total cost of the MYRRHA project is currently estimated to be about 950 million Euros.

The SAFARI-1 reactor and NTP's radioisotope production facility are both located at the Pelindaba site, near Pretoria, South Africa. This commercial enterprise, owned and operated by the South African Nuclear Energy Corporation (NECSA), is equipped with a range of facilities and services that support nuclear technology product development and radioisotope production. This facility has been in operation since the mid-1960s and continues to supply an ever-increasing range of quality products to users throughout the world. NTP Radioisotopes (Pty) Ltd., a subsidiary of NECSA, is a worldwide major supplier of ^{99}Mo and currently produces ^{99}Mo and ^{131}I using both LEU and HEU targets. NECSA plans to phase out the use of HEU entirely within the next several years.

NECSA is investigating the possibility of building a replacement research for SAFARI-1. Although the specifications of the new reactor have not been finalized, it is anticipated that its size will be in the range of 10–30 $\mathrm{MW_{th}}$ and utilize LEU plate type fuel produced in South Africa. The reactor is tentatively scheduled to begin operation around 2025. In the meantime, significant plant life extension



7.5 Conceptual design of SCK•CEN's accelerator driven reactor system.

projects are underway at SAFARI-1 to ensure its safe and sustainable operation until the new reactor is operational.

In the Netherlands, the PALLAS project consists of the construction and commissioning of a new 30–55 MW_{th} high flux reactor which will be designed for the purposes of medical isotope production and nuclear technology research and development. This reactor is to serve as replacement for the current High Flux Reactor (HFR) in Petten, which has been in service for about 50 years and is approaching the end of its economic life span.

The initiative for the PALLAS project was undertaken by the Nuclear Research & Consultancy Group (NRG), a subsidiary of the Energy Research Centre of the Netherlands (ECN). As operator of the HFR, NRG has grown into a worldwide leader in the field of nuclear consultancy and provision of irradiation services for the production of medical and industrial isotopes and nuclear technology research and development.

In the Republic of South Korea, HANARO, a 30 MW_{th} research reactor, has been operating since 1995. The reactor was designed for multi-purpose use in various science and engineering fields, such as material irradiation, nuclear fuel irradiation, neutron scattering and neutron radiography, as well as neutron transmutation doping for silicon. In order to cope with the growing demand of radioisotopes, including ^{99}Mo, and the neutron silicon doping service, the government of South Korea has decided to construct a new research reactor that will have a power rating of 15 MW_{th}. The decision was determined based on the findings of a feasibility study conducted jointly by the Korea Development Institute and the Korea Atomic Energy Research Institute. The project was officially launched in the spring of 2012; it has a 60 month timeline to complete all activities, from conceptual design through full-power commissioning.

As this project progresses, the role of HANARO will be changed to a neutron beam facility and the new research reactor will take over the neutron irradiation services now performed by HANARO. This new research reactor will be sited near Busan, which is the second largest city in South Korea. The city of Busan has an international airport and a harbor facility which will help facilitate the transportation logistics of the reactor facility's products.

In early 2012, BARC publicly announced their plan to build two new research reactors. The first new reactor, named the High Flux Research Reactor (HFRR), will have a thermal power rating of 30 MW. The second new reactor, currently named Dhruva-2, will have a thermal power rating of 125 MW. These new reactors are categorized as multi-purpose reactors. They will be used for materials testing as well as radioisotope production. The country of Brazil has announced its plans to build a new 30 MW open-pool type multipurpose reactor. The conceptual design of the reactor is based on the OPAL reactor in Australia. The reactor system will be designed by INVAP of Argentina. The governments of Brazil and Argentina have established a formal cooperative agreement to engage in the design, construction, and commissioning of this new reactor. The cost of the project is estimated to be approximately 500 million USD. The reactor will be constructed in the town of Iperó, which is located about 100 km west of São Paulo. The reactor will be operated by the Instituto de Pesquisas Energéticas e Nucleares (IPEN), which is the largest nuclear research institute of the Brazilian National Nuclear Commission.

7.4.3 Production of ^{99}Mo in the USA

Early commercial production in the U.S. employed irradiation of natural abundant high-purity molybdenum oxide or molybdenum metal. This method yielded ^{99}Mo that has a significantly lower specific activity than fission product ^{99}Mo. Through the 1970s and into the early 1980s, a number of reactors routinely produced neutron activation ^{99}Mo for the commonly used low specific activity ^{99m}Tc generators of the time period. As the demand for ^{99}Mo grew, fission product ^{99}Mo became the preferred and more economical means of producing ^{99}Mo.

The 5 MW_{th} Cintichem reactor located in Sterling Forest, New York, produced fission product ^{99}Mo from circa 1972 to 1989 at a production level equal to about 50% of the US demand. The reactor was permanently shut down in February of 1990. The decommissioning and dismantlement project was completed in 1997 at a cost of more than 100 million USD. Information applicable to the decommissioning of isotope production reactors and processing facilities is presented in International Atomic Energy Agency, Technical Reports Series nos. 463 and 446.[3,4]

7.5 Accelerator-based production technologies

As an alternative method to reactor fission or neutron capture, the use of accelerators is currently being explored to produce ^{99}Mo. One accelerator-based technique essentially mimics the reactor production route in that the accelerator becomes the source of neutrons which are then used to produce fission in a blanket of ^{235}U that surrounds the neutron source. The required fluxes are difficult to achieve in the required geometry in order to be economically competitive with reactor generated neutrons. Such an accelerator is expensive to build and operate, although less expensive than the construction and licensing of a new reactor.

Another technique would use an electron beam to generate high intensity photons, which in turn would be used to initiate a nuclear reaction of enriched Mo targets such that the ^{100}Mo(γ, n) reaction yields ^{99}Mo. This technique is under development by TRIUMF in Canada. The same issues as discussed above are present for this technique in addition to the technical challenges associated with producing a high energy electron machine with sufficient beam flux to be able to produce sufficient ^{99}Mo to be economically competitive. As a consequence, the use of electron Linacs (i.e. linear accelerators) capable of accelerating tens of milliamps of electrons is being explored as a viable option.

For both of these accelerator approaches, a series of machines operating in tandem would be required because the fluxes of neutrons and photons would not be sufficiently high to be economically competitive with a reactor. The cost of construction and operation of multiple machines needs to be analyzed to determine if a profitable business case can be developed for these approaches.

Another approach is photo-fission of ^{238}U using natural or depleted uranium targets. The technical challenge is the same as previously mentioned for the other photon induced reaction (^{100}Mo(γ,n)^{99}Mo); that is the need for a very high intensity beam to overcome the factor of about 1000 smaller cross section for this reaction versus neutron fission of ^{235}U. However, the fission yields are almost identical at approximately 6%.

Another option that has been explored is direct production of ^{99m}Tc from ^{100}Mo(p,2n)^{99m}Tc. The disadvantage of this approach is that the final product (the ^{99m}Tc used in nuclear medicine procedures) is directly produced and has a short half-life of about six hours. As a result, its effectiveness will be greatly limited if it must be shipped long distances to the nuclear medicine centers. Even a distribution logistics network of suppliers would be faced with a challenge.

The nuclear reaction cross section for the direct production of ^{99m}Tc from enriched ^{99}Mo is estimated to be about 17 mCi/μAh. At this level, even with a very high beam current facility and irradiation periods of a day (i.e. 24 hours), the most ^{99}Mo that could be produced at a single facility would be < 200 Ci per day. To meet the needs of the USA, there would have to be > 25 cyclotrons dedicated to this process. This does not take into account the losses associated with transport and chemical efficiencies for separating the ^{99m}Tc from the dissolved target solution matrix. A single site might be able to become self-sufficient, but this would not help the larger nuclear medicine community.[2] The Nuclear Energy Agency, Organisation for Economic Co-Operation and Development presents an overview of the various accelerator-based technologies that can, or could be used to, produce ^{99}Mo.[7]

7.6 Fundamental issues and challenges of medical isotope production

7.6.1 Radioactive waste

Uranium fission production of ^{99}Mo generates higher volume and activity waste compared with other production technologies described in this chapter. ^{99}Mo production facilities face the challenges of radioactive waste handling, temporary on-site storage and ultimate off-site disposal. Separation of the ^{99}Mo from the dissolved irradiated uranium generates high-activity liquid waste that must be placed in a solid form for transportation to an off-site waste disposal site. A waste disposal pathway must be established with the support of a facility's regulatory body. The regulations applicable to radioactive waste disposal vary from country to country. Production of ^{99}Mo using LEU targets will generate waste having the same characteristics as that produced from HEU targets. However, waste volumes could be different (larger or smaller) depending on the type target used. A discussion of the types of waste generated by those facilities that produce fission product ^{99}Mo is presented by the International Atomic Energy Agency.[5]

7.6.2 Regulatory compliance

^{99}Mo/^{99m}Tc must meet established regulatory criteria to ensure patient health and safety. The US Pharmacopeia (USP) is the official pharmacopeia of the USA, published with the National Formulary (NF). It establishes written (documentary) and physical standards for medicines, food ingredients, dietary supplement products and ingredients. These standards are used by regulatory agencies (e.g. US Food and Drug Administration) and manufacturers to help ensure that these products are of the appropriate identity, as well as strength, quality, purity and efficacy. Many other countries use the USP-NF instead of issuing their own pharmacopeia, or to supplement their government pharmacopeia. European countries use the European Pharmacopoeia developed by the European Directorate for the Quality of Medicines. Many other countries have adopted its use as well.

7.6.3 Production scale-up

Scaling of radiochemical production level shares many aspects applicable to the scaling of other chemical processes. Increasing batch size and/or production quantities typically require replacing the smaller size demonstration trial processing equipment with larger or more equipment, followed by validation that the larger batch size produces a product whose quality is essentially unchanged from the smaller scale. Also affected are the methods of raw materials procurement, waste handling and licensing, although each of these come with additional challenges in radiochemical production. Beyond typical chemical process scaling challenges, radiation shielding and radiolysis effects can be significant in scaling up an existing radiochemical process. Both radiation shielding and radiolysis effects change dramatically with scale and can lead to the ultimate scale-limiting factor in production. The intent here is not to provide a comprehensive method for scaling radiochemical processes, but to point out some of the more challenging aspects related to radiochemical production that are not typical considerations for other chemical processes.

Radiation shielding

Radiation shielding considerations are multi-facetted. Radioactive materials used in radiochemical processes must typically be transported in some form from the reactor site to a processing facility. Shielded containers (i.e. shipping casks) that are used for commercial freight transport of radioactive material within the USA require Department of Transportation (DOT) and Nuclear Regulatory Commission (NRC) certification and approvals. Obtaining regulatory certification can be expensive and may take several years to complete. Local transfer (within a single facility) will require a method of moving radioactive materials, often requiring several thousand pound mobile shields and/or a timely repetitive scheme to move smaller portions multiple times. Once irradiated materials are situated where the radiochemical processing is performed, radiation shielding efforts turn to processing technician safety while allowing required automation and/or remote manipulations to perform the process. Thick lead barriers with leaded glass viewing ports and product compatible linings in conjunction with mechanical robotic arms, and automation are typically employed. Radiation shielding can also be critical for systems and apparatus components to avoid damage to electronics (primarily semiconductor materials used in integrated circuits). Although in most cases it is preferable to keep integrated circuitry out of high ionizing radiation fields by hard wiring control circuits to protected areas, it is sometimes possible to locally shield the electronic components that are located in the high radiation area.

Radiolysis effects

Radiolysis is basically the molecular damage to a substance caused by ionizing radiation. Here, the term is applied to the radiochemical processing apparatus that cannot be protectively shielded, and the components of the product itself. Many radiochemical products contain water: the breakdown of water into hydrogen peroxide, and hydrogen and oxygen compounds is well known, and has been published providing data to formulate expectations. From this one can predict that hydrated and biological materials will be affected by radiolysis. Most other product components will likely need to be evaluated to some extent to confirm that their 'radiation stability' (maintaining chemical properties in a radiation field) as determined in early feasibility studies related to the product remains unaffected at the scaled-up production level. Production scale-up often results in higher levels of ionizing radiation that will exceed prior 'radiation stability' analyses. Having an understanding of how the most concentrated form of the radioactive materials is handled, and the duration of their contact with other process chemicals can help identify those materials that may be subject to degradation caused by higher radiation levels. As is often the case, only empirical data are available to determine if the entire process will be stable in the scaled-up radiation level production environment. This often requires additional time to evaluate, which can extend to months or years of testing and analyses to determine, resolve and remediate the undesirable radiolysis effects.

Raw material procurement

Procurement of raw materials used in radiochemical production can be subject to complications. Many radiochemicals rely on the activation of highly purified and/or isotopically enriched elemental materials. Although these materials are often available in small quantities suitable for research and development activities, and sometimes early clinical trials, larger production quantities are often not available and may require considerable lead time to procure. Just as in production scale-up, scaling of raw materials supply can often lead to potential undesirable changes to the material. In some cases, the scaling of supply for raw materials required to produce a radiochemical may pose as many or more challenges than the scale-up of the production level itself. Whether from scaling or simply inherent to a raw material, very low-level impurities (purity issues that would be undetectable in other chemical processes) have the potential to introduce long half-life contaminants during activation that may be difficult or impossible to remove from the finished radiochemical product, thus rendering it useless for human injection.

Waste handling

Waste related to radiochemical production comes from many parts of the overall production process. Waste can be related to the raw materials, materials used in relation to the activation of the target material, undesirable activation products (radioactive byproducts), chemical byproducts and contaminated used materials related to handling radioactive materials before, during and after the process. Waste material is categorized as solids, liquids and gases; as well as several classes by radiotoxicity, chemical toxicity, biological and/or mixed waste characterization. As it relates to radiochemical production scaling, it is important to realize that larger volumes of waste often will require additional segregation by category/class, and additional storage space.

Licensing

A regulatory approved license for possessing and handling radioactive materials related to radiochemical production is required at all levels of production, but may require significant effort when scaling a production system in the areas of transportation (discussed earlier), increased possession of radioactive material authorization and increased quality control documentation. Although an approved license is in place for small quantities of radioactive material, in most cases significant increases in activity levels will require license amendments and/or modifications that require regulatory approval. The time taken to obtain license revisions can be significant and will usually require a detailed plan for waste handling, and eventual decommissioning of facilities and equipment. Radiochemicals used in medical applications within the USA may require additional quality documentation up to and including full Good Manufacturing Practices (GMP) documentation accompanied by a supporting Drug Master File (DMF). Considerable time and effort is required to implement and comply with the US Food and Drug Administration (FDA) guidelines in this area, and it is often advisable to hire consultants that have experience preparing FDA required documentation.

7.7 Sources of further information

1. International Atomic Energy Agency, Vienna, Technical Reports Series No. 455, ‘Utilization Related Design Features of Research Reactors: A Compendium,’ 2007.
2. International Atomic Energy Agency, Vienna, ‘Research Reactors: Purpose and Future,’ November 2010.
3. International Atomic Energy Agency, Vienna, IAEA-TECDOC-1430, ‘Radioisotope handling facilities and automation of radioisotope production,’ December 2004.
4. International Atomic Energy Agency, Vienna, IAEA-TEC-DOC-1212, ‘Strategic planning for research reactors – Guidance for reactor managers,’ April 2001.
5. International Atomic Energy Agency, Vienna, ‘Research Reactors in Africa,’ November 2011.
6. International Atomic Energy Agency, Vienna, ‘Research Reactors: Purpose and Future,’ November 2010.
7. International Atomic Energy Agency, Vienna, ‘The applications of research reactors – Report of an Advisory Group meeting held in Vienna, 4–7 October 1999,’ August 2001.
8. Nuclear Energy Agency, Organisation for Economic Co-Operation and Development, ‘The Supply of Medical Radioisotopes, An Economic Study of Molybdenum-99 Supply Chain,’ NEA No. 6967, © OECD 2010.
9. TRIUMF, University of British Columbia, ‘Making Radioisotopes: Report of the Task Force on Alternatives for Medical-Isotope Production,’ 2008.

7.8 References

1. Report presented to the Ministry of Natural Resources of Canada by the Expert Review Panel on Medical Isotope Production, 30 November 2009.
2. National Research Council of the National Academies, ‘Medical Isotope Production Without Highly Enriched Uranium,’ The National Academies Press (2009).
3. International Atomic Energy Agency, Vienna, Technical Reports Series no. 463, ‘Decommissioning of Research Reactors and Other Small Facilities by Making Optimal Use of Available Resources,’ June 2008.
4. International Atomic Energy Agency, Vienna, Technical Reports Series no. 446, ‘Decommissioning of Research Reactors: Evolution, State of the Art, Open Issues,’ 2006.
5. International Atomic Energy Agency, Vienna, IAEA-TECDOC-1051, ‘Management of radioactive waste from ^{99}Mo production,’ November 1998.
6. Ross, C, Galea, R, Small, P, Davidson, W, Brown, P, Brown, D, Harvey, J, Messina, G, Wassenaar, R, De Jong, M. Using the 100Mo photonuclear reaction to meet Canada’s requirement for 99mTc, *Physics in Canada*, 66 (2010) 19–24.
7. Nuclear Energy Agency, Organisation for Economic Co-Operation and Development, ‘The Supply of Medical Radioisotopes: Review of Potential Molybdenum-99/Technetium-99m Production Technologies,’ © OECD 2010, November 2010.
8. International Atomic Energy Agency, Vienna, IAEA-TECDOC-1601, ‘Homogeneous Aqueous Solution Nuclear Reactors for the Production of Mo-99 and other Short Lived Radioisotopes,’ September 2008.

8

Management of nuclear-related research and development (R&D)

H. P. BERG, Federal Office for Radiation Protection, Germany, and P. BRENNECKE, Consultant, Germany

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Abstract: This chapter provides information on the research and development (R&D) work currently being carried out for nuclear installations. The principal aim of these investigations is to enhance the safety of nuclear power plants, nuclear facilities such as reprocessing plants and facilities for nuclear fuel element manufacture, and radioactive waste management installations, such as conditioning facilities and repositories. Nevertheless, R&D work has also always played a role in initiating or supporting new technical and technological developments. This chapter will cover work being undertaken by international organizations as well as in the USA, Germany, Sweden, Switzerland and the UK relating to all nuclear power plants and repositories for radioactive waste.

Key words: research and development (R&D) work, nuclear R&D, R&D management, R&D programme, nuclear installation.

8.1 Introduction

At the beginning of the twenty-first century the question of energy supply is a crucial issue to be addressed. Most countries using nuclear energy for commercial electricity production are required to perform safety assessments in order to keep facilities operating safely. The primary purpose of these safety assessments is to determine whether an adequate level of safety has been achieved for a facility or an activity and whether the safety objectives and safety criteria have been fulfilled. Safety assessments should be carried out for all nuclear applications, that is for all types of nuclear installations and activities. Two further key tasks for countries using nuclear energy are improvement in safety of nuclear power plants and other nuclear facilities, and safe disposal of radioactive waste originating from the operation, decommissioning and dismantling of those installations.

Safety-related studies have been carried out for a number of years in order to meet the requirements discussed above, and research and development (R&D) work has always played a key role, particularly in the assessment and enhancement of safety in the operational and post-operational or post-closure phase of nuclear installations. R&D work is also of basic importance with respect to new developments such as advanced nuclear power plant concepts, new technical solutions for retrofitting measures, new proposals regarding the nuclear fuel cycle and developments in radioactive waste management and disposal. A useful example in this respect is that, to date, operating repositories for spent nuclear fuel, high-level radioactive waste originating from reprocessing of spent fuel, or certain types of waste with long-lived radionuclides are not available worldwide, although disposal plans are well advanced in some countries. Productive R&D work is indispensible for the safe use of nuclear energy and for the successful management of nuclear projects. This chapter therefore aims to provide information on the ways in which R&D programmes and work on nuclear installations on a national and international level are managed.

8.1.1 Fundamental issues in the management of R&D for nuclear projects

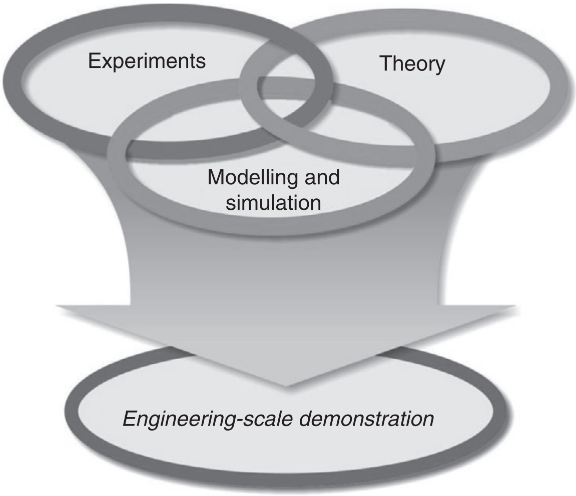
R&D needs to be carefully planned and managed to succeed. Appropriate project management is therefore the key to achieving the required aims of R&D projects. Clear objectives, time frames and budgets should be set out from the beginning, with deadlines mapped out for completion of key stages. At the end of each phase of the project, progress should be reviewed, and a decision made with regards to whether – and how – to proceed.

Good management is vital to reduce the risk of failure and to realize as many goals as possible. Effective project management requires:

- Ensuring that staff involved in R&D understand the overall strategy.
- Recognizing when a project is not going to work.
- Rejecting ideas that are not viable.
- Understanding the relative importance of different projects to the goals to be achieved.

The International Atomic Energy Agency (IAEA) published recommendations in 2008 that provide guidance for decision makers in nuclear R&D organizations on planning, implementing and sustaining knowledge management programmes to derive organizational benefit (IAEA, 2008). It uses existing IAEA nuclear knowledge management concepts and publications and extends their application to a range of activities currently undertaken by nuclear R&D organizations.

One example of a successful approach to the management of nuclear R&D programmes is the goal-driven, science-based approach (US Department of Energy, 2010), which is essential to achieving the stated objectives while also allowing new technologies and transformational advances to be explored. This approach combines theory, experimentation, and high-performance modelling and simulation to develop the fundamental understanding that will lead to the development of new technologies. It is illustrated in Fig. 8.1, along with a brief description of the principal elements.



8.1 Major elements of a science-based approach (US Department of Energy, 2010).

Experiments – These are generally small-scale experiments aimed at the observation of isolated phenomena or the measurement of fundamental properties. However, targeted integral experiments are also required in some cases.

Theory – Based either on first principles or observations made during phenomenological testing, theories are developed to explain fundamental physical phenomena.

Modelling and simulation – A range of mathematical models for diverse phenomena at very different time and spatial scales are developed and then integrated to predict the overall behaviour of the system. The principal objectives of this aspect are a reduction in the number of prototypes and large-scale experiments needed before demonstration and deployment, and quantification of uncertainties and design and operational parameters.

Demonstrations – Although current understanding can be significantly advanced through the combination of experiments, theory, and modelling and simulation, there may be instances where it is appropriate to work with the private sector to further develop and validate laboratory findings. Demonstrations can be a useful means of proving the viability of new technologies, but their high cost must be considered in the context of a variety of other factors. In particular, there must be sufficient industry commitment to the use of commercial technologies before such demonstrations can be considered.

In summary, the method involves the use of advanced modelling and simulation tools in conjunction with smaller-scale, phenomenon-specific experiments informed by theory in order to reduce the need for large, expensive integrated experiments. Insights gained through this type of advanced modelling and simulation can lead to new theoretical understanding and, in turn, to improvements in models and experimental design. This general approach to R&D is appropriate for both nuclear power plants and other types of nuclear facilities, including all aspects related to radioactive waste disposal.

8.2 R&D and its management for nuclear power plants and nuclear facilities: national procedures

Nuclear related R&D is necessary to ensure the safe operation of nuclear power plants and other nuclear facilities during operation, in particular when making decisions related to long-term operation, but also when the remaining lifetime of a plant is limited. In countries where nuclear facilities have long been established, R&D and its management play an important role in development of new designs and in construction and licensing of prototypes of nuclear facilities; it is also crucial in supporting countries that are in the initial stages of using nuclear energy generation. This section describes the national country-specific procedures adopted in Germany, the UK and the USA as well as experiences gathered on the international level, from the European Commission (EC), Organisation for Economic Co-operation and Development (OECD) and the IAEA.

8.2.1 National procedure in Germany

Against the backdrop of the events at Fukushima, the German government decided to phase out nuclear energy for commercial electricity generation. In August 2011 changes were introduced to nuclear energy legislation in the form of the thirteenth amendment to the Atomic Energy Act. Generation of electricity using nuclear energy will cease to be authorized in 2022 at the latest. From the German government's point of view, it has to be ensured that the nuclear power plants currently in operation remain safe and in accordance with the developing state-of-the-art in science and technology for the remainder of their working life. It is important that the nuclear safety research activities undertaken to ensure the safe operation of these plants are independent of any vested interest from industry and other related organizations (Tromm, 2011). Although nuclear power is being phased out in Germany, the state-of-the-art in nuclear science and technology continues to advance on the international level. Germany can therefore play a role in the safety of nuclear facilities worldwide, through ongoing and well-directed co-operation with partners in Europe and beyond.

Nuclear safety research in Germany is funded by different federal ministries:

- The Federal Ministry of Education and Research (BMBF) funds basic research activities; it also supports the work of the Nuclear Technology Competence Association, which was founded in 2000 in order to improve the coordination of R&D activities across Germany in the field of nuclear engineering and to specifically promote young scientists. It has implemented an enhanced exchange of information between research centres, which share results and discuss trends in nuclear engineering. Improvements made by the Association are confirmed by the international reputation of German nuclear safety research institutes, such as the Helmholtz Association.

- The Federal Ministry of Economics and Technology (BMWi) supports further development of methodologies and codes including validation and verification. The results of R&D projects funded by the BMWi are summarized in a report, usually at the end of each five-year period (Competence Pool for Nuclear Technology, 2011).
- The Federal Ministry for Environment, Nature Conservation and Nuclear Safety (BMU) funds projects that ensure that licensing and regulatory oversight activities are performed according to up-to-date scientific and technological principles. The BMU's projects are partially initiated by the Federal Office for Radiation Protection (BfS) as a governmental support organization of the BMU. In that context BfS sets out its own research programme (Bundesamt für Strahlenschutz, 2009).

International co-operation in all three of these research and funding areas is traditionally given high priority in German nuclear safety research. A key feature of all R&D work is close involvement in European and international joint ventures (such as the EURATOM framework programme, IAEA and OECD/NEA activities) and projects, in order to integrate international findings and safety concepts into its own research.

The general and continuing objective in all government-funded nuclear safety research is to contribute to the improvement of safety technology and continue to provide improved knowledge of and procedures for the realistic safety assessment of nuclear facilities. The tasks in the field of nuclear reactor safety research are performed in projects complementing one another within the framework of 'project funding' and 'institutional funding' (BMWi, 2011). The two can be used in combination and complement one another.

Project funding is used to support research projects in companies, research establishments, institutes and universities which run for a limited period of time and have clearly defined investigation objectives. Applicability and marketability are key characteristics of these types of projects; project funding thus usually involves work on reactors that are already in operation. Any innovative concepts, on the other hand, are almost entirely subject to institutional funding, whereby institutions such as (nuclear) research centres receive financial support as their basic funding with no detailed description required of the topics to be researched. Most activities relying on institutional funding are undertaken in the energy division of the Helmholtz Association, which is supported by the BMWi and BMBF. The research institutes of the Helmholtz Association typically examine issues that fall within the category of basic research or which, because of their complexity or need for specific large-scale equipment, can best be handled at large research establishments such as the Karlsruhe Institute for Technology or the Jülich Research Center.

Examples of the type of research activities carried out as part of government-funded projects and by government-funded institutions include experimental or analytic investigations into the behaviour of light-water reactor plants in the case of incidents, the safety of the pressure-retaining boundaries, core melt, the non-destructive, early detection of material damage that is known to be difficult to test, human behaviour related to nuclear safety and the development of methods for probabilistic safety analyses. However, the development of next generation reactor designs will no longer be funded by the German federal government.

Currently, the following issues in the field of nuclear reactor safety research have the highest priority from the German perspective, despite the planned end to commercial nuclear power generation in 2022:

1. Questions concerning the ageing of components and materials, and the consequential reduction of safety margins for components and functions are becoming ever more important as the operation time of the facilities increases.
2. The realistic description of processes in the reactor core and the cooling circuits during incidents and accidents is crucial for accurate safety assessment and for further improvements in precautionary measures. The development of systems engineering and operating procedures, as well as the increasing scope of simulations, pose new challenges.
3. The containment used as the final barrier against the release of radioactive substances into the environment must be assessed to establish its integrity in the face of extremely improbable accident sequences (see Section 8.5 in particular). A realistic assessment requires improvements in the understanding of incident and accident sequences and of the efficiency and reliability of measures to avoid undue containment loads.
4. Probabilistic methods must be further developed to allow improvement of the tools used to identify deficiencies in plant design and operating procedures; current uncertainties in existing assessments must be reduced.
5. Current competence and understanding of nuclear safety issues in Germany should continue to be used in the future with the aim of continuing to raise standards further.
6. Improvement of the safety of nuclear power plants of Russian design is one of the most pressing issues to be addressed in co-operation with Central and Eastern European countries. In this respect, the ageing effect because of neutron embrittlement of the reactor pressure vessel (RPV embrittlement) is of particular significance. Western, and in particular German, support is indispensable because of the outstanding knowledge available in Germany in the field of systems engineering.

The basic principles and areas of principal focus for future funding have been outlined by the German federal government in its sixth Energy Research

Programme, entitled 'Research for an environmentally sound, reliable and affordable energy supply'. It is the result of an extensive consultation process, and was developed on the initiative and under the direction of the BWMi (2011). The programme also involves the BMU and BMBF, as well as the Federal Ministry of Food, Agriculture and Consumer Protection (BMELV). As energy research activities in Germany are becoming increasingly differentiated and specialized, improved co-operation between the ministries involved, and better harmonization of their research efforts, is required. With this in mind, the 'Coordination Platform for Energy Research' will be expanded and reinforced. This is also intended to improve collaboration with the research activities of industry and scientific institutes of the German Länder (federal states), the European Union (see Section 8.4.2), and partner countries in the International Energy Agency (IEA).

Close collaboration between the ministries involved in the programme, based on individual specialized projects, defines the approach that has been adopted for the future funding of energy R&D:

- Project funding by the BMWi in the area of non-nuclear technologies encompasses the entire energy chain. Project funding by the BMWi in the area of nuclear safety and disposal of radioactive waste focuses on maintaining and expanding scientific expertise in relevant fields (see also Section 8.4.1).
- Project funding by the BMU within its UFOPLAN programme for radiation protection issues, safety of nuclear installations and radioactive waste management and disposal topics is significant both in terms of radiation protection and provision of policy guidance.
- The BMBF will continue to fund basic research, such as nuclear fusion research, as well as investigations and research into nuclear safety and into disposal and radiation. This ensures that the necessary skills and knowledge are retained in Germany.

Under the sixth Energy Research Programme, the German federal government has allocated, in total, approximately 3.5 billion euro for funding the research and development of energy technologies between 2011 and 2014 (BMWi, 2011). Of that sum, about 74 million euro will be spent annually for nuclear safety and radioactive waste disposal R&D projects. The biggest share in the funding for nuclear safety and radioactive waste disposal projects has been assigned to the BMWi. In order to facilitate efficient management of R&D in those areas, BMWi uses the services of the Project Management Agency Karlsruhe (PTKA). This agency provides assistance and help in R&D funding and, thus, in implementing and realizing R&D programmes. It is a partner and co-designer in the funding of scientific research and technical development, and prepares, implements and supports funding programmes on behalf of the BMWi and BMBF. As a service provider, the PTKA acts as a contact point and advisor for applicants, and supports and accompanies the beneficiaries in the execution of their R&D projects as well as in the dissemination of research results.

8.2.2 Procedures of the UK Office for Nuclear Regulation

The Office for Nuclear Regulation (ONR) was established as an Agency of the Health and Safety Executive (HSE) on 1 April 2011 in the UK. It sets nuclear safety and security standards at both civil and defence nuclear sites, and is the principal regulator of the safety and security of the nuclear industry in the UK.

The ONR does not undertake its own R&D; instead, contracts are placed with specialist providers, or support is given to R&D undertaken by other organizations, both in the UK and overseas. The ONR commissions research in the following areas:

- Existing nuclear power reactors, including aging and degradation.
- Nuclear chemical plants.
- Nuclear plant decommissioning.

The principal aim of programmes of nuclear safety research supported by the ONR is to obtain increased intelligence on any issues that have the potential to negatively impact the safe operation of nuclear facilities in the UK. They also seek to improve the research efforts undertaken to examine factors such as life ageing and the maintenance of adequate safety cases. Looking specifically at safety cases: the production of these cases is the first step in nuclear safety, and is required to ensure that a nuclear facility can operate safely. Operators must then initiate studies that gather data from the nuclear operating plant and allow the development of mathematical modelling techniques, in order to maintain ongoing validation of the safety cases. This type of research is essential in allowing nuclear facilities to operate safely for the longest period possible.

8.2.3 Procedures of the US Nuclear Regulatory Commission

In the USA several organizations perform nuclear related R&D, with various responsibilities:

- The Office of Nuclear Regulatory Research is part of the US Nuclear Regulatory Commission (NRC). It provides leadership in the field of nuclear R&D; plans, recommends, manages and implements programmes of nuclear regulatory research; and interfaces with all NRC Offices and the Commission on research issues. The Office of Nuclear Regulatory Research develops the technical basis for risk-informed, performance-based regulations in all areas regulated by the NRC and leads the agency's initiative for cooperative research with the US Department of Energy (DOE) and other federal agencies, the domestic nuclear industry, US universities and international partners. It coordinates research activities outside the agency and maintains technical capability to develop information for resolution of nuclear safety and security issues, and provides technical support and consultation to the Program Offices in the specialized disciplines involved in these issues. For example, it plans, develops and manages the agency's fire safety research programs, including fire modelling, fire probabilistic risk analysis methods and fire testing programs, and supports other NRC Offices by developing and validating fire analysis methodologies and supporting data.

- The Office of Nuclear Energy (NE) falls under the control of the DOE. A roadmap for the research, development and demonstration activities of the Office is provided in a report to Congress entitled 'Nuclear energy research and development roadmap' (US Department of Energy, 2010). NE's R&D activities will help address challenges and thereby enable the deployment of new reactor technologies that will support the current fleet of reactors and facilitate the construction of new ones. The main activities are organized along four principal R&D objectives that address challenges to expanding the use of nuclear power: (1) to develop technologies and other solutions that can improve the reliability, sustain the safety, and extend the life of current reactors; (2) to develop improvements in the affordability of new reactors to enable nuclear energy to help meet the Administration's energy security and climate change goals; (3) to develop sustainable nuclear fuel cycles; and (4) understanding and minimization of risks of nuclear proliferation and terrorism.
- The Electric Power Research Institute (EPRI) conducts comprehensive research activities to ensure that nuclear facilities remain a safe option for power generation. Their studies cover issues including material degradation, fuel reliability and long-term operation as well as risk and safety management.

8.3 R&D and its management for nuclear power plants and nuclear facilities: international R&D

Although nuclear R&D projects can be undertaken on a national level, as the examples from Germany, the UK and the USA have shown, larger projects are becoming increasingly difficult in this respect, necessitating further co-operation on the international level in order to solve key generic issues. In particular, larger experimental programmes such as the Halden project in Europe (OECD/NEA, 2012a) which is already performed on a broader international basis, or fire experiments conducted at national laboratories in the US (US Nuclear Regulatory Commission, 2012) may in future require more international support and international resources to achieve the intended goals.

8.3.1 European Commission

The EU's seventh Framework Programme for Research and Technological Development continues the work of previous programmes in encouraging and supporting research in the European Research Area (ERA). Funding for the programme began in 2007, with a budget of approximately 50 billion euro, and will be succeeded in 2014 by the six-year Horizon 2020 project. A recent set of calls for proposals under the framework was the largest ever, providing a significant increase in funding for European research and innovation efforts, with the aim of bridging the gap between the end of a number of major funded projects in 2011 and the start of the Horizon 2020 project. The Framework Programme for Nuclear Research and Training Activities of the European Atomic Energy Community (EURATOM), which is part of this seventh framework, has a maximum of 2751 million euro allocated for the implementation of the framework in the period 2007–2011.

In EURATOM's current programme, there are two specific related programmes: one covers projects in the fields of fusion energy research and nuclear fission and radiation protection, whereas the other involves projects with institutional funding in the nuclear field undertaken by the Commission's Joint Research Centre (JRC). The JRC was initially established by the EURATOM Treaty and has since become a leading institute of nuclear research in Europe.

Nuclear fission projects have in the past been the main focus of research and, indeed, of funding. Some attention is still given to these areas in the current programme, as it seeks to establish a sound scientific and technical basis for safer management of both energy and waste, as well as more resource-efficient, competitive and environmentally friendly strategies. However, a significant part of the 2751 million euro budget is being put towards financing an international nuclear fusion project known as ITER, standing for International Thermonuclear Experimental Reactor. Increased fusion research will be undertaken, focussing on the development of a knowledge base for the ITER project and the completion of the ITER construction phase, which should in turn lead to the development of prototype reactors before the operational phase is launched.

8.3.2 Organisation for Economic Co-operation and Development/Nuclear Energy Agency

The Nuclear Energy Agency (NEA) is a specialised agency within the Organisation for Economic Co-operation and Development (OECD), an intergovernmental organization of industrialized countries, with 30 members. The roles of the NEA are to:

- Provide a forum for in-depth exchanges of technical and programmatic information.
- Stimulate the development of useful information by initiating and carrying out co-operation/research on key problems.
- Develop common positions, including 'consensus opinions', on technical and policy issues.
- Identify areas where further work is needed and ensure that NEA activities respond to real needs.

- Organize joint projects to enable interested countries to carry out research on particular issues on a cost-sharing basis.

Within the NEA, one committee, the Committee on the Safety of Nuclear Installations (CSNI), has the task of assisting member countries in maintaining and further developing the scientific and technical knowledge base required to assess the safety of nuclear reactors and fuel cycle facilities. The clear priority is on existing nuclear installations and the design and construction of new reactors and installations. For the next generation of reactor designs, 'because nuclear safety is essentially science-based' (NEA/CSNI, 2011), CSNI will provide a forum for improving safety related knowledge and 'a vehicle for joint research' where the topics are described in a strategic plan for five years (NEA/CSNI, 2011).

Independently of these activities, several experimental and database projects are being conducted within the OECD. These allow OECD members to actively participate in planning, carrying out the tasks and evaluating the results. Current experimental projects being run by the OECD/NEA are:

- Behaviour of Iodine Project.
- Cabri Water Loop Project.
- Fire Propagation in Elementary, Multi-room Scenarios Project.
- Halden Reactor Project.
- Loss of Forced Cooling Project.
- Primary Coolant Loop Test Facility Project.
- Rig of Safety Assessment Project.
- Sandia Fuel Project.
- Source Term Evaluation and Mitigation Project.
- Steam Explosion Resolution for Nuclear Applications Project.
- Studsvik Cladding Integrity Project.
- Thermal-hydraulics, Hydrogen, Aerosols, Iodine Project.

As an example, the fuels and materials programme that is part of the Halden Reactor Project (McGrath, 2011) is illustrated in Fig. 8.2.

Current event records database projects run by the OECD/NEA are:

- Cable Ageing Data and Knowledge Project.
- Component Operational Experience, Degradation and Ageing Programme.
- Fire Incident Records Exchange Project.
- International Common Cause Failure Data Exchange (ICDE) Project.

The projects aim to reveal crucial information in the field of nuclear safety. For example, the results of the Fire Incident Records Exchange Project have shown that a majority of the fire events resulted from high energy arcing faults (HEAF), which led to a new experimental OECD project using equipment from nuclear power plants (e.g. switchgears) in order to better understand the HEAF phenomena and to find ways to decrease this type of event.

Fuel safety and operational margins

- Studies related to gas release under irradiation
- Thermo-mechanical studies
- Fuel behaviour under accident conditions
- Fuel behaviour under demanding operation conditions
- Innovative fuels and claddings

Plant ageing and degradation

- Irradiation assisted stress corrosion cracking
- Irradiation enhanced creep and stress relaxation
- Pressure vessel integrity study
- Other plant ageing issues

Contribution to Gen IV international research

- Instrument development
- Materials testing

8.2 Fuels and materials programme as part of the OECD Halden Reactor Project (McGrath, 2011).

8.3.3 International Atomic Energy Agency

According to its statute, the IAEA is authorized 'to encourage and assist research on, and development and practical application of, atomic energy for peaceful uses throughout the world' (IAEA, 1956, but subsequently amended). The IAEA therefore allows research contracts and agreements to be drawn up with institutions such as universities and laboratories in member states for subjects directly related to the remit of the IAEA.

These research contracts and agreements are awarded to institutions selected by the IAEA, following the submission of a research proposal. For an application to be successful, a project must show not only technical merit, but also compatibility with the IAEA's own functions and with other programmes it supports. The availability of personnel and facilities in the institution, and the quality of previous research work carried out in the same area, is also taken into account. The IAEA may also invite particular institutions to submit proposals: this happens when the IAEA recognize that a particular research contract, for example, would assist in the development of one of the IAEA's current projects, and have been able to identity institutions that have the necessary facilities and research personnel. In both scenarios, priority will usually be given to proposals received from developing member states.

Most of the research that receives IAEA funding is related to its coordinated research projects (CRPs), which have been developed in line with the overall aims of the IAEA. Where possible, the knowledge obtained through these CRPs is used to improve the quality of projects delivered via the IAEA's Technical Co-operation Programme to its member states. The results of IAEA-supported research and projects appear in the IAEA's scientific and technical publications, and often in other national or international journals, where appropriate; the information and knowledge gained is thus freely available to member states and the international scientific community.

8.3.4 Technology development through international co-operation

Power generation from the fusion process is a major area in which international co-operation can help with efficient technology development. In Germany, fusion research usually only receives institutional funding at national research centres. The research work undertaken is theory-based, using plasma physics, but increasingly also includes technological and engineering studies related to the ITER project discussed in Section 8.3.1, and to a future demonstration power plant project known as DEMO, such as plasma-wall interaction, plasma heating and the development of materials for future fusion reactors. One main goal of this research is the commissioning of the Wendelstein 7X experimental fusion reactor in Greifswald.

As noted above, the EURATOM framework has provided funding for the development of ITER, despite the framework's usual focus on fission projects. This has increased the efficiency of technology developments in this area. The completion of ITER will demonstrate the feasibility of power generation from fusion processes using burning fusion plasma in the 500 MW class for the first time. Although the construction and realization of large-scale fusion experiments are crucial, further steps are also required, which will in turn necessitate international research efforts in the field. These steps include: further developments in plasma modelling and plasma-wall interaction; R&D into the fuel cycle and tritium cycle; and the development of diverters, magnet technology and suitable structural materials for use in a fusion reactor. Fusion experiments are becoming increasingly important – and a major focus of well-funded international research activities – as they come closer to realizing a successful power reactor.

Another relevant topic in this regard, where international co-operation can help in the development of technology, is the use of advanced fuel in operating nuclear power plants. The performance of light water reactor (LWR) fuel under accident conditions is affected by changes in burn up, cladding material and service condition; current safety issues in the use of LWR fuel are mainly concerned with deciding where to establish safety limits in light of these changes in performance.

The most significant advances made by the industry in this area related to improvements in the cladding tube materials and in processing during fabrication. New zirconium alloys containing niobium were introduced, which are more resistant to corrosion. The change in cladding material necessitates a new assessment of the response to accident conditions, a large part of which is dependent on the correlation of data from in-pile and out-of-pile testing. It must be ensured that this database is extended to capture the new materials and the wide range of operational and accident conditions. Model development and validation must also keep up with the new empirical data.

Fuel reliability is critical to the safety viability of a nuclear power plant. Plant owners and operators must weigh the economic benefits of higher fuel burn-up rates against the prospects of fuel failures. The most common causes of fuel failure are grid-to-rod fretting, corrosion and crud, debris, pellet cladding interaction (PCI) and manufacturing defects. The prevention of future failures therefore requires an understanding of the conditions leading to failure, which is in turn dependent on a research programme with a substantial proactive component to establish operating margins under limiting conditions (e.g. changing water chemistry), to ensure that the fuel operates as designed. However, regulatory activities are also relevant in fuel reliability, with assessment of the plant required to ensure that its safety level is not decreasing. International co-operation in the use of LWR fuel, the assessment of fuel performance, prevention of fuel failure and associated regulatory activities, will speed up the research and development process, enabling more efficient use of advanced fuels by keeping or enhancing the safety level.

The development of new technologies, on the national or international level, will become increasingly dependent on the science-based approach as described in Section 8.2, as it allows all potential benefits and limits to be taken into account, both on the industry and regulatory sides.

8.4 R&D and its management for radioactive waste management and disposal

Cradle to grave planning work is essential for radioactive waste management and disposal. Any country's national policy should therefore specify the requirements for managing spent nuclear fuel and radioactive waste as well as initiating plans for delivering timely waste disposal facilities. The government, in partnership with regulators, industry and academia, should develop a long-term R&D roadmap to support the waste management and disposal strategy adopted. This roadmap should include joint studies and participation in relevant international R&D programmes, as well as contingency plans for addressing unforeseen changes in policy by keeping future management options open. The R&D work carried out in Sweden (Wikberg, 2012) and Switzerland (NAGRA, 2009) provides excellent examples of this type of strategy.

The major issues that must be addressed by R&D into radioactive waste disposal are site selection, planning, construction and start-up of a repository for heat-generating waste. A great deal of know-how and technological and scientific expertise has been accumulated in this area over the years, with numerous comprehensive R&D projects carried out, the priorities of which have been dependent on the host rock (e.g. salt, clay, crystalline). This section begins by examining the national procedures in Germany, where there is already a well-advanced understanding of the issues involved in the disposal of heat-generating radioactive waste, thanks to practical experience and skills obtained from salt mining and the disposal of chemotoxic and hazardous wastes in rock salt. However, as further R&D projects continue to contribute to the expansion of scientific and technological know-how, international co-operation and the performance of joint R&D projects will play a very important role

8.4.1 National procedure in Germany

Radioactive waste disposal policy in Germany is based on the federal government decision that all types of radioactive waste with short-lived and long-lived radionuclides are to be disposed of in deep geological formations within the country. Only solid and solidified radioactive waste is accepted for disposal; liquid and gaseous radioactive waste is excluded from disposal except when appropriately conditioned. According to the German approach to disposal, radioactive waste is basically subdivided into waste with negligible heat generation (covering low-level waste (LLW) and intermediate-level waste (ILW)) and heat-generating waste (covering high-level waste (HLW) and spent nuclear fuel (SNF)). LLW and ILW will be disposed of in the Konrad repository, which is currently under construction, whereas a repository site for the disposal of heat-generating and long-lived radioactive waste has not yet been determined. At the time of writing, the German federal government is envisaging a legislative proposal in the near future, and is discussing details of the planned act regarding the search for the required disposal site. Independently of these developments, various R&D projects continue to undertake projects relating to SNF, HLW originating from reprocessing and long-lived radioactive waste.

The Atomic Energy Act makes the federal government responsible for the disposal of radioactive waste, with the BfS (Federal Office for Radiation Protection) as the legally responsible authority. In order to perform its legal task, the BfS, being the applicant in the nuclear licensing procedure for a repository, is entitled to conduct specific R&D work that is specifically required for a repository site. The cost of this type of R&D work is to be reimbursed by the waste generators due to the repository pre-payment ordinance (the polluter pays principle). This type of repository site-specific R&D work has been carried out previously, for example, within the Konrad licensing procedure, encompassing a substantial number of different projects and investigations. The latest R&D projects focus the safety related comparison of potential repository sites, the monitoring of repositories in deep geological formations at the beginning of the post-closure phase, and the further development of waste containers for heat-generating radioactive waste.

The BfS launched a dedicated project in 2006 investigating selection of appropriate repository sites in various host rocks: Comparative Safety Assessments for Repository Systems to Evaluate Methodologies and Instruments (Vergleichende Sicherheitsanalysen für Endlagerstandorte zur Bewertung der Methoden und Instrumentarien), known as the VerSi Project. The objective of this project is to enable a comparison of potential repository sites in different host rocks and to provide appropriate means for selecting a site taking into account safety issues. However, the project is not intended to prove the long-term safety of the sites studied. Instead, the method is focused on long-term safety assessments in the post-operational phase of a repository under given simplifying boundary conditions.

As mentioned in Section 8.2.1, the sixth Energy Research Programme has allocated 74 million euro for nuclear safety and radioactive waste disposal projects, with the PTKA assisting the BMWi and BMBF in the efficient management of R&D and allocation of funding. With regard to waste disposal, it is the Water Technology and Waste Management (PTKA-WTE) division of PTKA that supervises R&D projects on behalf of the BMWi and BMBF. In the field of high-level radioactive waste disposal, projects are funded on the basis of the BMWi programme 'Future Main R&D Activities Related to the Disposal of Radioactive Waste', whereas the topics 'Disposal of Hazardous Waste in Deep Geological Formations' and 'Decommissioning and Dismantling of Nuclear Facilities' fall under the control of the BMBF and have been funded for many years.

According to the latest PTKA-WTE report (PTKA-WTE, 2012), the BMWi and BMBF are funding R&D projects on repository concepts and subareas of repositories (15 proposals), data and instruments ('tool box') for site-specific safety assessments (one proposal) and safeguards (one proposal). All this R&D work is being carried out with particular reference to the identification of a future repository for heat-generating radioactive waste. Basic nuclear chemistry research offers significant progress in elucidating the relevant chemical/geochemical processes as well as in the selective separation of minor actinides (Am, Cm, Np) from nuclear fuel for subsequent transmutation (Geckeis et al., 2012):

- Within the demonstration of long-term safety of a geological repository, it covers credible scenarios in which contact between water and the waste form is assumed. Over the past few years, significant advances have been made in understanding the chemical/geochemical processes involved. Research into the behaviour of spent nuclear fuel has therefore shown that, contrary to earlier assumptions, corrosion of the waste matrix under oxidizing repository conditions can almost be excluded.
- Understanding of the processes of radionuclide retention in the host rock, for example argillaceous rock, has substantially improved. This has led to the development of geochemical models that are able to take into account changes in geochemical conditions and that thus result in less conservative assumptions.

- Even if a partitioning and transmutation process becomes available in the future, a repository would still be required. However, the share of long-lived radiotoxic transuranium elements in the waste to be disposed of could be reduced by several orders of magnitude. Liquid-liquid extraction processes using highly selective extraction ligands are already very advanced.

Alongside the support of these projects the PTKA-WTE contributes to international R&D co-operation in preparing and performing bilateral workshops on salt repository research, design and operation (Steininger, 2010) and other projects in the field of radioactive waste management (see Section 8.4.3).

8.4.2 International R&D activities: collaboration for technology development

It is internationally agreed that deep geological disposal is the most appropriate solution for the safe long-term management of spent nuclear fuel, high-level waste and long-lived radioactive waste. This consensus is based on scientific and technical work that has been carried out over several decades, including extensive research, development and demonstration programmes. In 2006–2007 a representative set of waste management organizations from various European Union member countries and other bodies concerned with the implementation of deep geological disposal carried out a feasibility study called Co-ordination Action on Research, Development and Demonstration Priorities and Strategies for Geological Disposal (known as the CARD project). The project was financially supported by the European Commission and aimed to establish a technology platform for the disposal of radioactive waste in deep geological formations. Based on the discussion following the results of the CARD project, the 'Implementing Geological Disposal – Technology Platform' (IGD-TP) was launched. This platform is the appropriate tool to facilitate the construction and operation of deep geological repositories for spent fuel, high-level waste and other long-lived radioactive waste.

The main objectives of the IGD-TP are to initiate and to carry out the strategic planning and technical co-operation needed to facilitate the stepwise implementation of safe geological disposal of the above-mentioned waste types. A concerted effort is required to address the remaining scientific, technological and socio-political challenges, thereby supporting the waste management programmes adopted by the member states of the European Union. The platform will further enhance societal confidence in geological disposal, reduce duplication of work, enable savings in the total cost of research and implementation, and make better use of existing competences and research infrastructures. The Strategic Research Agenda (SRA) 2011 has been published, and the IGD-TP's Deployment Plan (DP) is in public consultation at the time of writing. The Vision Report provides information on the benefits of joining the IGD-TP and on how to participate in the work.

Finally it should be noted that the European Commission does not own or manage European Technology Platforms such as the IGD-TP, which are independent organizations. The European Commission did, however, support their creation and remains engaged with them in structural dialogue on research issues.

Today, technological developments in nuclear R&D, including those related to waste disposal, must increasingly be evaluated from a global perspective. With this in mind, the German federal government believes that a broad approach to funding R&D projects is appropriate and useful and is consequently seeking to extend international collaboration. In the field of radioactive waste disposal, the Federal Institute for Geosciences and Natural Resources (BGR) is involved in various research projects that are being carried out in foreign underground research laboratories (URL). In Europe, these laboratories are operated in Belgium (Hades facility in Boom clay), France (Bure facility in clay), Sweden (Äspö hard rock laboratory) and Switzerland (Grimsel test site in hard rock and Mont Terri laboratory in Opalinus clay). In addition, the Onkalo URL in hard rock is currently under construction in Finland.

The PTKA-WTE, in addition to its tasks discussed in Section 8.4.1, operates as the German National Contact Point within the EU's seventh Framework Programme for Research and Technological Development, in the thematic area '6.1. Environmental (incl. climate change) – water management, water, soil, waste management, water technologies' and within the Specific Programme EURATOM for Nuclear Research and Training Activities in the thematic area 'Management of radioactive waste'. Successful international collaboration in this project is vital for productive technological developments in the field of radioactive waste disposal.

The NEA (see Section 8.3.2) works in the areas of radioactive waste management and radiological protection, among others. Unlike the EU, the NEA does not fund R&D projects but instead launches projects using NEA working groups to carry out and prepare final reports. The OECD/NEA reports on the roles of long-lived radioactive waste storage (OECD/NEA, 2006), and reversibility and retrievability of radioactive waste (OECD/NEA, 2012c) are particularly useful examples of the organization's work.

As mentioned in Section 8.3.3, most of the research supported by the IAEA is related to its CRPs. For radioactive waste management and disposal, the IAEA invites contractors to contribute to the relevant CRPs, such as the successful project on the Disposal Aspects of Low and Intermediate Level Decommissioning Waste (IAEA, 2007). The project was conducted in recognition of the growing importance of the topic of decommissioning and dismantling of nuclear facilities in many IAEA member states. International co-operation in this project allowed a better understanding of decommissioning and dismantling waste, its behaviour and its influence on the design and performance of appropriate disposal facilities or repositories.

8.5 Challenges and lessons learned

In the field of nuclear safety R&D, perhaps the most significant recent example of the challenges faced by nuclear facilities is represented by the accident at Fukushima in March 2011; several lessons can also be learnt from the events at the Fukushima plant in an attempt to avoid similar occurrences in the future.

It was already well known that deterministic and probabilistic seismic safety assessments are an essential part of the safety review of nuclear power plants worldwide, because at locations with a non-negligible seismic hazard (such as at Fukushima), earthquakes can contribute significantly to the overall core damage frequency. In light of the Fukushima accident, several aspects will have to be considered in more detail in future at nuclear power plants worldwide:

- Possibility of secondary damage with regard to the event sequence (earthquake, fire or tsunami).
- Superposition of independent events even if the probability of occurrence appears low.
- Design of nuclear power plants to withstand earthquakes or flooding including tsunamis (how conservative should the assumptions be?).
- Probability of aftershocks days or even weeks after the main earthquake.
- Potential impact of the same external hazard(s) on multiple units.
- Impact of an event affecting one power plant unit on any neighbouring unit(s).

In part, this requires new R&D work to be undertaken, in particular to improve the probabilistic risk assessment tools so that they cover a broader set of independent initiators with the potential to lead to a safety significant event. Design improvements are also critical, not only when designing new reactors, but also for nuclear power plants that are already in operation or under construction. Moreover, accurate collection of the data needed in order to perform realistic safety assessments is essential. Researchers must adequately educate users in the correct application of any new or enhanced tools or codes that are developed; in addition, the nuclear community on the international level (e.g. via IAEA) has to provide clear boundary conditions in order to avoid a large spectrum of results depending on the choice of input data. Otherwise, the intended goal of establishing common quantitative safety goals for nuclear power plants might even become counterproductive.

One major lesson learnt from the accident in Fukushima is that new research results (in this case relating to the underlying causes of the earthquakes in the region) must be taken into account, and not disregarded because they may entail comprehensive correction measures to enhance plant safety. When new research of this type is not taken into consideration, as in the case of the Fukushima plant, any safety assessment is unreliable and the results may suggest an unrealistically high safety level.

8.6 Future trends

8.6.1 Nuclear R&D strategies and funding

A clear and coordinated strategy for nuclear R&D must be developed, both on the country-specific level and internationally, in order to identify the most important topics for further research, as well as to expand the activities carried out in certain countries and to establish international co-operation with fixed boundary conditions.

With regard to developments in the funding of nuclear R&D in Germany, eight large German industrial companies, along with universities and research centres, joined the Nuclear Technology Competence Association in Germany with the aim of strengthening their co-operation in common research projects, thereby sharing and maintaining knowledge and competence. This approach was initiated by the German Academy of Engineering Sciences (acatech) to draw attention to the need to maintain and advance nuclear competence despite the decision to phase out the use of nuclear power. In light of the recommendations expressed by acatech, the heads of R&D in the eight companies involved agreed on key topics for future nuclear research as perceived by industry under the auspices of the energy change. The representatives of industry and public nuclear research then used a scored matrix to identify and rank 143 research topics of mutual interest that could be eligible to receive grants from the federal government within the framework of existing research programmes (Haspel et al., 2012). The topics that emerged with the highest priority were those related to the mitigation of severe accidents. The execution of these research projects is intended to maintain and further develop nuclear competence in the industry as well as in research and teaching.

In general, this type of integrated approach should be supported; however, nuclear R&D funding should not be considered as simply a task to be undertaken by the government, but as a significant area of interest for the industry. In most countries, there is a significant decrease in industry responsibility for funding R&D, with a narrow focus on the short-term requirement of skills and competences in critical areas such as safety and radioactive waste management. Strategic planning was judged to be necessary to accommodate longer-term needs such as the development of innovative reactor systems, which could only be achieved in the absence of commercial pressures. A mix of industry and public funding was considered appropriate to support endeavours in this area, as both sectors would benefit from the results. International organizations have been urged to initiate activities to draw up good practice guidelines and to develop methodology, guidance and tools relating to various aspects of nuclear knowledge management, nuclear information management and human resource management.

One example of this type of activity is the Multinational Design Evaluation Programme (MDEP), which is a multinational initiative undertaken by national safety authorities. Its aim is to develop innovative approaches to leveraging the resources and knowledge of the national regulatory authorities who are currently or who will in the future be tasked with reviewing new reactor power plant designs (OECD/NEA, 2012b).

The MDEP programme incorporates a broad range of activities including:

- Enhanced multilateral co-operation within existing regulatory frameworks.
- Multinational convergence of codes, standards and safety goals.
- Implementation of MDEP products to facilitate licensing of new reactors, including those being developed by the Generation IV International Forum.

8.6.2 Radioactive waste disposal

Future trends in radioactive waste disposal will increasingly be related to the chemical composition of the waste to be disposed of. The safety of a repository – whether this is a near-surface facility or a disposal mine in a deep geological formation – is generally demonstrated by performing a site-specific safety assessment that examines normal operation, any incidents that may occur and non-excludable releases of radionuclides in the post-closure phase, among other factors. This type of safety assessment commonly addresses radiological aspects and, depending on the site-specific circumstances, looks specifically at the level of radiation exposure experienced by site staff and the wider environment, and ways of limiting that exposure.

The waste to be disposed of is mainly in the form of non-radioactive organic and inorganic substances including, for example, chemotoxic constituents such as cadmium, lead or mercury. The chemical composition of these substances is significant in the context of groundwater pollution; the chemical composition of the radioactive waste, the immobilization material (if used) and the waste containers/packaging should therefore also be carefully examined. In the past, insufficient attention was paid to the harmful constituents of waste and to their possible impact on human health and the environment. These issues are particularly significant in the long-term management of uranium mill tailings and tails originating from uranium enrichment plants.

Regulations regarding non-radioactive substances and their assessment in radioactive waste disposal are rather limited, as is the extent of experience in this area. Existing regulations on the protection of near-surface groundwater, for example European Communities' Council Directive 80/68/EEC, do not relate to nuclear waste but may be applied in this field in the absence of specific radioactive waste disposal related regulations. Only a small number of repositories or repository projects in France, Germany, Switzerland and the UK are able to offer any experience regarding the characterization of waste packages, for instance regarding certain harmful substances.

In the UK, comprehensive and detailed investigations were carried out for the Low Level Waste Repository (LLW Repository Ltd, 2011). In Germany, as part of the licensing requirements for the Konrad repository, the post-closure pollution of the near-surface groundwater by non-radioactive organic and inorganic waste package constituents was investigated and evaluated (Brennecke et al., 2010). In addition, R&D work has been initiated at the Jülich Research Center with the aim of developing spectroscopy-based measurement techniques and investigation technologies for the non-destructive detection of certain chemotoxic substances in radioactive waste packages. This initiative is in line with the need to develop better methods for integrating the characterization of radiological and hazardous contamination (such as polychlorinated biphenyls (PCB), which are widely used in decontamination coatings, and asbestos) in the process of decommissioning/ dismantling waste, and with the demand to decrease the costs of characterization by using innovative measurement and data evaluation techniques (OECD/NEA, 2012d). The results of the study may turn out to be important in particular for legacy waste that has either limited documentation or none at all.

8.7 Sources of further information

European Commission, http://ec.europa.eu/energy/nuclear/research.

European Union – Implementing Geological Disposal of Radioactive Waste, www.igdtp.eu.

International Atomic Energy Agency, www-crp.iaea.org.

Office for Nuclear Regulation: Nuclear research index (safety of operating reactors), www.hse.gov.uk/nuclear.

Roulstone T (2010), Nuclear energy R&D – a view from industry, January 2010.

8.8 References

Brennecke P, Kugel K, Steyer S, Boetsch W, Gründler D and Haider C (2010) ‘Implementation of Requirements on Non-Radioactive Waste Package Constituents’, in Proceedings WM 2010 Improving the Future by Dealing with the Past, Phoenix, WM Symposia, paper 10449.

Bundesministerium für Wirtschaft und Technologie – BMWi (2011), Research for an environmentally sound, reliable and affordable energy supply – 6th Energy Research Programme of the Federal Government, BMWi, Berlin, November 2011.

Bundesamt für Strahlenschutz – BfS (2009), Forschungsprogramm des Bundesamtes für Strahlen-schutz, Zeitraum 2009–2013, BfS, Salzgitter, 2009.

Competence Pool for Nuclear Technology (2011), Topics of nuclear safety and repository research in Germany, 2007–2011.

Geckeis H, Kienzler B and Gompper K (2012), Nuklearchemische Grundlagenforschung: Baustein für eine sichere Entsorgung radioaktiver Abfälle, *atw-International Journal for Nuclear Power* vol 57, no 7, pp 457–466.

Haspel N, Fuchs M, Kleen U, Nießen St, Steinwarz W and Wimmer H (2012), Kompetenzerhaltung in der Kerntechnik – Forschungsbedarf aus Sicht der Industrie, *atw-International Journal for Nuclear Power* vol 57, no 8/9, pp 520–523.

International Atomic Energy Agency (2007), Disposal Aspects of Low and Intermediate Level Decommissioning Waste, IAEA-TECDOC–1572, IAEA, Vienna, December 2007.

International Atomic Energy Agency (2008), Knowledge management for nuclear research and development organizations, IAEA-TECDOC–1675, IAEA, Vienna, May 2008.

International Atomic Energy Agency (1956, but subsequently amended) Statute of the International Atomic Energy Agency, available at http://www.iaea.org/About/statute.html.

LLW Repository Ltd (2011), The 2011 Environmental Safety Case – Assessment of Non-Radiological Impacts, Report LLWR/ESC/R(11)10029, LLW Repository Limited, Holmrook, May 2011.

McGrath M (2011), Introduction to IFE and the OECD NEA Halden Reactor Project, Nordic Nuclear Materials Forum for Generation IV – NOMAGE 4, Halden, Norway, October 30–November 01, 2011.

NAGRA (2009), The NAGRA Research, Development and Demonstration (RD&D) Plan for the Disposal of Radioactive Waste in Switzerland, Technical Report 09-06, NAGRA, Wettingen, November 2009.

Nuclear Energy Agency/CSNI (2011), Joint CSNI/CNRA strategic plan and mandates, NEA/CSNI/R(2011)1, 17 February 2011.

OECD/Nuclear Energy Agency (2006), The Roles of Storage in the Management of Long-Lived Radioactive Waste, NEA No. 6043, OECD, Paris 2006.

OECD/Nuclear Energy Agency (2012a), Main benefits from 30 years of joint projects in nuclear safety, NEA No. 7073, OECD, Paris 2012.

OECD/Nuclear Energy Agency (2012b), Multinational design evaluation programme, annual report, March 2011–March 2012, OECD, Paris, June 2012.

OECD/Nuclear Energy Agency (2012c), Reversibility of Decisions and Retrievability of Radioactive Waste, NEA No. 7085, OECD, Paris 2012.

OECD/Nuclear Energy Agency (2012d), Radiological characterisation for decommissioning, NEA News No. 30.1, OECD, Paris 2012.

Projektträger Karlsruhe Wassertechnologie und Entsorgung – PTKA-WTE (2012), BMBF und BMWi geförderte FuE zu "Entsorgung gefährlicher Abfälle in tiefen geologischen Formationen', Berichtszeitraum: 1. Januar–30. Juni 2012, interner Bericht PTE Nr. 43, PTKA, Karlsruhe, August 2012.

Steininger W (ed.) (2010), US-German Workshop on Salt Repository Research, Design, and Operation, KIT Scientific Reports 7569 – Projektträger Karlsruhe (PTKA-WTE)-Wissenschaftliche Berichte 12, KIT, Karlsruhe, 2010.

Tromm W (2011), Nukleare Energieforschung 2011: Forschungszentren – Status und Entwicklung, *atw-International Journal for Nuclear Power* vol 57, no 6, pp 410–416.

US Department of Energy (2010), Nuclear energy research and development roadmap, Report to Congress, April 2010.

US Nuclear Regulatory Commission (2012), Direct current electrical shorting in response to exposure fire (DESIREE-FIRE). Test results, NUREG/CR–7011 and SAND2012–0323P, April 2012.

Wikberg P (2012), The outcome of scientific research and its implementation in the Swedish nuclear waste disposal programme, *atw-International Journal for Nuclear Power* vol 57, no 2, pp. 102–105.

9
Managing radioactive waste

L. NOYNAERT, SCK•CEN, Belgium

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Abstract: This chapter presents the principles of waste and spent fuel management. It stresses the importance of a suitable waste management plan for each facility where wastes are generated. Based on the different waste streams identified, quantified and characterized, the chapter outlines methods to design and select appropriate facilities and treatment and conditioning techniques for sound management of waste materials. Potential treatment and conditioning techniques are briefly presented, with special attention to techniques which minimize the amount of radioactive waste. Reuse and recycling techniques for metal and concrete are covered. Different management options are also described and discussed, and some examples from the Belgian case are presented.

Key words: waste management, spent fuel, decontamination, recycling, reuse, waste minimization.

9.1 Introduction

General principles for managing radioactive waste in a safe manner were set out by the IAEA in a Safety Fundamentals publication (IAEA, 1995a):

- Protection of human health: ‘Radioactive waste shall be managed in such a way as to secure an acceptable level of protection for human health’.
- Protection of the environment: ‘Radioactive waste shall be managed in such a way as to provide an acceptable level of protection of the environment’.
- Protection beyond national borders: ‘Radioactive waste shall be managed in such a way as to assure that possible effects on human health and the environment beyond national borders will be taken into account’.
- Protection of future generations: ‘Radioactive waste shall be managed in such a way that predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today’.
- Burdens on future generations: ‘Radioactive waste shall be managed in such a way that will not impose undue burdens on future generations’.
- National legal framework: ‘Radioactive waste shall be managed within an appropriate national legal framework including clear allocation of responsibilities and provision for independent regulatory functions’.
- Control of radioactive waste generation: ‘Generation of radioactive waste shall be kept to the minimum practicable’.

- Radioactive waste generation and management interdependencies: ‘Interdependencies among all steps in radioactive waste generation and management shall be appropriately taken into account’.
- Safety of facilities: ‘The safety of facilities for radioactive waste management shall be appropriately assured during their lifetime’.

Sound management of radioactive waste and materials starts by applying the radiation protection principle of justification, that is ensuring no unnecessary use of radioactive substances. When building a nuclear facility is justified, its design must allow for minimization of the radioactive materials and wastes generated during its operation and decommissioning periods. Consideration should be taken of:

- Choice of materials for components, to avoid or at least limit their activation and to allow their reuse or recycling after appropriate treatments, for example decontamination, melting.
- Improvement in operating practices (limitation of operational waste, adequate sorting of the waste, etc.).

The cost related to management of radioactive materials, waste and spent fuel is a strong incentive for minimization of the radioactive waste. This minimization can only be effective through implementation of a waste minimization culture at all nuclear plants and all installations using radioisotopes.

Stakeholders such as the public are becoming more and more involved in the decision process related to construction, extension of the lifetime or the decommissioning strategy of a nuclear facility (e.g. nuclear power plant, waste repository). Therefore, it is important that objective information, including sound justification, is available to all stakeholders.

9.2 Management of radioactive waste materials by small-scale users

Hospitals, laboratories and industries generate small quantities of radioactive waste. The wastes mainly contain short-lived radionuclides, except wastes containing ^{14}C and ^{36}Cl and spent sealed sources. There is also secondary waste generated by handling of these materials in laboratories and hospitals. Wastes should be characterized, collected and segregated as much as possible at the point of origin according to their physical, chemical, special hazard and radiological properties. This segregation will facilitate their treatment and conditioning.

In the case of wastes containing a limited activity of short-lived radionuclides (e.g. half-life shorter than 100 days), the strategy generally applied is to organize decay storage at the site of production followed by clearance of the waste and a discharge. Other wastes will be stored until transport to a centralized off-site facility can be organized. If this kind of facility does not exist, then the waste must be stored until a treatment/conditioning campaign can be organized on-site using mobile equipment. Spent sealed sources may be returned to the supplier if this is covered in an agreement or by legislation.

9.3 Management of radioactive waste materials by large-scale users

9.3.1 Waste Management Plan

Management of radioactive waste starts during the initial design of a facility and ends after decommissioning with the final release of the facility by the safety authority. In the framework of the licensing process of a new facility or of its refurbishment/uprate or decommissioning, a Waste Management Plan must be set up. The main objective is to demonstrate that radioactive waste shall be managed in order to meet basic safety requirements of protection of workers, population and environment, and of protection of future generations against any undue burden. Radioactive waste should also be managed within the national legal framework, and with respect to international standards and recommendations.

Therefore, good design and sound management are required when the facility is operated/decommissioned to ensure that all releases into the environment are within regulatory legal limits. Waste handling, treatment and disposal also must follow good practice to avoid undue radiological exposure of employees, the public and the environment.

Minimization of generation of waste, and in particular of radioactive waste, requires taking all opportunities to prevent, minimize, recycle and reuse waste before disposal. The Waste Management Plan will also address the practical organization inside the licensee company to ensure that interfaces for waste management (i.e. safety authority, radioactive waste agency, external treatment/conditioning facilities, etc.) are clearly defined and understood by management and staff, and that training and awareness on waste management is carried out for all employees. Management of radioactive waste involves many processes including: waste characterization, identification, treatment and conditioning, packaging, transport, storage and disposal.

There is a great diversity of radioactive waste, differing in physical, chemical and radiological characteristics. From a management point of view, it is advantageous to classify the waste into categories based on any handling and transport issues and the disposal options. Six classes of waste have been derived based on the lifetime of the radionuclides, their radioactivity level requiring possible use of shielding and the heat emitted by some waste. The definitions are (IAEA, 2009):

- *Exempt waste.* Waste that meets the criteria for clearance, exemption or exclusion from regulatory control for radiation protection purposes.

- *Very short-lived waste (VSLW).* Waste that can be stored for decay over a limited period of up to a few years and subsequently cleared from regulatory control according to arrangements approved by the regulatory body, for uncontrolled disposal, use or discharge. This class includes waste containing primarily radionuclides with very short half-lives often used for research and medical purposes.
- *Very low-level waste (VLLW).* Waste that does not meet the criteria of VSLW, but that does not need a high level of containment and isolation and, therefore, is suitable for disposal in near surface landfill type facilities with limited regulatory control. Such landfill type facilities may also contain other hazardous waste. Typical waste in this class includes soil and rubble with low levels of activity concentration. Concentrations of longer-lived radionuclides in VLLW are generally very limited.
- *Low-level waste (LLW).* Waste that is above clearance levels, but with limited amounts of long-lived radionuclides. Such waste requires robust isolation and containment for periods of up to a few hundred years and is suitable for disposal in engineered near surface facilities. This class covers a very broad range of waste. LLW may include short-lived radionuclides at higher levels of activity concentration, and also long-lived radionuclides, but only at relatively low levels of activity concentration.
- *Intermediate-level waste (ILW).* Waste that, because of its content, particularly of long-lived radionuclides, requires a greater degree of containment and isolation than that provided by near surface disposal. However, ILW needs no provision, or only limited provision, for heat dissipation during its storage and disposal. ILW may contain long-lived radionuclides, in particular, alpha emitting radionuclides that will not decay to a level of activity concentration acceptable for near surface disposal during the time for which institutional controls can be relied upon. Therefore, waste in this class requires disposal at greater depths, of the order of tens of metres to a few hundred metres.
- *High-level waste (HLW).* Waste with levels of activity concentration high enough to generate significant quantities of heat by the radioactive decay process or waste with large amounts of long-lived radionuclides that need to be considered in the design of a disposal facility for such waste. Disposal in deep, stable geological formations usually several hundred metres or more below the surface is the generally recognized option for disposal of HLW.

Note that radioactive waste classification in the USA differs somewhat from the IAEA and the waste is classified into Classes A, B, C, Greater Than Class C (GTCC) and HLW. The classification is based on 10 CFR Part 61. The GTCC waste is not suitable for shallow land facilities and requires greater confinement and eventual disposal at greater depth.

Between its generation and its disposal the waste will undergo different processes in order to minimize the volume to be disposed of and to secure the safety of the repository. These processes may lead to concentration of the radioactivity into a smaller volume of waste. This waste may belong to a higher class than the waste prior to any treatment.

Besides the waste classes, another useful concept in the management of waste is the concept of waste streams. A waste stream groups waste with similar physical, chemical, biological and radiological properties so that the waste can undergo the same treatment and conditioning and can be characterized and disposed of in a similar way. In order to identify waste streams inside a nuclear facility, information on wastes is required regarding:

- Origin.
- Physical properties: physical state (solid, liquid or gaseous), size and weight, compactibility, dispersibility, volatility, miscibility, free liquid content.
- Chemical properties: chemical composition, solubility and chelating agents, potential chemical hazard, corrosion resistance/corrosiveness, organic content, combustibility and flammability, chemical reactivity and swelling potential, gas generation.
- Biological properties: potential biological hazards, bio-accumulation.
- Radiological properties: inventory of radionuclides (activity concentration, decay products and half-lives), dose-rate, heat generation, radioactive gas.
- Criticality: nuclear and fissile material inventory.

For each identified waste stream, a forecast is made of the total amount and annual throughput from generation. This allows for appropriate dimensions of treatment/conditioning facilities, storage and disposal capacities.

The Waste Management Plan details procedures for sorting, handling, treating, conditioning, packaging, transport and storage for each waste stream. The Waste Management Plan also provides information about the disposal routes. Waste streams for which treatment/conditioning facilities and/or disposal routes do not yet exist, become part of a R&D plan. This R&D plan is established to demonstrate feasibility of the management of these specific waste streams within a realistic period of time.

9.3.2 Overview of treatment and conditioning techniques

Treatment and the conditioning of material/waste is a technical step required to meet the acceptance criteria of a selected management route, that is recycling, reuse, clearance or waste disposal. These techniques are also used for safe handling, transportation, storage and/or disposal. Treatment and conditioning techniques for reuse, recycling or clearance of material are discussed in Section 9.5. The treatment techniques discussed below concern aqueous and organic liquid waste, burnable and compactable solid waste and spent ion exchange resins, sludges and evaporator concentrates. Attention is also paid to issues related to pathogenic and putrefiable waste, and to toxic and/or hazardous waste.

Pre-treatment stages may be required before some processes to avoid the presence of free liquid, enclosed gas or pyrophoric or explosive materials. In the case of irradiated graphite, release of stored Wigner energy may be required before any further treatment (IAEA, 2006a).

Liquid waste may contain both suspended and dissolved contaminants. These must be removed by appropriate treatment in order to reuse or recycle the liquid waste. The removal of suspended contaminants can best occur using well-known techniques of sedimentation, filtration or centrifugation based on hydrocyclone technology. For the removal of dissolved contaminants, techniques such as chemical precipitation, ion exchange resin, evaporation and carbon adsorption can be used. Chemical precipitation is a multistep process involving addition of reagents, pH adjustment, flocculation, sedimentation and finally separation between the solid phase and the liquid phase. The ion exchange/sorption process involves exchange of undesirable ions in a liquid waste with ions in a solid material (i.e. resin). When the resin becomes saturated it must be regenerated or discharged and treated as radioactive waste. Regeneration of the resin involves strong acids or bases leading to generation of radioactive liquid waste having a high salt and activity content (IAEA, 2001).

Organic liquid waste such as oils, scintillation fluids, solvents, etc., is generated by production and use of radioisotopes, and may present chemical or biological hazards. Its removal or destruction requires application of specific treatments. If the waste is burnable, incineration can be applied. Attention must be paid to formation of acid gases, which are corrosive under some conditions, and to capture of some volatile radionuclides. Other usual treatments of organic liquid waste are the pyrrolysis process which converts organic material like radioactive resins and reprocessing solvent into an inorganic residue, the wet oxidation process using hydrogen peroxide in the presence of a catalyst at 100°C and electrochemical oxidation using Ag(II) in a nitric acid solution (IAEA, 2001, 2006b).

Oils based on polychlorinated biphenyls (PCBs) are carcinogenic. The destruction of PCBs requires an appropriate incinerator. When an appropriate incinerator is not available, then PCB-containing oils must be embedded in an inert matrix (IAEA, 2006b).

Some reactors use as coolant sodium (Na) or sodium potassium alloy (NaK) or mercury (Hg). Na and NaK alloys are hazardous materials. They are very reactive (risk of fire/explosion). Therefore they must be stored and treated in an inert atmosphere. A common practice for NaK is to dilute it into a quantity of Na. The processes for bulk Na treatment are the NOAH and Argonne processes. The NOAH process is based on injection of small amounts of liquid sodium into a large flow of aqueous sodium hydroxide. The Argonne process is based on a two stage process involving a sodium hydroxide forming step and a carbonate forming step. For the treatment of pieces contaminated with Na residues, the water vapour nitrogen (WVN) process is usually used. This process is based on circulation of a nitrogen carrier gas containing a small proportion of water vapour (1–6 vol.%) (IAEA, 2006b).

Mercury is a toxic material. Contaminated mercury can be distilled to separate the contaminants from the mercury. However, distillation treatment cannot be applied to activated mercury because of its content in mercury isotopes. Therefore, activated mercury must be immobilized. Technologies for immobilization of mercury exist but have not yet been demonstrated on an industrial scale (IAEA, 2006b).

Burnable solid waste is best treated using an incineration process. Incineration techniques allow achievement of a high volume reduction factor and conversion of the waste into a stable form. Incineration is particularly recommended to treat putrefiable or pathogenic waste and organic waste. When biohazardous waste cannot be incinerated, it is necessary to deactivate the waste from all infectious agents using sterilization of irradiation processes (IAEA, 2001).

The usual approach for treatment of non-burnable waste is to reduce the volume by using hydraulic or pneumatic presses. There are two main categories: in-drum compaction and drum compaction. In the first category, the waste inside the drum is compacted, whereas in the second category, it is the drum containing the waste which is compacted. The pellets obtained are packaged into another package before disposal. In the case of low-level radioactive toxic waste generated in the medical sector, vacuum compaction technology is particularly recommended. This consists of packaging, creating a vacuum and sealing the waste in highly resistant plastic bags. The volume reduction depends on the waste material. Typical volume reduction factors for drum-compaction are 1 and 2 for rubble, 3 for thin scrap metal pieces and 10 for rubber. Metallic waste that cannot be recycled or reused can be melted in a resistance or plasma furnace instead. A volume reduction factor of 10 can be achieved by melting. The ingots produced may have the geometry of a final package ready for disposal.

Toxic solid materials like beryllium and cadmium are usually immobilized into their final packages without any fragmentation or compaction, to avoid the spread of toxic particles.

After treatment, liquid and solid wastes are immobilized into a solid form that can be managed and disposed of more safely. The immobilization requires the use of an appropriate package. The objective of the conditioning process is to immobilize and confine the waste. Some pre-treatment steps are generally required. These pre-treatment steps involve, for example, blending of different liquid waste streams (e.g. ion exchange resins, concentrates, etc.) and pH adjustment (pH=7). The conditioning matrix materials generally used are hydraulic cement, bitumen, polymers and glass. The selection of a conditioning matrix is mainly based on compatibility between the matrix and the waste, the impermeability and the mechanical resistance of the waste form and the retention capacity of the radionuclides. Technological waste, slib, evaporator concentrates (nitrates and borates) and ion exchange resins can be conditioned using hydraulic cement. In some cases, chemical pre-treatment is required. Also, the composition of the hydraulic cement has to be adapted. Adjuvants can also be used to avoid some reactions or to enhance the properties of the final form. Bitumen is usually the matrix for conditioning of evaporator concentrates, slib of chemical precipitation and ion exchange resins (IAEA, 2001). The use of polymers is rather limited to specific cases where difficulties are expected using cement or bitumen. Vitrification is generally used for conditioning of high-level waste generated by reprocessing of spent fuel.

9.3.3 Quality assurance and waste tracking system

Quality assurance is an essential aspect for management of radioactive waste. The quality assurance programme provides confidence that, at the least, each step in the waste management process (i.e. generation, characterization, treatment, conditioning and packaging and storage) meets the legislation and recommendations for protection of workers, population and environment, and in particular that the waste meets the acceptance criteria for transportation, storage and disposal. It also requires use of a comprehensive system for record keeping. A detailed record of an individual waste package includes the time and the location of its production, its full characterization (including physical and chemical properties and hazards) and details about each treatment and conditioning step up to its storage and disposal. The record keeping also provides a link to procedures, calibration reports, etc.

9.4 Spent fuel management and storage issues

9.4.1 Back-end options

The proper management of spent fuel arising from nuclear power production is a key issue for sustainable development of nuclear energy. Two options are generally considered: the closed fuel cycle and the once through fuel cycle.

In the closed fuel cycle, the spent fuel is, after a few years of cooling in the pool of the facility, transported to a reprocessing facility where the fissile material (e.g. uranium and plutonium) is separated from the fission products and other actinides. The recovered fissile material is recycled as uranium/plutonium mixed oxide (MOX) in thermal reactors in some countries as a result of lengthy delays in breeder reactor deployment. The fission products and the remaining actinides are solidified and encapsulated. This waste is transported back to the country of the producer and stored in a dedicated storage building or in storage casks awaiting availability of final disposal. In the once through fuel cycle, the spent fuel is disposed of in the geological repository without any recovery of valuable fissile material. Prior to disposal, the spent fuel must be suitably conditioned and packaged to meet the acceptance criteria of the geological repository (I Mech E, 1996).

The reprocessing of spent fuel allows gain of some 25% more energy from the original uranium, to reduce the volume of the material to be disposed of as high-level waste to about one-fifth and to decrease to a significant amount the level of radioactivity to be disposed of. In addition, after about 100 years, the level of radioactivity of the high-level waste falls much more rapidly than in spent fuel itself. High-level waste produced by reprocessing also emits less heat than the equivalent spent fuel. In a geological repository, strict temperature criteria must be met (e.g. maximum temperature in the waste forms, in the engineered barriers, in the geological layer and in the aquifer). Therefore, the duration of storage prior to disposal is shorter and the total length of galleries to be dug is less in the case of high-level waste disposal than in spent fuel disposal. From an economic point of view, studies reported no significant cost difference between the two options of fuel cycling. For the time being, the ultimate costs of encapsulation and disposal have a large degree of uncertainty attached to them as there is not yet a return of experience (IAEA, 2008a). For the time being, the political and public perception is no more in favour of reprocessing. The main reason is fear of proliferation and concerns regarding transport of radioactive waste and spent fuel.

In the first decades of nuclear energy, the closed fuel cycle by reprocessing of spent fuel had been considered the reference strategy for the back-end of the fuel cycle. The reference scenario was based on the assumption that the nuclear energy sector would grow exponentially. However, the lengthy delays in breeder reactor deployment and change in political and public opinion that have become unfavourable have led an increasing number of countries to abandon the closed cycle option. They have turned instead to the once through cycle. Based on a 2008 report from IAEA, it is estimated that by the end of the year 2010, 339 000 MHTM will have been discharged worldwide from nuclear power stations of which roughly 100 000 MHTM are reprocessed and the remaining 239 000 MHTM are stored awaiting direct disposal (IAEA, 2008a). The delays in commissioning of geological repositories for high-level waste disposal in the case of the reprocessing option or for spent fuel disposal led to construction of storage facilities at or away from the nuclear site.

The selection of an option for spent fuel management is a complex decision process strongly linked with the national legal and regulatory framework, safety and technical issues, economic considerations, environmental protection aspects and, last but not least, political and public perception. These are highlighted in three specific cases from the management of spent fuel from three research reactors in Belgium.

9.4.2 Specific issues for spent fuel from research reactors and/or laboratories in Belgium

In 1993 Belgium put a moratorium on the reprocessing of spent fuel from nuclear power plants. The specific case of spent fuel from research reactors was not addressed in the national policy.

BR2

The high flux materials testing reactor BR2 started operation in 1963 (neutron flux up to 1015 n/cm^2.s). It provides neutron irradiations both for industrial R&D (i.e. fission and fusion reactor fuel and materials research on performance, reliability and safety issues) and industrial production (i.e. radioisotopes and Si doping). The driver fuel of BR2 is highly enriched uranium (93% ^{235}U). A standard fuel element consists of up to six concentric rings of uranium-aluminium alloy sandwiched between aluminium plates. On average, about 30 fuel elements drive the BR2 core, each containing about 250 g U. The fuel elements last on average for 110 Effective Full Power Days (EFPD) within the core, reaching a burnup of up to 50%. With an operation regime of 100-200 EFPD/year, about 40 fuel elements are spent every year (IAEA, 1995b). Four different options were analysed for management of the spent fuel:

- Dry storage in thick containers in a dedicated building for a period of 40–50 years. After the interim storage, the fuel should be reconditioned for geological disposal or reprocessed.
- Dry storage in thin canisters in a dedicated building for a period of 40–50 years. After the interim storage, the fuel should be reconditioned for geological disposal or reprocessed.
- Reprocessing with recovery of uranium. After processing the fuel is recovered and reutilized as HEU (~72% enrichment) in the BR2 reactor. Cemented waste (estimated to be 40 m^3/ton total metal) is returned to Belgium.
- Reprocessing without recovery of the uranium. After processing (outside the country), the recovered uranium is diluted to 1% enrichment and recycled. Vitrified and technological waste (estimated to be 0.36 m^3/ton total metal) is returned to Belgium.

The various back-end options were evaluated against different criteria, for example available techniques, safety, waste production and overall costs (including the costs for the decommissioning of the interim storage equipment and infrastructure). For the BR2 spent fuel, the option of reprocessing without recovery of the uranium has been chosen for the following main reasons (Gubel and Collard, 1998):

- Some doubts remain about the long-term stability of aluminium fuels during interim storage.
- The disposal of BR2 spent fuel can rise to non-negligible risk of criticality.
- The disposal of thick casks in the Belgian geological repository must be avoided.
- Vitrified and technological waste is similar to the waste from reprocessing of the Belgian NPP spent fuel. This waste is well known and accepted.
- The use of HEU at 72% in the BR2 has some drawbacks for the exploitation of the reactor.

- It was the more economical option and its feasibility was guaranteed for the lifetime of BR2.

BR3

During its lifetime, the Belgian Research Reactor no. 3 (BR3) was used as a test reactor for new fuel types and assemblies. So, MOX fuel with enrichment up to 10.3% Pu_{fiss}, fuel pins containing burnable poison (Gd-contents) and LEU fuel with enrichment up to 8.26% U5 were tested. There are almost 200 fuel assemblies present in the plant representing about 5000 fuel pins (max. length 1235 mm; max. diameter 10.75 mm). Some pins have participated in R&D experiments in BR2. Parts of them have undergone destructive analyses (i.e. puncture test, cutting or decladding). All the remaining segments together represent an equivalent amount of 500 pins. The possibility of reprocessing the spent fuel was studied first, but it became evident that this solution had to be disregarded because of difficulty reusing the recovered uranium and plutonium in industrial production of fresh fuel and because of the low solubility of the Pu, which required an additional dissolution step and the use of a pilot reprocessing facility. Options for dry storage were then studied on the basis of the results of an open call for tender. The options were:

- Dry storage in seven casks with one in reserve (2.5 m height; 1.4 m diameter; 25 ton) in a dedicated building.
- Dry storage in one big cask (4.2 m height; 2.4 m diameter; 85 ton) in a dedicated building.
- Dry storage in three canisters (2.3 m height; 1.8 m diameter) inside a concrete bunker.

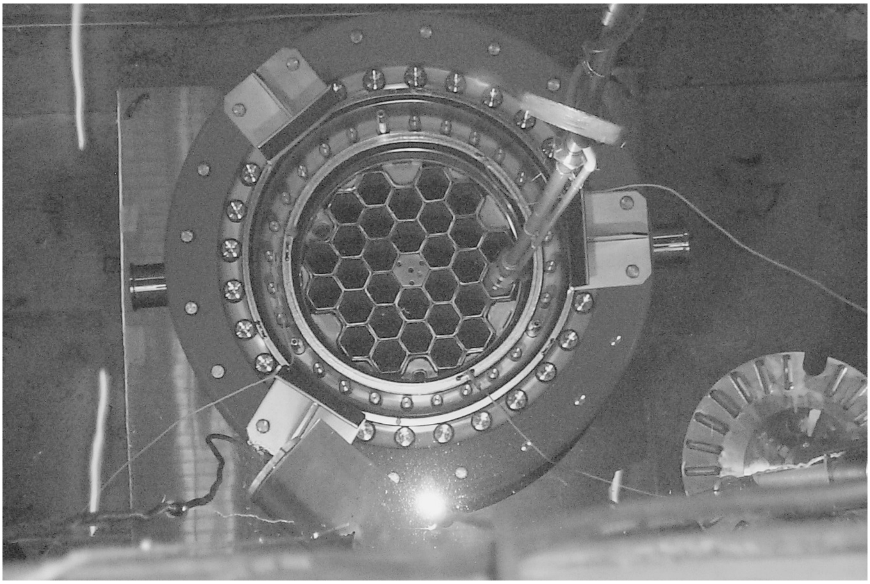
The results of the evaluation led to adoption of the first solution.

The transport and storage cask contains a basket which can be loaded with up to 30 spent fuel assemblies. The cask consists mainly of a thick-walled cylindrical cask body made of ductile cast iron and closed by two independent lids each bolted to the cask body and each sealed with a metal seal. The cask is shown in Fig. 9.1 and Fig. 9.2. For the non-intact pins, SCK•CEN has developed a bottle containing 15 loading tubes for the pin segments.

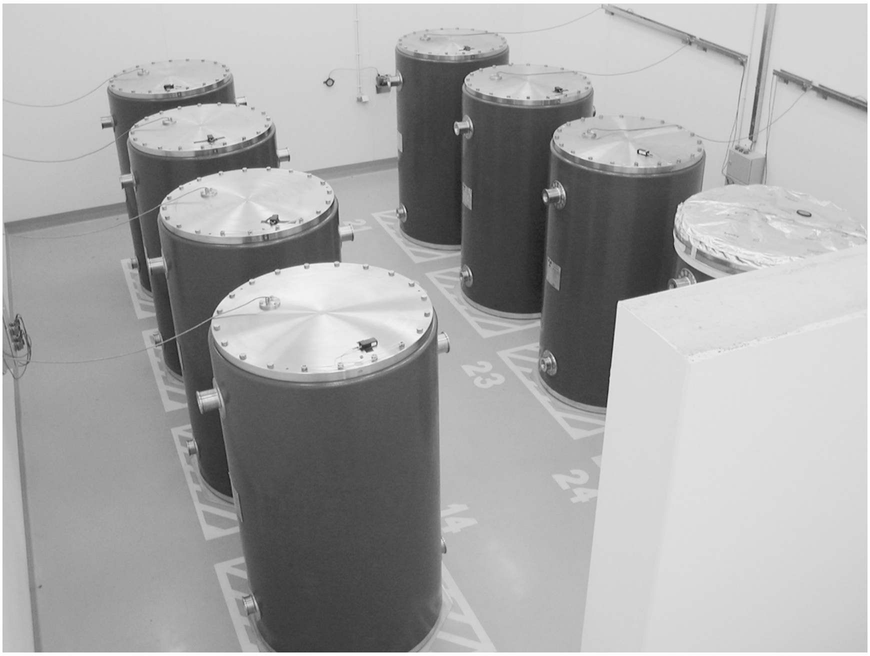
The loading of the containers and transport to Belgoprocess was performed in 2000. After interim storage, the assemblies can be retrieved, repacked and conditioned into welded canisters and disposed of in a geological formation (Noynaert et al., 1999.)

Thetis

The Thetis research reactor on the site of the Nuclear Sciences Institute of Ghent University was in operation from 1967 until December 2003. This light-water moderated graphite-reflected low-enriched uranium pool-type reactor has been



9.1 Loading BR3 spent fuel inside the CASTOR casks.



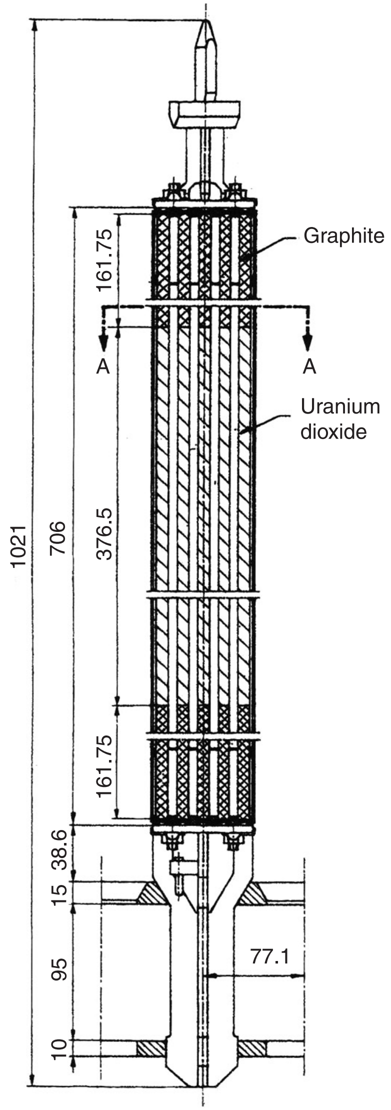
9.2 Loaded CASTOR casks in dry storage.

used for various purposes, for example production of radioisotopes and activation analyses. During its first years of operation, its core power was 15 kW. In the early 1970s, a core enlargement allowed for operation at typically 150 kW, with a maximum of 250 kW. The fuel was 5% enriched uranium clad with AISI304L stainless steel, with graphite plugs at both ends of the tubes. In order to decommission the reactor, the spent fuel had to be first removed from the reactor site. The Thetis reactor contained 20 fuel bundles placed in a 4 by 5 matrix. A bundle typically contained 25 fuel rods. Each rod was filled with 5% enriched uranium oxide fabricated following the VIPAC process (density: 8.5). The active pin height reached 376 mm. Each pin contained a graphite plug of 162 mm length at both ends. The rod was clad with 200 μm AISI304L stainless steel (Fig. 9.3). The average burn-up of the spent fuel reached only 3.15 GWd/t HM and maximum 5.15 GWd/t HM taking into account the radial and the axial buckling factor. Since the commissioning of the reactor, 25 fuel bundles have been used. During the operational period of the reactor the pool water remained free from any contamination with fission nuclides indicating that at shutdown there were no leaking fuel bundles. The options analysed for the back-end of the spent fuel were reprocessing, intermediate storage away from the reactor site awaiting final disposal and direct conditioning. The various options were evaluated against criteria: available techniques, safety, waste production and overall costs (including the costs for the decommissioning of the interim storage equipment and infrastructures). The results of the evaluations are summarized below.

The reprocessing of spent fuel is an interesting option if one can find an end-user for the recovered uranium and plutonium. Because of the graphite plugs inside the fuel pins, the spent fuel does not meet the acceptance criteria of the reprocessing facility. First the graphite plugs would have to be removed in a hot cell (e.g. at SCK•CEN). Then, the nuclear material would have to be repackaged and transported to the reprocessing facility. The reprocessing option was abandoned because of the amount of waste generated, technical issues and financial aspects.

Dry storage in casks was also considered. This option had already been implemented for the spent fuel from the BR3 reactor, and storage of the Thetis spent fuel could possibly have been performed in the same building. Nevertheless, at the end of the interim storage, the spent fuel would have to be repacked and conditioned to meet the requirements for safe disposal. This solution was considered as technically possible but still expensive because of the small amount of spent fuel to be managed.

As a result of the low burn-up, low heat emission and low dose-rate of the spent fuel, it appeared that direct conditioning was possible. This consisted of direct conditioning by cementation in qualified standard 400 l drums with specifically adapted baskets and further intermediate storage of the conditioned drums in the nuclear installations at Dessel. This solution was also economically the most advantageous. Indeed, it avoided the purchase of a storage cask and minimized the interim storage costs for Ghent University (Thierens et al., 2011).



9.3 Typical Thetis fuel element.

9.5 Recycling, reuse and clearance processes

Recycling, reuse and clearance of materials is now recognized worldwide as sound and responsible management practice. This practice is of particular importance in the case of refurbishment and decommissioning of nuclear installations (IAEA, 1988). As an example, one considers the decommissioning of a pressurized water reactor (PWR) of about 700 MWe. The decommissioning of this nuclear power plant involves handling 10 254 tons of metal and 130 040 tons of concrete.

From the 10 254 tons of metal,

- 5913 tons are free of any radioactivity and can be released without any treatment.
- 567 tons of suspected contaminated metal can be free released by a mapping/characterization.
- 2164 tons of contaminated metal can be free released after decontamination followed by a mapping/characterization.
- 500 tons of contaminated metal can be recycled/reused by melting.
- 716 tons of contaminated metal and 394 tons of activated metal have to be disposed of in a repository for radioactive waste.

From the 130 040 tons of concrete,

- 50 490 tons are free of any radioactivity and can be released without any treatment.
- 56 468 tons are free released after being controlled by a surface mapping.
- 14 115 tons of contaminated concrete can be free released after decontamination followed by a mapping/characterization.
- 177 tons of concrete are contaminated and need to be disposed of in a repository for radioactive waste.
- 8800 tons belong to the biological shield:
    - 2112 tons are activated above the clearance levels and need to be disposed of in a repository for radioactive waste.
    - 6688 tons can be free released after control.

These figures are only indicative and are sensitive to the decommissioning strategy (i.e. immediate or deferred decommissioning), the accessibility of the techniques and economic factors (e.g. wages, disposal fee, costs of techniques).

Recycling, reuse and clearance processes allow preservation of natural resources and the environment, and minimize the risks associated with production of ‘fresh material’. The necessity of waste minimization has been reinforced during recent decades by the increase in waste costs, that is the costs of conditioning, storage and disposal, as well as by the problem of public acceptance of disposal sites. One can consider that the recycle and reuse option will save almost 50% of the costs to dispose of the same amount of material as radioactive waste.

The recycling, reuse and clearance processes require that potential radiation exposure of the workers and the public shall be kept within allowable dose limits and will respect the ‘as low as reasonably achievable’ principle.

Available technologies for preparing materials for recycling and reuse are as detailed below.

For metal, the main decontamination techniques are:

- Mechanical decontamination: washing, ultrasonic cleaning, pressurized water jet, dry or wet abrasive cleaning, grinding, polishing, brushing, etc.
- Chemical decontamination: decontamination processes using Ce^{4+}, HNO_3/HF or HBF_4 foam, gels and pastes decontamination.
- Electrochemical decontamination: phosphoric acid, nitric acid, sulphuric acid and sodium sulphate processes.

Metal can also be melted. There are melting facilities that accept metal from abroad for recycling after free release by melting or decay storage or reuse for shielding blocks and transport/storage casks. These melting plants are Studsvik (Sweden), Siempelkamp (Germany) and Energy Solutions (USA) (IAEA, 2008b). Melting of lead can also be performed on-site. Several campaigns were organized at the BR3 reactor during its decommissioning.

For concrete, the main decontamination techniques used are scabbling, shaving, milling, scarifying, drilling and spalling. More details about these decontamination techniques are given by Laraia (2012). Concrete contaminated or activated at a low level can be recycled as aggregate for making 'fresh' concrete that can be used for a waste matrix, immobilization and construction material of a repository. SCK•CEN has demonstrated the feasibility of recycling of activated concrete from the biological shield of the BR3 reactor as a matrix for the conditioning of low-level waste (Klein, 2000).

The main challenge remains the ability to characterize the material in order to demonstrate compliance with the authorized clearance levels and/or the acceptance criteria for recycling or reusing materials. It must be pointed out that a similar challenge exists in characterization of radioactive waste in order to demonstrate compliance with the acceptance criteria for treatment/conditioning facilities, and, later, with those of the final repository.

The French situation is very specific as under the French regulations, waste produced in any part of a nuclear facility where it is liable to have been contaminated or activated must be disposed of in a traceable manner irrespective of its activity level. The clearance of material is therefore impossible. Only reuse/recycling is allowed in the nuclear sector. If this is not the case, the material must be disposed of in a repository. In 2003, France commissioned a site for the disposal of very low-level waste (IAEA, 2008b).

9.6 Challenges and lessons learned

The author considers the following three issues to be fundamentally important for the management of radioactive waste.

- Sound material management and waste management requires a detailed characterization of the materials, waste and spent fuel, concerning the radiological and the physicochemical characteristics, the toxic and hazardous risks. This detailed characterization is difficult to obtain when there is a lack

of waste traceability and documentation. This is particularly the case for historical waste, but also in facilities where awareness of the staff and operators is insufficient for waste management. The detailed characterization is a prerequisite for good waste classification and for selection of appropriate treatments and processes to be applied before reuse, recycling or disposal.
- There must be an integrated approach to management of radioactive materials, waste and spent fuel such that after treatments and eventually conditioning, the acceptance criteria for reuse, recycling or disposal will be met. In selection of a technique or a process, attention must be paid to minimization of the waste produced. Also, the waste generated by the treatment or by the process should be easily managed. The purpose is to solve a problem and not to create a new one!
- Another issue is the evolution of the disposal fee. This is a common feature in all developed countries. Therefore it is crucial to minimize radioactive waste production from the beginning of a nuclear facility (i.e. its design), through its operational period and up to its decommissioning.

He considers the following aspects to be particularly challenging:

- The first challenge to face is the set-up of a detailed description of the source term in the facility's Waste Management Plan. All waste streams must be fully characterized. As mentioned in the section above on fundamental issues, it is not just radiological characteristics that are important. Physical and chemical properties, toxicity and hazards also must be clearly identified. The total amount and yearly throughput of each waste stream are also needed. All these data are required to make a sound selection of the technologies and processes able to reuse, recycle, treat and condition materials or radioactive waste or spent fuel. All these aspects need to be fully described in the Waste Management Plan of the facility.
- Characterization is not only a key issue when identifying the waste streams, it is also important to demonstrate that clearance levels are reached or that the acceptance criteria for reuse, recycling, transport or disposal are met.
- The management of radioactive materials, waste and spent fuel needs to be integrated into a QA programme. The main purpose is to assure traceability and documentation of all the steps applied to each single unit of package before it escapes the facility.
- Another challenge is to keep the management of radioactive materials, waste and spent fuel inside the projected budget. This is a big challenge because of the constant increase of the disposal fee.

9.7 Future trends

To date, two options generally have been considered for management of spent fuel: the closed fuel cycle (i.e. the reprocessing option) and the once through fuel cycle (i.e. the disposal of the spent fuel after appropriate conditioning and packaging). However, based on considerations of the radiotoxicity of spent fuel and the vitrified waste generated by the reprocessing of the spent fuel, an idea has been raised to transmute plutonium and other actinides into radionuclides having a shorter half-life. This is known as Partitioning and Transmutation (P&T). Research has been carried out in the USA, Japan, France and Belgium, and is also part of a European Commission research programme. Belgium has recently launched a project in a new facility called MYRRHA to demonstrate among other things the feasibility of the transmutation. MYRRHA, a flexible fast spectrum research reactor (50–100 MWth), is conceived as an accelerator driven system (ADS), able to operate in sub-critical and critical modes. It contains a proton accelerator of 600 MeV, a spallation target and a multiplying core with MOX fuel, cooled by liquid lead-bismuth (Pb-Bi).

Regarding the treatment of radioactive liquid, processes based on membrane technology or reverse osmosis are studied. These are based on new developments in the treatment of industrial liquid waste. There is also research being conducted on new immobilization matrices, such as ceramic and polymer.

Many innovative decontamination techniques have been proposed in the framework of radioactive waste management research and development programmes. In most cases, the emerging technologies aim to improve the effectiveness of existing techniques or minimize some of their drawbacks. The most promising emerging decontamination techniques are those involving laser or microwaves.

In the framework of an industrial, cost-effective waste management project, the use of emerging techniques should be limited to specific cases only after completion of a test programme.

9.8 Sources of further information

More information about the management of radioactive materials, waste and spent fuel can be found on the websites of organizations or companies involved in services, studies or research to the nuclear industry. IAEA and NEA-OECD, DOE, etc., issue guidance and reports about the state-of-the-art in this field. Conferences such as Waste management, ASME/ICEM (International Conference on radioactive Waste management and Environmental remediation), PATRAM (International Symposium on the Packaging and Transport of Radioactive Materials), RRFM (International Conference on Research Reactor Fuel Management), also provide valuable information regarding new developments in treatment/conditioning of radioactive waste, reuse and recycling of materials and management of the back-end of the spent fuel cycles.

9.9 References

Gubel P., Collard G. (1998), ‘Spent fuel strategy for the BR2 reactor’, 2nd International Topical Meeting on Research Reactor Fuel Management (RRFM ’98), Bruges, Belgium pp 110–114.

IAEA (1988), ‘Factors Relevant to the Recycling or Reuse of Components Arising from the Decommissioning and Refurbishment of Nuclear Facilities’, Technical report series No. 293, IAEA, Vienna.

IAEA (1995a), ‘The Principles of Radioactive Waste Management’, Safety Series No. 111-F, IAEA, Vienna.

IAEA (1995b), ‘Experience with spent fuel storage at research and test reactors: Proceedings of an Advisory Group meeting held in Vienna, 5–8 July 1993’, TECDOC-786, IAEA, Vienna.

IAEA (2001), ‘Handling and Processing of Radioactive Waste from Nuclear Applications’, TRS 402, IAEA, Vienna.

IAEA (2006a), ‘Characterization, Treatment and Conditioning of Radioactive Graphite from Decommissioning of Nuclear Reactors’, TECDOC-1521, IAEA, Vienna.

IAEA (2006b), ‘Management of problematic waste and materials generated during the decommissioning of nuclear facilities’, TRS 441, IAEA, Vienna.

IAEA (2007), ‘New Developments and Improvements in Processing of “Problematic” Radioactive Waste: Results of a coordinated research project 2003–2007’, TECDOC-1579, IAEA, Vienna.

IAEA (2008a), ‘Spent Fuel Reprocessing Options’, TECDOC-1587, IAEA, Vienna.

IAEA (2008b), ‘Managing low radioactivity material from the decommissioning of nuclear facilities’, TRS462, IAEA Vienna.

IAEA (2009), ‘Classification of radioactive waste’, General safety Guide GSG-1, IAEA, Vienna.

I Mech E (1996), ‘International Conference on Storage in Nuclear Fuel Cycle’, 18–19 September 1996, ISSN 1356–1448.

Laraia M (2012), ‘Nuclear decommissioning: planning, execution and international experience’, Woodhead publishing series in energy No. 36.

Klein M (2000), ‘Recycling of radioactive concrete: crushing and sieving of barytine concrete from BR3’, Final report, SCK•CEN.

Noynaert L, Massaut V, Braeckeveldt M (1999), ‘The back-end management of fissile material’, SCK•CEN, RRFM.

Thierens H et al. (2011), ‘The removal, transportation and final treatment and conditioning of the THETIS research reactor spent fuel of the University of Ghent (Belgium)’, Proceedings of ASME 2011 14th International Conference on Environmental Remediation and Radioactive Waste Management, ICEM2011 25–29 September 2011, Rheims, France.

10

Managing nuclear decontamination and decommissioning projects

J-J. GRENOUILLET, EDF, France

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Abstract: Decommissioning of a nuclear reactor requires specific engineering, licensing and project management skills. After a description of the main steps that constitute the decommissioning of a nuclear power plant, this chapter details the main issues that must be considered for safe and efficient delivery of the project. The most critical stages of decommissioning projects are then illustrated by lessons learned from completed projects in the USA and in Germany or from ongoing projects in France.

Key words: reactor decommissioning, decommissioning engineering and project management, lessons learned from decommissioning.

10.1 Introduction

Decommissioning constitutes the last stage in the lifecycle of a nuclear power plant (NPP). Its objective is to shut down the plant, remove the spent fuel and the radiological contaminants from the facility and place the site in an end-state that is safe for the public and the environment. In the case of a power reactor this involves physical dismantling of the facility and its components, the conditioning and removal of waste and the rehabilitation of the site.

The IAEA lists three decommissioning strategies that may be implemented by the owner/licensee of the facility:

- Immediate Dismantling: '. . . The equipment, structures and parts of a facility containing radioactive contaminants are removed or decontaminated to a level that permits the facility to be released for unrestricted use, or with restriction imposed by the regulatory body. In this case decommissioning implementation activities begin shortly after the permanent cessation of operations'.
- Deferred Dismantling (sometimes called safe storage, safe store or safe enclosure): '. . . Parts of a facility containing radioactive contaminants are either processed or placed in such a condition that they can be safely stored and maintained until they can subsequently be decontaminated and/or dismantled to levels that permit the facility to be released for unrestricted use

or with restriction imposed by the regulatory body'. This strategy postpones final removal of controls for a period of 40–60 years.

- Entombment: '. . . Radioactive contaminants are encased in a structurally long lived material until radioactivity decays to a level permitting the unrestricted release of the facility, or release with restrictions imposed by the regulatory body'. This strategy usually involves reducing the size of the area where radioactive material is located.

As such, from the point of view of the licensee or regulator, the ultimate objective of this last stage is termination of the license. When this stage is completed, the site may be released from any nuclear regulation. Usually decommissioning itself is subject to licensing or authorization by the regulatory body.

From an economic standpoint, decommissioning is also an important issue, not only because funds have to be collected during the operation period of the facility to cover the actual cost of decommissioning activities, but also because decommissioning cost is a parameter to be considered in the decision to invest in erection of a new NPP. The main financial risks related to decommissioning occur because of difficulty in assessing the safety and environmental requirements that will exist when the plant is shut down and the cost estimate for waste disposal when some national waste management facilities – such as a spent fuel and high-level waste repository – do not yet exist.

Public acceptance of a decommissioning project is also very important. On one hand, the local communities will no longer receive any revenue from operation of the power plant and the decrease of permanent staff and contractors on-site will result in significant economic effects on the local communities. On the other hand, they will bear for a long time the effects of any potential contamination. Therefore site remediation and site reuse strategies are key for acceptance of the project by the public.

So it appears that decommissioning is an issue that must be considered all along the lifecycle of a NPP, that is from the decision to build a new facility until site rehabilitation and site reuse.

From a project manager's perspective, decommissioning is mainly an industrial process that produces waste. Therefore a strong and clear project organization, mobilizing efforts from contractors, in touch with stakeholders must be set up. Considering waste as a product means that waste packages have to meet specific quality requirements that will ensure their acceptance by the repositories or interim storage facilities.

These are several issues that must be kept in mind for the implementation of a decommissioning project. All these issues will be addressed in the following sections, which detail the main steps of a decommissioning project, give an insight into the main project management issues and summarize the lessons learned from completed or ongoing projects.

10.2 Overview of a reactor decommissioning project

10.2.1 Phases of the project

Project initiation begins when the decision is made to permanently shut down a facility and proceed to decommissioning.

After a transition period, where the decommissioning project objectives and organization are defined, the activities to be performed within a reactor decommissioning project can be broken down into the following phases:

- Deactivation.
- Conventional island dismantling.
- Electromechanical equipment dismantling.
- Concrete decontamination and demolition.
- Site restoration.

These phases are not necessarily sequential and some overlapping is possible.

Deactivation of the NPP

Activities in this phase are aimed at reducing nuclear and non-nuclear hazards on-site. Another objective is reduction of surveillance and maintenance cost, which can be achieved through relaxation of safety requirements when significant changes are made to the plant configuration. Usually, those activities are executed under the operation license and the lapse of time necessary to get the decommissioning license may be used to implement them.

After a few years of radioactive decay, spent fuel will be moved from the spent fuel pool to an interim storage facility or sent to a reprocessing facility. Circuits that are not essential to decommissioning will be drained and de-energized in order to be ready for later dismantling. Other systems, such as ventilation or liquid waste treatment, that are needed to support dismantling or decontamination activities remain active and will eventually be reconfigured to meet the specific requirement for decommissioning activities.

Cleaning and decontamination of the nuclear steam supply system may be performed during this period so as to benefit from the existing capabilities before they are lost.

This period may be used also for the erection of waste interim storage or waste treatment facilities.

Conventional island dismantling

There is no technical difficulty regarding dismantling of the conventional part of the plant such as the turbine hall, workshops or administrative buildings. These activities are implemented with the same techniques as those used in any demolition work.

The main issue regarding this phase is that some buildings, because of their size or the fact that they have high capacity cranes, may be modified and used for decommissioning purposes. For example, the turbine hall may be reused for the installation of waste treatment facilities or for interim storage. Of course a cost benefit analysis has to be performed to demonstrate that this option is better than the erection of a new facility.

Because the licensing process for conventional island dismantling is usually short, the demolition of this part of the facility may be used as an early sign to the local community that decommissioning is becoming a reality and that the plant will not operate anymore. Rehabilitation of the sites of demolished buildings may be used as a demonstration to the public of the owner's commitment to site restoration.

Electromechanical equipment dismantling and decontamination

It is recommended to start this phase only when waste management solutions – clearance, interim storage or disposal – required for the waste streams that will be generated, are in place.

Regarding technical activities to be performed at this stage, components must be size-reduced to fit into transportable and disposable containers. Contamination spreading during cutting activities has to be controlled to avoid cross-contamination of clean components or facility areas.

Mechanical or chemical system decontamination is sometimes needed to reduce occupational exposure prior to dismantling works. The processes used may be more aggressive than those used during plant operation, because the equipment will not be used anymore, and in some cases, this can facilitate recycling, free-release or waste management optimization as well.

Many processes exist for dismantling a NPP using remote controlled techniques or conventional techniques operated from behind radiation shielding, within airlocks equipped with mobile ventilation and filtration, together with provision of protective personal equipment such as air suits, breathing equipment and masks.

Nevertheless, even when they have been successfully implemented on reactor decommissioning projects, they are not fully mature because the extent of the market for NPP decommissioning is limiting the development and improvement of innovative products. Furthermore, techniques that were developed for one type of reactor may sometimes be difficult to apply to another reactor type. For example, reactor vessel internals under water segmentation have been drastically improved for light water reactors since the first implementations in the 1990s. Unfortunately, their application to gas cooled reactors, heavy water gas cooled reactors or fast breeder reactors is still an issue because these plants were not designed for underwater activities to be implemented during the operation period such as refueling or internals removal for inspection.

Concrete decontamination and demolition

Once the contaminated concrete floors and walls have been removed, usually by scrabbling techniques, a final survey of the buildings will be performed in order to demonstrate that all contamination has been removed. The results of this investigation will be supplied to the regulatory body and, further to a formal approval, the buildings are released from regulatory control and demolished.

Site restoration

The aim of this stage is to achieve the end-state that is described in the decommissioning license. This requires sampling of remaining media to various depths and lab analysis, interpretation of the results and final report preparation.

If the data indicate that the criteria defined for the end-state have not been met, additional decontamination or soil remediation is performed.

For a nuclear power plant, the end-state may be 'Greenfield' in case of a release for unrestricted use or 'Brownfield' when the site will be reused by the owner, for the erection of a new power plant for example.

A final radiological survey of the site has to be submitted to the regulatory body to demonstrate that the license termination criteria have been met.

10.2.2 Engineering and licensing processes

Usually and preferably, the first decommissioning studies are performed during the operation of the plant. They are periodically updated to take into account changes in plant configuration, evolutions of dismantling and decontamination techniques, availability of new waste management routes and modifications in regulations or policies. These include selection of a decommissioning strategy, the definition of the end-state for the site and determination of the level of funding required.

When permanent cessation of operations is decided, the owner prepares the documentation required by the regulatory body to apply for a decommissioning license. This includes generally a Safety Analysis Report and an Environmental Impact Assessment. Support studies are necessary to substantiate those documents, such as site and plant characterization, conceptual design to define dismantling and decontamination scenarios, describe the techniques to be used and precise provisions for radiation protection of the workers and environmental protection.

This documentation is reviewed by the regulatory body and its technical support organization to check that the decommissioning plan is compliant with the regulation and that the proposed end-state is acceptable. A public participation process has to be initiated in parallel, so as to provide stakeholders with an opportunity to review the decommissioning plan and provide comments to the regulator prior to its approval.

Usually, dismantling activities are performed by contractors. The scope of work to be contracted is broken down into several packages with the objectives:

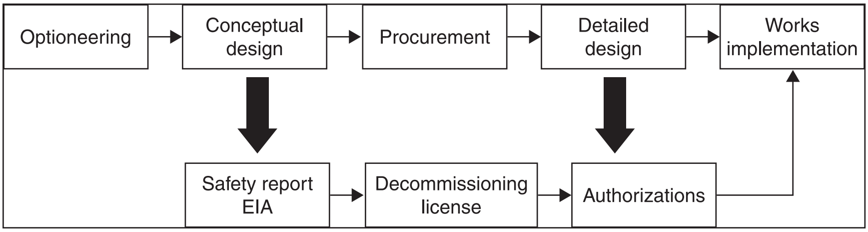
- To mobilize in each contract similar dismantling techniques or capabilities.
- To avoid any discontinuity in implementation of the works.
- To be located in the same geographical area.

Simultaneously to the application for the license, bid specifications for the identified contracts are prepared by the owner in order to start the procurement process. Major contracts may be: decontamination and dismantling of the primary circuit, reactor pressure vessel and reactor vessel internals segmentation, erection of interim storage facilities, conventional dismantling and demolition

The approval process by the regulatory body may take several months or even years and ends with the issuance of the decommissioning license. Additional licenses or authorizations may be required for specific activities that are susceptible to generating the highest level of risk regarding safety for the workers or the environment. For those activities, a more precise safety assessment is required on the basis of the detailed design of the processes to be implemented.

For efficient execution of the project, it is crucial to have detailed planning of the design deliverables that are required by the regulatory body all along the various stages of the project.

The design and licensing processes, and the way they interact together, are summarized in Fig. 10.1.



10.1 Design process interaction with the licensing process.

10.3 Fundamental issues for managing a reactor decommissioning project

This section deals with tools that may be used for management of any project, but shows how they have to be applied to reactor decommissioning projects and what has to be specifically considered to cope with decommissioning challenges.

The specific challenges faced by reactor decommissioning projects are mainly a result of:

- The changes in comparison with the operation period.
- A high level of risk because of uncertainty.
- The necessity to take into account the plant history.
- The difficulty to benefit from experience feedback because of the permanently evolving activities.

10.3.1 Project organization and structure

Because of the duration of reactor decommissioning projects, the project organization has to evolve in order to fit with continuously evolving activities and plant status. Furthermore, no 'one-size-fits-all' organizations because of strategic choices such as utilization of operation personnel to perform decommissioning activities and level of contractor involvement in the project.

Nevertheless, there are a few activities that the project team must perform in order to keep control of the project, whatever the strategic choices mentioned previously or the situation of the project. The capabilities of the project team shall cover at least the following fields of expertise:

- *Engineering*. This area includes selection of alternatives for decommissioning, conceptual design, drafting of technical specifications for tendering of decommissioning, dismantling and decontamination activities, supervision of design studies made by contractors. Environmental Impact Assessment, Safety Analysis Report, Basic Design and Detailed Design may be carried out by contractors or by in-house resources depending on the supply chain strategy selected.
- *Safety and licensing*. The project team has to have dialogue with the regulatory body at the early stage of the project for application for the decommissioning license. Then it has to demonstrate the compliance of the performed activities with the safety requirements or to ask for specific approval if changes have to be made, which can be the case further to the detailed design made by the contractors for example. The project team also has to anticipate evolution of regulations in order to facilitate integration by the project when they are in force.
- *Waste management*. One key issue for a reactor decommissioning project is comprehensive identification of all the waste streams that will be generated during the project. For every waste stream, a waste route or a recycling route must be defined, including selection of waste treatment processes in order to minimize the volume of waste generated such as compaction, incineration or decontamination. This area includes activities such as radiological characterization, physical inventory, design of cask for transportation and storage or design of waste treatment processes. This area includes also the verification that waste acceptance criteria for transportation and storage or disposal are met by waste packages conditioned by the contractors.

- *Radiation protection.* Although radiation protection is already an issue during plant operation, it becomes a growing concern during decommissioning because dismantling activities are more likely to spread contamination than maintenance activities. Furthermore, segmentation operations usually require more time than replacement of a component or verification of its characteristics, generating a longer exposure to high dose rates. Therefore, working methods have to be optimized according to the ALARA principle in order to ensure safety of the workers. This includes cost benefit analysis for shielding, decontamination or remote controlled processes. Thus, the project team has to provide contractors with detailed information about dose rates, hot spot locations and available protection measures in the rooms where decommissioning activities are implemented. The collection and analysis of occupational exposure records is also very important in this area of activity.
- *Work supervision.* Usually, decommissioning tasks are performed by contractors. The project team has to verify the compliance of this work with safety and radiation protection requirements approved by the regulatory body. Industrial safety is also an important issue to be managed in this field. This includes the approval of safety practices, monitoring of worker areas and specification of personnel protective equipment.
- *Operation.* During all the steps of a decommissioning project, there are some systems that need to operate such as, for example ventilation, fire detection, power or fluid supply and liquid waste treatment. Additional systems, such as water filtration for segmentation of the vessel internals may also be necessary. Usually, systems that play a major role in the safety demonstration, or that are cross-cutting to most activities, are operated by the project team. Conversely, a system that is specific to one activity, such as water filtration for reactor vessel internal segmentation, may preferably be operated by the contractor. Irrespective of who is operating the safety required systems, the project team must at least verify that these systems are operated according to the technical specification approved by the regulatory body.

Of course, as in any other project, support functions for schedule and cost control, reporting and procurement are also necessary. Nevertheless, they do not require arrangements specific to decommissioning.

10.3.2 Cost estimate – cost control

Cost estimate for decommissioning has to be initiated during the early years of a NPP erection project. It constitutes an element, among others, of the business plan of the project. It also provides an evaluation of the money that will be collected during operation of the facility to ensure that the implementation of the decommissioning strategy can be carried out when desired and in a safe manner.

Of course, many of the final conditions of the facility are not known at the design stage, but assumptions can be made and documented in the cost estimate. Therefore, uncertainties within the defined project scope are generally included as contingencies within the cost estimate, whereas uncertainties outside the defined scope are usually addressed within the funding arrangements, for example by funding guarantees.

As the NPP operates, the cost estimate is periodically updated to take into account changes in the facility conditions but also changes in safety or waste management regulations, experience feedback from other similar projects and evolution of available technologies.

The cost estimate process is generally regulated and the regulatory body usually plays a major role reviewing the cost estimates developed and the funding mechanism used to assure adequate funding for decommissioning. Owners are generally responsible for developing cost estimate and funding mechanisms. They are required to submit them to the regulator for approval periodically. Reviews of cost estimates are generally performed every three to five years. An accurate, verifiable and reproducible cost estimate is deemed essential by most regulatory bodies and should be a concern for managers responsible for updating decommissioning cost estimates. Quality control is also critical for assuring adequate provisions of decommissioning activities, and consistency between cost estimate and actual cost from the ongoing decommissioning project is also crucial.

10.3.3 Risk management

In this section and in the following sections of this chapter, risk has to be understood as the probability of occurrence of an event multiplied by its consequences, whether positive or negative, on the performance of the project. Therefore risk appraisal is clearly linked to the level of uncertainty regarding parameters that will influence the occurrence of an event.

The level of knowledge at the beginning of a reactor decommissioning project is quite low. One objective of the project team is to increase its level of knowledge through additional studies such as scoping, optioneering, feasibility study or input data collection. Conversely, the possibility of acting on the project decreases all along the project duration, ending in a paradox: at the end of the project you know everything about it but you cannot change anything anymore.

For a decommissioning project, as long as you have not dismantled a component you cannot be completely sure about its content regarding contamination or hazardous materials. Physical and radiological characterizations are not comprehensive, and unexpected situations are always possible. And once the content is conditioned in a waste package, you cannot even be sure that it will be accepted in a repository that does not yet exist.

So, making a decision in a reactor decommissioning project means taking risks provided that there is enough confidence that these risks will not significantly affect the performance of the project. Therefore, risk management is key to efficient management of a decommissioning project: it will help in reducing occurrence of risks through additional feasibility or characterization studies, or by mitigating their consequences using identified action plans.

The main risks to be dealt with in a reactor decommissioning project are related to:

- *Public acceptance.* Acceptance by the public of the decommissioning strategy or dismantling scenario or waste storage options may be a long process that delays the beginning of decommissioning activities. During decommissioning, new activities, unknown by the public during operation of the plant, will start on-site. Although the risk of an accident or an incident is much lower during decommissioning than during operation, the new activities performed on-site may generate new issues of concern for the public such as dose rate for the workers, the interim storage of waste or the remediation of the site. Anti-nuclear activists may also use the public participation process to require some technical or legal provisions that are not related to the actual risks generated by the project, in order to delay decommissioning. This increases the cost, thus demonstrating that nuclear energy is not an economically viable option. The definition of a project for site reuse may help in building public support and acceptance of a decommissioning project. Early meetings with stakeholders can be used to get their confidence about decommissioning end-state and waste management issues.
- *Reliability of input data.* Radiological characterization and physical inventory are never fully comprehensive. Radiological characterization partially relies on the plant history and it is sometimes difficult to have access to a comprehensive history of the plant: some records may be lost or not precise enough to assess the contamination or activation of the components or structures consequently to an operation event. Characterization is also achieved by taking samples and analyzing them. Because of time, budget and safety considerations this process has also to be limited. Regarding physical inventory, as-built drawings may be lost or may be non-existent. In this case the inventory will rely on design data of the plant components and structures that may be wrong.
- *Regulation changes.* Because decommissioning projects usually span a long period, the environment protection, worker radiation protection and safety regulations may become more stringent to cope with the growing concerns of the public regarding those issues. Therefore, increased requirements for additional information and detail may occur during the implementation of a decommissioning project. The lack of clear, precise and detailed safety rules, mainly for critical activities, is also an issue. Many authorizations are given on a case-by-case basis, and it is never possible to consider something that was previously authorized as granted.

- *Waste management.* Spent fuel management, whether through reprocessing or by interim storage, is not an issue specific to decommissioning. It has to be addressed during operation of the plant. Regarding other types of waste, decommissioning generates a higher quantity than operation and, moreover, with different chemical, physical and radiological characteristics. Therefore, new waste routes are to be made available. For example, dismantling the reactor components will generate highly activated wastes, which are rarely generated during operation. New waste streams will arise such as graphite, in the case of a graphite moderated reactor, or sodium, for a fast breeder reactor. All these aspects require new repositories. The availability of such repositories does not lie in the hand of the decommissioning project, but is dependent on the government waste management policy and its acceptance by the public. Therefore, the delay for their commissioning places a high level of risk on the project. This risk can be mitigated through the erection of an interim storage facility provided that the requirements for conditioning and transportation of waste to the final repository are clearly defined. Of course, this will significantly increase the project cost.

10.3.4 Procurement and supply chain management

Supply chain management may be defined as the strategic coordination of all parties that are involved in delivering the combination of inputs, outputs or outcomes that will meet a specified requirement.

The decommissioning market is limited compared with the maintenance of operating units. As such, it cannot benefit from a perpetual improvement process. Even if proven decommissioning techniques exist, they have been implemented discontinuously, in various contexts, making experience feedback difficult to utilize.

Basically, procurement and supply chain management aim to deliver the project on time, within budget and in accordance with specific technical requirements. Usually this goal is achieved through a competitive tendering process that brings technical innovation and value for money.

A range of contracting strategies may be considered, ranging from cost re-imbursement through to fixed cost arrangements:

- Reimbursable Costs with a fixed fee paid against milestone events.
- Reimbursable Costs with an efficiency based fee mechanism.
- Target Cost with an efficiency based fee.
- Fixed Price.

Usually, Fixed Price contracts do not suit decommissioning activities because of the high level of risk inherent to the project and the fact that usually they are one-off projects and as such their cost estimate cannot rely on relevant experience. Conversely, Reimbursable Cost contracts are not incentive enough. Target Cost contracts, including risk sharing mechanisms, may be interesting because they comply simultaneously with the need to meet the project budget and to take into account a high level of uncertainty.

Then the question comes about the most appropriate way to share risks between the client and the contractor. It can be recommended to leave the risk to the party most efficient to manage it. Usually, licensing risks – that is the liability to receive approval by the regulatory body – have to be managed by the owner, whereas risks induced by the implementation of a technical process remain the contractor's liability.

Sometimes procurement strategies intend to achieve specific goals that may seem antagonistic: on one hand, the aspiration to benefit from innovation in order to reduce cost or improve performance results regarding safety or dose to the workers, and on the other hand, the desire to secure the issue of the required authorizations by the regulatory body. It is clear that the best way to get an approval by the regulatory body is to apply for a process that has been implemented previously on a similar project. This is the best way to kill innovation. A possible approach to cope with these two difficult to reconcile objectives is the following:

- Get a first approval by the regulatory body at an early stage of the project on the basis of basic safety options. At this stage, the detailed implementation cannot be described.
- Include in the Technical Specifications the safety options approved by the regulatory body. They will become requirements to be fulfilled by the tenderers.
- Encourage the bidders to propose innovative solutions through incentivization mechanisms.
- Award the contract to the best proposal according to the planned performance results.
- Get the detailed implementation approved by the regulator on the basis of the detailed design provided by the contractor.

This practice is compliant with the design and licensing processes, and the way they interact together, as described in Section 2 of this chapter.

10.4 Lessons learned

10.4.1 Transition from operation to decommissioning

Transition from operation to decommissioning is key for the success of a decommissioning project from technical, economical and safety perspectives.

From a technical point of view, the plant has to be fitted to new conditions. Systems that were required during operation are no longer required and can be shut down. This removal has to be implemented as soon as possible in order to reduce the maintenance cost of the plant. Of course, operating procedure and maintenance documentation has to be updated to reflect the actual status of the facility. Sometimes existing systems have to be upgraded to meet new safety requirements. For example, because fire hazard is higher during decommissioning than during operation, an upgraded fire detection system may be installed. Similarly the ventilation system has to be reconfigured to provide dynamic containment to the multiple dismantling workplaces in the facility.

Because dismantling activities are implemented by room and not by function, some equipment, whose function is still required, may exist in a room where most of the pieces of equipment are shut down and ready for dismantling. In this case, a physical and visible separation from fluid supply has to be made on shutdown components in order to show which can be safely dismantled by decommissioning workers. A painted indication on valves, pipes, motors or cables may also be used to clearly segregate the materials to be dismantled from still operating equipment.

Because fire is an important hazard during dismantling activities, this risk has to be reduced before starting utilization of segmentation techniques. This can be achieved by reduction of the fire load capacity through the removal of non-used cables or electrical cabinets.

The transition of personnel from operating to decommissioning perspective is also a key issue to be addressed at the beginning of the project. On one hand, the plant staff has to be reduced because operation activities have decreased. On the other hand, key personnel have to be retained on-site in order to benefit from their knowledge of the plant to safely and efficiently complete the project.

Significant cultural and organizational changes will occur during this period and need appropriate consideration for a smooth transition. The work as an operator is completely different from the work as a member of a project organization: when the operator environment – status of the plant, operating procedures – is stable, the environment of a decommissioning project is perpetually evolving.

10.4.2 Large components dismantling

Dismantling of large components is a major issue in a reactor decommissioning project. Because of their weight, special handling devices may be required for their removal. Because of their size, enough space in the facility is needed for their treatment – segmentation or decontamination – and as long as this space is needed, the project cannot go ahead with other activities. Finally, they are usually the most activated equipment of the facility: the vast majority of the contamination in a PWR lies in the steam generators and in the reactor vessel. Consequently, their removal requires specific treatment such as remotely handled process, shielding or decontamination.

For all these reasons, dismantling of large components is usually on the critical path of the project and represents a significant part of the decommissioning budget. Additionally, transportation and disposal aspects are also very important issues to be addressed because these components are non-standard objects that are not included in the existing regulations or repository safety cases.

Therefore, an overall optimization of the complete cycle from removal to disposal has to be sought out because the most relevant management option is not necessarily the most relevant option at each step of the cycle. This optimization process will involve all the stakeholders – the owner, the transportation authority, the regulatory body, the repository management authority – at the earliest stage of the project.

Example

For dismantling of their shutdown NPP, EDF has defined a Waste Management Policy that is encouraging waste management optimization across the whole decommissioning process involving not only dismantling activities but also conditioning, transportation and disposal. The main goals of this policy are optimization of the volume of waste to be disposed of, the selection of the most appropriate waste route available and the best use of the repository capacity.

This policy was applied for the dismantling of large components at Chooz A NPP, such as the 4 Steam Generators, the Reactor Pressure Vessel and the Reactor Vessel Internals.

Located in the north of France, close to the Belgian border, Chooz A is the first PWR to be dismantled in France. The unit was designed by Westinghouse as an upscale of Yankee Rowe with a capacity of 300 MW.

The plant was shut down in 1991 and placed in safestore conditions waiting for about 40–50 years for deferred dismantling. In 2001, EDF decided to adopt a new dismantling strategy – that is immediate dismantling – and in 2007, a new license was obtained to complete the final dismantling of the plant.

Feasibility studies were undertaken by EDF for the long-term management of those components. A multi-criteria analysis technique was used. For the steam generators, a reference option involving de-categorization from LLW to VLLW followed by one-piece disposal was compared with an option involving segmentation (thermal cutting of the walls and mechanical cutting of the tube bundles). The reference option required a greater degree of decontamination than the latter option, as well as a parallel study by ANDRA, the French radioactive waste management agency, to confirm that disposal of one-piece steam generators in the VLLW repository was feasible.

The reference option was selected for implementation, as it yielded significant benefits in terms of dose to the workforce, time for removal, waste volume and decommissioning cost (although this factor was balanced by an increase in disposal costs).

For the pressure vessel, segmentation (except for the vessel head and vessel bottom), including interim storage of the internals, was compared with one piece removal (including the least activated internals) and interim storage of the most activated internals. The study found that transport of the vessel by boat was the most feasible option (if the one piece disposal option were selected). Although many factors favored one piece disposal (as for the steam generators), the assumed level of alpha contamination in the internals made it difficult to make a case for disposal at ANDRA's LLW repository, as a result of the problem of potential human intrusion. Because of the time needed to undertake more extensive characterization of the internals, the segmentation option was preferred.

10.4.3 Decommissioning experience in the USA, Germany and France

For the first generation of NPP that started to operate in the 1960s, the time has come for decommissioning. Many of these units are currently being decommissioned and, for a few of them, decommissioning activities are completed and their license has been terminated. During the past two decades, through the implementation of those decommissioning projects, the nuclear industry has encountered and dealt with such a wide range of technical and organizational challenges, that it can be considered that decommissioning of NPP has become a mature industry.

Experience in the USA

In the late 1990s, a number of large power reactor decommissioning projects were initiated. As of the present, most of these reactors have been successfully decommissioned to unrestricted use. Examples include Trojan, Big Rock Point, Maine Yankee, Yankee Rowe and Connecticut Yankee.

Many innovative dismantling and decontamination approaches were developed during the course of performing their decommissioning projects including:

- Bulk removal of contaminated equipment or structures to a waste disposal facility. The complete removal has been found to be less expensive than the time and labour intensive process of performing final status surveys.
- The use of off-site facilities for decontamination and free release of materials has allowed waste materials to be removed from project sites more rapidly.
- One piece removal of large components such as reactor pressure vessel and steam generators. This option has reduced labour costs and shortened schedules when compared with segmentation. It has reduced also waste disposal, packaging and transportation costs through averaging of radioactivity over a large single mass.
- Primary system decontamination has allowed the use of less expensive and faster hands-on techniques rather than the implementation of robotics and remote processing.

Segmentation techniques for reactor pressure vessel and reactor vessel internals have been continuously improved from the first implementations in the early 1990s to the last one in 2006.

At Yankee Rowe, the RVI were segmented under water from 1993 to 1995 with Plasma Arc Cutting. The RPV was shipped intact at the repository (Barnwell, SC).

At Connecticut Yankee, Maine Yankee and San Onofre, the reactor vessel internals were segregated in two parts:

- The most activated part was segmented and conditioned in Greater Than Class C waste packages and stored on-site
- The least activated part was packaged and shipped with the RPV.

At those three units, the RVI were segmented under water with abrasive water jet cutting.

At Trojan, the whole internals and the RPV were shipped intact to the repository (US Ecology, Richland, WA).

At Rancho Seco, the RVI were 100% segmented using underwater mechanical cutting – sawing and milling – because of the lower activity due to very limited operating time of the plant (around six Equivalent Full Power Years). Only Class B & C were generated and stored on-site to be transported at a future date to a national repository site.

The RPV was segmented with abrasive water jet cutting in dry condition. The lower activation of the vessel – a short operation life and a decay period of approximately 17 years – allowed the utility to segment and dispose of this component as Class A waste.

Experience in Germany

Because all radioactive waste in Germany will be disposed of in a deep repository and because this repository was not in operation for the NPP decommissioning projects performed so far, huge efforts have been made to minimize the quantity of radioactive waste generated through the decommissioning process including:

- Primary circuit full loop decontamination.
- Large components melting (steam generators, turbine for boiling water reactors).
- Recycling.
- Free release.

A significant experience has been developed for the decommissioning of the GREIFSWALD NPP where 5 WWER units (WWER is a Russian design equivalent to PWR) with a capacity of 440 MWe each have been in the process of decommissioning since 1991. As a result of German policy for waste minimization, less than 1% of the total mass of the facility will be disposed of as radioactive waste.

An interim storage building was built on-site for the storage of large components (reactor vessels, steam generators) and spent fuel. This 20 000 m^2 building hosts also some waste treatment tools such as a high pressure compactor, a band saw for large components, a scrap shear and a drying facility.

RVI from reactors 1 and 2 were segmented under water, whereas RVI from reactors 3–5 were transported in one piece into the interim storage facility for decay storage. The reactor pressure vessels from units 1–5 are stored in the interim storage facility.

At Würgassen NPP, a 650 MWe BWR operated from 1971 to 1995; the RVI were segmented under water in the 2000s using mechanical processes (band saw, jigsaw). Some parts of the RVI were segmented with water abrasive suspension cutting, an enhancement to the traditional abrasive water jet cutting that generates less secondary waste and delivers higher performance.

Hydraulic compacting and additional cutting with mechanical nibbler were used to reduce the total volume of waste from the project.

The reactor pressure vessel was segmented with a band saw for the vertical cuts of the flange and with water abrasive suspension cutting for the horizontal cuts of the flange and the remainder of the vertical and horizontal cuts.

At Stade NPP, a 660 MWe PWR operated from 1972 to 2003; the steam generators have been removed from the site intact and shipped to the STUDSVIK facility in Sweden for decontamination and recycling of the material.

The RVI were segmented in the late 2000s with water abrasive suspension cutting and mechanical cutting (band saw, compass saw).

The RPV was segmented in 2010 using primarily a high performance thermal cutting system (Oxygen Torch). The segmentation was performed in a sealed housing with ventilation system in order to prevent spreading of contamination or aerosol migration into other areas of the plant.

Experience in France

A significant experience is currently being developed for the decommissioning of Creys-Malville NPP, a fast breeder reactor with a capacity of 1200 MWe. Connected to the grid in 1986, the plant was shut down in 1998 further to a government decision. According to the decommissioning license issued in 2006, the plant is being decommissioned in three phases:

- *Phase 1, Sodium treatment*. Sodium is pumped from the vessel and transferred to a new facility that was built to transform sodium into soda through hydrolysis. Simultaneously, the large components – four primary pumps and eight intermediate heat exchangers – are removed from the vessel and dismantled. When the reactor vessel is completely drained, the sodium residues will be treated by carbonation.
- *Phase 2, Reactor vessel dismantling and reactor building remediation.* The dismantling reactor vessel is a very challenging issue because of the size of the component (20 m in diameter and height), the complexity of the structure (the primary circuit is integrated in the vessel) and the activation (the dose rate in the vessel is above 100 Sv/h). Conversely, the reactor building remediation will be facilitated because 80% of the equipment outside the vessel is not

contaminated and will be dismantled as conventional equipment. Only the vessel slab and the vessel pit require to be decontaminated prior to their declassification.

- *Phase 3, Demolition*. After removal of the contamination, the building will be declassified and demolished as conventional waste.

10.5 Sources of further information

Additional information may be found at the following websites:

IAEA, http://www.iaea.org/Publications/index.html.
OECD – Nuclear Energy Agency (NEA), http://www.oecd-nea.org.
European Commission (EC), http://ec.europa.eu/energy/nuclear/decommissioning/decommissioning_en.htm.
A map of the main documents issued by the previous organizations is available at http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote–EA/RWM/WPDD(2012)4&docLanguage=En.
US Department Of Energy (DOE), http://www.em.doe.gov/EM20Pages/DDFE.aspx.
US Nuclear Regulatory Commission (NRC), http://www.nrc.gov/about-nrc/regulatory/decommissioning.html.

10.6 References

IAEA Safety Standards Series No. Ws-r-5 – Decommissioning of facilities using radioactive material.
OECD – NEA 'Cost Estimation for Decommissioning – An International Overview of Cost Elements, Estimation Practices and Reporting Requirements'.
US DOE – Tailoring D&D Engineering/Design Activities to the Requirements of DOE Order 413.3A.

11

Managing site remediation: the Environmental Protection Agency (EPA) Superfund program

S. WALKER, B. DONOVAN, M. TAYLOR and
M. AGUILAR, US Environmental Protection Agency, USA

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Abstract: This chapter discusses US Environmental Protection Agency cleanup levels at radioactively contaminated Superfund remedial sites. The theme emphasized in this chapter is that within the Superfund remediation framework, radioactive contamination is dealt with in an identical way to chemical contamination, except to account for technical differences.

Key words: EPA radiation site cleanups, Superfund radiation site cleanups, CERCLA radiation site cleanups, NCP and radiation, remediation of radioactively contaminated sites.

Note: This chapter was prepared by Stuart Walker, Betsy Donovan, Melissa Taylor, and Mark Aguilar as part of their official duties for the US EPA. However, it has not been formally reviewed by the Agency, and it does not necessarily reflect the views of the US EPA.

11.1 Introduction

In the USA, agencies involved in nuclear materials regulation, site remediation, decontamination and decommissioning include the Nuclear Regulatory Commission (NRC), the Department of Energy (DOE), the Environmental Protection Agency (EPA), the Department of Defense (DOD), the US Department of Transportation (DOT), the Defense Nuclear Facilities Safety Board (DNFSB) and the individual states. This chapter focuses on the EPA Superfund remedial process and standards for cleanup of radioactively contaminated sites.

The EPA was created in 1970 to address a growing public demand for protection of human health and natural resources: cleaner water, air and land. EPA was given authority to improve and preserve the quality of the environment at national and global levels by implementing and enforcing environmental laws, setting environmental guidelines, monitoring pollution, performing research and promoting pollution prevention. The Comprehensive Environmental Response, Compensation and Liability Act CERCLA, also known as Superfund, was enacted to protect citizens from the dangers posed by abandoned or uncontrolled hazardous waste sites, including radioactively contaminated sites. A comprehensive regulation known as the National Oil and Hazardous Substances Pollution Contingency Plan, or NCP, contains the guidelines and procedures for implementing the Superfund program.

This chapter provides a brief overview of the approach used by EPA's Superfund remedial program to conduct cleanups at contaminated sites, including those that are contaminated with radionuclides, to ensure protection of human health and the environment. The chapter addresses how it is determined at Superfund sites if a site poses a risk to human health and the framework used to determine cleanup levels. The theme emphasized throughout the chapter is that within the Superfund remediation framework, radioactive contamination is dealt with in a consistent manner to chemical contamination, except to account for the technical differences between radionuclides and chemicals. This consistency is important as at every radioactively contaminated site being addressed under Superfund's primary program for long-term cleanup, the National Priorities List (NPL), chemical contamination is also present.

11.1.1 DOE facilities

DOE-owned facilities are subject to DOE's authority under the Atomic Energy Act (AEA), as well as the nation's environmental laws including CERCLA. Radionuclides are defined as CERCLA hazardous substances and in most cases, DOE facilities and sites are currently decommissioned under CERCLA. Requirements of CERCLA and other laws may be combined and integrated in an interagency agreement (IAG) or Federal Facility Agreement (FFA) that establishes the roles and responsibilities of DOE, EPA and the state in completing remedial actions. The IAG also establishes schedules and identifies milestone dates for completion of the cleanup. Remedial actions at a site covered by an interagency agreement often include decommissioning of facilities.

11.2 EPA Superfund remedy selection: introduction and risk assessment

Because every Superfund site is unique, cleanups must be tailored to the specific needs of each site. There are, however, two requirements established by CERCLA and defined in the NCP that must be met for every remedy selected. CERCLA requires that all remedial actions at Superfund sites must be protective of human health and the environment. Therefore, cleanup actions are developed with a strong preference for remedies that are highly reliable, provide long-term protection and provide treatment of the principal threat, to permanently and significantly reduce the volume, toxicity or mobility of the contamination. Superfund site cleanups should also protect groundwaters that are current or potential sources of drinking water, to maintain drinking water standards whenever practicable. In addition, CERCLA specifically requires Superfund actions to attain or waive the standards and requirements found in other state and federal environmental laws and regulations. This mandate is known as compliance with ‘applicable or relevant and appropriate requirements’ or ARARs.

The NCP establishes the requirements for the Superfund program. The NCP reiterates CERCLA’s goal of selecting remedies that protect human health and the environment, that maintain protection over time and that minimize untreated waste. The NCP sets forth nine criteria for selecting Superfund remedial actions. These evaluation criteria are the standards by which all remedial alternatives are assessed and are the basis of the remedy selection process. The criteria can be separated into three levels: threshold, balancing and modifying. The first two criteria are known as ‘threshold’ criteria. They are a reiteration of the CERCLA mandate that remedies must: (1) at a minimum assure protection of human health and the environment, and (2) comply with (or waive) requirements of other federal environmental laws, more stringent state environmental laws and state facility-siting laws. They are the minimum requirements that each alternative must meet in order to be eligible for selection as a remedy.

After the threshold criteria are applied, seven other NCP evaluation criteria are considered. Five of the criteria are known as the ‘balancing’ criteria. These are factors with which tradeoffs between alternatives are assessed so that the best option will be chosen, given site-specific data and conditions. The criteria balance long-term effectiveness and permanence; reduction of toxicity, mobility or volume; short-term effectiveness; implementability; and cost. The final two criteria are called ‘modifying’ criteria: information or comments from either (1) the state, or (2) the community may modify the preferred remedial action alternative or cause another alternative to be considered or selected.

Communities and/or the state often are able to provide valuable information on local history, citizen involvement and site conditions that bear on remedy selection. To ensure community participation, the EPA’s Superfund remedial program or the party conducting the cleanup usually conducts a number of activities. For example, EPA conducts community interviews and develops a community involvement plan to help EPA determine the community’s level of interest in the site, major concerns and issues. EPA creates an information repository and administrative record for every site and makes it available to community members. As required by CERCLA, EPA develops a document specifically for the community that explains the various cleanup options being considered, holds at least one public meeting to explain the options and invites the community to submit comments on them. EPA also makes funding available to eligible community members so they may obtain technical assistance to better understand the often complex issues associated with cleaning up a Superfund site. By identifying the public’s concerns, EPA is able to fashion a response that more effectively addresses the community’s need.

11.2.1 Risk assessment

To help meet the Superfund program's mandate to protect human health and the environment from current and potential threats posed by uncontrolled hazardous substance (both radiological and non-radiological pollutant or contaminant) releases, the Superfund program has developed a human health evaluation process as part of its remedial response program. The process of gathering and assessing human health risk information is adapted from well-established chemical risk assessment principles and procedures. The Superfund Baseline Risk Assessment provides an estimate of the likelihood and magnitude of health problems occurring if no cleanup action is taken at a site.

Risk-based cleanup levels

Cleanup levels for radioactive contamination at CERCLA sites are generally expressed in terms of risk levels (e.g. 10^{-4}), rather than millirem or millisieverts, as a unit of measurement. CERCLA guidance recommends the use of slope factors when estimating cancer risk from radioactive contaminants, rather than converting from millirem. Current slope factors are based on risk coefficients in Federal Guidance Report 13.

Compliance with the requirements of other federal environmental laws, more stringent state environmental laws or state facility-siting laws may be the determining factor in establishing cleanup levels at CERCLA sites. These requirements are known as ARARs. However, where ARARs are not available or are not sufficiently protective, at Superfund sites site-specific remediation levels are generally set for: (1) carcinogens at a level that represents an upper-bound lifetime cancer risk to an individual of between 10^{-4} to 10^{-6}, and (2) non-carcinogens such that the cumulative risks from exposure will not result in adverse effects to human populations (including sensitive sub-populations) who may be exposed during a lifetime or part of a lifetime, incorporating an adequate margin of safety. The specified cleanup levels account for exposures from all potential pathways, and through all media (e.g. soil, groundwater, surface water, sediment, air, structures and biota).

The 10^{-4} to 10^{-6} cancer risk range can be interpreted to mean that a highly exposed individual may have a one in 10 000 to one in 1 000 000 increased chance of developing cancer because of exposure to a site-related carcinogen. Once a decision has been made to take an action, the Superfund remedial program prefers cleanups achieving the more protective end of the range (i.e. 10^{-6}). The Superfund remedial program uses 10^{-6} as a point of departure and establishes Preliminary Remediation Goals (PRGs) at 1×10^{-6}.

To assess the potential for cumulative non-cancer effects posed by multiple contaminants, EPA has developed a hazard index (HI). The HI is derived by adding the non-cancer risks for site contaminants with the same target organ or mechanism of toxicity. When the HI exceeds 1.0, there may be concern for adverse health effects because of exposure to multiple contaminants. Radioisotopes of uranium are generally the only radionuclides for which EPA will evaluate the HI.

Combining radionuclide and chemical risk

Excess cancer risk from both radionuclides and chemical carcinogens should be summed to provide an estimate of the combined risk presented by all carcinogens. Exceptions would be cases in which a person cannot reasonably be exposed to both chemical and radiological carcinogens. Similarly, the chemical toxicity from uranium should be combined with that of other site-related contaminants in calculating the HI.

There are generally several differences between cancer slope factors (the cancer risk (i.e. proportion affected) per unit of dose used in EPA's Integrated Risk Information System chemical files) for radionuclides and chemicals. However, similar differences also occur between different chemical slope factors. In the absence of additional information, it is reasonable to assume that excess cancer risks are additive for the purposes of evaluating the total incremental cancer risk associated with a contaminated site.

Preliminary Remediation Goals

Preliminary Remediation Goals (PRGs) are used for site 'screening' and as initial cleanup goals if applicable. PRGs are not de facto cleanup standards and should not be applied as such. The role of the PRG in site 'screening' is to help identify areas, contaminants and conditions that do not require further federal attention at a particular site.

PRGs not based on ARARs are risk-based concentrations, derived from standardized equations combining exposure information assumptions with EPA toxicity data. PRGs based on cancer risk are established at 1×10^{-6}. PRGs are identified early in the CERCLA process. PRGs are modified as needed based on site-specific information.

Superfund risk and dose soil and water models

The EPA has developed a PRG for Radionuclides electronic calculator, known as the Rad PRG calculator. This electronic calculator presents risk-based standardized exposure parameters and equations that should be used for calculating radionuclide PRGs for residential, commercial/industrial and agricultural land use exposures, tap water and fish ingestion exposures. The calculator also presents PRGs to protect groundwater, which are determined by calculating the concentration of radioactively contaminated soil leaching from soil to groundwater that will meet Maximum Contaminant Levels (MCLs) or risk-based concentrations. The Rad PRG calculator may be found at the EPA website (http://epa-prgs.ornl.gov/radionuclides/).

To address ARARs that are expressed in terms of millirem per year, an approach similar to that taken for calculation of PRGs was also used to calculate soil 'compliance concentrations' based on various methods of dose calculation in another EPA tool, the 'Dose Compliance Concentrations', or DCC calculator. The DCC calculator equations are identical to those in the PRG for Radionuclides, except that the target dose rate (ARAR based) is substituted for the target cancer risk (1×10^{-6}), the period of exposure is one year to indicate year of peak dose and a dose conversion factor (DCF) will be used in place of the slope factor. The DCC calculator may be found at the EPA website (http://epa-dccs.ornl.gov/).

Superfund decommissioning models

The EPA Superfund remedial program has two risk assessment tools that are particularly relevant to decommissioning activities conducted under CERCLA authority. The Preliminary Remediation Goals for Radionuclides in Buildings (BPRG) electronic calculator was developed to help standardize the evaluation and cleanup of radiologically contaminated buildings at which risk is being assessed for occupancy. BPRGs are radionuclide concentrations in dust, air and building materials that correspond to a specified level of human cancer risk. The BPRG calculator may be found at the EPA website (http://epa-bprg.ornl.gov/).

The Preliminary Remediation Goals for Radionuclides in Outside Surface (SPRG) calculator addresses hard outside surfaces such as building slabs, outside building walls, sidewalks and roads. SPRGs are radionuclide concentrations in dust and hard outside surface materials. The BPRG and SPRG calculators include both residential and industrial/commercial exposure scenarios. The SPRG calculator may be found at the EPA website (http://epa-sprg.ornl.gov/).

To facilitate compliance with dose-based ARARs while conducting decommissioning activities under CERCLA, EPA developed two electronic calculators. These are the Radionuclide Building Dose Cleanup Concentrations (BDCC) and the Radionuclide Outside Hard Surfaces Dose Cleanup Concentrations (SDCC) electronic calculators. Both of these ARAR dose calculators are set up in a similar manner to the BPRG and SPRG calculators. They include the same exposure scenarios. Also, the equations in the scenarios are essentially the same except the ARAR dose calculators use dose conversion factors instead of slope factors, and a year of peak dose instead of risk over a period of exposure such as 30 years. The BDCC calculator may be found at http://epa-bdcc.ornl.gov/. The SDCC calculator may be found at the EPA website (http://epa-sdcc.ornl.gov/).

Superfund ecological risk model

The EPA Superfund remedial program is also developing the Radionuclide Ecological Benchmark calculator. This calculator provides biota concentration guides (BCGs), also known as ecological screening benchmarks, for use in ecological risk assessments at CERCLA sites. This calculator is intended to develop ecological benchmarks as part of the Superfund remedial guidance Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments. The calculator will develop ecological benchmarks for ionizing radiation based on cell death only.

11.3 EPA Superfund remedy selection: compliance with environmental laws and other guidance

Compliance with (or waiver of) requirements of other federal environmental laws, more stringent state environmental laws and regulations and state facility-siting laws is a cornerstone of CERCLA. Cleanups conducted under the Superfund program must comply with these laws unless a waiver is justified. These laws, as well as ARARs, assist in identifying preliminary remediation goals and alternatives. Complying with ARARs both during implementation and on completion of an action helps the lead agency define the ways in which the activity can be carried out in a manner that is protective of human health and the environment.

Because the diverse characteristics of Superfund sites preclude the development of prescribed ARARs, it is necessary to identify ARARs on a site-by-site basis. There are many radiation standards that are likely to be used as ARARs to establish cleanup levels or to conduct remedial actions. Some of the radiation standards most frequently used as ARARs at Superfund sites are the soil cleanup and indoor radon standards developed to address contamination at sites that are subject to the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA). When used as an ARAR at Superfund sites, the soil cleanup level for radium 226 and radium 228 combined, or thorium 230 and thorium 232 combined, is 5 picoCuries per gram (pCi/g) (0.185 Becquerel per gram (Bq/g)) above background, whereas the indoor radon level is 0.02 working levels inclusive of background. For a list of Likely Federal Radiation Applicable or Relevant and Appropriate (ARARs), see Attachment A of the Superfund remedial program's guidance (EPA 1997a).

11.3.1 Groundwater

One extremely important ARAR that should be noted are MCLs that are established under the US law for drinking water standards, called the Safe Drinking Water Act. The NCP states that contaminated groundwater should be restored to beneficial use, whenever practicable. This means that sites where the contaminated groundwater is a potential or current source of drinking water should be remediated to concentrations corresponding to drinking water standards (e.g. concentrations corresponding to MCLs or more stringent state drinking water standards). The Superfund program requires MCLs be met within the aquifer, not at the tap. The Superfund program's phased approach to addressing contaminated groundwater at CERCLA sites is discussed in *Presumptive Response Strategy and Ex-Situ Treatment Technologies for Contaminated Ground Water at CERCLA Sites, Final Guidance* (EPA 1996).

The Superfund remedial program's policy is to defer to state determinations of groundwater use when such determinations are based on a Comprehensive State Ground Water Protection Program (CSGWPP) that has 1) been endorsed by EPA, and 2) allows such determinations to be made at specific sites. In the absence of a CSGWPP, other state classification schemes and EPA's classification guidelines which use criteria defining groundwaters of sufficient quantity and quality to supply the needs of a single family household, are considered. The use of CSGWPPs at CERCLA sites is discussed in *The Role of CSGWPPs in EPA Remediation Programs* (EPA 1997b).

The current MCLs for radionuclides are set at 4 mrem/yr (0.04 millisieverts per year (mSv/yr)) to the whole body or an organ for the sum of the doses from beta particles and photon emitters, 15 picoCuries per liter (pCi/l) (0.555 Becquerels per liter (Bq/l)) for gross alpha, and 5 pCi/l (0.185 Bq/l) combined for radium-228 and radium-226, and 30 micrograms per liter of uranium. EPA has published concentration tables for each radionuclide that correspond to the 4 mrem/yr MCL, which can be found at the EPA website (http://www.epa.gov/safewater/radionuclides/pdfs/guide_radionuclides_table-betaphotonemitters.pdf).

11.3.2 Other criteria, advisories and guidance

Many federal and state environmental and public health agencies develop criteria, advisories, guidance and proposed standards that are not legally enforceable but contain information that would be helpful in carrying out selected remedies, or in determining their protectiveness. These materials are meant to complement the use of ARARs, not to compete with or replace them. Because they are not ARARs, their identification and use are not mandatory. These are known as to-be-considered (TBC) material. However, it is EPA's policy that dose-based (millirem or millisievert) recommendations should generally not be used at TBCs, instead site managers should use the 10^{-4} to 10^{-6} risk range or ARARs. Sometimes the Superfund remedial program develops guidance on interpreting a particular ARAR to assist site decision makers. These guidance documents on compliance with ARARs at radioactively contaminated CERCLA sites may be found at the following webpage, http://www.epa.gov/superfund/health/contaminants/radiation/radarars.htm.

11.3.3 Land use and institutional controls

The concentration levels for various media that correspond to the acceptable risk level established for cleanup will depend in part on land use at the site. Land uses that will be available following completion of a response action are determined as part of the remedy selection process considering the reasonably anticipated land use or uses along with other remedy selection factors. EPA's policies for how to determine a site's reasonably anticipated land use are discussed in *Land Use in the CERCLA Remedy Selection Process* (EPA 1995).

Institutional controls are generally included as a supplemental component to cleanup alternatives, not as a substitute for treatment or containment. Institutional controls are non-engineering measures – usually, but not always legal controls – intended to affect human activities in a way that prevents or reduces exposure to hazardous substances, pollutants or contaminants. Institutional controls usually restrict land use to prevent unanticipated changes in use that could result in unacceptable exposures to residual contamination, for example a zoning restriction that prohibits building residential properties at a site. At a minimum, institutional controls are intended to alert future users to the residual risks and the need to monitor for any changes in use. EPA's CERCLA policy states that if a site cannot be cleaned up to a protective level (i.e. generally within the 10^{-4} to 10^{-6} risk range) for the 'reasonably anticipated future land use' because it is not cost-effective or practicable, then a more restricted land use should be chosen that will meet a protective level.

Under the CERCLA statute where waste is left on-site at levels that would require limited use and restricted exposure to ensure protectiveness, a review will be conducted at least once every five years to monitor the site for any changes that may result in the remedy no longer being protective, including changes in land use. Such reviews need to analyze the implementation and effectiveness of any institutional controls with the same degree of care as other parts of the remedy. Should land use change in spite of land use restrictions, it will be necessary to evaluate the implications of that change for the selected remedy, and whether the remedy remains protective.

11.3.4 Community involvement tools

The Superfund remedial program has developed two tools to facilitate public involvement at radioactively contaminated Superfund sites which may be found at the following webpage, http://www.epa.gov/superfund/health/contaminants/radiation/radcomm.htm.

The first is a booklet entitled *Common Radionuclides Found at Superfund Sites*. The information in this booklet is intended to help the general public understand more about the various common radionuclides found at Superfund sites. The booklet contains 12 radionuclide-specific fact sheets that answer questions such as: How can a person be exposed to the radionuclide?, How can it affect human health?, How does it enter and leave the body?, What levels of exposure result in harmful effects? and What recommendations has EPA made to protect human health from the radionuclide?

The second is a video entitled *Superfund Radiation Risk Assessment and How You Can Help, an Overview*. This 19-minute video describes the Superfund risk assessment process for radioactive contamination: what it is, how it works and, most importantly, how members of the public can be involved.

11.4 EPA/NRC Memorandum of Understanding (MOU)

The EPA Superfund remedial program and NRC signed in 2002, a 'Memorandum of Understanding between the Environmental Protection Agency and the Nuclear Regulatory Commission: Consultation and Finality on Decommissioning and Decontamination of Contaminated Sites'. This section provides a brief overview of the origin of the Memorandum of Understanding (MOU), the major features of the MOU and how the MOU has been implemented site-specifically.

11.4.1 History and purpose of MOU

EPA and NRC developed the 2002 MOU in response to direction from the House Committee on Appropriations to EPA and NRC to work together to address the potential for dual regulation of NRC licensed facilities. Although both EPA and NRC have statutory authority to clean up these sites, the MOU provides consultation procedures between EPA's Superfund remedial program and NRC to eliminate dual regulation. Under the MOU, EPA and NRC identified the interactions of the two agencies for the decommissioning and decontamination of NRC-licensed sites and the ways in which those responsibilities will be exercised. Except for Section VI, which addresses corrective action under the Resource Conservation and Recovery Act (RCRA), this MOU is limited to the coordination between EPA, when acting under its CERCLA authority, and NRC, when a facility licensed by the NRC is undergoing decommissioning, or when a facility has completed decommissioning, and the NRC has terminated its license. It was expected that implementation of the MOU between the two agencies will ensure that future confusion about dual regulation does not occur regarding the cleanup and reuse of NRC-licensed sites.

11.4.2 Consultation procedures under the MOU

Under the MOU, NRC will contact EPA's Superfund remedial program when NRC determines one or more of the following four situations will or may occur during the license termination process:

- Groundwater contamination is present in excess of EPA drinking water standards, the MCLs.
- NRC is considering a restricted release under 10 CFR 20.1403.
- NRC is considering under 10 CFR 20.1404, a site-specific allowable dose of greater than 25 mrem/yr.
- Radioactive soil contamination in excess concentrations in Table 1 of the MOU (these concentrations correlate to a cancer risk of 1×10^{-4}, a non-cancer HI of 1, or a common federal soil ARAR).

These consultation triggers represent situations where EPA and NRC would benefit most from sharing knowledge and technical experiences to address the situation. These triggers were developed to identify the potential areas that would benefit most from an EPA/NRC dialogue and that would have the highest potential for CERCLA involvement. These consultation triggers provide information to industry and other stakeholders of when it is most likely that EPA and NRC will interact on these sites. Under the MOU, the site-specific consultation is to occur between EPA and NRC headquarter offices, and both headquarter offices will coordinate with their regional offices as appropriate.

Within EPA this MOU was distributed through a transmittal memo entitled ‘Distribution of Memorandum of Understanding between EPA and the Nuclear Regulatory Commission’ (OSWER 9295.8-06a, 9 October 2002). This transmittal note includes guidance to the EPA Regions to facilitate Regional compliance with the MOU and to clarify that the MOU does not affect CERCLA actions that do not involve NRC (e.g. the MOU does not establish cleanup levels for CERCLA sites).

11.4.3 Site-specific MOU consultations

NRC and the EPA Superfund remedial program have so far exchanged MOU consultation letters on 16 NRC sites. These sites are as follows:

- Rancho Seco Nuclear Generation Station, Herald, California.
- Connecticut Yankee Atomic Power Company Haddam Neck, Haddam Neck, Connecticut.
- ABB Incorporated, Windsor, Connecticut.
- Low Level Radioactive Burial, Beltsville, Maryland.
- Hematite Former Fuel Cycle Facility, Festus, Missouri.
- Mallinckrodt Inc., St. Louis, Missouri.
- NWI Breckenridge, Breckenridge, Michigan.
- Kirtland Air Force Base, Albuquerque, New Mexico.
- Battelle Memorial Institute, West Jefferson, Ohio.
- Kaiser Aluminum Specialty Products, Tulsa, Oklahoma.
- Kerr-McGee, Cimarron, Crescent, Oklahoma.
- Kerr-McGee, Cushing, Cushing, Oklahoma.
- Cabot Performance Materials, Reading, Pennsylvania.
- Saxton Nuclear Experimental Corporation, Liberty Township, Bedford County, Pennsylvania.
- Nuclear Fuel Services, Erwin, Tennessee.
- Union Carbide Corporation, Lawrenceburg, Tennessee.

The EPA Superfund remedial program has responded to each consultation request with a letter expressing its views on actions that NRC should consider that address the site-specific matter that triggered consultation. Over the course of consultations on 16 sites, there have been some reoccurring themes to EPA's views. Primarily, EPA's views are:

- Recommending that NRC consider selecting institutional controls to ensure that some NRC assumptions about future human exposure at the site are not exceeded.
- Recommending that NRC consider using more site-specific information when conducting dose assessment modeling.
- Recommending that NRC consider a flexible approach to groundwater protection that still ensures the public is not exposed to contamination levels over drinking water limits.
- Recommending that NRC consider an approach similar to how EPA implements supplemental standards under 40 CFR 192 as an ARAR when the UMTRCA soil standard of 5 pCi/g is not being met.

11.4.4 Sources of further information on the MOU

For further information on the MOU and its implementation, the materials discussed in this section are publicly available. The MOU, EPA's transmittal letter for the MOU to its regions, and the letters between EPA and NRC concerning site-specific implementation of the MOU are posted on EPA's website at http://www.epa.gov/superfund/health/contaminants/radiation/mou.htm.

11.5 Superfund site examples

The following three sites are examples that illustrate how the Superfund approach is used to clean up radioactively contaminated sites. These site examples should be viewed as illustrative, and not a comprehensive set of examples of how the Superfund approach could be used at sites.

11.5.1 Montclair/West Orange and Glen Ridge Radium Superfund sites

The Montclair/West Orange and Glen Ridge Radium sites were included on the Environmental Protection Agency's (EPA) Superfund NPL in 1985. The NPL contains the US highest priority cleanup projects based on a risk-based scoring system. The sites are located in New Jersey and include three non-contiguous areas located in five suburban residential communities, about 12 miles west of New York City. The sites cover a total area of approximately 250 acres, and include 900 residential and 24 municipal properties such as city streets, lots and parks.

Cleanup was determined to be necessary at 355 properties. A total of about 300 000 tons of contaminated soil and debris was removed from the project boundaries and transported by rail for disposal at regulated landfills. The EPA's soil cleanup effort took approximately 14 years to complete (1990–2004) and cost about $220 million. EPA pursued numerous allegations involving the source of the waste materials that were found at the Montclair/West Orange and Glen Ridge sites. No corporate assets were available to pursue for recovery of costs.

The US Radium Corporation, formerly known as the Radium Luminous Material Corporation, operated a facility from 1915 through 1926 in nearby Orange, NJ. The main activity at the facility involved the extraction and purification of radium from carnotite ore. At its peak, up to two tons of ore per day were processed at the plant. A large volume of process wastes, or tailings, containing residual radioactive materials was generated and dumped in undeveloped, low-lying and marshy areas. The US Radium Corporation also manufactured radium-based luminous paint and employed young women to paint watch dials and other instruments. Many of the women suffered, and some died, from the harmful effects of the radium paint. Two books, entitled *Radium Girls* and *Deadly Glow: The Radium Dial Worker Tragedy*, have been written on the history of the radium paint industry and its health effects. By the early 1930s, the radium industry had left the area as a result of the emergence of more economical sources in other countries as well as lawsuits concerning the workers' plight.

The Montclair/West Orange and Glen Ridge sites were originally identified in 1979 by the New Jersey Department of Environmental Protection (NJDEP) as part of a state program to investigate former radium processing facilities. A 1981 aerial gamma radiation survey of a 12-square-mile area surrounding a former ore processing facility identified a number of locations with elevated levels of gamma radiation. In 1983, follow-up ground investigations were conducted in the areas exhibiting elevated surface gamma radiation as identified by the aerial survey. Investigations found that the soil was contaminated primarily with radionuclides in the uranium decay chain, including isotopes of radium, thorium, uranium and lead. The main radionuclide of concern was radium-226, because its radioactive decay can cause elevated indoor concentrations of radon gas and radon decay products. Radon monitoring in the study areas found many homes with radon gas above the recommended action level. In addition, some properties exhibited elevated levels of indoor and outdoor gamma radiation.

In December 1983, the Centers for Disease Control (CDC) issued a health advisory, recommending immediate action to reduce human health risks at the sites. EPA recognized that cleanup of the radiological contamination would take a considerable period of time to complete, given the magnitude of the problem. In response to the CDC health advisory, EPA installed temporary ventilation systems to reduce indoor radon gas concentrations in several homes where radon measurements exceeded the recommended levels. Shielding (e.g. lead) was also installed in areas with elevated gamma radiation readings to reduce potential exposures. These interim engineering measures were designed to reduce residential risks within homes until a permanent remedy could be implemented.

In 1984 a pilot study at 12 properties, conducted by NJDEP, demonstrated that excavation of the contaminated soil was a feasible cleanup approach; however, problems associated with the interim storage and eventual disposal of the contaminated material were encountered. Fifteen thousand waste containers were stranded for three to four years in a residential neighborhood and rail yard, after the disposal facility revoked the disposal permit. A court battle ensued and eventually reached the US Supreme Court. A permanent remedy consisting of excavation and off-site disposal for all contamination above the established criteria was selected by EPA in 1990, after a disposal facility that could accept a large quantity of radiological waste became available.

EPA also initiated groundwater investigations at the sites in 1984 to determine if the soil contamination had impacted the groundwater. Thirty-six wells were installed and samples were collected from these wells from 1984 through 2001. The groundwater investigation for the project areas determined that no further action was necessary. Downgradient storm sewers were also sampled in 1992 and 2004 to determine if contaminated soil had migrated off the sites (Fig. 11.1).

11.5.2 Nuclear Metals, Inc. Superfund site

Starting in 1958 and continuing until November 2011, the Nuclear Metals, Inc. Superfund site in Concord, Massachusetts, has been used by various operators at

11.1 Lorraine Street home with temporary structural supports during excavation. Technician testing soil post excavation to make sure cleanup goals are met.

various times as a specialized research and metal manufacturing facility, which was licensed to possess and process low-level radioactive substances. At various times, site operators used depleted uranium, beryllium, titanium, zirconium, copper, acids, solvents and other substances at the site. Manufacturing at the site consisted mainly of producing depleted uranium munitions for the US Army. From 1958 to 1985, site operators disposed of manufacturing byproducts, including waste solutions containing depleted uranium mixed with copper, spent acid and lime, into an unlined holding basin located on-site. Other areas of the site, including but not limited to a bog, a cooling water recharge pond, septic leaching fields, a sweepings pile and a small landfill, are also believed to have been used for the disposal of manufacturing wastes. The facility was initially licensed by the NRC; however, in 1997, the Commonwealth of Massachusetts became an agreement state and subsequently the license was transferred from the NRC to the state. The Commonwealth terminated the radioactive materials license in November 2011 once the final entities had vacated the site and EPA assumed control.

From approximately the late 1980s to 2000, the current site owner/operator, Starmet Corporation (Starmet), performed certain site investigations and a partial cleanup of the site under the oversight of the Massachusetts Department of Environmental Protection (MADEP). In 1997, Starmet, with the financial support of the US Army, excavated approximately 8000 cubic yards of contaminated soils from the on-site holding basin and disposed of these soils at an off-site disposal facility licensed to accept low-level radioactive wastes.

During previous investigations, soils and groundwater beneath the site were found to contain elevated levels of depleted uranium and elevated levels of beryllium. Past sampling of sediments at the site has revealed elevated levels of depleted uranium, copper and volatile organic compounds.

The site was proposed for inclusion on the NPL on 27 July 2000. The site was listed on the NPL on 14 June 2001. Based on prior sampling at the site, EPA identified contaminants of concern that include depleted uranium, beryllium, copper and nitrate. EPA conducted its first time-critical removal action in 2002, which consisted of lining the holding basin with an HDPE barrier, capping the on-site landfill with the same material and installing a fence around the perimeter of the facility. Throughout 2006, the state Department of Environmental Protection, with army funding, removed thousands of drums of depleted uranium and hundreds of tons of depleted uranium metal and other wastes from the facility buildings (Fig. 11.2). Later, in 2008, EPA conducted a second time-critical removal action to address the hazardous and flammable materials inside the facility, which was prompted by a fire that occurred inside the facility in 2007 as a result of poor housekeeping practices. Another interim action was initiated in 2011, called a non-time critical removal action, or NTCRA, because it will take longer than 6 months to complete. This NTCRA will address the facility buildings and will consist of removing all interior equipment and materials and demolition

11.2 Drums containing depleted uranium and other wastes prior to a removal action conducted by MADEP in 2006.

of the facility buildings with off-site disposal. It is anticipated that this action will take three years to complete.

At the same time, the Remedial Investigation Sampling Program was also taking place. Field work consisted of installing over 50 groundwater monitoring wells, collecting over 200 groundwater samples, 80 surface water samples, 400 sediment samples and 450 soil samples. The Remedial Investigation was completed in 2011. Currently, the Human Health and Ecological Risk Assessments are in Final Draft. Once the risk assessments are complete, the Remedial Investigation Report and Feasibility Study will further evaluate the nature and extent and type of contaminants in the environment, and various alternatives to address those contaminants which pose an unacceptable risk. A final remedy for the site will then be selected in a Record of Decision currently scheduled for 2013.

11.5.3 Rocky Flats

The Rocky Flats site located in Golden, Colorado is a former nuclear weapons manufacturing plant that was listed on the NPL in 1989 as a result of the presence of radioactive contamination. Investigation of the site revealed large quantities of volatile organic compounds (VOCs), plutonium, beryllium, uranium and

11.3 Size reduction of gloveboxes in building 771 (once known as the most contaminated building in America).

americium that had contaminated both groundwater and soil. The cleanup of this site required the decommissioning, decontamination, demolition and removal of more than 800 structures, including six plutonium processing and fabrication building complexes; removal of more than 500 000 cubic meters of low-level radioactive waste; and remediation of more than 360 potentially contaminated environmental sites. The cleanup was completed in 2005. Cleanup activities were organized under the Rocky Flats Cleanup Agreement (RFCA), which established a regulatory framework for decommissioning between EPA, DOE and the State of Colorado. This agreement determined the lead regulatory agency for different areas of the site, establishing the State of Colorado as the lead regulatory agency for the industrial area where D&D activities would occur.

Several technologies were employed in the D&D of the Rocky Flats site to address specific contamination issues. The use of specialized technology, described below, allowed the decontamination of plutonium process equipment from transuranic waste (TRU) to low-level waste (LLW) classification. This step reduced the size-reduction effort and lowered the labor requirements and safety concerns involved in the decontamination of plutonium process equipment. Instrumentation was also developed that allowed for the detection of contamination levels in the range of 10–100 million dpm alpha. Furthermore, cerium nitrate and proprietary chemicals were used to address in-glovebox decontamination (Fig. 11.3).

In total, cleanup activities at Rocky Flats removed over 15 000 cubic meters of TRU and 500 000 cubic meters of LLW. D&D efforts continued on the 1308 acre (529.3 hectares) Central Operating Unit until 2006, when physical completion of the cleanup was achieved. DOE has retained the 1308 acre COU in perpetuity and will continue to monitor it under the Rocky Flats Legacy Management Agreement (2006). Costs for the ten-year cleanup of the Rocky Flats site totaled $10 billion in 2005 dollars (€6.5 billion), and resulted in the removal of 6240 acres (2525.2 hectares) from the NPL in May of 2007. Notably, cleanup was achieved nearly one year ahead of schedule and $530 million (€344 million), under the contract budget. Management of nearly 5000 acres of the decontaminated land has been transferred to the US Fish and Wildlife Service, and has been designated the Rocky Flats National Wildlife Refuge.

11.6 Conclusions

Actions under Superfund must result in the protective cleanup of sites. The CERCLA framework for addressing hazardous sites ensures that risks from radiological contamination will be addressed in a manner consistent with risks from non-radiological contamination, except to account for technical differences posed by radionuclides, and that cleanups for all contaminants will achieve protection of human health and the environment. The same set of principles and decision making criteria apply equally to both chemical and radioactive hazards. The goal is to provide lasting, protective site restoration while taking into account the cost and achievability of different approaches to attaining these protective goals.

11.7 Future trends

EPA's Superfund program regularly faces challenges at sites contaminated with NORM and radioactively contaminated legacy sites which are no longer operating but need some form of remediation to address contamination resulting from past operations. For example, radium and thorium residential sites and DOE sites are continuing issues for the Superfund program. In recent years, the Superfund program has become increasingly involved in the remediation of former uranium mines. Because of the extent of contamination, this trend is likely to continue.

From 1944 to 1986, nearly 4 000 000 tons of uranium ore were extracted from lands in Arizona, New Mexico and Utah, primarily on Navajo Nation land. Today the mines are closed, but a legacy of uranium contamination remains from more than 500 abandoned uranium mines, homes built with contaminated mine waste rock and contaminated water wells.

EPA has led the development and implementation of a coordinated Federal plan to address the uranium legacy on the Navajo Nation. This federal Five-Year Plan was developed in 2008 in conjunction with the Bureau of Indian Affairs, Indian Health Service, the Agency for Toxic Substances and Disease Registry, DOE, NRC, and the Navajo Nation. The federal Five-Year Plan outlines the federal commitments to address contaminated homes, water sources, and abandoned uranium mines, and lays out a framework for addressing the highest risks while gaining a solid understanding of longer-term problems.

In addition to the federal Five-Year Plan to address legacy uranium mining on tribal lands, EPA, the Agency for Toxic Substances and Disease Registry, the Department of Energy, the Nuclear Regulatory Commission (NRC), the Department of the Interior, and the State of New Mexico developed a Five-Year Plan in 2010 that lays out the goals, objectives, and tasks for multiple agencies to assess and address health risks and environmental impacts resulting from the extraction, processing, disposal, and releases from legacy uranium mining and milling activities in the Grants Mining District in New Mexico. While the Grants Mining District has been the primary location of uranium mining historically, there are additional legacy uranium mines located throughout New Mexico. In deciding which uranium mines to investigate and prioritize, the New Mexico Five-Year plan focuses on legacy uranium mines with reportable production and mining activities with surface disturbances. There are 97 legacy uranium mines in the district with the potential for physical hazards such as open adits and shafts, and for potential releases to soil, surface water and groundwater.

Although significant progress has been made in addressing the contamination from prior uranium mining, the extent of the contamination indicates that future challenges will remain for some time in addressing these issues.

11.8 Sources of further information

For more information and copies of EPA Superfund remedial program guidance documents for addressing radioactively contaminated CERCLA sites, see the EPA's Superfund Radiation webpage at http://www.epa.gov/superfund/health/contaminants/radiation/index.htm.

For more information and copies of EPA Superfund remedial program guidance documents for developing cleanup levels for long-term CERCLA sites, see EPA's Remedy Decisions webpage at http://www.epa.gov/superfund/policy/remedy/sfremedy/index.htm.

Both of these webpages contain numerous OSWER Directives, which are EPA's official guidance for the Superfund program, and other material that is useful for cleaning up CERCLA sites.

11.9 References

EPA (1995), Land Use in the CERCLA Remedy Selection Process, Washington, DC. Available from: http://www.epa.gov/superfund/community/relocation/landuse.pdf [accessed 9 January 2013].

EPA (1996), Presumptive Response Strategy and Ex-Situ Treatment Technologies for Contaminated Ground Water at CERCLA Sites, Final Guidance, Washington, DC. Available from: http://www.epa.gov/superfund/health/conmedia/gwdocs/gwguide/index.htm [accessed 9 January 2013].

EPA (1997a), The Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination, Washington, DC. Available from: http://www.epa.gov/superfund/health/contaminants/radiation/pdfs/radguide.pdf [accessed 9 January 2013].

EPA (1997b), The Role of CSGWPPs in EPA Remediation Programs, Washington, DC. Available from: http://www.epa.gov/superfund/health/conmedia/gwdocs/pdfs/role.pdf [accessed 9 January 2013].

12

Quality assurance and audits in the nuclear industry in the USA

D. TAGGART, Taggart Quality Consulting, USA

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Abstract: This chapter discusses the elements of the nuclear quality assurance program, a historical perspective of its development and the characteristics and objectives for quality assurance audits. The chapter addresses the relevance of auditing to the nuclear industry and how it is integrated within the overall nuclear quality assurance program. It includes details such as the types and application of audits, the phases of the audit process, senior management support for the audit process, industry standards associated with the nuclear audits, a historical perspective and challenges associated with audits.

Key words: quality assurance, quality audits, quality systems, third-party audits, performance-based audits.

12.1 Introduction

Quality assurance (QA) and auditing programs are critical to the success of nuclear projects. This chapter discusses the elements of the quality assurance program as well as a historical perspective of its development in the nuclear industry. It further discusses the characteristics and objectives for quality assurance audits in support of nuclear projects. The chapter addresses the relevance of auditing to the nuclear industry and how it is integrated within the overall nuclear quality assurance program. It includes details such as the types and application of audits, the phases of the audit process, senior management support for the audit process, industry standards associated with the nuclear audits, a historical perspective and challenges associated with audits.

12.2 Overview of quality assurance standards and requirements

12.2.1 Historical background

Quality assurance has been applied to the military and space programs since World War II. For instance, each service branch in the US military had its own unique quality requirements such as MIL-Q-5932A, B and C for the Air Force and MIL-Q-21549A and B for the Navy. In 1959, MIL-Q-9858 'Quality Program Requirements' replaced the previous requirements and became the mandatory of quality assurance requirement for the US Department of Defense. In addition, as the National Aeronautics and Space Administration (NASA) developed its own standards based on the military standard, these requirements were further expanded upon. These early quality standards provide the basis on what was to later become nuclear quality assurance standards.

During the 1960s, there was an expansion of nuclear plants being built and planned to be built. During this period, the Atomic Energy Commission (AEC) adopted a broader definition of quality assurance. This was based on the early experiences of both the naval and commercial nuclear power industry at that time. In 1965, the AEC developed Appendix A to 10CFR, Part 50 and that established Criterion 1 'Quality Standards and Records'. These standards required the use of national standards and codes.

In 1968, during the AEC hearings for the Zion Nuclear Plant, the need for greater specificity of quality assurance requirements was identified by the Atomic Safety and Licensing Board. This was a crucial time in the development of quality assurance requirements. The Zion QA Plan served as the model for other utilities. It was based on MIL-Q-9858A and had been modified for application for the utility. The Zion QA Plan also used input from both the navy and NASA quality assurance requirements.

One of the most important sources of input was AEC Reactor Development and Technology (RDT) RDT F2-2 'Quality Assurance Program Requirements', an internal standard used for the AEC development and test reactors. This document and MIL-Q-9858A formed a major basis of 10CFR50, Appendix B.

The 10CFR50 Appendix B QA requirements first appeared in the US Federal Register in April 1969. In response to public input and safety concerns, the AEC provided additional guidance through development of Safety Guides. In 1973, the AEC revised the name 'Safety Guides' to 'Regulatory Guides' as it is today. In parallel to this regulatory effort, the nuclear industry itself was very active in the development of its own industry standard to support the design, construction and operation of nuclear plants. This effort was through the ASME Boiler Pressure and Vessel Code and the American National Standards Institute N45.2 Series. Up until 1967, the ASME Boiler and Pressure Vessel Code primarily covered inspection requirements for nuclear vessel fabrication. In 1967, this was expanded to quality control and non-destructive examination requirements. The code was further expanded in scope to apply to primary containment vessel manufacturers. The code further required a quality assurance program subject to ASME evaluation and approval. This evolved to requiring a QA program for the design, manufacturing and installation of vessels, piping, pumps, valves and other pressure-retaining components. In 1971, these broadened to be responsive to all 18 of the 10CFR50 Appendix B criteria (Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants).

Parallel to this activity were the industry efforts being pursued by the N45 American Standards Committee. This effort included the development of ANSI

N4.2 in 1972 for general industry use. This standard was endorsed by the AEC in Regulatory Guide 1.28 (Quality Assurance Program Criteria, Design and Construction) as an acceptable basis for satisfying 10CFR 50 Appendix B. In 1974, the ASME Boiler and Pressure Vessel Code incorporated quality assurance requirements into Section NA 4000 of Section III that were more compatible with the industry QA Standard ANSI N45.2. During this period, a number of N45.2 series quality assurance standards were developed and became known as the 'N45.2 QA daughter standards'.

In January 1975, an amendment to 10CFR50 was issued and expanded on Criterion 1. In 1982, the addition of Three Mile Island related requirements were added to 10CFR50.34, which supplemented 10CFR50, Appendix B.

NQA-1, 'Quality Assurance Program Requirements for Nuclear Facilities' was initially published in 1979 by ASME. This document consolidated the 'N45.2 QA daughter standards' that had been previously developed. NQA-1 has been revised a number of times. This most recent was endorsed by the Nuclear Regulatory Commission within Regulatory Guide 1.28.

In 1983, the US Congress directed the NRC to study how to improve the quality of nuclear plant design and construction. The need was based on a number of quality assurance problems that occurred during the design and construction of the Diablo Canyon, Marble Hill, Midland, South Texas and Zimmer nuclear power plants. The resultant study is included in NUREG-1055, 'Improving Quality and the Assurance of Quality in the Design and Construction of Nuclear Plants'. The study concluded: '. . . The primary cause of the quality problems in the nuclear industry was shortcomings in management. Real improvements to address this root cause must come from the industry itself. The NRC cannot write a regulation that will achieve good utility management [and] . . . cannot inspect quality into the plant'.

Internationally, the International Organization for Standardization standard ISO 9001 (Quality Management Systems – Requirements) had been incorporated into the laws of a number of European countries.

The AEC Reactor Development and Technology (RDT) issued RDT F2-2 in 1969 and the document was amended several times between 1969 and 1983. In 1985, RDT F2-2 was withdrawn in favor of a single consensus standard for reactor and technology development programs and ANSI/ASME NQA-1-1983 standard was endorsed for application. The US Department of Energy (DOE) Order 5700.6 (Quality Assurance) was issued in 1981 and DOE Order 5700.6C referenced ASME NQA-1, ASME NQA-2, ASME NQA-3 and a number of DOE and other standards.

12.2.2 Quality assurance program requirements

10CFR50, Appendix B

As discussed earlier, 10CFR50, Appendix B provides the regulatory requirements for nuclear projects in the USA. Appendix B consists of 18 criteria that form the basis of a quality management process for nuclear projects. It includes requirements for various key phases and activities for nuclear projects plants and fuel reprocessing plants. A copy of 10CFR50 Appendix B may be found on the US NRC webpage at www.nrc.gov. The following are the 18 criteria topics contained within 10CFR50, Appendix B:

I Organization.
II Quality Assurance Program.
III Design Control.
IV Procurement Document Control.
V Instructions, Procedures, and Drawings.
VI Document Control.
VII Control of Purchased Material, Equipment, and Services.
VIII Identification and Control of Materials, Parts, and Components.
IX Control of Special Processes.
X Inspection.
XI Test Control.
XII Control of Measuring and Test Equipment.
XIII Handling, Storage and Shipping.
XIV Inspection, Test, and Operating Status.
XV Nonconforming Materials, Parts, or Components.
XVI Corrective Action.
XVII Quality Assurance Records.
XVIII Audits.

The requirement for audits is further described in Section 12.3.

The application and detailed methods in meeting the criteria vary with complexity. For instance, established processes for design engineering, procurement and corrective action can be quite extensive and rigorous.

The requirements of 10CFR50 Appendix B also form the basis for new nuclear plant quality assurance programs being licensed under the provisions of 10CFR Part 52 including Design Certification (DC), Early Site Permit (ESP) and Combined License (COL) quality related activities.

The QA Program requirements also form the basis for quality assurance requirements applied to dry cask storage facilities and decommissioning activities. Recently the nuclear industry through the Nuclear Energy Institute has developed a QA Program Template to be used to support ESP and COL applications. This is outlined within NEI 06-14 ‘Quality Assurance Program Description’. This has been reviewed and accepted by the NRC as a QA Program Template on which to base a QA Program.

12.2.3 The International Atomic Energy Agency (IAEA)

The IAEA is the international organization established in 1957 as the world’s ‘Atoms for Peace’ organization within the United Nations family. The Agency works with its member states worldwide to promote safe, secure and peaceful nuclear technologies. The IAEA develops nuclear safety standards to promote the achievement and maintenance of high levels of safety. As part of their mission, the IAEA has developed 75-INSAG-3 Rev. 1, 'Basic Safety Principles for Nuclear Power Plants'. This international document serves as an international consensus of the basic safety principles for current and future nuclear reactors worldwide. It provides both the objectives and principles reflecting the best industry safety policies. It includes expectations on quality assurance provisions as well a number of other provisions such as safety culture, self-assessment, human factors, peer reviews, safety assessment and verification, operating experience, proven engineering practices, accident mitigation, accident prevention and defense in depth.

12.2.4 The International Organization for Standardization

The International Organization for Standardization, Quality Management System Requirements, ISO 9001-2000 establishes requirements for a quality management system for organizations that wish to demonstrate ability to consistently provide products that meet customer and applicable regulatory requirements. The focus is to enhance customer satisfaction, and this provides for a management process of continual improvement to the system. The standard also focuses on conformity to customer and applicable regulatory requirements. Within nuclear projects, a number of facilities and suppliers have applied such a standard to their quality management systems. Some of the elements are compatible; however, the NRC has concluded that it is not fully equivalent to current regulatory requirements. This analysis is contained in a detailed gap analysis between ISO-9001-2000 and 10 CFR Part 50, Appendix B that was provided in NRC document SECY-03-117. The major differences identified in the gap analysis performed by the NRC were that ISO-9001 does not require independence in the design review process, does not require the inspectors to be independent from the individuals who performed the work and does not require the audit program to consist of independent auditors. The gap analysis also concluded that ISO-9001 programs are audited by auditors under a commercial contract to the supplier and could result in a possible conflict of interest.

However, a number of organizations supplement their regulatory programs with the ISO program, and they often apply the ISO program to the non-safety related aspects of their scope.

12.3 Special challenges of nuclear audits

12.3.1 Background

Quality assurance requirements for conducting audits originate back to the original AEC QA criteria for Zion. The requirements were included in Criteria 15 and stated: 'The applicant-licensee should establish a system of audits to assure compliance with all aspects of the quality assurance program and to determine the effectiveness of the program'. These requirements have been updated and independent, planned and periodic audits have been formally required within the nuclear power industry since the issuance of 10CFR50, Appendix B.

Specifically, Criteria 18 of 10CFR50 Appendix B state the following:

> A comprehensive system of planned and periodic audits shall be carried out to verify compliance with all aspects of the quality assurance program and to determine the effectiveness of the program. The audits shall be performed in accordance with the written procedures or check lists by appropriately trained personnel not having direct responsibilities in the areas being audited. Audit results shall be documented and reviewed by management having responsibility in the area audited. Follow-up action, including reaudit of deficient areas, shall be taken where indicated.

Other prescriptive requirements have been developed over the last 40 years and were included within ANSI N45.2.12 and N45.2.23, and then later incorporated within NQA-1.

12.3.2 Audit objectives

The objective of the audit process is to independently determine program effectiveness, adequacy and implementation including adherence to established quality program requirements. The schedule frequency for the conduct of audit is defined by quality assurance requirements and may vary as a result of regulation and activity. Normally, audits are performed on an annual or biennial basis, or at least once during the life of the project. Supplier audits are normally done on a triennial basis. The frequency is normally measured from audit entrance date to the entrance date for the next required audit.

Audits are normally always announced before they are conducted. However, there may be a need to conduct a special unannounced audit. This need may be derived to independently assess an emerging issue of technical nuclear safety or quality consequence.

Audits are more than just meeting a regulatory commitment; they are intended to provide independent feedback to senior and responsible line management. They also provide insights and feedback on the values and principles by which organizations operate.

All audits are required to be performed in accordance with written procedures or checklists. Elements selected to audit are evaluated against specified requirements. Objective evidence is examined to the depth necessary to determine if the elements are implemented effectively. They further provide the required confidence by verifying that plant systems, structures and components will perform their intended function, the 'end products' of processes meet the intended objectives of the processes and programmatic measures are in place to meet regulatory commitments and are being implemented consistently.

An effective assessment process should include the expectation that auditors exhibit a questioning attitude by challenging assumptions, investigating anomalies and considering potential adverse consequences of their identified audit findings.

The independent feedback provided by the audit process contributes to the nuclear project's success through diversity of thought and serves as prevention to organization 'groupthink'.

Conditions requiring prompt corrective action are reported immediately to the management of the audited organization.

12.3.3 Management support of the audit process

The role of senior management is critical for the success of the audit process. Senior management needs to embrace the audit process as a means to improve overall program adequacy and effectiveness. Improvement comes from an introspective search for performance shortfalls. Independent audits also place independent 'eyes on the problem' and provide an opportunity to reinforce management standards. The quality organizations and audit processes need to be leveraged by senior management to help in establishing a culture of excellence throughout the organization.

It should be an expectation that senior management get and receive perceptions as well as facts from the audit process. This should include potential latent organizational weaknesses that can aggravate minor events.

12.3.4 Expertise and training of auditors

The qualification requirements for auditors and the selection and application of other audit team members for an effective audit process are defined in current industry standards such as NQA-1. Lead auditors (also referred to in the industry as Audit Team Leaders) and auditors are certified that they are qualified in accordance with pre-established criteria that are consistent with regulatory requirements and commitments. This includes minimal experience requirements, education, specific training in auditing conduct and satisfactory completion of audit performance in a training capacity.

The audit organization's technical capabilities should reflect a diagonal slice of the overall organization as a whole in the areas being assessed. Often times, this is met by the addition of a technical specialist acquired to be part of the overall audit team. Technical specialists, when used, are also indoctrinated, trained and qualified in accordance with regulatory requirements and commitments.

The auditing organization selects auditors who are independent of any direct responsibility for the performance of the activities being audited. Independence is critical to ensure there is no bias during the assessment process. Such independence is required by the quality assurance standards and requirements for nuclear projects. Another key aspect for a successful audit is that the audit team has the sufficient authority and organization freedom to make the audit process meaningful and effective.

Staffing an audit department requires a staff with a good technical foundation. There should be a mix of direct line management experience in conjunction with a broad based knowledge of the quality field and an understanding of how to apply this knowledge to each functional area of the organization being assessed. The auditing organization should also leverage external peer resources to ensure standards are current to the industry.

The lead auditor, prior to the start of the audit, ensures that the assigned audit team has the collective experience or training commensurate with the scope, complexity or special nature of the activity to be audited.

12.4 Conducting an audit

12.4.1 Summary of internal, supplier and third-party audits

Internal audits of work to verify QA Program compliance typically are performed at intervals to exceed 12 months or at least once during the life of the work, whichever is shorter.

External audits (or supplier audits) for compliance and effectiveness are performed as a minimum, triennially or at least once during the life of the work, whichever is shorter. Regularly scheduled external audits are typically supplemented by additional audits of specific subjects when necessary to provide an adequate assessment of compliance or effectiveness. Preaward surveys, if applicable, may serve as the first triennial audit.

12.4.2 Approach for audits

Audits should gather information using both ‘compliance-based’ and ‘performance-based’ techniques.

Performance-based audit techniques differ from compliance-based approaches in that these are performed to emphasize safety and reliability, not trivial matters that have no real impact on project or facility performance. The key elements of performance-based auditing are the following:

- Performing direct observation of work in progress (e.g. welding, testing, construction and training) or independently verifying work (e.g. engineering calculations, safety analysis).
- Focusing on activities that most directly impact operations, safety, reliability, maintainability and meeting license requirements – not on trivia.
- Proving an evaluation of the extent that systems, structures and components or activity objectives are being achieved.
- Interviewing personnel to ascertain their knowledge.

- Using team members with the applicable technical expertise and capability to accurately observe and evaluate an activity.

Compliance-based auditing is the traditional approach that has been developed early in the development of nuclear quality assurance programs. It is still important to ensure that quality programs and activities are consistent with regulatory requirements. Historically, compliance-based auditing tended to limit its activities to an assessment of whether regulatory requirements were incorporated into plant programs. This approach can simply be one-to-one correlations of the requirements to the implementation practices established. The key elements of compliance-based audit techniques are the following:

- Reviewing completed documentation and records as required by procedures and quality programs to determine whether an activity was performed.
- Reviewing the procedures to the quality program requirements and regulatory requirements for consistency.
- Reviewing completed training records.

Both audit approaches have their benefits and disadvantages. It is recommended that the audit process include both approaches. Performance-based auditing starts with the direct observation of activities that are important to safety and reliability. Identified discrepancies and uncertainties lead to assessing other activities. The approach looks at a problem and inquires as to the implications or effects of the problem. If the activity is not available for observation, then an alternative approach is to discuss the activities with responsible personnel and to review pertinent documents. However, direct observation is always the preferred method. Interviews and documentation reviews are used by the audit team to verify direct observations. Where compliance-based auditing will focus on the documentation reviews, sometimes the documentation may differ from the actual activity. Therefore, it is critical that the auditing process include both approaches.

12.4.3 Planning an audit

After the lead auditor has been selected by the management of the auditing organization, the first activity to be completed is to develop the audit plan and to identify the team members. Audit team selection should include members independent of areas that they will be assessing. For complex or high risk regulatory areas to be assessed, the audit team composition should include industry ‘peers’ or industry technical experts.

The audit plan is the ‘starting-point’ for any audit. The plan will contain valuable information of key documents and procedures, and sometimes key equipments that will be assessed. The scope statement in the plan cues the team as to where it should focus its time and effort. The audit plan should have the following sections:

- Audit Identification.
- Activity to be Audited.
- Organization(s) to be Notified.
- Audit Scope.

The Audit Scope should include a description of the activities, issues, concerns and programs to be audited. This provides the audit team with direction and emphasis. The Scope will define systems, components, programs or activities to be assessed. A well-defined Scope precludes an uncontrolled open-ended assessment. However, it is very important to not limit the time for an adequate review.

- Previous Audits or Assessments.
- Previous Problems or Audit Finding(s).
- Audit Checklists that identify the key activities to be audited in list or outline form. Sometimes such checklists may be predefined into auditing procedures or instructions.
- Supplemental Information that may be needed to expand or clarify points within the plan.
- Schedule
- Notification Date as to when the audit will be formally identified to the audited organization.
- Audit Performance Dates including identification of the Pre-audit Conference and Post-audit Conference.
- Date that the Audit Report will be issued. This is required by regulations and standards to be issued within 30 calendar days.
- Identification of the audit team members by name and classification (e.g. auditor, technical specialist, observer). This section needs to ensure independence of the audit team to provide an objective perspective and to ensure the audit team has the technical and program capability to evaluate the scope of the audit. Audit team selection should consider industry ‘peers’ or industry experts, especially for complex or high risk regulatory areas being assessed.
- Identification of Audit Plan approval by the lead auditor and responsible auditing organization management where required by internal procedures.

12.4.4 Conduct of the audit

Pre-audit Conference

The assigned lead auditor begins the audit with a Pre-audit Conference. During the audit conduct, the lead auditor will perform many different management tasks including acting as a liaison to solve problems arising during the audit, mentoring the audit team members, validating objective evidence, keeping the audit on schedule and keeping the audited organizations up-to-date on preliminary findings and recommendations. These roles should be discussed by the lead auditor with the audit team prior to the Pre-audit Conference.

At the Pre-audit Conference, the scope of the audit will be reviewed with the audited organization, the points of contact between the auditing and audited organizations are established, times for periodic daily briefings are scheduled, and confirmation of the Post-audit Conference schedule will be established. During the Pre-audit Conference, the participants will identity key contact personnel from the audited organization who are responsible and knowledgeable to interface with the audit team.

Monitoring audit performance

During the conduct of the audit, good on-going communication eliminates misconceptions, unwarranted findings and permits work on problem areas to begin immediately.

It is extremely important that the audit team internally coordinates and frequently communicates. Typically, this will include a daily debrief among the audit team members and it is encouraged that there be good team synergism and open discussion. The internal team debriefs should address observations, perspectives and any preliminary conclusions.

The attitude and audit team environment are critical. The attitude should be one of constant questioning, persistent second checking, creatively inquisitive, aggressive following-up on leads and contingency planning. Additionally, auditors should not always limit their reviews to their own discipline if there is a need to pursue a potential issue. It is also important that potential issues identified consider the training aspects related to the identified problem. Audit team members should also actively pass on potential leads of issues to other audit team members during the course of the assessment.

Typically, the audit team member's role during the audit is to observe, review documentation and interview key personnel connected with the assigned activity. For design audit, the role may be to perform independent engineering analysis to validate the design being assessed. Based on object evidence obtained from these observations, documentation reviews and interviews, the team member develops preliminary audit conclusions, potential findings and recommendations for presentation to the audit team and subsequently to the audited organization at the Post-audit Conference.

Interviews can provide input to the audit team not only on validation of the practices applied, but also on the training and knowledge of the process of the individual being interviewed. The audit team should be sensitive in recognizing 'body language' tools (defensive or evasive behaviors) to identify potential problem areas that warrant further investigation and validation. As in all phases of the audit process, preparation prior to the interview is important. Such preparation needs to include thorough research of the subject matter. Each interview needs to have a purpose that will support the overall objective of the audit. Preparation for the interview should include development of a series of questions. The setting for the interview itself is important to ensure that the location provides a comfortable setting and avoids distractions. When meeting with the interviewee, the interviewer needs to explain the objective of the interview as part of the audit process and needs to include how the information will be used. Clarification needs to be made as to the need for any information to be provided in confidence should that be necessary. There are four types of questions that may be used in the interview process. These are open, closed, probing and leading. Each approach has its benefits. Open questioning allows the person being interviewed to structure their response. This has the benefit of providing information beyond the specific question being asked and may include the individual's perceptions and attitudes. An example is 'Please provide a summary of your experience and training that is pertinent to your function'. The closed question is structured to limit the response with a simple phrase. For instance, 'Have you completed the quality assurance program training class?'. Probing questions are used to obtain clarifying information. An example is 'Please explain more about . . .'. A leading question is one that has a hidden agenda. Leading questions are discouraged. It is very important that the interviews be conducted in a professional and respectful manner. The interview should not be overly aggressive nor should it appear to be an inquisition. At the conclusion of the interview, the auditor should close by thanking the interviewee.

During the conduct of the audit, documentation of the areas being assessed by the auditor including the interviews is extremely important. Note taking and identification of key documents reviewed, results of walkdowns, personnel interviewed and activities observed including time and location are critical to provide 'foot prints' of the audit investigation and assessment. Interview notes should be completed as soon as possible after the interview. This documentation will serve as objective evidence to support the audit's conclusions.

Another aspect used by the audit team includes facility walkdowns where applicable. The audit process should always consider actual facility and system walkdowns to provide additional perspective and status of the material condition. This is used to supplement the audit results. For supplier facilities, this would include a walkdown of the manufacturing or fabrication facility. For construction, this would include a walkdown of the construction site where key activities are being performed. For an operating plant, this would involve a walkdown of key plant systems and components.

Post-audit Conference

At the conclusion of the audit assessment phase, the audit team will meet with responsible audited management to review the results and observations of the audit. The Post-audit Conference is chaired by the lead auditor. The presentation of the audit results may be made by the lead auditor or by a combination of the lead auditor and audit team members. This should include a discussion of both positive and problems areas. Any identified problems should include a statement by the audit team of its significance and potential safety impact. Auditors need to discuss the issues in detail prior to the Post-audit Conference, and there should not be any surprises introduced during the conference. At the Post-audit Conference, the auditing and audited organization should attempt to reach an agreement of the facts pertaining to audit findings. It is emphasized that the audit process is an 'independent' process; therefore, both organizations may not reach agreement as to the audit conclusion. However, an attempt should be made by the auditing organization to reach such an agreement if possible. The Post-audit Conference presentation by the audit team will include a summary of the identified program strengths, weaknesses and an overall quality assurance program effectiveness conclusion. The audit team also will confirm the scheduled date of the audit report. The lead auditor during the Post-audit Conference should also communicate the date for any required response by the audited organization for audit findings and the need to include sufficient objective evidence that demonstrates satisfactory completion. Should new facts be identified that could impact the conclusion of the audit or any identified findings, the audited organization will need to immediately contact the lead auditor.

Reporting

Following the Post-audit Conference, the next key step in the audit process is to compile an audit report. This report is typically issued no later than 30 days after the Post-audit Conference.

The report should be well written or reviewed by someone with sensitivity to the nuances of words and the effect they can have. To maintain credibility of the audit, results should always be communicated in a professional manner, avoiding use of inflammatory words. The results should make a clear statement of the assessed performance and its effectiveness. The report needs to contain a concise 'Executive Summary' that provides an overview of the audit results and the important conclusions. The report also needs to include a description of audit scope, audit team members, detailed discussion of the audit investigation and results, identification of strengths, weaknesses, audit findings or problems, recommendations, insights, specific conclusions for the areas assessed, personnel contacted, specific documents reviewed, Pre-audit Conference date and participation, post-audit date and participation, and any follow-up actions. The report should establish audit performance ratings to summarize the results.

When audit findings documenting quality problems are entered into the audited organization's normal corrective action system, sometimes the level of significance is determined by a corrective action screening team that does not include the auditing organization. Assurance should be made that the level of significance of the quality problem is at least at the level determined by the audit team. This is very important to maintain and not undermine the independence of the audit process.

Follow-up

Timely evaluation of audit responses and verification of corrective actions to identified audit findings is the final critical step in the audit process. Typically, the follow-up is assigned to the lead auditor (or audit team members) for confirmation that the corrective action investigations by the audited organization have been timely and thorough. It is important that objective evidence of completion be provided and independently confirmed prior to closure.

12.5 Large-scale facility audits or 'vertical' audits

Implementing an aggressive vertical audit program is a major undertaking which imposes considerable stress on an organization. This may take the form of a thorough plant system assessment. This demands a major commitment from the line organization staff – time to investigate and resolve the kinds of issues that are raised during an intensive system review. Such an audit is intrusive in its evaluation of design features, maintenance practices and operating procedures. Despite this stress, the entire organization comes away from a comprehensive vertical audit with far more insight.

12.6 Types of audit

Power plant audits include assessments associated with many varied aspects of the plant's activities. This will include audits of early site development and license application activities, engineering, procurement, construction, operational, radioactive waste storage and decommissioning phases associated with nuclear power plants. Audits may include areas such as shift operations, refueling, radiation protection, radioactive waste control, chemistry controls, maintenance, work control, in-service testing, calibration, major plant modifications, geotechnical investigations, licensing, fitness for duty, security, safety analysis, environmental monitoring, emergency preparedness, document control, records management, inspection, design, surveillance testing, corrective action, human performance, operating experience, non-conformance controls, personnel qualifications and training.

There are a number of different types of nuclear industry third-party audits and assessments that supplement or are in addition to the other nuclear audit processes. These include Nuclear Industry Evaluation Program (NIEP) Management Audits, Nuclear Procurement Issues Committee (NUPIC) supplier audits, INPO evaluations, WANO evaluations, ISO-9000 audits and ASME surveys. In addition, the NRC performs independent inspections of licensed facilities that are very similar to audits.

12.6.1 Nuclear Quality Management Leadership Committee – NUPIC Audits and NIEP Assessments

The nuclear industry has standardized supplier audit programs through development of shared audit teams. This has been an international approach. The audits of suppliers are coordinated within NUPIC and shared. NUPIC functions as part of the Nuclear Quality Management Leadership Committee and performs under the oversight of the Nuclear Energy Institute. This has improved industry leveraging of resources and has resulted in minimized impact to the audited organizations. This process is implemented through NUPIC, consisting of nuclear power plants organizations internationally. The approach by NUPIC was first used during the development of the Coordinating Agency for Supplier Evaluation (CASE) that started out as a loose association of contractors to exchange supplier preaward survey and audit quality data that resulted in reduced survey and audit costs. NUPIC expanded the process, improved the standardization used by international nuclear utilities and has developed regulatory creditability.

Commercial nuclear utilities in both the USA and Canada with operating plants have developed assessment criteria to evaluate the effectiveness of utility quality assurance organizations. Assessment criteria were established by NIEP and include assessment objectives and attributes. These assessments are actually independent management audits of the quality assurance organization functions of the respective utility. The assessment criteria are contained within Nuclear Quality Management Leadership, Nuclear Industry Evaluation Program Performance Objectives and Criteria, and (NQML 07-001). The assessment process applied is included in Nuclear Quality Management Leadership (NQML), Nuclear Industry Evaluation Program, and (NQML 07-002). These assessments are performed every two years at nuclear operating facilities.

12.6.2 Institute of Nuclear Power Operations (INPO)/ World Association of Nuclear Operators (WANO) evaluations

INPO, which was established following the Three Mile Island event, provides periodic evaluations of operating facilities. Its international counterpart WANO performs such evaluations worldwide at operating nuclear plants. They have established numerous industry good practices and use documents to assess the performance of the facilities. Such evaluations are very similar to an audit, but have a very performance-based focus.

12.7 Independent engineer's reports – asset assessment

Other variations of audits may take the form of an independent engineer's report. Although not specifically a quality audit, it may form a basis for an independent appraisal of the technical adequacy of a given product or process.

12.8 Conclusions and future trends

Poor industry audits have led to additional regulatory scrutiny, lack of confidence in the quality assurance program, lack of effectiveness, and inadequate quality programs and implementation. The US NRC and the US DOE have numerous examples posted on their website as part of their communication of lessons learned. Additionally, both INPO and WANO have also identified such lessons to their members.

To ensure a successful audit process, audits need to be value-added and need to be performed by qualified personnel within the industry. Over the years, experience and adverse industry events such as the Browns Ferry fire and the accident at Three Mile Island have resulted in additional regulations and guidance. Successful approaches for nuclear auditing have moved to include major elements of performance-based techniques. More recent events such as Davis-Besse Power Plant Degradation of the Reactor Pressure Vessel Head provided additional perspectives where quality assurance needed to improve. Both the NRC and INPO continue to establish new expectations related to independent oversight organizations.

The industry continues to leverage resources through increased standardization and allocation of resources through alliances and industry initiatives. Initiatives being considered by the NQA-1 Committee include development of standardized qualification and third-party audit certification processes.

12.9 Sources of further information

Sources of further information and trends may be found at the US Nuclear Regulatory Commission (nrc.gov), the Institute of Nuclear Power Operations (INPO), the Nuclear Procurement Issues Committee (NUPIC) (nupic.com) and the American Society for Quality (asq.org).

12.10 Source documents

10CFR50, Appendix B – Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants.

Basic Safety Principles for Nuclear Power Plants, 75-INSAG-3 Rev.1, INSAG-12, IAEA, 1999.

CER Corporation, History of 10CFR50, Appendix B, And Its Impact on Nuclear Power Plant Performance, A CER Topical Report, November 1993.

Good Practices for Improved Nuclear Power Plant Performance TECDOC-498, 1989.

Institute of Nuclear Power Operations, Principles for a Strong Nuclear Safety Culture, November 2004.

Institute of Nuclear Power Operations, Principles for Excellence in Nuclear Project Construction, (INPO 09-007), Revision 0, May 2010.

International Organization for Standardization, Quality Management System Requirements, ISO 9001-2000.

Johnson John H., 'Performance-Based Auditing/Assessment'.

Johnson John H., Value Added Auditing, first presented at the 1995 ASQ National Audit Conference, Baltimore.

Johnson L. Marvin, Quality Assurance Program Evaluation, L. Marvin Johnson & Associates, Inc., Stockton Trade Press, Inc.; 1974.

Management of Operational Safety in Nuclear Power Plants, INSAG-13, IAEA, 1999.

Managing the First Nuclear Power Plant Project, IAEA-TECDOC-1555, 2007.

Manual on Quality Assurance Programme Auditing, Technical Report Series 237, 1984.

NQA-1 – Quality Assurance Requirements for Nuclear Facility Applications, American Society for Mechanical Engineers (ASME), 2008.

Nuclear Quality Management Leadership (NQML), Nuclear Industry Evaluation Program, (NQML 07-002), January 2007.

Nuclear Quality Management Leadership, Nuclear Industry Evaluation Program Performance Objectives and Criteria, (NQML 07-001), January 2007.

Qualification of Quality Assurance Program Audit Personnel for Nuclear Power Plants, ANSI/ASME N45.2.23 – 1978.

Quality Assurance in Nuclear Power Plants and Other Nuclear Installations: Code and Safety Guide Q1-Q14, Safety Series No. 50-C/SG-Q, IAEA 1996.

Quality Assurance Requirements For Control of Procurement of Items and Services for Nuclear Power Plants, ANSI N45.2.13 – 1976.

Quality Assurance Standards: Comparison between 50-C/SG-Q and ISO 9001:1994, IAEA-TECDOC-1182, 2000.

Quality Standards: Comparison between IAEA 50-C/SG-Q and ISO 9001-2000, IAEA Safety Reports Series No. 22

Requirements for Auditing of Quality Assurance Programs for Nuclear Power Plants; ANSI/ASME N45.2.12 – 1977, ANSI Standards.

Reiman Tonya, The Power of Body Language, Pocket Books, 2007

US Nuclear Regulatory Commission (USNRC) Regulatory Guide 1.28, Quality Assurance Program Criteria (Design and Construction, (Revision 4) June 2010.

US Department of Energy, DOE O 414.1C Quality Assurance.

US Nuclear Commission (USNRC) Regulatory Guide 1.123, Quality Assurance Requirements for Control of Procurement of Items and Services for Nuclear Power Plants, (Revision 1), July 1977.

US Nuclear Regulatory Commission (USNRC) Regulatory Guide 1.144, Auditing of Quality Assurance Programs for Nuclear Power Plants, (Revision 1), September 1980.

US Nuclear Regulatory Commission (USNRC) Regulatory Guide 1.146, Qualification of Quality Assurance Program Audit Personnel for Nuclear Power Plants, August 1980.

US Nuclear Regulatory Commission (USNRC) SECY-03-0117, Approaches for Adopting More Widely Accepted International Standards, 9 July 2003.

US Nuclear Regulatory Commission, Performance-Based Inspections, (NUREG/CR-5151), June 1988.

US Regulatory Commission, NRC Improving Quality and the Assurance of Quality in the Design and Construction of Nuclear Power Plants A Report to Congress (NUREG-1055), May 1984.

13

Licensing procedures for nuclear installations

P. BRENNECKE, Consultant, Germany

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Abstract: This chapter provides information on licensing procedures for nuclear installations, the institutions involved, the regulatory interface and experiences that have been gained through such procedures. Covering various countries, the chapter first reviews the main elements of the legal framework, the regulatory body and the general principles of licensing procedures. The chapter then considers the responsibilities of the applicant/operator and the involvement of stakeholders, before it finally discusses aspects of licensing decision and supervision activities.

Key words: nuclear installation, legal framework, licensing procedure, regulatory interface, nuclear license.

13.1 Introduction

In many countries, nuclear legislation is implemented in order to take precautions in the form of protective measures and structures that avoid endangerment of humans and the environment. The regulatory framework has often been prepared in parallel to the operation of technical facilities, and amended as a result of experiences gathered or new developments. In line with this objective, legislation addressing the peaceful use of nuclear energy particularly focuses on the principle of giving priority to the safety of nuclear facilities and installations in order not to harm workers, the people living in the vicinity of a nuclear installation and the environment. Thus, such legislation is distinguished by its preventive character, that is all possible risks have been considered beforehand in order to grant protection and safety without restriction and/or reservation.

The assurance of nuclear safety is the primary task to be completed by the competent authority and the operator/licensee. The legal provisions on licensing a nuclear installation (e.g. a nuclear power plant or a reprocessing facility for spent nuclear fuel) and its supervision during operation serve the primary safety objective. These provisions include that the competent authority may impose obligations and additional requirements, if necessary, in order to achieve the protection goal and to assure protection of humans and the environment against detrimental effects of ionizing radiation. The operator of a nuclear installation can receive a license for its construction, operation and decommissioning/dismantling, provided that, in the licensing documents, priority to safety is clearly demonstrated as well as the fulfillment of respective administrative and technical prerequisites over all other business objectives.

The nuclear legal framework including the procedure for licensing and supervision is rather complex and very detailed as compared with the legal framework addressing non-nuclear domains of interest. The construction, operation and decommissioning/dismantling of a nuclear installation is not allowed unless valid official approval has been obtained. The licensing process, including the conditions for granting and maintaining a license, is prescribed in acts, ordinances and technical regulations as well as in codes and standards depending on the national situation. According to national legislation, an authorization procedure may be stipulated, followed by a series of licenses issued at the main stages of the particular installation. There are other approaches including, for example, preliminary and final applications, which may be applied.

Nevertheless, independent of the individual national approach, the necessity to comply with legal requirements must be demonstrated in the licensing procedure as well as through the fulfillment of other regulatory activities concerning, for example, the amendment or withdrawal of a license, the enforcement of obligations or the supervision of constructing, operating and decommissioning/dismantling a nuclear installation.

The objective of this chapter is to provide information on licensing procedures for nuclear installations, the institutions involved, the regulatory interface and the experiences that have been gained through such procedures. Reference will be made to Germany, the USA, the UK, France and Finland, addressing in particular nuclear power plants and repositories for radioactive waste. The chapter first reviews the main elements of the legal framework, the regulatory body and the general principles of such procedures. The chapter then considers the responsibilities of the applicant/operator/licensee and the involvement of stakeholders, before it finally discusses aspects of the licensing decision, supervisory activities and future developments and trends.

13.2 Regulations and regulatory systems

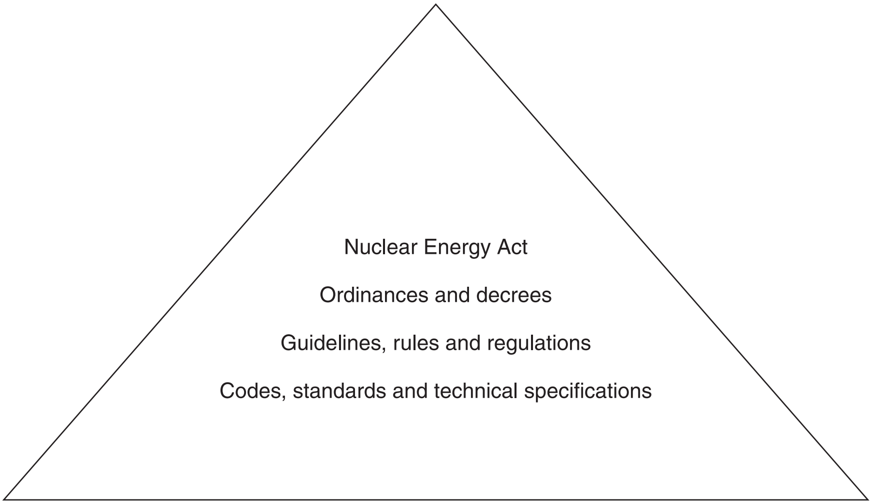
The government of a country has the responsibility to decide on nuclear energy programs for the commercial production of electricity and/or the application of radioisotopes and the use of nuclear material in medicine, research, industry and agriculture. The responsibilities for nuclear legislation and law enforcement including the further development of the nuclear law are assigned to competent institutions, and in general to ministries. Such institutions have to establish and maintain a legislative and regulatory framework to govern the safety of nuclear installations and/or the safe application of radioisotopes.

The preparation and implementation of an appropriate legislative and regulatory framework is a national task and must take the specific situation of the country into account. It is not to be restricted to nuclear aspects and procedures but must involve other national regulations laid down in building law, water law or environmental protection law as well. When developing such a framework, international conventions and treaties signed by the country must be observed. In addition, recommendations published by international organizations such as IAEA, OECD/NEA, ICRP or WENRA should be considered as far as applicable.

13.2.1 National regulations

The national nuclear safety regulations can be arranged in the form of a regulatory pyramid (Fig. 13.1) with a nuclear energy act at the top (in most cases) and the other regulations with their increasing degree of detail at lower levels, thus indicating their hierarchy within the national system and their degree of binding force. The nuclear energy act includes basic provisions on the legislative and administrative competences of the country and addresses fundamental safety principles and protection goals. In a more general way, such an act determines the national standard to be applied to the protective and preventive measures at nuclear installations and includes authorization for issuing associated ordinances. In particular, it requires that nuclear installations are subject to regulatory licensing and specifies respective prerequisites and procedures. Moreover, according to the extent of the national program, a nuclear energy act may comprise surveillance regulations, liability provisions, non-proliferation and safeguards commitments, nuclear security appointments or general regulations on competencies of the authorities involved.

However, most of the regulations laid down in a nuclear energy act are not very detailed and are further specified in the subsequent hierarchy levels of the



13.1 Regulatory pyramid.

regulatory pyramid. Thus, the second level is designated to substantive legal requirements by ordinances and decrees, for example regarding radiation protection or on costs. Ordinances may include additional authorizations for issuing general administrative provisions. Such provisions (i.e. regulatory guidance instruments) regulate the actions of the authorities, thus only having a direct binding effect for the administration. Nevertheless, they have an indirect effect of serving as a basis for concrete administrative decisions.

The third and fourth levels of the regulatory pyramid are designated to guidelines issued by competent national institutions or by advisory bodies (e.g. safety criteria and guidelines on design basis accidents) and to codes, conventional technical standards or specifications for components and systems (e.g. national and ISO standards).

13.2.2 International provisions

In setting up or amending a legislative and regulatory framework, a country has to take care of international provisions. In the case of being a contracting party to the Convention on Nuclear Safety or the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, respective obligations must be adhered to. Both conventions do not contain safety requirements as such. They oblige contracting parties to take care of nuclear safety as well as safety of spent fuel and radioactive waste management by establishing and implementing an adequate regulatory system, establishing safety requirements or performing nuclear safety checks. In both conventions the safety-related objective is expressed in such a way that practically every article begins with ‘Each Contracting Party shall take the appropriate steps to ensure that . . .’.

Examples of international treaties are the Non-Proliferation Treaty or the Paris Convention on Nuclear Liability. Member states of the European Union (EU) are bound by EU law, that is legislation and administrative work must take into account any binding requirement from EU regulations.

For example:

- Council Directive 96/29/EURATOM, which lays down basic safety standards for the radiation protection of workers and the general public, has to be transferred into national law.
- Council Directive 2009/71/EURATOM including provisions regarding the establishment of a legislative and regulatory framework for nuclear safety, the organization and tasks of the nuclear authorities, the obligations of the operators of nuclear installations, the education and training of the staff of all parties involved and the information of the public. These provisions have to be considered in order to provide for appropriate national protective arrangements and measures on nuclear safety.

- Council Directive 2011/70/EURATOM including provisions for a high level of safety in spent nuclear fuel and radioactive waste management, which have to be applied in order to ensure the required level of safety.

Thus, despite their non-binding character, international provisions may influence the national legislative and regulatory framework.

13.2.3 Regulatory systems

To illustrate the diversity of existing national legislative and regulatory frameworks, two examples are described.

In the USA the nuclear safety goals are prescribed in the Atomic Energy Act, section 182, requiring adequate protection of the health and safety of the public, and in Appendix A to 10 CFR Part 50, introduction, it states the requirement that there must be reasonable assurance the facility can be operated without undue risk to the health and safety of the public. The licenses for nuclear installations are issued by the Nuclear Regulatory Commission (NRC), according to 10 CFR Part 52, a combined license (COL) covering construction and operation. The US Nuclear Regulatory Commission (NRC) was created as an independent agency by Congress in 1974 to ensure the safe use of radioactive materials for beneficial civilian purposes while protecting people and the environment. It regulates commercial nuclear power plants and other uses of nuclear materials, such as in nuclear medicine, through licensing, inspection and enforcement of its requirements. NRC as a regulator has substantial resources and staff and a high level of authority in rulemaking, licensing, surveillance and inspection.

In Germany, the nuclear safety goals are prescribed in the Atomic Energy Act, article 7, requiring every precaution against damage that is possible with state-of-the-art science and technology. In addition to that, the importance of lawsuits in defining and/or interpreting the legal safety requirements should be acknowledged, for example the risk of harm has to be practically excluded. In the Kalkar lawsuit the decision of the Bundesverfassungsgericht (Federal Constitutional Court), issued on 8 August 1978 (BVerfGE, 1978), addressed the necessity to achieve the best possible protection, security and risk prevention in order to realize the protection objective of the Atomgesetz (Nuclear energy act). According to the federal structure of Germany, the structure is more complicated than in other countries. The top regulator is the Federal Ministry for Environment, Nature Conservation and Nuclear Safety, who supervises the competent ministries of the federal states (Länder) who are responsible for issuing the licenses for nuclear installations and for supervision. The two levels of administration, a complicated status of technical regulations, and a high level of surveillance mainly performed by technical support organizations on behalf of the Länder ministries are characteristic of the German regulations system (Fillbrandt and May, 2002).

13.3 Nuclear installation licensing: an overview

The general principle of licensing may be defined as the necessity to assess and evaluate an activity that could become potentially hazardous to legally protected interests. The responsibility and jurisdiction over such an assessment, that is the performance of a licensing procedure, is assigned to the regulatory body.

With respect to the performance of a nuclear licensing procedure, some countries amended the national licensing system by offering alternatives. In order to ensure predictability, it is advantageous to issue a combined construction and operating license (so-called one step licensing), for example according to 10 CFR Part 52 in the USA. Otherwise, if the issue of the operating license is subject to a separate step, comparable assurance that the operating license will be issued once construction has been completed should be supplied. In order to ensure efficiency, it is beneficial to use pre-licensing, that is to have recourse to already existing design approvals of parts of the nuclear installation such as specified components and systems held by the vendors. Such approvals (positive statements) can then be referenced within a nuclear licensing procedure.

13.3.1 The applicant

The license for construction, operation or dismantling of a nuclear installation is only issued if the applicant (i.e. the future operator/licensee) proves that all the necessary technical, financial and organizational precautions for a safe operation have been taken, the prerequisites for granting the license accomplished and that there are no further legally required demands to be complied with. To that extent, the applicant, in general a privately owned company, must demonstrate compliance with all nuclear and non-nuclear (as far as applicable) requirements in a competent and comprehensible way. In preparing the licensing documents and in performing the licensing procedure, the applicant may enlist contractors for support, for example engineering consultants, research establishments or vendors and suppliers. In order to achieve a high level of safety, during the preparation of licensing documents it must be ensured that the use of state-of-the-art science and technology is included. All activities of the applicant and their contractors must be performed with the objective of obtaining the license applied for.

13.3.2 The regulatory body

The general mission of the nuclear regulatory body is to ensure that nuclear activities are conducted with proper regard to the health and safety of workers and the public, national security and environmental concerns. Subject to the respective nuclear program, the status, organization and independence of the regulatory body are a matter of national legislation. To fulfill its responsibility, this body must be entrusted with the implementation of the legislative and regulatory framework, and provided with adequate authority, competent staff and financial resources. In particular, there must be a distinction between the functions of the regulatory body and those of any other body or organization concerned with the operation of a nuclear installation and/or the application of radioisotopes.

The main functions of the regulatory body may be summarized in licensing, supervision, enforcement of obligations and the establishment of administrative and/or technical nuclear rules and regulations. Regulatory agencies in selected countries are noted below:

• USA	NRC	Nuclear Regulatory Commission.
• UK	HSE	Health and Safety Executive.
• Germany	BMU	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety and the regulators of the federal states (Länder).
• France	ASN	Nuclear Safety Authority.
• Finland	STUK	Radiation and Nuclear Safety Authority.

According to this short survey, most countries have implemented a central regulatory authority. However, in Germany, such a regulatory body has not been enacted, that is competencies and responsibilities are assigned to the federation level and to the federal states' level. However, the federal states (Länder) are acting on behalf of the federation (Bund).

The activities of the regulatory body (i.e. the nuclear licensing and supervision authority and all other authorities involved in the licensing procedure) are based on the national nuclear and non-nuclear (as far as applicable) legislation. This body is responsible for issuing a license, its withdrawal or revocation as well as for supervision of construction, commissioning and operation of the licensed nuclear installation. The regulatory body has to thoroughly examine and evaluate the licensing documents forwarded by the applicant. If necessary, additional requirements have to be imposed in order to achieve the safety objectives and safety levels specified in the national legislation. In parallel to the applicant, the regulatory body may use the assistance and help of independent experts and/or technical support organizations. In addition, depending on the national legal framework, they may rely on advisory bodies, for example regarding matters of nuclear safety or radiation protection. Experts and/or technical support organizations are selected on the basis of their technical knowledge, experience, objectiveness and reliability. They support the work of the regulatory body without having the authority to take decisions.

13.3.3 The regulatory interface

According to the national regulatory framework, there are many nuclear and non-nuclear regulations to be dealt with. Some examples dealing with different styles of regulatory interface are given below:

- The USA and Germany implemented a coherent and comprehensive set of regulations featuring a high level of detail.
- Finland enacted a coherent and comprehensive, but not as detailed, set of regulations.
- France recast the set of regulations in starting to introduce new decrees and to consolidate the general technical regulations.
- The UK applies obligatory standard license conditions and safety assessment principles.

The safety provisions and regulations usually laid down in respective acts and in associated ordinances or decrees are put into concrete terms by general administrative provisions, in particular on the licensing procedure, by regulatory guidelines, nuclear safety standards, recommendations given by advisory bodies and technical committees or conventional technical standards. On that basis, the joint action and cooperation of all bodies, institutions and companies involved form the regulatory interface. This interface reflects the interaction between the applicant (i.e. the future operator/licensee) and the nuclear regulatory body and other competent authorities. It deals specifically with the application procedure, the submittal of supporting documents and the participation of the general public (Section 13.4.3). Furthermore, it deals with the assessment of environmental impacts and the consideration of all other nuclear and non-nuclear licensing requirements.

The competent regulatory body may involve authorized experts or technical support organizations in order to assist them in legal, engineering, technical or scientific issues related to regulatory licensing and supervision. Supervision may be performed by the regulatory body or be assigned to an independent authority. The supervisory authorities regard all of their activities performed within the framework of regulatory supervision as independent reviews that aim to determine to what extent the operator/licensee fulfills their responsibilities regarding the safety of their nuclear installation. Such authorities, depending on their responsibilities, may be established at the federal or local level.

Further information on the regulatory interface and on licensing and supervision is outlined in Section 13.5.

13.4 General principles and challenges of licensing procedures

A license is required for the construction and operation of a new nuclear installation, for essential modification of parts of an already existing installation or its mode of operation, and for its decommissioning and dismantling. It should be pointed out that a license according to the national nuclear energy act is not the only license that is needed. When applying for a license, for example for a nuclear power plant, the power utility or its subsidiaries are the license applicants for its construction and operation. They have to submit a written license application to the competent regulatory body.

The basic requirements and safety objectives regarding the licensing of a nuclear installation (nuclear power plant) are commonly regulated in the national nuclear energy act. According to this, the applicant has to demonstrate to the regulatory body that the licensing prerequisites and applicable safety requirements have been met. Important prerequisites are:

- Necessary precautions against damage based on state-of-the-art science and technology.
- Trustworthiness and qualification of workers/staff.
- Necessary financial security with respect to legal liability for paying damage compensation.
- Protection against interference by third parties.
- Consideration of environmental impacts.

Thus, supplementary documents and verifications are required. Details, for example type and extent of such documents, are commonly specified in further legal regulations such as a nuclear licensing procedure ordinance or corresponding administrative provisions. These specifically deal with the application procedure, with the submittal of the supporting documents, with the participation of the general public or with the possibility to split the procedure into several licensing steps and to issue partial licenses, for example on the construction or on the commissioning. This may include pre-licensing steps addressing generic design assessments and/or design certifications. In addition, they deal with the assessment of environmental impacts including envisaged protection measures, and, finally, with the consideration of other documents or permission procedures in order to obtain permits for the possible release or controlled discharge of pollutants and permits from water protection agencies. All documents are subject to regulatory examination and review, enabling examination to ensure the fulfillment of licensing prerequisites.

The most important document to be handed over to the regulatory body is the safety analysis report, in which precautionary measures to avoid damage and harm as a result of the construction and operation of the nuclear installation are highlighted. This document allows a conclusion to be drawn as to whether the licensing requirements have been met, including supplementing plans, technical drawings and descriptions of the nuclear installation and its anticipated operation. It describes the safety concept, all hazards associated with the nuclear power plant and the safety-related measures, systems and equipment provided, including the safety-related design features. Thus, all characteristics that are important to safety of the nuclear installation are described: the conditions for safe operation are specified, the measures to cope with abnormal operations are explained and design basis accidents are also addressed. The main topics of the safety analysis report are:

- The nuclear site.
- The design of the nuclear installation (e.g. nuclear power plant).
- Design of the auxiliary systems.
- Organizational structure and responsibilities.
- Nuclear material and envisaged physical protection measures.
- Protection against internal and external impacts.
- Operation of the nuclear power plant.
- Analyses of design basis accidents.

Details on the future decommissioning and dismantling of the plant are to be addressed as well.

With the provision of the safety analysis report and a brief description of the nuclear power plant including information on the probable impacts on the general public and the environment in the vicinity of the nuclear installation, third parties have the opportunity to assess whether their rights could be violated by the nuclear power plant and the impacts associated with its operation.

13.4.1 Submission of supplementary documents

According to national legislation, the license application comprises the construction and operation, otherwise two separate licenses are to be applied for. In the first case, of course, the safety analysis report has to address both construction and operation, whereas in the latter case a preliminary safety analysis report is sufficient to support the license application for construction and a final safety analysis report is needed to support the license application for operation. For example, this procedure is practiced in Finland (STUK, 2010). According to Finnish legislation, when the applicant applies for a construction license, they must submit to STUK (being the competent regulatory body):

- A preliminary safety analysis report.
- A design phase probabilistic risk assessment.
- A proposal for a safety classification document.
- A description of quality management during the construction of the nuclear installation.
- Preliminary plans for the arrangements of security and emergency preparedness and response.
- A plan for arranging the safeguards controls.

For the operating license, the applicant must submit:

- The final safety analysis report.
- The probabilistic risk assessment.
- The safety classifications document.
- The quality management program for the operation of the nuclear installation.
- Operational limits and conditions.

- A program for periodic inspections.
- Security and emergency plans.
- A description on administrative rules for safeguards.
- A program for radiation monitoring in the environment of the nuclear installation.
- A description of how safety requirements are met.
- A program for the management of aging.

Beyond that, the above lists of documents may serve as an example clearly indicating and specifying the amount of information that is needed to support a license application.

In addition to the nuclear regulatory body, various other competent authorities are involved in the licensing procedure. To provide for their interests, specific documents including all necessary data, limits and planned measures must be prepared and submitted for review and assessment. For example, information required by the competent authorities under building legislation comprises:

- The safety analysis report.
- Application for the construction permit.
- Preparation of the construction site.
- The structural works, shell and core.
- Surveillance of construction.
- Acceptance of structural works, shell and core.
- Interior work and corresponding quality assurance.
- Final acceptance tests and inspections.

Along with the described information that is required for issue of the construction permit, all other supporting documents and data according to respective areas and corresponding legislation must be supplied. The impact on the environment is addressed in a separate permission according to the environmental impact assessment law, the extraction and discharge of cooling water requires a permit from the water protection agency and security issues are specifically regulated (to name a few).

In the case of application for a modification license, examination of the licensing prerequisites does not only refer to the object of modification, but also to those parts of the nuclear installation or its operation on which the envisaged modification will have an impact. The documents supporting the modification appliance have to cover these implications too. In order to verify that the respective licensing prerequisites are fulfilled, appropriate documents on the issues concerned by the modification are to be submitted to the regulatory body.

Nevertheless, performance of a nuclear licensing procedure is a complex task dealing with different interests and objectives of bodies and institutions involved. From the applicant's perspective, issues of utmost importance are the preparation of comprehensive technical documents needed for supporting the license application or demonstrating nuclear safety, the revision and/or supplementation of such documents according to the progress of the licensing procedure, and the requirements of the regulatory body on the level of detail or on additional information and verification documents. This applies to those documents needed for permitting processes or referring to the organization of the applicant/future operator, including quality management and control programs as well.

According to the progress of the examination and evaluation of the forwarded licensing documents, the regulatory body and the other competent authorities involved may ask for additional information or raise requirements on specific issues. This enhances the number of documents supporting the license or modification application or, in many cases, results in revision and amendment of forwarded documents. However, to obtain the license applied for, submission is indispensable.

13.4.2 Challenges for the licensing manager of a nuclear site

At present, many utilities are privately owned or at least managed according to commercial principles. In many countries, markets are unregulated. For this reason, a utility has to assess whether investment can be recovered from electricity sales at market prices. This background must be taken into consideration when decisions on the construction and operation of a new nuclear power plant are to be made. The financing of a nuclear power plant deals with many specific aspects compared with other power generation projects, such as a higher share of capital costs (construction and financing costs), higher costs of capital and a longer period of construction and commissioning, that is amortization will start later. Thus, it is crucial that the overall project risk related to the construction of a new nuclear power plant is under control in order to give confidence to the investors.

A substantial part of the project risk is driven by the regulatory and licensing risk (Raetzke, 2011). Within a nuclear licensing procedure, various risks are included, the consequences of which may disadvantageously affect the projected construction of a new nuclear power plant. Possible adverse influences are:

- A delay in issuing the license or partial licenses, resulting in schedule delays and financial problems (cost overrun).
- Substantial re-designs of the nuclear installation or parts of it required in the licensing procedure resulting again in delays, cost overruns and troubles with the vendor.
- Construction and/or operating license not granted resulting in severe investment losses.
- License or partial licenses cancelled by lawsuits resulting in delays and financial problems (if an amended license will be issued) or in a loss of investment (if not).

Thus, from a utility's point of view, the performance of a predictable, streamlined, efficient and effective licensing procedure is needed to reduce potential regulatory and licensing risks.

To ensure a smooth performance of a nuclear licensing procedure, the company/utility/applicant appoints a nuclear licensing manager. They bear the prime and all encompassing responsibility for the performance of the nuclear licensing procedure. Their work predominantly aims to ensure efficient and timely performance. The nuclear licensing manager must survey and streamline all of the different activities that are to be dealt with in order to meet legal prerequisites, for example provisions and obligations laid down in the national nuclear legislation and in other relevant fields of law, and requirements imposed by the regulatory body. They serve as the competent contact person for the project under licensing. For this reason they have to approve all of the documents that are to be forwarded to the regulatory body and to ensure an intense interaction with the members of the regulatory body regarding all questions and requirements that arise during that procedure.

The work scope of a nuclear licensing manager is not restricted to the nuclear licensing procedure. According to their facility-related broad knowledge and comprehensive experience, they may be involved in accompanying controls during construction and commissioning. Such controls extend to the installation and testing of safety relevant equipment. By means of accompanying controls, the operator of the nuclear installation as well as the regulatory body examine, for example, whether the actual design of the components and systems important to safety meet the requirements specified in the license.

Further tasks for a nuclear licensing manager comprise the application of nuclear procedures for major modifications of the nuclear installation or its operation, for periodic renewals of the license (if required by national nuclear legislation), for the withdrawal of the license or, finally, for the decommissioning and dismantling of the installation.

To exercise the function of a nuclear licensing manager, requirements include technical and licensing knowledge as well as basic understanding of the nuclear installation including its operation, experience in the management of large-scale projects, pronounced organizational skills and cost awareness. The most important characteristics are project governance, enhanced control and coordination capabilities, and the ability to assert oneself while also delegating subtasks.

13.4.3 Managing stakeholders and their expectations

Involving interested parties in every stage of the lifecycle of a nuclear installation is an essential prerequisite to enhancing mutual trust and understanding. Beyond the groups traditionally involved in the decision making process, such as the nuclear industry, scientific bodies and relevant national and local governmental institutions, the concept of stakeholders also includes the media, the public, local communities and non-governmental organizations. The information and participation of stakeholders relies on a number of principles that are widely accepted today. This gives rise to recommendations proposing a route to effective stakeholder involvement through the main phases of the lifecycle of a nuclear installation, and the use of up-to-date methods to implement stakeholder involvement programs (IAEA, 2011).

In addition to that according to the national legislative and regulatory framework, the involvement of stakeholders may be prescribed in an ordinance, decree or further regulations. To take the Republic of Korea as an example, a legal basis for stakeholder consensus was established, that is the amendment of the Korean Radioactive Waste Management Act dated December 2009 provided a basis for stakeholder involvement. Thus, the roles and responsibilities of stakeholders are clearly outlined and their participation stipulated on a legal basis.

An important task for both the applicant and the regulatory body is the involvement of the public, in particular the citizens living in the vicinity of a planned or an existing nuclear installation, non-governmental organizations and stakeholders. From an applicant's point of view, it is of utmost importance for the acceptance of the construction and operation of, for example, a nuclear power plant or a repository that the public and, above all, the citizens whose basic rights might be affected are informed in detail on the planned facility and its effects on humans and the environment. In addition, the arguments and opinions raised by stakeholders need to be addressed and evaluated. The transparency of the whole nuclear licensing procedure and the continuous information of the public, as well as of the inclusion of non-governmental organizations and stakeholders from the beginning, contributes to success in realizing the envisaged nuclear project.

In some national legislations, the involvement of the general public is described and it therefore must be implemented by the regulatory body. For example, in Germany the Nuclear Licensing Procedure Ordinance (AtVfV, 2006) includes regulations on:

- The conditions according to which the regulatory body may waive the public participation or must involve the public.
- The announcement of the planned nuclear project and public disclosure of the application documents at a suitable location near the nuclear site including the request for raising any objections within the legally specified period of time.
- The holding of a public hearing to discuss the objections raised between the regulatory body, the applicant and the objector.

If the nuclear licensing procedure is conducted with public participation, the applicant has to submit a brief, readily understandable description of the nuclear installation for informing the general public. Using this description and the accessible application documents, citizens that might be affected by the construction and operation of the planned facility can judge whether or not their rights are being violated. In the further course of the licensing procedure, the regulatory body has to assess all the concerns and objections and to consider them in its decision making process.

When a nuclear license has been issued, objectors (e.g. stakeholders or members of the public) may take legal actions against the regulatory body's decision and initiate lawsuits against the nuclear license. In this way administrative courts get involved.

Another example addresses public participation in the UK. For potential new nuclear power plants, as part of the generic design assessment process, a public involvement process was launched. It allows the public to view and comment on detailed design information published by the design companies. The generic design assessment process has established stakeholder engagement arrangements that include non-governmental organizations. The intention of the regulatory body is to ensure that generic design assessment is carried out in an open and transparent manner. The public is given access to reports prepared for the design without compromising commercial and security considerations.

13.5 Submission of license application and ongoing supervision

The licensing of a nuclear installation is basically regulated in the nuclear energy act. Such facilities require a license for the construction, commissioning, operation, essential modification of the installation or its operation and, at the end of its operational lifetime, for its decommissioning and dismantling. When granting a license, obligations and additional requirements may be imposed for achieving the respective objectives of safety and protection. Any such activities performed without a license are punishable by law.

13.5.1 Submission of license application

The written license application is submitted to the competent regulatory body. In addition to the license, the applicant/future operator of the nuclear installation has to submit further documents and verifications detailing and specifying the license, thus enabling an in-depth examination of the fulfillment of the licensing prerequisites and required objectives of safety by the regulatory body.

On the basis of the submitted documents, the regulatory body examines whether or not the licensing prerequisites have been fulfilled. For that examination, all responsible authorities whose jurisdiction is involved, even at the regional and/or local level, take part in the licensing procedure. The authorities are usually responsible for regional or local planning work, building law or water law. Because of the large scope of nuclear and non-nuclear issues, in particular regarding safety, it is common practice to contract independent experts or technical support organizations to assist the regulatory body and/or other competent authorities in the examination and review of the licensing documents. Nevertheless, the regulatory body finally assesses and decides on the basis of their responsibility and judgment.

The final evaluation is the basis for the decision of the regulatory body about the permissibility of the nuclear installation applied for. This decision embraces the application and the supporting documents, the evaluation reports by authorized experts, the statements of all authorities involved and the findings from the consideration of objections raised and discussed in the public hearing. If all licensing prerequisites and legal requirements are satisfactorily fulfilled, the regulatory body issues the license applied for.

13.5.2 Supervision

Having issued a license, the subsequent activities and duties of the regulatory body comprise the regulatory inspection and assessment of the respective nuclear installation and, if necessary, the enforcement of regulations and provisions. The continuous regulatory supervision of the construction, commissioning, operation, decommissioning and dismantling of a nuclear installation is basically regulated in the national nuclear energy act and detailed in accessory nuclear ordinances and decrees.

As in licensing, the primary objective of regulatory supervision of nuclear installations is the protection of workers, the general public and the environment against effects and impacts (i.e. harm) connected with construction, operation or dismantling of the nuclear installation.

The regulatory body or a supervising authority, depending on the national situation, pays particular attention to:

- Fulfillment of the obligations, provisions and requirements imposed by the regulatory body in the license of the respective nuclear installation.
- Fulfillment of any additional legal requirements.
- Fulfillment of any supervisory order.

To ensure safety, the supervisory body, assisted by authorized experts and by other competent authorities, monitors, for example:

- Compliance with the operating procedure.
- Performance of in-service inspections of components and systems that are important for safety.
- Radiation protection of workers and the vicinity of the nuclear installation.
- Trustworthiness and technical qualifications and the maintenance of the qualification of workers and responsible persons.
- Quality assurance measures.

Authorized experts or technical support organizations called in by the regulatory body and the supervisory authority, respectively, have access to the nuclear installation at any time and are authorized to perform necessary examinations and to demand pertinent information to be supplied by the operator (BMU, 2010).

The operator of the nuclear installation supplies written operating reports to the supervisory authorities at regular intervals. Such reports include data and information on the operation of the nuclear installation, on maintenance measures and impactions and, in particular, on radiation protection. Any events that are relevant to safety and to physical protection must be reported. In addition to the continuous regulatory supervision, depending on the respective nuclear installation, comprehensive periodic safety reviews are to be performed.

In case of deviation from legal requirements, the terms and conditions given in the license or any subsequently imposed obligation, the regulatory body may in particular order that:

- Additional protective measures are taken.
- Operation may only be continued with restrictions or subject to certain conditions.
- Operation is to be discontinued temporarily until the causes of an event are clarified and necessary remedial actions against recurrence are successfully taken.

In case of non-fulfillment of legal and/or licensing provisions or of supervisory orders, the regulatory body is authorized to enforce their fulfillment or to revoke the issued license.

13.5.3 Verification of safety during supervision

Subsequent to the issue of a license, the safety assessment during construction, commissioning and subsequent power operation of a nuclear power plant is performed by the regulatory body. This authority verifies that the conditions and prerequisites on which the license was based continue to be maintained during operation. The regulatory body, assisted by authorized experts, will also perform inspections during the construction phase. These accompanying inspections are performed independently of those by the manufacturer. They are required to verify the values, dimensions or functions specified in the submitted documents. This includes verification of materials composition, checking the assembling of components and the performance of functional tests at the manufacturing plant. Similar inspections are also carried out at the construction site.

On behalf of the regulatory body or the supervisory authority, the authorized experts perform measurements, inspections and evaluations, or they participate in the measurements and inspections made by the licensee or on their behalf. This concerns the following areas:

- Discharge of radioactive materials.
- Radiation monitoring of workers and the environment.
- In-service inspections of systems, components and civil structures of the nuclear installation.

In addition to the regular measurements and inspections, the supervisory authority and their authorized experts may perform inspections on specific aspects. If deficiencies are found, the regulatory body requests a corresponding correction by the licensee. In extreme cases where a situation might pose a high safety risk, this could result in an order for immediate shutdown of the plant (BMU, 2010).

Reportable events, modifications to the plant or its operation, maintenance tasks or new findings relevant to safety can lead to specific safety reviews of certain systems, components or items, on which the supervisory authority may request detailed documentation. Such a safety review may also be carried out systematically for the nuclear installation as a whole, taking probabilistic safety analyses into account. These reviews and analyses are generally also evaluated by the authorized experts consulted.

Each operator/licensee of a nuclear installation has to meet their reporting obligations and to report regularly to the supervisory authority on the operation of their nuclear installation.

Supervision under nuclear legislation extends over the whole lifetime of a nuclear installation and ends only after all radioactive material has been removed from the site, or if radioactivity has dropped to a value below the limit set for mandatory surveillance. Only in this case can the regulatory body/supervisory authority release the nuclear installation from supervision under nuclear legislation.

13.5.4 Verification of safety by the operator

Within the responsibility for the safety of their nuclear installation, each licensee adjusts its safety level to be in correspondence with state-of-the-art science and technology over the entire operating life of the plant. If relevant new safety findings are available, the need for and appropriateness of improvements is evaluated. In addition, safety assessments are continuously performed as part of the regulatory supervisory procedure, and discontinuously or periodically carried out as a specific safety review, for example probabilistic safety reviews or risk studies. It is obvious that the extent and detail of such safety-related activities depends on the respective nuclear installation.

The license applicant submits safety verifications for the first time with the application for construction and operation of a nuclear installation. During operation, a regularly repeated verification is required to show that system functions important to facility safety are executed properly and also that quality characteristics have not deteriorated below acceptable levels. To this end, the systems are subjected to in-service inspections graded according to their individual safety relevance. As to nuclear power plants, functional tests are performed to verify that the systems are in functioning order after a shutdown period, for example for maintenance work. The operator or licensee plans and performs regular preventive maintenance of all systems during operation and evaluation of the operational experience. In planning and executing quality assurance, a distinction is generally made between in-service inspections of systems and components important to safety and other quality assurance activities.

Apart from the mandatory in-service inspections of systems and components important to safety, the licensee performs additional inspections under their own responsibility. These serve primarily to increase plant availability.

The operation of nuclear power plants, in particular regarding extended operational periods, necessitates a thorough analysis of available experience. Thus, in connection with the in-service inspections and the evaluation for operational experience, special attention is paid to the early detection of cause for failures as a result of aging. The causes of such failures are often systematic phenomena. There are specific regulatory requirements regarding aging of certain systems, structures and components. In nuclear power plants, comprehensive measures are taken to counter the unacceptable effects from aging, such as monitoring equipment and operating conditions in order to detect any deterioration that could affect safety, regular replacement of parts known to be susceptible to failure, upgrading or replacing technical equipment in case weaknesses are detected that affect safety and continuous evaluation of the operating experience. Thus, the back flow of experience gained in operation and maintenance is of great importance.

With respect to aging, in the USA, the GALL report (NRC, 2010) contains a generic evaluation of existing nuclear power plant programs and documents the technical basis for determining where existing programs are adequate without modification and where existing programs should be augmented for the period of extended operation. This document contains an evaluation of a large number of structures and components that may be in the scope of a typical license renewal application. The evaluation results documented in the GALL report indicate that many existing, generic aging management programs are adequate to manage aging effects in particular structures or components and allow license renewals without changes. It also contains recommendations on specific areas for which existing programs should be augmented for license renewal and documents the technical basis for each such determination.

Aging phenomena are usually detected at an early stage and remedies taken because of the high frequency of inspections of safety equipment, for example in US and German nuclear power plants. This is why failures as a result of aging caused by systematic phenomena have so far been rarely observed.

13.6 Challenges and lessons learnt: specific examples

As a result of the intense regulatory supervision during construction, commissioning, operation, decommissioning and dismantling of nuclear installations, any inadmissible condition is usually detected at an early stage before legal actions have to be taken. Within the framework of licensing a nuclear installation and within the framework of supervision of its operation, the regulatory body – or authorized experts or technical support organizations performing this work on its behalf – checks which provisions are implemented by the applicant or the operator to fulfill their responsibility for the safe operation of the nuclear installation and to give priority to safety. Supervision is structured systematically according to the different areas to be supervised, for example maintenance, in-service inspections and radiation protection. Regular evaluation of the findings from supervising procedures allows the competent authority to adapt its supervision activities, for example by undertaking additional inspections, such that safety-related issues are always given due attention.

The existing rules, regulations and regulatory instruments have proven their effectiveness so that, apart from the optimization in detail, the introduction of specific new features and the harmonization of the comprehensive body of legislation, with respect to international developments and recommendations, mean that no fundamental changes are required.

This result, among other things, is based on the reporting criteria and the detailed reports on operational experiences to be compiled and analyzed by the operator of a nuclear installation. The requirements of the regulatory side are described in INSAG-23, CNRA and WGOE reports. This operational experience feedback enables the regulatory body to evaluate the fulfillment of requirements laid down in the license and, thus, the fulfillment of safety objectives within the implemented legislative and regulatory framework.

However, there are some important lessons learnt which have to be transferred into further developments of the legal framework. A selection of such findings is compiled in the following sections.

13.6.1 Safety management systems

When operating a nuclear installation, the necessity and availability of a safety management system is of significant importance. An effective management system supports the emphasis and improvement of safety culture and the attainment of increased levels of safety performance. Thus, it is a management tool to steer and measure the performance of all activities. All key terms must be clearly defined and must become an integral part of training programs to ensure that communication and understanding are constantly lived throughout a nuclear installation. Basically, such a system describes the principles and objectives of safety management in the nuclear power plant in order to ensure high safety levels. Within the framework of supervision, the introduction and application of the safety management system is checked, in particular whether and how priority to safety is anchored in the basic principles of the management system. In addition to the basic principles, the focus of supervision is on those processes in which priority to safety becomes particularly evident, for example company objectives. Further development and optimization of the safety management system based on the results of effectiveness reviews are ongoing tasks for the operator. This process will generally be monitored within the framework of supervision (BMU, 2010).

It should be emphasized that Council Directive 2009/71/EURATOM requires EU member states to ensure the establishment and implementation of management systems that give due priority to nuclear safety and are regularly verified by the competent regulatory body.

13.6.2 Harmonizing decommissioning and dismantling regulations

For decommissioning and dismantling nuclear installations, in particular nuclear power plants, various approaches have been applied worldwide. In the past, some degree of technical consultation and harmonization of safety approaches has been achieved, but further standardization, especially in the areas of site and material release criteria, is still desirable (Devgun, 2011). With respect to regulations on decommissioning, significant advances have been made to provide a more uniform regulatory procedure in the USA. The NRC decommissioning process is well defined and the requirements are well understood by those responsible for carrying out such activities; 10 CFR Part 20.1402 provides the criteria for release of a site without restrictions. The MARSSIM (Multi-Agency Radiological Survey and Site-Investigation Manual) methodology is a good example of the status survey approach for site release. Nevertheless, having deviations in procedure and applicable criteria in mind, further development in harmonizing respective rules and regulations and the provision of guidance in decommissioning and dismantling is still required.

13.6.3 Developments in regulations on radioactive waste disposal

Licensing on nuclear installation is performed according to national legislation and a regulatory framework. This may comprise the application of different types of licensing procedures. With respect to nuclear power plant licensing, the issue of partial licenses on construction, commissioning and operation has turned out to be successful.

A special type of licensing procedure is conducted for repositories in Germany. According to German legislation, a so-called plan-approval procedure pursuant to the atomic energy act must be initiated and carried out. It is the objective of the plan-approval procedure to examine a project (e.g. a repository) that is important for the region concerned, balancing the interests of the body responsible for the project with public and private interests affected by the construction and operation in only one procedure encompassing all nuclear and non-nuclear issues (with the exception of mining law and water law) as well, and to reach a decision that is legally binding in relation to third parties. This procedure includes the participation of all authorities concerned, and a public hearing. It is terminated by the plan-approval decision, that is the license. This decision unfolds the so-called integration effect, that is it includes (and thus replaces) all other required approvals and permits in only one licensing step. In addition to the plan-approval decision, licenses are required by mining law and water law.

Such a plan-approval procedure was performed for the Konrad repository (Berg and Brennecke, 1990; Brennecke, 2011). In August 1982, the license application was filed to the competent regulatory body; in May 2002, the license was issued. Thus, the licensing procedure lasted for about 20 years. Within that period of time, several rules and regulations (e.g. the ordinance on radiological protection) were amended, each change resulting in time and cost consuming revisions of many licensing documents as a consequence. As a result of that experience, there were discussions to amend the licensing procedure under nuclear law and to potentially introduce a stepwise procedure, including the possibility of issuing partial licenses.

To some extent, this idea was taken up when preparing the Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste of September 2010. These requirements provide the safety-related framework that must be compiled with in designing, constructing, operating and closing a repository for high-level radioactive waste and spent nuclear fuel that has been declared to be waste (Brennecke, 2011). The safety requirements address and regulate, among other things, the step-by-step approach and permanent optimization with respect to radiation protection, operational safety and reliability of the safe long-term containment/isolation of radioactive waste.

However, the safety requirements do not include a definition of the legal procedures for selecting the final repository site for heat-generating radioactive waste. At present, a new approach to disposal of that type of waste is being prepared, including amendment of the existing legislative and regulatory framework as well as the implementation of new legislation. Thus, future developments must be closely followed.

13.7 Future trends

The assurance of a high level of safety, today and in the future, in constructing and operating a nuclear installation or in applying radioisotopes and using nuclear material requires advancements on the engineering and technical level as well as on the administrative and legal level. Because of the safety objective, among other things, the nuclear legislative and regulatory framework is constantly being developed and enhanced. The main issues in future trends are focused on harmonization of the comprehensive body of legislation and cooperation between the regulatory bodies. National and international activities and trends are to be distinguished.

13.7.1 National developments

In an ongoing procedure, safety standards and technical standards are examined and revised if required and new standards are initiated as a result of the constant progression of science and technology.

In licensing nuclear installations, there are new developments in licensing construction and operation as well as on decommissioning and dismantling. In the USA, there are two approaches to licensing. The original approach, published by the regulatory body NRC in 10 CFR Part 50, requires two separate licenses on construction and on operation of, for example, a nuclear power plant. All current operating nuclear power plants were licensed by NRC in this way.

In 10 CFR Part 52, NRC established an alternative approach which provides for certified standard designs and combined licenses for construction and operation. The basic concept underlying this approach is that NRC can approve nuclear reactor designs through generic rulemaking. Through the new combined construction/operating licensing application (COLA) process, NRC has put in place a simplified procedure for new reactor projects. This approach may be applied in licensing of new nuclear power plants using the modular construction technique (Devgun, 2010). Modular construction will play a key role in the design of new plants and has the advantage of simplifying their complex construction and significantly reducing the construction schedules and the capital costs.

Recently, NRC amended 10 CFR 52 in order to improve the effectiveness of its processes for licensing future nuclear power plants. In particular, the amendments clarify the overall regulatory relationship between 10 CFR Part 50 and 10 CFR Part 52 and also comprise the addition of new sections. In February 2012, after a break of approximately 30 years, NRC voted to approve the issuance of the Combined Construction and Operating License (COL) for Plant Vogtle units 3 and 4 near Waynesboro in Georgia – the first such license ever approved for a US nuclear power plant (EQES Inc., 2012). Receipt of the COL signifies that construction of the two 1100 MW AP1000 units can begin. In addition, in March 2012 South Carolina Electric & Gas and Santee Cooper received approval (COLs) for two new nuclear units at Jenkinsville in South Carolina.

With respect to amendments of nuclear legislation, there is an increasing trend to include international recommendations and safety standards in national rules and regulations. As an example, the joint development of safety reference levels based on IAEA safety standards for nuclear installations and facilities for storage and disposal of spent nuclear fuel and radioactive waste is taken into consideration. Work is performed by the Western European Nuclear Regulators' Association (WENRA). WENRA is dedicated to ensuring that all EU member states, candidate countries and Switzerland have harmonized high levels of nuclear safety. To this end, WENRA has developed reference levels that represent good practices for nuclear power plants as well as for storage facilities and repositories. However, WENRA has no ruling competence.

The European regulatory bodies have agreed to respect the safety reference levels in the regulatory framework and are performing detailed benchmark processes. Thus, the WENRA levels represent the basis of national self-assessments. The aim of such assessments is about the identification of major deviations between national approaches and the joint approach reflected in the reference levels. The deviations serve as starting point for the further development of national nuclear legislation. The aim is not to fully standardize the safety approaches and practices in the various European countries but to constantly continue developing the respective national rules and regulations. For this purpose, the WENRA member states develop national action plans that serve to eliminate deviations or deficiencies that have been identified. During recent years, action plans for transposition of the WENRA safety reference levels have been developed or updated. The progress of this work is reported to the WENRA Reactor Harmonization Working Group (RHWG) and the Working Group on Waste and Decommissioning (WGWD).

13.7.2 International developments

Member states of the EU are obliged to implement the contents of Council Directives 2009/71/EURATOM and 2011/70/EURATOM by establishing community frameworks for the safety of nuclear installations and the responsible and safe management of spent fuel and radioactive waste. Both directives supplement the provisions of the Convention on Nuclear Safety, the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, and implement them at European level. Thus, an important step for harmonizing international nuclear safety-related practices and regulations has been initiated:

- Directive 2009/71/EURATOM requires all member states to introduce and adopt a legislative framework for nuclear safety as well as an independent safety authority, and provides a peer-review system based on the IAEA’s Integrated Regulatory Review Service (IRRS). Finally, it includes various public information, training and competency issues.
- Directive 2011/70/EURATOM requires all member states to establish a national program that includes comprehensive measures for the sustainable management of spent nuclear fuel and radioactive waste already (present and future). The program aims to establish and increase transparency and traceability regarding decisions on spent fuel and radioactive waste management, in particular on disposal.

Many countries, including the USA, UK, Germany, France and Finland, continue to actively participate in the future developments of the IAEA safety standards for nuclear installations and spent nuclear fuel and radioactive waste management facilities. Experts of the competent authorities, authorized experts or representatives of the operators contribute to this work. In this way such countries use the international findings to further develop their own nuclear legislation and regulatory framework as well as to make their experience from the development and implementation of national acts, ordinances, rules and regulations available internationally.

In addition to the increasing number of initiatives aiming to harmonize practices and regulations at the international level, with respect to bilateral or multilateral relations, regulatory bodies are sharing nuclear experience and developing information exchanges with their foreign counterparts on regulatory systems and practices, on missions and duties of regulators – notably regarding independence and transparency of decisions – and by promoting the best practices. Thus, various regulatory bodies continue to conduct or participate in IRRS missions in other countries (IAEA, 2006). In this way, not only will information be available on the steps taken to solve encountered problems, but also the generalization of such audits contributes to the construction of a network of experts originating from nuclear regulatory bodies and, thus, to the harmonization of practices. It is obvious that such activities strengthen and enhance the effectiveness of the regulatory infrastructure.

Furthermore, regulatory bodies are following the vision of mutually accepting design approvals. As an initiative taken by national safety authorities, the multinational design evaluation program (MDEP) was launched. This program aims to develop innovative approaches to leverage the resources and knowledge of the national regulatory bodies that are currently or will in future be tasked with the review of new nuclear power plant designs.

13.8 Sources of further information

The Convention on Nuclear Safety and the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management stipulate a review meeting to be held by the contracting parties in intervals not exceeding three years. The review meeting serves to present and discuss the status of nuclear safety and advancements that are envisaged for the future. For the preparation of each review meeting, contracting parties are obliged to submit a national report addressing the safety-related measures taken to implement each of the obligations of both conventions. The report prepared by a contracting party gives, in particular, a complete survey on the national nuclear situation including detailed information on legal aspects, the legislative and regulatory framework, and the nuclear licensing procedures. Information given in these documents was used in the preparation of this chapter. Country reports are available via the webpages of the competent national institutions or of the IAEA.

Recommendations published by international organizations are available via their webpages. Some examples include:

- International Atomic Energy Agency (IAEA), http://www.iaea.org.
- Organisation for Economic Co-operation and Development/Nuclear Energy Agency (OECD/NEA), http://www.oecd.org.
- International Commission on Radiological Protection (ICRP), http://www.icrp.org.
- Western Union Nuclear Regulators' Association (WENRA), http://www.wenra.org.

In addition, information on the European situation is offered by the EU via its webpage, http://www.europa.eu.

13.9 References

Berg H P and Brennecke P (1990), The Konrad mine – the planned German repository for radioactive waste with negligible heat generation, report ET-6 / 90, Salzgitter, Bundesamt für Strahlenschutz.

Brennecke P (2011) 'Radioactive waste disposal challenges in Germany', in Proceedings WM 2011 Global achievements and challenges in waste management, Phoenix, WM Symposia, paper 11442.

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (2010), Convention on Nuclear Safety – Report by the Government of the Federal Republic of Germany for the Fifth Review Meeting in April 2011, Bonn, BMU.

Commission Directive 96/29/EURATOM of 13 May 1996 laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiation. OJ L 159, 29.06.1996, p. 1.

Commission Directive 2009/71/EURATOM of 25 June 2009 establishing a Community framework for the nuclear safety of nuclear installations. OJ L 172, 02.07.2009, p. 18.

Commission Directive 2011/70/EURATOM of 19 July 2011 establishing a community framework for the responsible and safe management of spent fuel and radioactive waste. OJ L 199, 02.08.2001, p. 48.

Committee on Nuclear Regulatory Activities – CNRA (2006), Regulatory challenges in using nuclear operating experience, report NEA No. 6159, Paris, OECD/NEA.

Convention on Nuclear Safety, IAEA, INFCIRC/449, 05.07.1994.

Devgun J (2010), 'Modular construction for eventual deconstruction and decommissioning', in Proceedings WM 2011 Improving the future by dealing with the past, Phoenix, WM Symposia, paper 10300.

Devgun J (2011), 'Harmonization of decommissioning approaches and design features', in Proceedings WM 2011 Global achievements and challenges in waste management, Phoenix, WM Symposia, paper 11092.

Entscheidungen des Bundesverfassungsgerichts (BVerfGE), vol. 49, p.89, 08.08.1978.

EQES, Inc. (2012), New Energy: Vogtle, Nuclear Plant Journal, vol. 30, no. 2, p. 8.

Fillbrandt M and May H (2002), Nuclear licensing and supervision in Germany, report GRS-5-42, Cologne, Gesellschaft für Reaktor- und Anlagensicherheit

International Atomic Energy Agency (2006), The Management System for Facilities and Activities, Safety Standards Series report no. GS-R-3, Vienna, IAEA.

International Atomic Energy Agency (2011), Stakeholder Involvement throughout the Life Cycle of Nuclear Facilities, Nuclear Energy Series report no. NG-T-1.4, Vienna, IAEA.

International Nuclear Safety Group – INSAG (2008), Improving the international system for operating experience feedback, report INSAG-23, Vienna, IAEA.

Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. IAEA, INFCIRC/546, 24.12.1997.

NRC, 10 CFR Part 50 Domestic licensing of production and utilization facilities. Code of Federal Regulations, 29.03.2012.

NRC, 10 CFR Part 52 Licenses, certifications and approvals for nuclear power plants. Code of Federal Regulations, 29.03.2012.

NRC, 10 CFR Part 20.1402 Radiological criteria for unrestricted use. Code of Federal Regulations, 29.03.2012.

NRC (2010), Generic aging lessons learned (GALL) report, NUREG-1801, revision 2 – final report, Washington, NRC

Nuclear licensing procedure ordinance (Verordnung über das Verfahren bei der Genehmigung von Anlagen nach § 7 des Atomgesetzes (Atomrechtliche Verfahrensverordnung – AtVfV)). BGBl, part I, 14.12.2006, p. 2819.

Raetzke C (2011), Main elements of a regulatory framework, Training course R 3: Nuclear law, licensing, oversight and standards, Munich, Institute for Safety and Reliability.

Safety requirements governing the final disposal of heat-generating radioactive waste, BMU, 30.09.2010. http://www.bmu.de/fileadmin/bmu-import/files/english/pdf/application/pdf/sicherheitsanforderungen_endlagerung_en_bf.pdf.

STUK – Radiation and Nuclear Safety Authority (2010), Finnish report on nuclear safety – Finnish 5th national report as referred to in Article 5 of the Convention on Nuclear Safety, report STUK-B 120, Helsinki, STUK.

WENRA Reactor Harmonization Working Group (RHWG), WENRA reactor safety reference levels, 2008.

WENRA Working Group on Waste and Decommissioning (WGWD), Decommissioning safety reference levels report – version 1.0, 2007.

WENRA Working Group on Waste and Decommissioning (WGWD), Waste and spent fuel storage safety reference levels report – version 2.1, 2011.

Working Group on Operating Experience – WGOE (2008), The use of international operating experience feedback for improving nuclear safety, NEA/CNRA/R (2008) 3, Paris, OECD/NEA.

14

Emergency management at nuclear plants: the US approach

R. RITZMAN, Consultant, USA

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Abstract: The purpose of emergency management is to protect the health and safety of the public in the unlikely event of a nuclear accident that results in the release of radioactivity. A key component of the mission of regulatory agencies is to ensure that adequate protective actions are in place to protect the health and safety of the public. Protective actions are taken to avoid or reduce radiation dose and are sometimes referred to as protective measures. This chapter discusses the role of planning, facilities, emergent preparedness equipment, and training and drills for the protection of the public.

Key words: defense in depth, emergency preparedness plans, emergency preparedness facilities, emergency classification schemes.

14.1 Introduction

A nuclear power plant is much like any other power plant in that steam is produced to run a turbine generator to make electricity. However, its major difference is that the heat used to make the steam is produced from uranium. When uranium atoms are split, in addition to heat being produced, radiation is also produced. Normally, a nuclear power plant releases very little radiation. The purpose of emergency management is to protect the health and safety of the public in the unlikely event of a nuclear accident that results in the release of radioactivity.

A key component of the mission of regulatory agencies, including the Nuclear Regulatory Commission (NRC) in the USA, is to ensure that adequate protective actions are in place to protect the health and safety of the public (NRC, 2012a). Protective actions are taken to avoid or reduce radiation dose and are sometimes referred to as protective measures.

The overall objective of emergency preparedness (EP) is to ensure that the nuclear power plant operator is capable of implementing adequate measures to protect public health and safety in the event of a radiological emergency. As a condition of their license, operators of US nuclear power plants must develop and maintain EP plans that meet comprehensive NRC EP requirements. Increased confidence in public protection is obtained through combined inspection of the requirements of EP and evaluation of their implementation through both inspection and emergency drills.

This chapter reviews emergency management at nuclear sites, concentrating on the US approach as set out by the NRC.

14.2 Defense in depth

Emergency management at nuclear sites, as well as many other aspects of nuclear power, is based on the principle of defense in depth. Defense in depth is a concept in which multiple layers of controls (defense) are utilized. Its intent is to provide redundancy in the event of an equipment failure or other unforeseen circumstances. Defense in depth relies on, and applies to, equipment, personnel and procedures.

In general, safe operation of nuclear power plants is assured by maintaining three basic safety functions:

- Controlling reactivity.
- Cooling the fuel.
- Maintaining containment integrity.

This can be generalized to apply to the safe operation of any activity involving the use of radioactive material by stating that safe operation is assured by maintaining three basic safety functions:

- Controlling the reactivity or the process conditions.
- Cooling the radioactive material
- Radiological control (e.g. confinement of radioactive material and shielding).

Each of the safety functions is assured by good design, well-controlled operation and a range of systems and administrative controls. A defense in depth approach is generally applied to each of these aspects, and allowance is made for the possibility of equipment failure, human error and the occurrence of unplanned developments.

Defense in depth is a combination of conservative design, quality assurance, surveillance and testing, mitigation measures and a general safety culture that strengthens each of the successive levels. Defense in depth is fundamental to the design and operation of major nuclear and radiological facilities.

Defense in depth can be considered in a number of different ways. For example, one can consider the number of barriers provided to prevent a release (e.g. fuel, cladding, pressure vessel, containment). Additionally, one could consider the number of diverse and redundant systems (or pieces of equipment) that would have to fail before an accident would occur. For example, the loss of all off-site power sources, coupled with the failure of all emergency diesels would result in a loss of all alternating current (AC) power. This situation is referred to as a station blackout (SBO) and is considered to be a beyond design basis accident in the USA.

Within the safety justification for the facility, operational systems may be distinguished from designed (engineered) safety features. If operational systems fail, then the safety features will operate to maintain the safety function. Safety features are typically additional equipment – either passive or active systems – but can also be procedures or other administrative controls. Typically, the more important functions also have greater diversity, redundancy and/or protection.

The frequency of challenge of the safety provisions is minimized by good design, operation, maintenance and surveillance testing. For example, the frequency of failure of the primary circuit of a reactor is minimized by such things as design margins, quality control, operational constraints and surveillance. Similarly, the frequency of reactor transients is minimized by operational procedures and control systems. Normal operational and control systems contribute to minimizing the frequency of challenges to safety provisions. Therefore, the first aspect of emergency management is the prevention of emergencies through a diverse and redundant design (defense in depth), proper maintenance and testing, and conservative operating principles.

In the USA, the Nuclear Regulatory Commission (NRC) requires nuclear power plants to withstand the most severe natural phenomena that can occur in the region where the plant is located, including earthquakes, tsunamis, hurricanes, tornadoes, fires and floods. The NRC requires an additional safety margin to account for any uncertainties and to ensure that the plant remains safe in the event that an accident and a severe natural phenomenon occur at the same time. This helps to ensure that the plant can withstand a more severe natural phenomenon than expected. The series of barriers also helps to ensure that no hazardous level of radiation escapes from the plant into the environment.

With regard to emergency management, defense in depth can apply to equipment, emergency management response facilities and organizations that are available to provide assistance. Emergency management is also the last step of defense in depth relied upon to protect the health and safety of the public if, for any reason or because of a highly unlikely sequence of internal and external events, the combination of design, maintenance and operating principles discussed above do not prevent the accident.

14.3 Emergency preparedness and emergency plans at nuclear sites

This section discusses the EP plans at nuclear power plants, including details on required facilities, equipment, data, training, drills and classification schemes, as well as other infrastructure required to be pre-planned and available prior to an emergency occurring (this section is based on information available from NRC documents and the NRC website).

14.3.1 Emergency preparedness plans

EP plans are required for every US nuclear power plant. In addition, the state and local government agencies must also have EP plans. Although federal agencies are available to assist, the responsibility for emergency planning predominantly belongs to the plant and the state and local government.

To facilitate a preplanned strategy for protective actions during an emergency, there are two emergency planning zones (EPZs) around each nuclear power plant. The exact size and shape of each EPZ is a result of detailed planning which includes consideration of the specific conditions at each site, unique geographical features of the area and demographic information. This preplanned strategy for an EPZ provides a substantial basis to support activity beyond the planning zone in the extremely unlikely event it would be needed, and provides a characterization of the zones that must be addressed in the EP plan.

One of the EPZs is called the plume exposure pathway EPZ and has a radius of about 10 miles from the reactor site. Predetermined protective action plans are in place for this EPZ and are designed to avoid or reduce dose from potential exposure of radioactive materials. These actions include sheltering, evacuation and the use of potassium iodide (discussed later in the chapter) where appropriate.

The other EPZ is called the ingestion exposure pathway EPZ and has a radius of about 50 miles from the reactor site. Predetermined protective action plans are in place for this EPZ and are designed to avoid or reduce dose from potential ingestion of radioactive materials. These actions include monitoring food and water for contamination, and determining when the food and water is unsafe for human consumption.

14.3.2 Emergency preparedness facilities

This section will discuss how the utility should react in case of emergency and will include activating a response team and response facilities, both to address the emergency and to provide information to government organizations, the media and the public. There are several emergency response facilities that are activated at various times during an emergency.

Control Room

The first line of defense in the case of an emergency is the Control Room. The Control Room is staffed at all times by highly trained, qualified and licensed operators. The Control Room is the location from which the reactor is operated at all times – both normally and during an emergency. During an emergency situation, the Control Room is the immediate focal point and remains in charge of the emergency until relieved by another facility, allowing the Control Room to return to its normal function of operating the reactor as well as the rest of the plant.

Operations Support Center

The Operations Support Center (OSC) is the assembly area for operations support personnel where logistic support can be coordinated for:

- Damage assessment team dispatch and direction.
- Personnel radiological protection.
- Chemistry control and post-accident sampling.
- Fire brigade.
- First aid.
- Search and rescue operations.

Priorities are set by the Control Room Operators and the Technical Support Center (TSC, discussed below) and are carried out by OSC personnel.

Technical Support Center

The TSC is an emergency response center separate from the control room where technical support is provided to operations and the Operations Support Center during an emergency.

Senior site management respond to the TSC and take responsibility for managing the event, allowing Control Room personnel to focus on maintaining operation of the plant. Personnel in the TSC provide solutions and anticipate the direction the event could be headed. Drills and exercises focus on 'what if' thinking in preparation for dealing with unexpected and unanticipated events. This includes developing innovative engineering solutions to combat the emergency and protect the health and safety of the public.

Emergency Off-site Facility

The function of the Emergency Off-site Facility (EOF) is to provide a nearby off-site support facility for overall coordination of the emergency response effort and the evaluation of the off-site effects of the event in support of site personnel. At some utilities, EOFs are a primary source of event status information; therefore, emergency public communications personnel may be assigned to operate from this facility during an emergency. Some utilities transfer the overall responsibility for managing the event to the EOF, whereas others maintain control on-site throughout the event.

Joint Information Center

The function of the Joint Information Center (JIC) is to provide an area for the coordination of news releases and for the utility, state, county, local and federal agencies to provide information to the media and, through the media, to the general public. Other functions conducted in the JIC include tracking of misinformation, rumor control and answering telephone inquiries from the media and the public.

The size and layout of the JIC should be large enough to accommodate response personnel from the following groups:

- Communications organization from the utility.
- Technical staff from the utility.
- NRC.
- Federal Emergency Management Agency.
- State and local government agencies.
- Media.

The layout should allow space for a briefing area that is of sufficient size to accommodate the news media (print, web, radio and television), including modern electronic media equipment. Work space and communications equipment should also be available for use by the media.

JICs are normally activated at a 'site area emergency' or 'general emergency' classification, but may be activated earlier at the utility's discretion. JICs may also be activated in response to non-radiological or even non-utility-related events.

14.3.3 Equipment

Equipment and supplies needed to perform the emergency communication function should be identified, and stored, at each facility. This material runs the gamut from routine administrative supplies to visual aids, computers, and sophisticated audio and video equipment. The visual aids should assist in providing a simplified, yet technically accurate, portrayal of the event in progress. Interface between the site and the Emergency Response Facilities is mainly conducted electronically; however, telephones and facsimile machines are relied on to provide a backup means of communicating. The audio and video equipment can be used both for the technical staff to understand the event and for the public information staff to communicate information about the event.

Equipment and supplies stored at the facilities should not be removed without the knowledge of the emergency public communications group as the emergency response facilities must be kept in a constant state of readiness. Some methods used to enforce this prohibition include locked doors to the facility or storage area, postings on doors requiring notification of the emergency public communications group prior to removal of equipment, and/or assigning an individual or a group the responsibility for the facility, including conducting an inventory of the equipment and supplies.

Each emergency response facility should also be equipped with sufficiently reliable and diverse equipment to accommodate communications among emergency public communications personnel, the utility headquarters, governmental agencies, other assistance agencies and the news media. The system should allow for voice communication between the JIC and the other utility emergency response facilities.

Telephone equipment should be available in the JIC to support the rumor control function and to accommodate federal, state and local government representatives.

14.3.4 Training and drills

The NRC assesses the capabilities of each US nuclear power plant operator to protect the public by requiring the performance of a full-scale exercise at least once every two years that includes the participation of government agencies. These exercises are performed in order to maintain the skills of the emergency responders, and to identify and correct weaknesses. They are evaluated by NRC inspectors and FEMA evaluators. Between these two-year exercises, additional drills are conducted by the nuclear power plant operators that may be evaluated by NRC inspectors. The primary purpose of the additional drills is to provide training opportunities to the site staff and prepare them for 'what if' thinking in case of an actual emergency.

In the US, the NRC and the FEMA determine the two-year evaluated EP exercise requirements for nuclear power plant operators and state and local governments. In this manner, both on-site and off-site EP capabilities are adequately evaluated. NRC headquarters and regional staff members typically participate in four full-scale emergency response exercises each year, selected from among the list of full-scale FEMA-graded exercises required of nuclear facilities. Regional staff members and selected headquarters staff also participate in post-plume, ingestion phase response exercises. On-scene participants include the NRC licensee, as well as state, county and local emergency response agencies. These exercises are designed to test the entire gamut of the EP plan.

14.4 Emergency classification schemes

14.4.1 Emergency Action Level (EAL) development

Each operating nuclear power plant is required to include in its emergency plans a standard emergency classification and EAL scheme. An EAL is a predetermined, site-specific, observable threshold for a plant condition that places the plant in an emergency class. The EALs are developed from an industry template to ensure that similar emergency situations are adequately covered by all sites, but also include plant-specific parameters based on each individual design.

14.4.2 Emergency Classification

An Emergency Classification is a set of plant conditions which indicate a level of risk to the public. Both nuclear power plants and research and test reactors use the four emergency classifications listed below in order of increasing severity. The vast majority of events reported to the NRC are routine in nature and do not require activation of the incident response program.

- *Notification of Unusual Event.* Under this category, events are in process or have occurred which indicate potential degradation in the level of safety of the plant. No release of radioactive material requiring off-site response or monitoring is expected unless further degradation occurs. There is no danger being posed to the health and safety of the general public. However, federal, state, and local governmental agencies are notified immediately.

- *Alert.* If an alert is declared, events are in process or have occurred which involve an actual or potential substantial degradation in the level of safety of the plant because of either a plant problem or a security issue. Any releases of radioactive material from the plant are expected to be limited to a small fraction of the Environmental Protection Agency (EPA) protective action guides (PAGs) and would not pose any danger to the health and safety of the general public. Federal, state and local governmental agencies are notified immediately and will begin EP activities such as activating their facilities in preparation in case of further degradation at the plant.
- *Site Area Emergency.* A Site Area Emergency involves events in process or which have occurred that result in actual or likely major failures of plant safety functions needed for protection of the public. This could be caused by equipment failure, a security event or a natural disaster. Any releases of radioactive material are not expected to exceed the EPA PAGs except at the site boundary. Sirens will sound and the local radio and television stations will activate the emergency alert system. Federal, state and local governmental agencies are notified immediately and will act to ensure the health and safety of the general public.
- *General Emergency.* A General Emergency involves actual or imminent substantial core damage or melting of reactor fuel with the potential for loss of containment integrity. Radioactive releases during a General Emergency could exceed the EPA PAGs for more than the immediate site area. Federal, state and local government agencies are notified immediately and will work with plant officials to protect the health and safety of the general public. People in the EPZ may be advised to evacuate or seek shelter.

14.4.3 Protective action recommendations

Immediately on becoming aware that an incident has occurred that may result in a radiation dose that exceeds federal government PAGs, nuclear power plant personnel in an emergency response facility evaluate plant conditions and then make protective action recommendations (PARs) to the state and local government agencies on how to protect the population. Nuclear power plant personnel are required to report the PARs to the state or local government agencies (within 15 minutes). State and local officials make the final decision on what protective action is necessary to protect public health and safety, and then relay this decision to the public in a timely manner (normally within approximately 15 minutes).

The NRC monitors the actions of the nuclear power plant to ensure that the protective actions taken or recommended by the nuclear power plant personnel are appropriate. Additionally, state and local agencies may independently assess the situation to ensure that the correct protective action decisions are made. Independent assessments performed during an accidental radiological release from a nuclear power plant ensure that the best possible action is taken. Often, independent agencies provide radiological experts to assist in making recommendations.

In the unlikely event of a nuclear power plant accident, it is important to follow the direction of the state and local government in order to make sure protective actions are implemented safely and effectively for the affected population.

14.4.4 International Nuclear Events Scale (INES)

The International Nuclear and Radiological Event Scale (INES) was introduced in 1990 by the International Atomic Energy Agency (IAEA) in order to enable prompt communication of safety-significant information in case of nuclear accidents. INES is a tool for promptly communicating to the public in consistent terms the safety significance of reported nuclear and radiological incidents and accidents throughout the world, excluding naturally occurring phenomena such as radon. The scale can be applied to any event associated with nuclear facilities, as well as the transport, storage and use of radioactive material and radiation sources.

The primary purpose of the INES Scale is to facilitate communication and understanding between the technical community, the media and the public on the safety significance of nuclear events (INES, 2012) The aim is to keep the public, as well as nuclear authorities, accurately informed on the occurrence and potential consequences of ongoing events.

The scale was designed by an international group of experts convened jointly by the IAEA and the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development (OECD/NEA). Since then, the IAEA has overseen its development in cooperation with the OECD/NEA and with the support of more than 70 designated INES National Officers who officially represent the INES member states at biennial technical meetings.

INES, to facilitate understanding, uses a numerical rating to explain the significance of nuclear or radiological events. This is just like using ratings for earthquakes or temperature, which would be difficult to understand without well-known and commonly accepted scales.

INES applies to any event associated with the transport, storage and use of radioactive material and radiation sources. Such events can include industrial and medical uses of radiation sources, operations at nuclear facilities, or the transport of radioactive material. Events are classified at seven levels: Levels 1–3 are ‘incidents’ and Levels 4–7 ‘accidents’. These levels consider three areas of impact: people and the environment, radiological barriers and control, and defense in depth. The scale is designed to be logarithmic, so that the severity of an event is about ten times greater for each increase in level on the scale. Events without safety significance are called ‘deviations’ and are classified Below Scale/Level 0.

Level 7 is the highest level and is referred to as a Major Accident. Level 7 includes major release of radioactive material with widespread health and environmental effects requiring implementation of planned and extended countermeasures. There have been two such events to date. The first was at Chernobyl in the Ukraine in April 1986. A power surge during a test procedure resulted in a criticality accident, leading to a powerful steam explosion and fire that released a significant fraction of core material into the environment. As a result, the city of Chernobyl was largely abandoned, the larger city of Pripyat (pop. 49 400) was completely abandoned and a permanent 30 km exclusion zone around the reactor was established.

The second was the Fukushima Daiichi nuclear disaster in Japan in March 2011. Major damage to the backup power and containment systems was caused by the Tōhoku earthquake and tsunami, which resulted in overheating and leaking from some of the Fukushima nuclear plant's reactors. Each reactor accident was rated separately; out of the six reactors, three were rated level 5, one was rated at level 3 and the situation as a whole was rated level 7. A temporary exclusion zone of 20 km was established around the plant as well as a 30 km voluntary evacuation zone.

Level 6 is the second highest level and is referred to as a Serious Accident. Level 6 includes significant release of radioactive material likely to require implementation of planned countermeasures. There has been only one such event to date. It occurred at Kyshtym in the Soviet Union in September 1957. A failed cooling system at a military nuclear waste reprocessing facility caused a steam explosion that released radioactive material into the environment.

Level 5 is the third highest level and is referred to as an Accident with Wider Consequences. Level 5 includes a limited release of radioactive material that is likely to require implementation of some planned countermeasures. In addition, there is severe damage to reactor core and a release of large quantities of radioactive material with a high probability of significant public exposure that could arise from a major criticality accident or fire. Several deaths from radiation would be expected.

An example of a Level 5 accident, and the most serious event in the USA, is the Three Mile Island (TMI) accident that occurred in March 1979. A combination of design and operator errors caused a gradual loss of coolant, leading to a partial meltdown. Radioactive gases were released into the atmosphere; no deaths have been attributed to this accident, but significant changes to the approach to nuclear safety in the USA occurred after TMI.

Level 4 is the lowest level that is characterized as an accident and is referred to as an Accident with Local Consequences. Level 4 includes a minor release of radioactive material unlikely to result in implementation of planned countermeasures other than local food controls, at least one death from radiation, fuel melt or damage to fuel and the release of significant quantities of radioactive material with a high probability of significant public exposure.

Level 3 is the highest level that is not characterized as an accident and is referred to as a Serious Incident. Level 3 includes exposure in excess of ten times the statutory annual limit for workers, non-lethal health effects from radiation and severe contamination with a low probability of significant public exposure. It is considered to be a 'near accident', with no safety provisions remaining.

Level 2 is the second lowest level on the scale and is referred to as an Incident. Level 2 includes exposure of a member of the public in excess of 1 Rem (or 10 millisievert), exposure of a worker in excess of the statutory annual limits, radiation levels in an operating area of more than 5 Rem (or 50 millisievert) per hour, significant contamination within the facility into an area not expected by design, or significant failures in safety provisions but with no actual consequences.

Level 1 is the lowest level of incident of the scale and is referred to as an Anomaly. Level 1 includes the overexposure of a member of the public in excess of statutory annual limits or minor problems with safety components with significant defense in depth remaining.

14.5 Federal, state and local responsibilities and use of potassium iodide

The TMI accident in the USA in 1979 revealed that better coordination between nuclear power plant operators and federal, state and local government emergency response organizations was needed. Following the accident, the NRC's EP regulations were changed to require each nuclear power plant operator to submit the radiological emergency response plans of state and local governments that are within the 10-mile plume exposure pathway EPZ, as well as the plans of state governments within the 50-mile ingestion pathway EPZs.

14.5.1 Federal

The roles and responsibilities of the NRC and FEMA with regard to EP are found in their respective regulations and in a Memorandum of Understanding (MOU) between the two agencies relating to nuclear power plant EP.

NRC roles and responsibilities

The NRC is responsible for evaluating nuclear power plant emergency plans to determine if they are adequate to protect public health and safety. The nuclear industry also works together to ensure all of the emergency plans are adequate. The NRC also evaluates nuclear power plant emergency plans to determine if they can be used by off-site emergency response personnel (state and local officials and volunteers) and that the plans provide for sufficient resources and equipment during an emergency.

The NRC reviews FEMA evaluations of off-site EP and places requirements on the utilities to ensure that issues are adequately addressed. The NRC is responsible for making decisions on the overall state of EP, such as issuing of nuclear power plant operating licenses or taking enforcement actions (e.g. violations, civil penalties, orders or shutdown of operating reactors). FEMA is the federal interface with state and local governments with regard to EP for nuclear power plants. NRC provides assistance in off-site preparedness through its membership on the Regional Assistance Committees (RAC), which is coordinated by FEMA.

Department of Homeland Security roles and responsibilities

The Department of Homeland Security (DHS) is responsible for evaluating state and local emergency plans to determine if they are adequate to protect the health and safety of the general public. DHS is also responsible for determining if state and local emergency plans can be used by emergency response personnel and to provide for sufficient resources and equipment during an emergency. During emergencies, requests for assistance and additional equipment are coordinated through the state and local governments, but any resource can be made available for use at the site.

DHS evaluates the alert and notification system for nuclear power plants, including outdoor warning sirens, reverse 911, radio systems or whatever other technology is used to ensure that people in the areas surrounding nuclear power plants can be warned in the case of an emergency.

DHS is responsible for EP training of state and local officials as a supplement to state, local and utility efforts. They oversee the development of the coordinated response of federal agencies to a nuclear power plant radiological emergency. Command and control is an important aspect of emergency response, and DHS is the lead agency. Knowing who is in charge before the event occurs alleviates the need for determining command and control responsibilities as the event is occurring.

DHS also assists in the review of the adequacy of EP plans related to nuclear power plants as requested by the NRC, particularly the portion that applies to the state, local and federal response.

Together, NRC and FEMA will determine the two-year evaluated EP exercise requirements for nuclear power plant operators and state and local governments. In this manner, both on-site and off-site EP capabilities are adequately evaluated. This projected schedule includes a list of full-scale FEMA and NRC evaluated exercises required of nuclear facilities. The list includes identification of the date and type of exercise (e.g. plume, ingestion, partial), and the participants. NRC headquarters and regional staff members typically participate in four full-scale emergency response plume exercises each year and also participate in select ingestion exposure exercises. Exercise participants may include licensee, state, county and local governmental and emergency response agencies, NRC, FEMA and other appropriate federal agencies.

14.5.2 State and local

State and local government officials have overall responsibility for deciding and implementing appropriate protective actions for the public during a nuclear power plant radiological emergency. They are responsible for notifying the public to take protective actions, such as evacuation, sheltering in place or taking potassium iodide pills as a supplement. State and local officials base their decisions on the protective action recommendations by the nuclear power plant operator and their own radiological or health organizations. The NRC provides advice, guidance and support to the state and local government officials. Neither the nuclear power plant operator nor the NRC can order the public to take protective actions.

14.5.3 Use of potassium iodide

Potassium iodide (KI) is an over-the-counter drug that, if taken properly, may reduce the amount of radioactive iodine absorbed by the thyroid gland from radioactive iodines, and can reduce the risk of thyroid cancer (NRC, 2012b, 2012c). The Food and Drug Administration (FDA) has issued guidance on the dosage and effectiveness of KI. The NRC has supplied KI tablets to states requesting it for the population within the 10-mile EPZ. If necessary, KI is to be used to supplement evacuation or sheltering in place, not to take the place of these actions. If radioactive iodine is taken into the body after consumption of KI, it will be rapidly excreted from the body.

KI offers protection only to the thyroid gland and should only be used in conjunction with sheltering and/or evacuation. If one evacuates prior to being exposed to radioactive iodine, there is no need to take KI. Likewise, there is no need to take KI prior to being advised that there is a release of radioactivity in progress at a nearby facility. KI should not be taken by people who are allergic to iodine, normally people who are allergic to shellfish.

The population closest to the nuclear power plant, that is within the 10-mile EPZ, is at greatest risk of exposure to radiation and radioactive materials. When the population is evacuated out of the area, and potentially contaminated foodstuffs are removed from the market, the risk from further radioactive iodine exposure to the thyroid gland is essentially eliminated. Beyond 10 miles, the major risk of radioiodine exposure is from ingestion of contaminated foodstuffs, particularly milk products. Both the EPA and the FDA have published guidance to protect consumers from contaminated foods. These protective actions are preplanned in the 50-mile ingestion pathway EPZ.

In the unlikely event of a nuclear power plant accident, it is important to follow the direction of the state or local government in order to make sure protective actions, such as taking KI pills, are implemented safely and effectively for the affected population.

14.6 Emergency preparedness in response to terrorism

Since the terrorist attack in New York City on 11 September 2001, NRC took immediate action by advising nuclear power plants to go to the highest level of security (NRC, 2012d). Shortly afterward, NRC and the industry reevaluated physical security at the nation's nuclear power plants. In February 2002, the NRC issued Interim Compensatory Measures (ICMs) requiring all US nuclear power plants to perform specific plant design studies, recruit additional security personnel, enhance physical protection features, improve EP and provide additional training. Nuclear industry groups and federal, state and local government agencies assisted in the prompt implementation of these measures, and participated in drills and exercises to test new planning elements.

Protecting public health and safety has always been paramount in nuclear power plant design and operation. Robust structures, such as reactor containment buildings, protect the reactor. Safety systems, such as diesel generators, are redundant and independent. These design features provide excellent protection from external hazards, such as tornadoes and hurricanes, as well as nuclear accidents. The same design features also protect against potential acts of terrorism, making nuclear power plants among the most robust and well-protected civilian facilities in the country.

Physical security at nuclear power plants is provided by well-armed and well-trained security personnel who remain ready to respond to an attack 24 hours a day, seven days a week. The sites are protected by sensitive intrusion detection equipment, fences and barriers all of which are monitored by cameras and security patrols. The NRC conducts force-on-force (FOF) exercises using trained adversaries to ensure that nuclear power plant security personnel can implement many new security improvements. NRC security specialists observe these exercises to ensure that the licensee can implement emergency plans during a terrorist event. Additionally, NRC conducts routine inspections to ensure licensees comply with EP, security and all other regulations.

The events on 11 September 2001 also highlighted the need to reexamine the way the NRC is organized. As a result, the NRC created the Office of Nuclear Security and Incident Response (NSIR) to more effectively bring together staff expertise to focus on security and EP. In addition to pulling staff from other areas within the NRC, the new NSIR office hired experts in security with civilian and military experience. Within NSIR, the NRC established the Division of Preparedness and Response (DPR) to integrate EP with emergency response. The establishment and placement of this organization reflects another step in the NRC's ongoing efforts to increase attention on activities that affect EP. DPR is responsible for developing EP policies, regulations, programs and guidelines for both currently licensed nuclear reactors and potential new nuclear reactors, as well as for certain materials and licensee facilities such as fuel cycle facilities.

14.6.1 Consideration of potential terrorist activities with respect to emergency preparedness

NRC continues to conduct studies to determine the vulnerability of nuclear power plants and the adequacy of licensee programs to protect public health and safety in the post-9/11 threat environment. Whether the initiating event is terrorist-based or a nuclear accident, the EP planning basis provides reasonable assurance that public health and safety will be protected. EP plans have always been based on a range of postulated events that would result in a radiological release, including the most severe.

14.7 Sources of further information

1. US NRC website, www.nrc.gov.
2. IAEA, Manual for First Responders to a Radiological Emergency, IAEA Vienna, 2006.
3. IAEA, Development of an Extended Framework for Emergency Response Criteria: Interim Report for Comments, TECDOC-1432, Vienna.
4. IAEA, GS-G-2: Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency, 2002.
5. IAEA, GS-R-2: Preparedness and Response for a Nuclear or Radiological Emergency.
6. IAEA, GS-G-2.1: Arrangements for Preparedness and Response for a Nuclear or Radiological Emergency, 2007.
7. OECD, Short-Term Countermeasures in Case of a Nuclear or Radiological Emergency, 2003.
8. OECD, Strategy for Conducting Nuclear Emergency Exercises, NEA no. 6162, 2007.

14.8 References

INES (2012) The International Nuclear and Radiological Event Scale, http://www-ns.iaea.org/tech-areas/emergency/ines.asp (accessed 4 December 2012).

NRC (2012a), About Emergency Preparedness, http://www.nrc.gov/about-nrc/emerg-preparedness/protect-public.html (accessed 4 December 2012).

NRC (2012b) Federal, State, and Local Responsibilities, http://www.nrc.gov/about-nrc/emerg-preparedness/about-emerg-preparedness/federal-state-local.html (accessed 4 December 2012).

NRC (2012c) Use of Potassium Iodide, http://www.nrc.gov/about-nrc/emerg-preparedness/about-emerg-preparedness/potassium-iodide-use.html (accessed 4 December 2012).

NRC (2012d) Emergency Preparedness in Response to Terrorism, http://www.nrc.gov/about-nrc/emerg-preparedness/respond-to-emerg/response-terrorism.html (accessed 4 December 2012).

15

Management of nuclear crises: accidents and lessons learned

T. VARJORANTA, Director General,
Radiation and Nuclear Safety Authority (STUK), Finland

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Abstract: The major nuclear accidents at Three Mile Island, Chernobyl and Fukushima Daiichi are discussed from a crisis management viewpoint. Nuclear crisis management consists of four phases: avoiding a crisis, preparing for the unexpected, managing the acute crisis phase and long-term far-reaching aspects. The most important phase is the first one. To avoid a crisis, safety culture, division of responsibilities, defence in depth, technical means, IAEA action plan and performed stress tests are discussed. The main lessons learned show how nuclear power plant safety has developed over the years and continues to do so.

Key words: crisis management, nuclear safety, safety culture, defence in depth, IAEA action plan.

15.1 Introduction

A crisis is seldom, if ever, a result of one single major cause. Rather, it is a result of many, often small, things going wrong simultaneously or in sequence. Large-scale industrial accidents and air-crash investigations have demonstrated this. Events with low probability and medium consequences have in a few cases developed into very high consequence severe accidents.

We try to think of everything and take all reasonable measures to avoid a severe accident. In nuclear safety, it is recognized that equipment fails, humans make mistakes and no design is perfect. Accidents fill the gaps. Following an accident, the accident is carefully studied, and lessons are learned and shared to ensure that technical and human actions are improved to eliminate, as far as practically possible, reoccurrence.

This chapter discusses nuclear crisis management, reflecting the three severe nuclear accidents of Three Mile Island (TMI), Chernobyl and Fukushima Daiichi. A severe accident in this chapter refers to an accident in which nuclear fuel in the reactor was at least partially melted. The three severe nuclear accidents are briefly described, then lessons learned are divided into four crisis management phases: avoiding the crisis, preparing for the unexpected, managing the acute phase of a crisis and managing long-term and far-reaching aspects of the crisis. Finally, the importance of learning and sharing the lessons from each accident is highlighted, that is ‘never waste a crisis’.

The most important crisis management phase is the first one: to avoid the crisis happening in the first place. Much effort, nationally and internationally, has been invested in this phase, and results and lessons shared. This phase is therefore discussed in more detail than the others.

15.1.1 International consequences and cooperation

Severe nuclear accidents can be limited in terms of the danger they pose to members of the public (TMI) or very wide and far-reaching (Chernobyl). Common to all severe accidents is that an accident anywhere is an accident everywhere. Also, people not directly affected may be affected in other ways. For instance, in the Fukushima Daiichi accident, no lives were lost as a result of the radiation; however, over 90 000 people were evacuated from the area and their psychosocial suffering was substantial. Note that the earthquake and tsunami resulted in approximately 22 000 people dead or missing.

Crisis management is a very broad and cross-cutting matter both within a country and between countries, as severe nuclear accidents can have transboundary effects. There are many different 'stakeholders' involved, such as the plant operator, owner, regulator, evacuated public, other people, media and neighbouring countries. For crisis management to be successful, different actions are required from different stakeholders at different times.

The International Atomic Energy Agency, IAEA, plays an important role in the overall crisis management framework. Under the auspices of the IAEA, safety standards are developed and issued, training is provided to implement these standards and peer-reviews are organized to help member states understand how well the standards are applied and where to improve. The IAEA facilitates, in many different ways, the information gathering and sharing which benefit the national and global safety framework. For example, in a crisis situation it is unreasonable to expect that the country in which the accident is happening is in a position to inform all other countries. The IAEA is the gateway for information sharing at a global level. There are many other regional organizations and professional associations that also play important service roles in all phases of crisis management.

15.2 Major nuclear accidents

15.2.1 Three Mile Island

On 28 March 1979 at the unit of the Three Mile Island nuclear power plant, maintenance work was performed on the unit's feed water system. As a result of a mistake, the feed water system stopped operating. As expected, the water level at the steam generators started to lower, decreasing the heat transfer from the primary circuit to the secondary circuit. Therefore, the temperature and pressure in the primary circuit started to rise. As a result of the rise, the release valve of the pressurizer opened. In this way, a leakage route of the primary circuit coolant was established.

The reactor was automatically shut down when the pressure and temperature rose. When the pressure in the primary circuit dropped, the pressurizer relief valve should have closed but it remained open. When the pressure dropped further, plant automation started the high pressure emergency cooling system, which pumped an equal amount of water to the reactor as was leaked through the open relief valve. From the reactor viewpoint, the situation was safe; there was enough water in the reactor and the leakage was fully compensated.

All this happened very quickly. It took only 15 seconds from the moment when the feed water pumps stopped operating to the leakage through the relief valve, and only two minutes to the operation of the emergency coolant system. At this point in time, there were various alarms in the main control room.

The operators' attention was captured by the rising water level of the pressurizer, which would result in substantial problems in controlling the primary circuit pressure. As trained, they decreased water pumping to the circuit. This actually resulted in decreasing the water inventory in the primary circuit. Because of the decreasing pressure, water was boiling in the primary circuit and therefore the rising water level in the pressurizer was misleading the operators to believe that there was too much water in the primary circuit, when, in fact the opposite was occurring.

As a result of the symptoms of overpressure and rising temperature in the containment building, it became evident to the operators that there was a leak in the primary circuit. In the main control room panel, an indicator light made the operators believe that the pressurizer relief valve was closed. However, this light only indicated that the valve had received a command to close, in other words the indicator light did not indicate the open/closed status of the valve.

The operators faced new challenges with boron control and vibrations in primary circuit main circulation pumps. The water level in the reactor continued to decrease resulting in about two-thirds of the core being without cooling water. The fuel overheated and resulted in severe core damage. All this had taken place in less than 2.5 hours.

An operator, who came in from the other unit, closed another valve in the out-blowing line in the pressurizer relief line, which finally closed the leak from the primary circuit. Finally, the situation was brought under control by starting one of the main circulation pumps.

During the accident, the integrity of the containment building as a radionuclide release barrier was not compromised. Because the reactor pressure vessel and the containment building maintained their integrity, the accident did not have considerable environmental impacts. The actual scale of severe damage to the reactor core was revealed only six years later, when visual observations from the core could be made using remote camera equipment.

15.2.2 Chernobyl

On 25 April 1986, about 100 km from Kiev, Ukraine, the power of Unit 4 of the Chernobyl nuclear power plant was decreased in order to shut the unit down for maintenance. During this process a test, which was not done in the commissioning phase, was to be carried out. The purpose was to test how the plant would react when the connection to the external electrical grip is lost and steam flow to the turbine is closed. The objective was to ensure that there would be enough time for the diesel generators to start in order to supply electricity needed. The test was to be carried out at a low reactor power level of 700 MW.

The decrease of the power of the reactor started as planned, but the decreasing had to be stopped for several hours in order to supply electricity to the grid because of the need for electricity in Ukraine.

As the beginning of the test was delayed for several hours, Xenon continued to build up in the reactor and the operators removed control rods from the core to maintain the power level. Finally, the test started and went as planned. After 36 seconds from the beginning of the test, the operators carried out a manual shutdown of the reactor as they considered that the test had been successful and could be ended.

The control rods entering the core did not decrease the reactor power level, but instead produced a violent power explosion that broke the reactor and caused the worst nuclear power accident ever. As a result of the explosion, radioactive material, including fragments of nuclear fuel and core graphite spread over the site. Core graphite burned and, with other hot core materials, provided lift for radioactive nuclides.

Fire fighters and operator staff participating in emergency work received high radiation doses, several being fatal. For the first few days water was used to try to cool the destroyed core and put out the graphite fire. As these efforts were unsuccessful, sand was dropped from helicopters for six days. This helped to put out the core fire, but it also introduced a new problem as the sand precluded removing the decay heat from the core. Therefore, the temperature of the destroyed core remained very high and releases of radioactive nuclides continued until early in May. Also, liquid nitrogen was pumped to the core remains.

Releases to the environment started to decrease only after the molten fuel, graphite and core materials penetrated through the reactor tank base slab and flew to the lower floors of the building to be met with cooling water.

The Chernobyl accident had huge consequences: it led to the deaths of about 50 people engaged in the emergency and recovery operations, some 600 000 people were affected by high radiation doses, around 4000 of them may die prematurely as a result of their exposure. The social consequences of the accident were extensive: more than 100 000 residents were evacuated and the total number of evacuees from severely contaminated areas reached 350 000.

15.2.3 Fukushima Daiichi accident

At 14:46 on 11 March 2010, the Great East Japan Earthquake took place about 130 km from Sendai at a depth of about 25 km. Rated a magnitude 9.0, it was the most powerful earthquake ever known to have hit Japan.

Four nuclear power plants on the eastern coast of Japan were affected: Oganawa (units 1–3), Fukushima Daiichi (units 1–6), Fukushima Daini (units 1–4) and Tokai-2. As of today, information available indicates that all the units reacted to the earthquake as designed and no safety relevant damage took place. Units in operation shut down automatically, and safety systems started to cool down the reactors removing the decay heat as designed.

At Fukushima Daiichi, units 1–3 were operating and units 4–6 were in refuelling/maintenance outage. The connection to the grid and thereby to the external electrical power was lost, and the safety systems were powered by diesel generators. All safety relevant systems were operating as they were designed to do.

About 46 minutes after the earthquake, the first tsunami wave, with a height of about 15 metres and speed of about 40 km/h, hit the Fukushima Daiichi site. The tsunami exceeded the design basis at all units.

Flooding at the site was extensive. The tsunami destroyed a large amount of equipment and systems as a result of mechanical impact and flooding. Serious damage was caused to diesel generators, fuel and fresh water tanks, most important electricity distribution equipment and systems and the instrumentation and control systems of the units. It is estimated that during the worst moments of flooding, electrical systems and many safety important systems were 4–5 metres under water.

When the tsunami waters finally escaped, the site was covered with lots of debris, which substantially hampered operations at the site.

From a safety viewpoint, two major things occurred. As a result of the loss of electrical power (outside and diesel generator powered) and the ultimate heat sink, the decay heat from the reactors resulted in mechanical damage to the systems and cooling function was lost in the reactors and spent fuel pools.

The following timeline shows the main course of events at the site. It is emphasized that such serious events taking place at multiple units of one single site was a new situation.

March 11, at:

- 15:37, unit 1: tsunami hits causing loss of AC power, station blackout, loss of ability to inject water to the reactor.
- 15:41, unit 2 and unit 3: tsunami hits causing loss of AC power, station blackout, loss of ability to inject water to the reactor.
- 15:38, unit 4: tsunami hits causing loss of AC power, station blackout.
- About 17:00, unit 1: water level drops below top of fuel at the core, fuel and reactor core damage starts.

- Evacuation of residents within 3 km and shelter-in-place for residents within 10 km takes place.

March 12, at:

- 14:30, unit 1: primary containment is vented releasing radioactive nuclides to the atmosphere.
- 15:36, unit 1: as a result of extensive overheating of the core fuel, the Zr-cladding of fuel reacts with the steam generating substantial amounts of hydrogen, which, after escaping to the upper parts of the reactor building, explodes. The explosion causes serious damage to the reactor building and spreads a large amount of contaminated debris, further hampering operations at the site.
- Evacuation of residents within 20 km takes place.

March 13, at:

- About 08:00, unit 3: level drops below top of fuel at the core, fuel and reactor core damage starts.
- About 11:00, unit 2: primary containment is vented releasing radioactive nuclides to the atmosphere.

March 14, at:

- 05:20, unit 3: primary containment is vented releasing radioactive nuclides to the atmosphere.
- 11:01, unit 3: as a result of extensive overheating of the core fuel, the Zr-cladding of fuel reacts with the steam generating substantial amounts of hydrogen, which, after escaping to the upper parts of the reactor building, explodes. Explosion causes serious damage to the reactor building and spreads a large amount of contaminated debris, further hampering operations at the site.
- About 18:00, unit 2: water level at the core drops below the top of fuel at the core, fuel and reactor core damage starts.

March 15, at:

- About 06:00, unit 2: the suppression chamber ruptures because of overpressure meaning that the primary containment is seriously damaged.
- About 06:00, unit 4: explosion in the reactor building, which spreads a large amount of contaminated debris, further hampering operations at the site. As the unit was in reloading/maintenance, it is clear that the cause of the explosion is different from the one in unit 1. For the time being, the cause is unknown.
- Evacuation of residents within 30 km takes place.

It was also recognized that all units had spent nuclear fuel in their fuel pools in addition to the common spent fuel storage. Part of the fuel was discharged less than a year ago from the reactors. If the coolant and cooling of the fuel pools were lost, overheating, fuel damage, and, in the worst case, fuel Zr-cladding fire accident scenario could take place. This accident scenario is analyzed to have serious on- and off-site consequences.

Because of the mechanical damage and radiological situation at the site, the condition of the fuel pools could not be verified and external exceptional cooling measures, such as pump-trucks, were used to ensure sufficient cooling water inventories at the pools.

Releases of radioactive nuclides to the environment were worst on 15–16 March 2011. In the beginning, the release contained mostly iodine, later also caesium.

External cooling water to the reactor and fuel pools combined with the damage resulted in substantial amounts of contaminated water finding its way to lower parts of the reactor buildings, and finally to the basements of the turbine buildings.

About 90 000 residents were evacuated and 800 km^2 of land was contaminated as a result of the accident. Substantial remediation efforts beyond the 20 km exclusion zone are ongoing. However, because of the extensive damage done to the infrastructure by the earthquake and tsunami, it could be a long time even after remediation and decontamination efforts before residents are able to return to their homes. Despite the important fact that no lives were lost as a result of radiation, suffering among the residents remains substantial.

Comparing the Chernobyl and Fukushima Daiichi accidents, the following observations can be made:

- Reactors were severely damaged but in very different ways. The reactor at Chernobyl exploded, spreading fuel fragments on-site and exposing the core remains to the atmosphere. At Fukushima Daiichi, the severe core damages were because of fuel overheating.
- Releases of radioactive nuclides in Fukushima Daiichi were about 10% of that in Chernobyl.
- Land-use in contaminated off-site areas is quite different. In areas affected by the Fukushima Daiichi accident, 73% is forest and mountainous areas, paddy fields about 10% and urban areas less than 5%. In areas affected by the Chernobyl accident, the landscape is flat, forests cover about 39% of the area and about 43% is used for agricultural purposes.
- The lesson learned from Chernobyl was the major importance of socio-psychological consequences to the residents evacuated and relocated.

15.3 Avoiding a crisis

Avoiding a crisis happening is the most important phase of crisis management. Over the years, the nuclear energy community has invested much time and effort in minimizing the probabilities of accidents occurring. One very important element has been learning lessons from the three nuclear accidents that resulted in reactor core damage, as well as learning from the smaller accidents and near-miss accidents and events. In the Convention on Early Notification of a Nuclear Accident, INFCIRC/335, IAEA, Vienna (1986), a nuclear accident is defined as 'Any accident involving facilities or activities from which a release of radioactive material occurs or is likely to occur and which has resulted or may result in an international transboundary release that could be of radiological safety significance for another State'.

To avoid a nuclear crisis, the key is to ensure nuclear safety, in other words to prevent damage to the reactor core, nuclear fuel that has been irradiated and plant radioactive wastes and consequent release of radioactive nuclides to the environment.

To ensure nuclear safety, several concepts, principles, requirements, best practices guides and measures have been developed, implemented and improved. Some are generic, some are specific for siting of the nuclear plant, for design, manufacturing and construction, commissioning, operations, decommissioning, accident management and emergency preparedness. Some are cross-cutting, in other words applicable to all phases and operational statuses of the nuclear plant.

The most important cross-cutting concepts and measures include safety culture, division of responsibilities, 'defence in depth', quality assurance, use of proven technologies, safety reviews and assessments, human factors, radiation protection system, use of operational experience and safety research.

15.3.1 Safety culture

Safety culture was born as perhaps the most important lesson from the Chernobyl accident. Safety culture can be defined as 'The assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, protection and safety issues receive the attention warranted by their significance' (IAEA safety glossary).

When designing, constructing and operating a nuclear plant, an advanced safety culture needs to be maintained which is based on the safety oriented attitude of the topmost management of the organizations in question and on motivation of the personnel for responsible work. This presupposes well-organised working conditions and an open working atmosphere as well as the encouragement of alertness and initiative in order to detect and eliminate factors that endanger safety.

Safety is made in every working level of the organization by every individual. Therefore, safety is strongly and directly influenced by:

- How any organization is managed.
- What kind of atmosphere and culture there is in the everyday working place.
- What kind of attitudes the management has and reflects to the staff, both verbally and non-verbally.

Key elements of safety culture include the following:

- Visible commitment of the management.
- Complying with rules, regulations and guides.
- Conservative decision making.
- Reporting on deviation and anomalies.
- Reacting to factors weakening or jeopardizing safety and safety functions.
- Intention and ambition to learn from experience.
- Good, frequent, open and timely communication.
- Selection of safety improvements based on safety function priorities, and clear justification of priorities as well as selections made.
- Clearly defined structure, functions, responsibilities and rights of the organization.
- Ability to produce required quality.
- Everybody's vigilance, and ability of the organization to manage issues openly.

15.3.2 Division of responsibilities

The ultimate responsibility for the safety of a nuclear power plant rests with the operating organization. This is also the case if the plant is built as a turn-key project. How well the plant is designed in detail and built impacts to a large extent how reliably and safely it will operate. Therefore, it is in the primary interest of the plant operator and the national regulator that the plant is designed and built to the highest quality.

The government is responsible for the adoption within its national legal system of such safety legislation, regulations, and other standards and measures as may be necessary to fulfil all its national responsibilities and international obligations effectively, and for the establishment of an independent regulatory body.

The main responsibilities and functions of an independent regulatory body include:

- Authorization of the plant and activities.
- Review and assessment.
- Inspection of facilities and activities.
- Enforcement.
- Regulations and guides.
- Communication and consultation with the interested parties.

15.3.3 Defence in depth

Preventing a nuclear accident (the reactor core, nuclear fuel that has been irradiated and plant radioactive wastes damage and consequent release of radioactive nuclides to the environment) from happening requires that the following three basic safety functions are executed:

- Control of reactivity.
- Cooling of radioactive material, in other words removal of decay heat from the reactor core and from the nuclear fuel that has been irradiated in the reactor.
- Confinement of radioactive material.

The safety functions must be available and operable in all situations. This is ensured

- Firstly, by means of inherent safety features, such as negative temperature coefficient and negative void coefficient. The first means that as the temperature increases, the efficiency of the reaction decreases. The second means that if steam is formed in the cooling water, the nuclear reaction slows down because there is a decrease in moderating effect so that fewer neutrons are able to cause fission.
- Secondly, by safety systems as mentioned above. These safety systems must be reliable, and therefore need to be protected from internal and external hazards.

Recognizing that equipment can fail, designs are not necessarily perfect and humans make mistakes, redundant levels of protection including successive barriers are provided to ensure that the three basic safety functions can be executed in all situations. This concept is known as ‘defence in depth’.

This key nuclear safety concept can be defined as ‘A hierarchical deployment of different levels of diverse equipment and procedures to prevent the escalation of anticipated operational occurrences and to maintain the effectiveness of physical barriers placed between a radiation source or radioactive material and workers, members of the public or the environment, in operational states and, for some barriers, in accident conditions’.

There are four barriers between fission products and the environment: ceramic fuel matrix, fuel rod cladding, primary coolant boundary and the containment.

Defence in depth consists of the following five levels:

- Level 1: Prevention of deviation from normal operations.
- Level 2: Control of abnormalities and detection of failures.
- Level 3: Control of accidents within the design basis.
- Level 4: Control of severe plant conditions, including prevention of accident progression and mitigation of the consequences of severe accidents.
- Level 5: Mitigation of radiological consequences, off-site emergency response.

Safety systems referred to above are used as a backup to prevent operations deviations from developing into accidents. Safety systems make use of redundancy and diversity of design and the physical separation of parallel components to reduce the likelihood of the loss of a safety function.

15.3.4 Other cross-cutting technical means to avoid a crisis developing into a severe accident

Other cross-cutting technical means to avoid a nuclear crisis include the following: quality assurance, use of proven technologies, safety reviews and assessments, human factors, radiation protection system, use of operational experience and safety research.

Nuclear power is based on technology which is proven by testing and experience, and which is reflected in approved codes and standards.

Quality assurance is applied to all safety-related structures, systems and components and activities at a nuclear power plant to ensure that they are of high quality and meet specified requirements.

In order to detect problems (and potential problems) concerning safety and performance, solving them and learning from others' good practices, two assessment mechanisms are relevant:

- Self-assessment, that is the involvement of personnel performing line functions.
- Independent peer-reviews, where peers provide constructive critical assessment of practices and programmes employed at plants, and in return can learn from good practices they identify during the review process.

Personnel engaged in safety-related activities are trained and qualified to perform their duties. The possibility of human error is recognized and means to facilitate correct decisions by operators, prevent wrong decisions and detect, correct and/or compensate for errors must be planned, documented and implemented whenever needed.

Safety assessment is a systematic critical review of ways in which structures, systems and components perform and might fail, and identifies the consequences of such failures. To be realistic and useful, safety assessment must be site- and plant-specific.

Two complementary methods, deterministic and probabilistic (probabilistic safety assessments, PSA), are currently in use. Both methods are used in evaluating and improving the safety of design and operation.

In the deterministic method, design basis accidents are selected to represent a range of possible accidents that could challenge the safety functions of the plant. Analysis is used to show that the response of the plant and its safety systems are acceptable. The deterministic method uses accepted engineering analysis to predict the course of events and their consequences.

PSA is used to identify failure scenarios and for deriving numerical estimates of risk related to severe accidents. It is also used to evaluate multiple failures, to identify components important to risk and to adjust the requirements for important components to be consistent with their risk.

There are typically three levels in PSA:

- Level 1 involves the assessment of the frequency of the reactor core damage.
- Level 2 involves the assessment of containment response, leading, together with Level 1 results, to the determination of frequencies of failure of the containment and release to the environment of a given percentage of the reactor core's inventory of radionuclides.

- Level 3 includes the assessment of off-site consequences, leading, together with the results of Level 2 analysis, to estimates of public risks.

Through a system of practices, consistent with recommendations of the ICRP and the IAEA standards, radiation protection measures are implemented to all phases of the plant's lifecycle, starting from the design until the plant has been decommissioned.

Each operating organization seeks to learn from its own experience as well as those of others. Therefore, an effective system for collection and interpretation of operating experience is important. Safety significant information is promptly disseminated among plant staff and to other relevant organizations. The sharing of operating data is coordinated nationally and internationally.

15.3.5 Rules of nuclear power will change: the IAEA Action Plan

After the Fukushima Daiichi accident, in June 2011, the IAEA organized an international Ministerial Conference on Nuclear Safety. The Ministerial Declaration adopted by the conference requested that the Director General of the IAEA prepare a draft Action Plan on Nuclear Safety aiming at improving nuclear safety worldwide, and thereby contributing to the first phase of crisis management.

Based on broad consultations with nuclear safety experts and the IAEA member states, a draft action plan was prepared by the IAEA Secretariat and approved by the IAEA Board of Governors. The Action Plan was presented to the IAEA 2011 General Conference in September 2011. The Action Plan was endorsed by all 151 member states, which was a remarkable achievement in global efforts to try to avoid a nuclear crisis happening in the future.

The Action Plan contains 12 actions for the IAEA, states, regulators, operators and other relevant stakeholders. As a result of their importance to the global safety framework, each action is briefly discussed in the following sections.

Action 1: Safety assessments in light of the accident at TEPCO's Fukushima Daiichi nuclear power station

Member states were requested to undertake a national assessment of the design of nuclear power plants against site-specific extreme natural hazards, and to implement necessary corrective actions in a timely manner. These are known as 'stress tests', and are discussed in more detail later.

The IAEA Secretariat, upon request, was requested to carry out peer-reviews of national assessments and to provide additional support to member states.

Action 2: IAEA peer-reviews

The IAEA Secretariat was requested to strengthen existing IAEA peer-reviews by incorporating lessons learned and by ensuring that these reviews appropriately address regulatory effectiveness, operational safety, design safety and emergency preparedness and response. One challenge in organizing effective peer reviews is to find available experts from the member states to function as reviewing peers. Therefore, the action also calls for member states to provide experts for peer-review missions.

Member states were also strongly encouraged to voluntarily host IAEA peer-reviews, including follow-up reviews, on a regular basis.

Action 3: Emergency preparedness and response

Member states were asked to conduct prompt national reviews of their arrangements and capabilities regarding emergency preparedness and response, with the IAEA Secretariat providing support. The IAEA Secretariat, member states and relevant international organizations were requested to review and strengthen the international emergency preparedness and response framework.

The IAEA Secretariat, member states and relevant international organizations were also asked to strengthen the assistance mechanisms to ensure that necessary assistance is made available promptly. Member states were encouraged to consider, on a voluntary basis, establishing national rapid response teams that could also be made available internationally.

Action 4: National regulatory bodies

This action calls for strengthening the effectiveness of national regulatory bodies through national review of an assessment of their effective independence, adequacy of human and financial resources and the need for appropriate technical and scientific support, to fulfil their responsibilities.

The IAEA Secretariat was requested to enhance the Integrated Regulatory Review Service (IRRS) for peer-review of regulatory effectiveness. Each member state with nuclear power plants was asked to voluntarily host, on a regular basis, an IAEA IRRS mission; a follow-up mission was to be conducted within three years of the main IRRS mission.

Action 5: Operating organizations

Member states were requested to ensure improvement, as necessary, of management systems, safety culture, human resources management, and scientific and technical capacity in operating organizations. Each member state with nuclear power plants should voluntarily host at least one IAEA Operational Safety Review Team (OSART) mission during the coming three years.

The IAEA Secretariat should strengthen cooperation with the World Association of Nuclear Operators (WANO) to enhance information exchange on operating experience and on other relevant areas, and to explore mechanisms to enhance communication and interaction among operating organizations.

Action 6: IAEA Safety Standards

The IAEA was requested to review and strengthen IAEA Safety Standards and improve their implementation.

Action 7: International legal framework

State parties were asked to explore mechanisms to enhance the effective implementation of the Convention on Nuclear Safety, the Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management, the Convention on the Early Notification of a Nuclear Accident and the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency, and to consider proposals made to amend the Convention on Nuclear Safety and the Convention on the Early Notification of a Nuclear Accident.

IAEA member states were also asked to work towards establishing a global nuclear liability regime.

Action 8: Member states planning to embark on a nuclear power programme

This action calls for facilitating the development of the infrastructure necessary for member states embarking on a nuclear power program. This would include member states voluntarily hosting Integrated Nuclear Infrastructure Reviews (INIR) and relevant peer-review missions, including site and design safety reviews, prior to commissioning the first nuclear power plant.

Action 9: Capacity building

This action calls for member states with nuclear power programmes and those planning to embark on such a programme to strengthen, develop, maintain and implement their capacity building programs, including education, training and exercises at the national, regional and international levels. They should continuously ensure sufficient and competent human resources necessary to assume their responsibility for safe, responsible and sustainable use of nuclear technologies.

Action 10: Protection of people and the environment from ionizing radiation

Member states, the IAEA Secretariat and other relevant stakeholders were asked to facilitate the use of available information, expertise and techniques for monitoring, decontamination and remediation both on and off nuclear sites, the removal of damaged nuclear fuel and the management and disposal of radioactive waste resulting from a nuclear emergency.

Member states, the IAEA Secretariat and other relevant stakeholders should share information regarding the assessment of radiation doses and any associated impacts on people and the environment.

Action 11: Communication and information dissemination

Member states were requested to strengthen their emergency notification systems, and reporting and information sharing arrangements and capabilities.

Member states were also asked to enhance the transparency and effectiveness of communication among operators, regulators and various international organizations, and strengthen the IAEA's coordinating role in this regard, underlining that the freest possible flow and wide dissemination of safety-related technical and technological information enhances nuclear safety.

The IAEA Secretariat is requested to provide member states, international organizations and the general public with timely, clear, factually correct, objective and easily understandable information during a nuclear emergency on its potential consequences, including analysis of available information and prognosis of possible scenarios based on evidence, scientific knowledge and the capabilities of member states.

The IAEA Secretariat is requested to organize international experts meetings to analyze all relevant technical aspects and learn the lessons from the Fukushima Daiichi nuclear power station accident.

The IAEA Secretariat and member states, in consultation with the OECD/NEA and the IAEA International Nuclear and Radiological Event Scale (INES) Advisory Committee, was asked to review the application of the INES scale as a communication tool.

Action 12: Research and development

This action is aimed at relevant stakeholders to conduct necessary research and development in nuclear safety, technology and engineering, to utilize the results and to share them, as appropriate, to the benefit of all member states.

15.3.6 Stress tests

Protection of safety functions from external hazards, such as earthquakes, fires and aeroplane crashes has received much attention in the design of current nuclear power plants. The Fukushima accident showed that a hazard which has not been adequately considered is tsunami; it warrants more attention and improved protection. Concerns were also expressed on whether there were other hazards that perhaps had been overlooked.

The existing safety analysis for nuclear power plants covers a large variety of situations. In light of the extreme conditions faced in Fukushima and the IAEA Action Plan's Action 1, many countries, the Council of the European Union, and the IAEA quickly concluded that the current safety analysis needed to be complemented by comprehensive and transparent risk assessments, so called 'stress tests'. A 'stress test' was defined as a targeted reassessment of the safety margins of nuclear power plants in the light of the events which occurred at Fukushima, that is extreme natural events challenging the plant safety functions and leading to a severe accident.

Some European countries, the Western European Nuclear Regulators' Association (WENRA) and the European Nuclear Safety Regulatory Group (ENSREG) moved quickly to develop scope and modalities of these tests in a coordinated framework.

More specifically, the technical scope of the stress tests covers the following three parts:

- Initiating events conceivable at the plant site:
    - Earthquake.
    - Flooding.
    - Other extreme natural events.
- Consequential loss of safety functions:
    - Loss of electrical power, including station blackout (SBO).
    - Loss of the ultimate heat sink (UHS).
    - Combination of both.
- Severe accident management issues:
    - Means to protect from and manage loss of core cooling function.
    - Means to protect from and manage loss of cooling function in the spent fuel storage pool.
    - Means to protect from and manage loss of containment integrity.

However, the considered initiating events have not been limited to earthquake and tsunami; flooding is included regardless of its origin. Furthermore, bad weather conditions are often considered. Also, assessment of the consequences of loss of safety functions is relevant if the situation is provoked by indirect initiating events, for example large disturbance from the electrical power grid impacting AC power distribution systems, or by other events such as malevolent acts.

The assessment approach is essentially deterministic: when analyzing an extreme scenario, a progressive approach is followed in which protective measures are sequentially assumed to be defeated.

The plant conditions represent the most unfavourable operational states that are permitted under plant technical specifications (limited conditions for operations). All operational states are considered. All reactors and spent fuel storages will be supposed to be affected at the same time. The possibility of degraded conditions of the site surrounding area is also taken into account.

Points of main interest include the following:

- Provisions taken in the design basis of the plant and plant conformance to its design requirements.
- Robustness of the plant beyond its design basis. For this purpose, the robustness (available design margins, diversity, redundancy, structural protection, physical separation, etc.) of the safety-relevant systems, structures and components and the effectiveness of the defence in depth concept is assessed.
- Any potential for modifications likely to improve the considered level of defence in depth, in terms of improving the resistance of components or of strengthening the independence with other levels of defence.
- The means to maintain the three fundamental safety functions (control of reactivity, fuel cooling, confinement of radioactivity) and support functions (power supply, cooling through ultimate heat sink), taking into account the probable damage done by the initiating event.

As mentioned earlier, it is important to address the design basis and the related safety margins of the plant for each of the severe conditions.

15.4 Preparing for the unexpected

15.4.1 Plans and procedures

Crisis and emergency plans are based on threat assessments. These assessments take into account domestic and international experience regarding a variety of incidents, events and accidents. They are not limited to domestic plants and activities, but also consider nationals abroad that might be affected by an accident, businesses operating abroad and all transportation modes in and through contaminated areas. Likewise, assessments also consider incidents, events and accidents of unlawful origin.

These plans and procedures describe in a coherent manner:

- roles, responsibilities and tasks of various authorities and stakeholders;
- overall organization of authorities and stakeholders into a streamlined crisis management system;
- infrastructure, where operations take place;
- sequence and synchronizing of activities and decisions.

Lessons learned from Chernobyl and Fukushima Daiichi show how important it is to agree beforehand the basic crisis management elements listed above. As a result of the possible far-reaching, even cross-border, effects of nuclear accidents, many national and international players will be involved. In particular, in the early phases of an accident, quick decision making, coordination and communication are key success factors in managing the crisis.

Plans and procedures must allow the organizations to react flexibly, from a small initiating event to more serious situations. A conservative approach can be used, in other words first actions can be more than needed and the crisis management activities can then be gradually decreased when uncertainties related to the development and potential consequences for the event or accident are better known.

From an overall, coordinating plan, more detailed plans and procedures can be drawn. Lessons learned from Fukushima Daiichi show how important it is to consider also combinations of various crisis situations. In Japan, three major crises took place one after another. Managing the last one, the nuclear accident, was severely impacted by both the earthquake and tsunami.

The main objectives of plans and procedures include the following:

- Return the plant to a safe condition in a controlled and systematic manner.
- Ensure that radioactive materials are not released in an uncontrolled manner.
- Issue early notifications and alerts about the abnormal situation.
- Take necessary precautions and actions to notify, alert and protect people in the vicinity of the plant.
- Communicate how the situation is developing.
- Monitor the situation on- and off-site.

15.4.2 Staffing and training

Crisis management needs competent staff. However, it should not be person-dependent. The system must be robust, and the staff well trained. Therefore, to be successful, plans and procedures should be function oriented and then a sufficient number of people trained to carry out the function effectively.

In many small and medium size nuclear countries, it is not possible to have all full time nuclear crisis management personnel on duty. Recognizing how important the early phases of an accident can be, a good practice is to train a large number of staff to handle the first steps of emergency situation management.

It is good practice to have a systematic and regular emergency management training programme in place. In an emergency situation, a large variety of technical and communicational competences are needed. Therefore, rosters on competences are needed to manage the whole situation. Systematic training, including drills, is also essential. One of the most essential and difficult features to simulate is the stress in an emergency situation. Unannounced drills and presence of outside evaluators can help to create extra stress in training.

It should be kept in mind that drills are not tests, but in addition to training, they provide important opportunities to test and assess the emergency systems and processes in order to identify weaknesses and areas for improvements. The aim is to have a robust, well functioning and competent system in place should it ever be used in a real situation.

Drills should vary in scope. They can be topical and well focused on technical problems or limited to different phases of the emergency, such as early phase, intermediate phase or recovery and remediation phase. Also, full-scale drills, where all stakeholders, including members of the media, participate should take place at regular intervals.

Lessons learned from Fukushima Daiichi show how important it is to maintain the performance of crisis management crews. Shifts, rest and food need to be addressed from the very beginning.

15.4.3 Roles and responsibilities

Roles and responsibilities must be well defined and agreed upon for a crisis management situation. Many important lessons learned from aircrash investigations show how important it is to have a 'cockpit' in operational command of the situation.

With respect to nuclear crisis management, at least the following two major strategies and decisions have to be made well before any emergency:

- In case of a security-related initiating event, how safety and security measures are integrated. Namely, from the safety viewpoint, the plant in an emergency should be opened to the extent possible to crisis management crews as in security-related events; the plant should be closed to the extent possible to isolate the threat from access to different parts of the plant.
- In case of the need for controlled release of pressure from the primary containment as a measure to protect the integrity and functionality of the containment, a release containing radioactive nuclides might be required before evacuation is completed.

In particular, having roles and responsibilities clearly defined regarding informing the public is essential.

15.4.4 Cooperation and coordination

Nuclear emergency affects the entire society. Also, areas that are not in danger of being contaminated are affected. The longer the situation takes, the more stakeholders there will be. Therefore, coordinating all actions and communications in a manner that ensures no conflicting measures and messages is essential.

15.4.5 Informing the public

There are two basic public information strategies available:

- Only full-proof, reliable and authenticated information is released to the public.
- Best available information is released as soon as known and corrected later if needed.

In a nuclear crisis, the need and vacuum for information grows very quickly. This vacuum is filled quickly with information available and if there is no information coming from crisis management actors in a coordinated and planned manner, the vacuum is filled with rumours and misleading information creating additional anxiety and frustration among the public. This can quickly lead to loss of credibility of the organization responsible for managing the nuclear crisis, which in turn can complicate and hamper the authorities' efforts to protect the public. The public may then over- or under-react to the messages from the crisis management authorities.

15.4.6 Facilities and tools

Crisis management organizations and crews need facilities and tools immediately available and operational when the crisis starts. The Fukushima Daiichi accident shows that operations may need to be performed over substantial periods of time without normal electrical power supply.

Need and implementation of redundancy and diversity of crisis management facilities and tools must be addressed. It is good practice to train staff to perform certain analytical tasks manually and to equip the facilities with sufficient hardcopies of technical manuals in case electricity or computers are not operable.

15.5 Managing the acute crisis phase and long term, far reaching aspects

15.5.1 Managing the acute phase of a crisis

Managing a situation which develops from an operational transient towards a safety jeopardizing event and an accident, is dealt with in accordance with a nuclear plant's emergency preparedness arrangements and procedures. These are discussed in Chapter 14 of this book.

15.5.2 Managing long-term and far-reaching aspects

In case of radioactive releases to the environment, the crisis management in the areas affected can continue for much longer than the acute severe accident phase at the nuclear site. Depending on the scale of environmental contamination and actions taken to protect the public, such as evacuations, remediation of large contaminated areas can take from months to years until the crisis is over from the affected residents' viewpoint.

Long-term crisis management involves all levels of society and requires allocation of necessary legal, economic and technology resources to develop and implement an effective remediation programme to bring relief to the affected people.

At the outset, it is vital to recognize and appreciate the fact that successful crisis management, such as remediation of large contaminated areas, is very labour intensive and depends greatly on the involvement of trained operatives in the cleanup activities.

Key success factor: cleanup strategy

A strategy is needed to make decisions regarding what to remediate. All cleanup steps and activities should be considered as a whole in which the output of one step is suitable input for the next step. Namely, without due consideration of the whole cleanup process, one seemingly good step can create major problems in consequent steps.

Two examples illustrate the importance of this.

- If, in light of an extra safety margin, a thicker layer of soil is removed than would be necessary from the contamination viewpoint, this seemingly safe solution would cause additional major problems later in the radioactive waste management and disposal phases, thereby causing unnecessary anxiety among the public.
- If cleanup activities are only or mainly concerned with contamination concentrations (surface contamination levels (Bq/m^2) or volume concentrations (Bq/m^3)) rather than dose levels, the investment of time and effort in removing contamination beyond certain levels from everywhere, such as all forest areas and areas where the additional exposure is relatively low, does not automatically lead to a reduction of doses for the public. It also involves a risk of generating unnecessarily huge amounts of residual material that, depending on the national regulatory framework, could be required to be classified as 'radioactive waste'. It is important to focus on remediation activities that bring the best results in reducing doses to the public.

The optimization principle of the radiation protection is therefore particularly important to be implemented throughout the cleanup process.

A remediation strategy depends on many factors, such as:

- National protection requirements and classifications regarding what is considered as radioactive material subject to regulatory control, and if there exist clearance levels in the national regulatory framework.
- Objective of each remediation technology, see below.
- Constraints of implementation.
- Effectiveness objectives and requirements.
- Waste to be generated.
- Radiation doses received during implementation.
- Side effects.
- Experience gained.
- Cost/benefit considerations.

There are about 60 remediation technologies available. Different technologies are applicable for:

- Buildings (public, industrial and commercial buildings, homes): such as fire hosing, roof brushing, high pressure hosing, chemical treatment, mechanical abrasion, peelable coatings, vacuum cleaning, surface removal, ultrasonic treatment, electrochemical cleaning.
- Roads and paved areas: such as fire hosing, high pressure hosing, vacuum sweeping, surface removal, turning paving slabs, relocations, access restrictions.
- Agriculture, soil and grass areas: such as ploughing, deep ploughing, skim and burial, triple digging, digging and covering, plant and topsoil removal, relocations, access restrictions.
- Trees and shrubs: such as collection of leaves, removal, restrictions.

Generic handbooks have been developed for assisting in selecting optimum technologies for a particular purpose and use. These handbooks guide decision makers through the available recovery options, and contain technical data and information in the form of data sheets for each technology.

Social and communicational issues

Important lessons learned from Chernobyl include the following:

- Psychological consequences were clearly observed and documented.
- Many people were traumatized by their evacuation and relocation, the subsequent breakdown of their social contacts, their fear and anxiety about health effects they might ultimately suffer from.
- Elevated levels of anxiety and unexplained physical symptoms among affected people were reported.
- Self-perception as ‘Chernobyl victims or invalids’ and not as ‘Chernobyl survivors’ was observed.
- Over the years, the most significant problems have become the severe social and economic depression of the affected Belarusian, Russian and Ukrainian regions. and the associated serious psychological problems of the general public and emergency workers.
- Recent research shows that social and economic restoration of the affected regions must be a priority.

Therefore, addressing the issue of informing and involving the public plays a crucial role in successful crisis management.

15.6 Learning from crises

Major hazards involved in the use of nuclear energy had been recognized before initiation of the development of power reactors. Potential risks and accident scenarios were researched and explored by theoretical and experimental studies. Safety objectives, concepts and regulations were developed in parallel with evolution of the new technology.

The ‘first generation’ of nuclear power plants was constructed from the mid-1950s to 1964. None of these early reactors suffered a serious accident during their lifetimes.

In the development of new technologies, progress requires learning from past mistakes and taking corrective actions to avoid repeating them. Nuclear technology was and is no exception.

All major transients, events and accidents are studied in detail to learn all relevant lessons. In the following, efforts not to waste the lessons from the three nuclear accidents which led to severe reactor core damage, are summarized.

The Three Mile Island reactor accident had significant impacts to the safety research, operations of nuclear power plants and safety regulations.

After the accident, extensive research and developments programs were established to address the severe accident problematic. Based on their results, many nuclear plants were equipped with systems and structures to manage severe accidents.

Also, the accident demonstrated that originally small disturbances could lead to severe accidents. The need to assess a variety of transients in terms of their risk importance substantially increased development and use of probabilistic risk assessments (PRAs).

Lessons learned from the Three Mile Island accident also include the need to pay more attention to training operators, human error and interface issues and to the support systems of the operators.

The Chernobyl accident increased and improved greatly international cooperation in the field of nuclear safety. Improvements include the following:

- Development of safety culture.
- Four safety conventions.
- Two Codes of Conduct.
- Fundamental safety principles.
- Globally recognized IAEA Safety Standards.
- Development of national and international emergency preparedness systems and procedures, an international coordinated response system, with the IAEA’s Incident and Emergency Centre at its heart.
- Development of IAEA peer-review system, based on the Agency’s Safety Standards, which involves the deployment of international teams of experts to study and advise on the operational safety of a country’s nuclear reactors or the effectiveness of its regulatory system.
- Developments in areas of remediation of affected cities and farmland, monitoring of human exposure to radiation in affected areas and dissemination of information.
- Also, the international nuclear liability regime was strengthened.

The Fukushima Daiichi accident happened at a time when nuclear expansion programs were moving forward in many countries utilizing nuclear power as well as those embarking on it.

Early lessons learned from the accident are captured in the IAEA 'Nuclear Safety Action Plan', which is based on the results of the Ministerial Meeting organized by the IAEA, approved by the IAEA Board of Governors and endorsed by the 151 member states of the IAEA in the IAEA General Conference in September 2011. This action plan is discussed in Section 4.1 of this chapter, as well as the 'stress tests'.

It took several years to learn lessons from the TMI accident. Lessons from the Chernobyl accident are still being learned. Therefore, it is clear that many years will pass before all lessons from Fukushima Daiichi accident are learned and shared.

15.6.1 Post-Fukushima activities

Following the Fukushima accident, international organizations such as IAEA and OECD-NEA, and many national regulatory bodies and the nuclear industry have initiated studies and actions focusing on the points made in Section 3, that is how to avoid such a crisis in the first place. Such activities are expected to continue into the future and lessons be incorporated into the design and operation of the plants. In that regard a few of the activities are summarized below.

In the USA, many of the utilities have initiated examination of the long-term SBO readiness to respond to design basis events and beyond-design basis events, spent fuel cooling, spent fuel storage integrity and hydrogen control. The US Nuclear Regulatory Commission recently released the report from its Near-Term Task Force. Of the 12 recommendations made, several (summarized and re-paraphrased) are related to the design of the reactors:

- Re-evaluate and upgrade the necessary design basis seismic and flooding protection of SSCs for operating reactors.
- Potential enhancements to the capability to prevent or mitigate seismically induced fires and floods.
- Station blackout mitigation capability at all operating and new reactors for design basis and beyond-design basis external events.
- Reliable hardened vent designs in boiling water reactor facilities with Mark I and Mark II containments.
- As part of the longer-term review, identify insights about hydrogen control and mitigation inside containment or in other buildings.
- Enhancing spent fuel pool makeup capability and instrumentation for the spent fuel pool.

The Office of Nuclear Regulation (ONR) in the UK released a report in September 2011 on the implications of the Fukushima events on the UK nuclear industry, even though none of the UK's reactors are of the BWR design (as in Fukushima) and all except Sizewell B (a PWR) are gas cooled reactors.

15.7 Sources of further information

American Nuclear Society, Fukushima Daiichi: ANS committee Report Issued March 2012.

International Atomic Energy Agency, Preparedness and Response for a Nuclear or Radiological Emergency, GS-R-2.

International Atomic Energy Agency, www.iaea.org, 25 Year Anniversary of Chernobyl Accident.

International Atomic Energy Agency, www.iaea.org, Fukushima Nuclear Accident Update Log.

Organisation for Economic Co-operation and Development- Nuclear Energy Agency (OECD-NEA), http://www.oecd-nea.org/, Fukushima information.

US NRC, http://www.nrc.gov/, Backgrounder on the Three Mile Island Accident.

US NRC, The Near Term task Force Report, Recommendations for Enhancing the Reactor Safety in the 21st Century, Review of Insights from Fukushima Dai-ichi Accident, July 12, 2011.

World Nuclear Association, http://www.world-nuclear.org/, Fukushima Response information.

15.8 References

Convention on Early Notification of a Nuclear Accident, INFCIRC/335, IAEA Vienna (1986).

Generic handbook for assisting in the management of contaminated drinking water in Europe following a radiological emergency, EUSRANOS, EURANOS(CAT1)-TN(06)-09-02.

International Atomic Energy Agency, IAEA Safety Glossary, IAEA 2007 Edition.

International Nuclear Safety Advisory Group, Defence in Depth in Nuclear Safety, INSAG-10.

UK Office of Nuclear Regulation, Japanese Earthquake and Tsunami: Implications for the UK Nuclear Industry, September 2011.

US NRC, The Near Term task Force Report, Recommendations for Enhancing the Reactor Safety in the 21st Century, Review of Insights from Fukushima Dai-ichi Accident, July 12, 2011.

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International nuclear cooperation

M. LARAIA, International Atomic Energy Agency (retired), Austria, and C. PESCATORE, OECD/Nuclear Energy Agency

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Abstract: The goals of international nuclear cooperation are to establish effective channels of communication and mutual assistance between policy and decision makers, academia and research institutions, nuclear operators and any entities involved with the complex role of nuclear energy in society. Nuclear cooperation organizations serve as international forums and clearing-houses for the sharing of views, issues and prospects on the global implications of nuclear technology for economic growth, sustainable development, safety and security. They also aim to promote and coordinate developments in the field of energy resources. The international dimension is essential to overcome cultural and national barriers and to meet the needs of international progress.

Key words: cooperation, energy, programme, research, safety, training.

16.1 Introduction

The foundation stone for international nuclear cooperation was laid by the famous 'Atoms for Peace' speech US President Eisenhower delivered to the UN Assembly in December 1953. That speech marked the birth of the International Atomic Energy Agency (IAEA), which was officially established on 29 July 1957.

The IAEA is an autonomous intergovernmental organization dedicated to increasing the contribution of atomic energy to the world's peace and well-being and ensuring that agency assistance is not used for military purposes.

Its activities include research on the application of atomic energy to electricity generation, medicine, agriculture, water location and industry; the operation of conferences, training programmes, fellowships and publications to promote the exchange of technical information and skills; provision of technical assistance to less developed countries; and establishment and administration of safeguards. Other organizations devoted to international nuclear cooperation include OECD/NEA, WANO and others, and are described in this chapter.

16.1.1 The genesis of international nuclear cooperation

The IAEA (1997) provides a good introduction to the genesis of international nuclear cooperation:

> . . . In 1945 only one country [the United States of America] had the massive industrial infrastructure, the wealth, the material and the concentration of scientific expertise that would be needed to make nuclear weapons. North America was also beyond the reach of enemy bombers and safe from invasion . . . In September 1949, the Soviets carried out their first nuclear test. The timing came as a shock to many US officials . . . They had assumed that it would take as much as 20 years for the Soviets to become the world's second nuclear armed State. The United Kingdom became the third in October 1952.
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> Once the main scientific and technical breakthrough to a nuclear device had been made and had become public property, replicating such a device would be largely a matter of engineering. Hence, technical fixes to prevent proliferation would not work in the long term . . . The end of the US nuclear monopoly, the hardening deadlock at the UN and the growing tensions of the Cold War gradually extinguished all hope of a world free of nuclear weapons.
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> . . . In January 1953, Eisenhower had succeeded Truman [as US President] and on 5 March 1953 Stalin died. . . . At the beginning of December 1953, Eisenhower met Churchill in Bermuda and showed him the draft of [a] speech, which Churchill warmly praised. On 8 December Eisenhower presented the speech to the General Assembly [of the United Nations], which greeted his ideas with applause. A year later, on 4 December 1954, it [the UN] unanimously endorsed the creation of the [a] new agency.

Although it is rarely possible to assign a date as the beginning of a historical process, 8 December 1953 can be marked as the beginning of international nuclear cooperation for all practical purposes.

16.2 The International Atomic Energy Agency (IAEA)

This section is based on IAEA sources, including IAEA, 2011b, 2006, 2002 and 1997.

16.2.1 Mandate and scope of the International Atomic Energy Agency

The IAEA is the world's leading forum for scientific and technical cooperation in the peaceful uses of nuclear technology. Established as an independent organization under the UN, the IAEA represents the realization of President Eisenhower's visionary 'Atoms for Peace' speech to the UN General Assembly. He proposed the creation of an international body to both control and promote the use of atomic energy. The IAEA's broad spectrum of services and activities serves 158 member states (as of November 2012).

The IAEA and its then Director General, Mohamed ElBaradei, received the Nobel Peace Prize in 2005 'for their efforts to prevent nuclear energy from being used for military purposes and to ensure that nuclear energy for peaceful purposes is used in the safest possible way'.

The IAEA has its headquarters in Vienna and it also has local offices in New York, Geneva, Toronto and Tokyo. In addition, the IAEA also runs the International Centre for Theoretical Physics in Trieste, the Marine Environmental Laboratory in Monaco and laboratories at Seibersdorf in Austria.

The bodies that ensure the activities of the IAEA are the Board of Governors (BG) and the General Conference (GC). The GC consisting of all member states meets annually to approve the budget and programme; the BG carries out the Agency's statutory functions; the Secretariat, consisting of professional and general staff, executes the IAEA programmes. The IAEA has a staff of approximately 2300.

The Director General is the main administrator who heads the IAEA Secretariat and he is aided by six Deputy Directors of major departments.

The IAEA's (2011b) six departments are:

- Technical Cooperation: Technology transfer and sustainable development.
- Nuclear Energy: Nuclear power, fuel cycle and waste management.
- Nuclear Safety and Security: Nuclear, radiation and waste safety, and nuclear security.
- Nuclear Sciences and Applications: Uses of nuclear technology in health, agriculture, industry and other fields.
- Safeguards: Verification of peaceful uses of nuclear energy.
- Management: Budget and finance, legal advice and administrative support, public information.

Key functions of the IAEA are discussed below.

16.2.2 The safeguards

As detailed in the IAEA Primer fact sheet (IAEA, 2011b):

> The IAEA implements a scheme of safeguards agreements to help prevent the further spread of nuclear weapons. Safeguards are a set of activities by which the IAEA seeks to verify that a State is living up to its international undertakings not to use nuclear programmes for nuclear weapons purposes or to produce nuclear weapons.
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> Most safeguards agreements are with States that have internationally committed themselves not to possess nuclear weapons through the global Treaty on the Non-Proliferation of Nuclear Weapons (NPT), for which the IAEA is the verification authority. To date, 178 States have entered into safeguards agreements with the IAEA, submitting their nuclear programmes to the scrutiny of IAEA inspectors.
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> IAEA verification helps to provide assurances about the peaceful uses of nuclear materials, facilities and activities. This, in turn, helps to allay security concerns among States with respect to the development of nuclear weapons.

> IAEA verification is further strengthened through an 'Additional Protocol' to a country's safeguards agreement. Under such a Protocol, States are required to provide the IAEA with broader information on all aspects of its nuclear fuel cycle-related activities. They must also grant the IAEA wider access rights and enable it to use the most advanced verification technologies.

The strengthening of safeguards in the early 1990s introduced new methods and techniques, for example remote monitoring or environmental sampling.

Perhaps the IAEA's chief claim to a place in history will be as the body that pioneered the practice of international on-site inspection – in nuclear weapons as well as non-nuclear-weapons states. It thus helped to prepare the way for major advances in disarmament in nuclear as well as chemical and conventional areas. It was also this form of international cooperation (and for the most part it has been a cooperative effort) that helped to maintain US–Soviet links through the most difficult times of the Cold War.

16.2.3 Nuclear safety and security

Regarding nuclear safety and security, the IAEA (2011b) states that:

> The future role of nuclear energy depends on a consistent, demonstrated record of safety in all applications. The IAEA's nuclear safety programme concentrates on providing standards for the safety of nuclear installations and radioactive sources, safe transport of radioactive materials and management of radioactive waste.
>
> Although the IAEA is not an international regulatory body, its nuclear safety efforts are directed towards creating agreed multilateral norms. These are increasingly important mechanisms for improving nuclear safety, radiation safety and waste safety around the world. [As one example, the Agency convenes review meetings under the Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management to promote transparency, best practices and steady improvement.]
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> The IAEA safety recommendations are used by many countries as a basis for domestic standards and regulations. They include guidance for the siting, design and operation of nuclear power plants. The IAEA also performs safety evaluations on request, including on-site review of nuclear power plants by international expert teams.

In areas of nuclear security, the IAEA helps member states to be better prepared to combat the risk of nuclear terrorism. The key priorities of the IAEA Nuclear Security team are: to increase nuclear security through adequate physical protection and proper regulatory controls; effective interdiction of illicit trafficking in nuclear and radioactive material; integration of nuclear safety and security systems; and readiness for implementing emergency response plans.

In regard to nuclear safety, a basic contradiction has been often quoted by detractors of the IAEA, namely, between the promotional role and that of safety advisor. However, the IAEA does not 'sell' nuclear energy to any member state. IAEA's job is to compile objective data to assist governments in their decision making. If a member state decides to include a nuclear component in its energy mix, then naturally the IAEA will provide whatever support and assistance the country feels appropriate. Public debate and political decision making then take over.

16.2.4 Technology development

Nuclear power plants

The IAEA (2006) states that agency activities for nuclear power plants

> target improvements in quality management, maintenance, on-line monitoring, instrumentation and control, modernization programmes, outage management, corrosion control, structural integrity, staff training and knowledge management.
>
> The Agency also helps to cost effectively schedule replacements, improvements, upgrades, licence renewals and decommissioning. Agency assistance comes in many forms. The Agency:
>
> - Assembles expert teams to peer-review facilities to identify potential improvements;
> - Maintains databanks on operating experience;
> - Disseminates operating experience, new knowledge and best practices;
> - Provides direct training and computer packages for distance learning;
> - Publishes standards and guidelines;
> - Publishes technical guidance and reference documents and
> - Coordinates research among groups working on common problems.

Fuel cycle front-end

The *Nuclear Energy and the IAEA* booklet (IAEA, 2006) goes on to say that:

> The Agency disseminates authoritative data on uranium and thorium resources, exploration mining and production. It assists developing countries in uranium exploration. Through published guidelines, on-site missions, technical exchanges, on-line resources and international conferences, the Agency promotes best environmental practices in uranium mining production and mine remediation.
>
> The reliable performance of nuclear fuel is a major determinant of cost-effectiveness and safety. The Agency provides an important forum for the exchange of information, research, practical experience and best practices on all aspects of nuclear fuel. Agency efforts focus on more demanding operational strategies, lower failure rates, greater operational flexibility and advanced fuel designs.

Fuel cycle back-end

The IAEA (2006) provides a concise account of the fuel cycle back-end:

> The nuclear industry has half a century's successful experience with spent fuel storage. The Agency helps Member States extend storage capacity by providing on-site evaluations, guidance and information. It maintains multiple spent fuel, waste management and fuel cycle facility databanks, and is an authoritative source of independent analyses on nuclear fuel cycle issues worldwide.
>
> . . . It directly aids countries in disposing of used radiation sources from medical and industrial applications, and provides guidance, information, best practices and planning assistance for decommissioning nuclear facilities, for site remediation, for preparing radioactive waste and for final repository design, operation and closure.

To quote just one example out of hundreds of IAEA activities, the International Decommissioning Network (IDN) aims to strengthen capabilities in the member states for implementation and oversight of decommissioning. This project is designed to address ongoing fundamental problems in facility decommissioning. The magnitude of such problems is often such that individual member states do not have the institutional or resource capacity to address them, and this presents a barrier to acceptance of the continued/expanded application of the peaceful uses of nuclear technology. This lack of capacity is characterized by inadequate institutional control, limited sharing of experience and lessons learned, and a failure to consolidate these to form consensus views on international good practice. Underlying these symptoms is a widespread lack of suitably trained personnel for implementation and regulatory activities.

Nuclear technology for food, environment and human health

In their publication *Building a sustainable future* (IAEA, 2002), the IAEA states that:

> Good health, sufficient food and water, and a safe environment are fundamental to our quality of life. Yet in many parts of the world, these basic needs remain beyond the reach of far too many people.
>
> Nuclear technology offers unique tools in the quest for sustainable development. Such technology is often the best to gather information and provide solutions that would not otherwise be possible or practical: to diagnose and treat disease, to breed better crops and fight insect pests; to assess new sources of fresh water; and to monitor pollution. While many may only think of energy, nuclear technology has a much larger role to play in human development.
>
> . . . Isotopes, stable and radioactive forms of chemical elements, can be used to 'label' materials under study. Since both stable and radioactive isotopes can be identified and measured using appropriate equipment, labeling is often used in

> diagnostic medical tests, in studies of underground sources of water, and to trace pollutants, such as heavy metals and pesticides. Stable, non-radioactive, isotopes are used in nutritional studies to trace the metabolism of vitamins and trace minerals in supplements.
>
> Other nuclear techniques use radiation which can be focused into beams and, depending on its intensity, can be used to kill cancer cells, to sterilize tissue grafts for burn victims, to sterilize food against insects or disease causing pathogens, to make insects sterile so they cannot reproduce, to induce desirable genetic changes in crops, or to scan body organs for abnormalities.
>
> In developing countries, malnutrition, low birth weight, early childhood diseases, . . . and cancer are significant barriers to good health. The IAEA's activities focus on the use of nuclear technology to improve human nutrition and to prevent, diagnose and cure communicable and other diseases.
>
> . . . Although the climate in the poorest regions of the world is generally favorable to growing food, soil conditions, insect pests, and lack of water can severely affect crop yields. Jointly with the Food and Agriculture Organization, the IAEA supports the use of nuclear technology in developing countries to increase food production by combating insect pests, by improving crop varieties used, and by improving irrigation practices.

Some examples of the use of nuclear technology for food production, environment and human health are described in the IAEA's publication *Building a sustainable future* (IAEA, 2002):

> Insect pests can be controlled using the sterile insect technique (SIT). In SIT, male insects are first raised in the lab and then gamma radiation is used to make them sterile, so they cannot reproduce when released into the environment. The technique is being used successfully to combat the tsetse fly, the source of human sleeping sickness and the livestock disease nagana, in sub-Saharan Africa. SIT has also been used to control the medfly, a threat to some 250 species of fruit and vegetables. As a result, the medfly has been eradicated from Mexico and Chile, and from parts of Guatemala and parts of the United States. The programme has been expanded into Argentina, Southern Peru, and the Middle East.

The comprehensive IAEA document provides an extensive outlook on the organization's nutrition programmes:

> Malnutrition and hunger can have devastating consequences, contributing to low birth weight, developmental problems, mental retardation, and a weakened immune system. Supplementation programmes have been used for decades to improve nutrition in developing countries, where nearly 200 million children under 5 years of age suffer from malnutrition. The IAEA's nutrition programmes use nuclear techniques to monitor a wide variety of nutritional problems and improve the management of food supplementation programmes. In Latin America, roughly 80 million poor people in the region receive some nutritional

> support at a cost of billions of dollars to governments. An Agency regional project is providing the information needed to evaluate the effectiveness of these supplementation efforts and is assisting national governments to set baseline nutritional guidelines tailored to local conditions and needs.
>
> . . . Tuberculosis (TB) and malaria are serious threats to human health in the developing world. TB kills an estimated 1.5 million people each year. Malaria accounts for one in five of all childhood deaths in sub-Saharan Africa. The IAEA has developed molecular methods that are able to detect drug-resistant strains of both TB and malaria in a matter of hours, rather than the several weeks required by traditional methods. Several projects have been undertaken in Africa using these methods to detect drug-resistant strains, so that appropriate treatment can be started early.
>
> . . . While communicable diseases continue to be a priority, the impact of other diseases, like cancer, in the developing world is not insignificant. The IAEA is working to improve access to radiation therapy in developing countries, where, for example, roughly 200 000 women die each year from cancer of the cervix. Treatment was not available in Ethiopia, where women make up about 70 percent of all cancer patients, until a radiotherapy centre was opened in 1997 with support from the government and the IAEA. Another Agency programmer in Africa is working to improve the safety and effectiveness of existing radiotherapy treatments . . . and to introduce new and improved techniques at these facilities.

16.2.5 Technical cooperation with the developing world

The main aim of the IAEA's technical support programme is to help its member states to attain a level where they can rely on their own ability in the application of nuclear science and technology for peaceful purposes. The social and economic conditions of each country, their culture and the respective technology, create an interactive system which results in growth and progress and hence a higher standard of living for the people. The development of new technologies is essential to this end.

The development of human resources is one of the key elements in achieving a scientific and technological level of reliance. In this field, the IAEA organizes training courses, provides scholarships for training specialists in states with advanced technology and sends specialists in various disciplines of nuclear science and technology to states which request such services (SNS, 2006)

The IAEA's *History of the International Atomic Energy Agency* (IAEA, 1997) provides a good account of the introduction of nuclear technology to the developing world:

> For the great majority of the IAEA's developing Member States the use of nuclear energy to generate electricity, or to heat or desalt water was and remains a distant prospect. For these developing nations the chief beneficial uses of nuclear energy were and still are the myriad, relatively small scale, applications of nuclear techniques in agriculture, human health, industry, environment, hydrology and

> biological and physical research, as well as the use of research reactors as educational tools, and for the production of radioisotopes, especially for medical use.

The agency has developed norms of good practice for all aspects of the research reactor fuel cycle. It helps develop strategic utilization plans covering increased commercial use, refurbishment of ageing equipment, managing growing spent fuel inventories and planning for decommissioning. It promotes regional cooperation for expanded mutual advantage.

To reduce proliferation risks, the agency supports programmes to convert research reactors from highly enriched uranium (HEU) fuel to low enriched uranium (LEU). The agency brings together fuel developers, manufacturers and users to set guidelines for LEU fuel; it participates directly in returning HEU research reactor fuel to its country of origin; and it maintains databases essential to programmes on both fuel conversion and HEU fuel return.

16.3 OECD/Nuclear Energy Agency (NEA)

The Nuclear Energy Agency (NEA) is a specialized agency within the Organisation for Economic Co-operation and Development (OECD), an intergovernmental organization based in Paris, France grouping developed countries, all democratic with market economies. The NEA's current membership (November 2012) consists of 30 countries in Europe, North America and the Asia-Pacific region. Together they account for approximately 85% of the world's installed nuclear capacity.

The mission of the NEA is to assist its member countries in maintaining and further developing, through international cooperation, the scientific, technological and legal bases required for the safe, environmentally friendly and economical use of nuclear energy for peaceful purposes. The NEA has a staff of some 65 persons. The 2011-2016 strategic plan of the NEA identifies six work areas in the following order: Nuclear Safety and Regulation; Radioactive Waste Management; Radiological Protection and Public Health; Nuclear Science; Development and Uses of Nuclear Energy; Legal Affairs; Data Bank Services; Information and Communication. The work programme in each of the first five areas is managed by a standing technical committee. As an example, work in the area of radioactive waste management and decommissioning is carried out mostly under the aegis of the NEA Radioactive Waste Management Committee (RWMC) (see www.oecd-nea.org/rwm/). In order to understand how these committees operate, the work of the RWMC is explained in more detail below. The section on the NEA RWMC is based on OECD-NEA 2010.

In their document *Radioactive waste management and decommissioning at the NEA* (OECD-NEA, 2010), the OECD-NEA provides a comprehensive account of their role in international nuclear management:

> The NEA Radioactive Waste Management Committee (RWMC) is a long-established International committee of senior representatives from regulatory

> authorities, radioactive waste management and decommissioning organisations, policy making bodies, and research-and-development institutions from the NEA countries. The International Atomic Energy Agency (IAEA) participates in the work of the RWMC, and the European Commission (EC) is a full member of the Committee. The RWMC maintains strong ties with national high-level advisory bodies to governments and with transnational bodies such as the International Commission on Radiological Protection (ICRP). Collaboration also takes place with the Governance directorate of the OECD. . . . The Committee implements a programme of work that:
>
> - fosters a shared and broad-based understanding of the state of the art and emerging issues;
> - facilitates the elaboration of waste management strategies that respect societal requirements;
> - helps to provide common bases to the national regulatory frameworks;
> - enables the management of radioactive waste and materials to benefit from progress of scientific and technical knowledge, e.g., through joint projects and specialist meetings;
> - contributes to knowledge consolidation and transfer, e.g., through the publication of technical reports, consensus statements and short flyers; and
> - helps to advance best practice, e.g., by supporting international peer reviews.
>
> The regulator members of the RWMC also participate in a separate Regulators' Forum (RWMC RF) through which they discuss and report on topics of specific regulatory interest and which determines, where appropriate, how such issues are progressed within the full Committee.

Principal responsibility for establishing global nuclear safety norms and standards remains with the IAEA. The NEA contributes to this effort by addressing detailed technical issues and by promoting individual R&D projects by its members, for example on geological disposal of nuclear waste. The NEA and IAEA have continued to work closely with each other by co-sponsoring scientific meetings, in preparing the 'Red Book' (the periodic worldwide survey of uranium reserves, production and demand) and, particularly, in regard to nuclear safety, waste management and decommissioning, the three topics on which the NEA has increasingly focused its work.

Examples of recent RWMC initiatives and products include:

- The RWMC has produced collective statements on a variety of topics. The latest collective statement of the RWMC (2008) recommends 'moving forward with geological disposal of radioactive waste'. In 2011 three collective statements are in preparation, one on the comparability of decommissioning costs.
- The NEA also offers the framework for international peer reviews. Ongoing at present is the peer review of the SR-Site as requested by the Swedish

government. SR-Site is part of the application to construct a geological disposal facility for spent fuel in Sweden.

- The RWMC holds multi-stakeholder national workshops from which important lessons have been drawn. The latest workshop (May 2011) was held in Sweden, in the siting region for the national spent fuel repository.
- The RWMC manages a regularly updated database of country information, in the form of 30-page country reports and 10-page country profiles. A summary of the regulatory infrastructure in NEA countries is also maintained.
- Recent or current RWMC projects include: an international project on the topic of ‘retrievability and reversibility’ and another on preserving records, knowledge and memory across generations; examples of ongoing initiatives are the Cooperative Programme for the Exchange of Scientific and Technical Information Concerning Nuclear Installation Decommissioning Projects (CPD, see below) and the Thermo-chemical Data Base project.
- Current technical and conceptual topics in the field of disposal include: optimization, dealing with very long time scales, assessing the state of the art in safety assessment methods and the operation phase of repositories.
- Current topics in decommissioning include: the management of large components, research and development needs, standardization of reporting norms for decommissioning cost estimates and cost control on decommissioning projects.
- Current study areas in societal confidence include: the interests and roles of regional authorities, how to increase the knowledge base of journalists, providing added value (beyond economic benefits) to communities hosting waste management facilities.

For an overview of the most recent NEA-wide initiatives or to stay informed on the work of other committees, the reader should consult the NEA website: www.oecd-nea.org.

As an example of a specific project, the CPD is a joint undertaking among 40+ decommissioning projects actively executing or planning the decommissioning of nuclear facilities. Initiated in 1985, the CPD recently completed 25 years of operation. The CPD members share hands-on information from operational experience in conducting specific decommissioning projects. Such information includes, but is not limited to, project descriptions and plans; data obtained from research and development; and data and lessons learnt resulting from the execution of a decommissioning project. Although the information exchanged within the CPD is generally confidential, experience of general interest formulated under the programme auspices is also released for broader use. Fig. 16.1 depicts decommissioning work at Vandellos 1 NPP (Spain), a decommissioning experience that has been significantly shared within the CPD and NEA.

16.1 Vandellos 1 NPP, Spain. Hot cells used in the decommissioning process. Vandellos 1 is one of the numerous installations covered by NEA's programmes.

16.4 World Association of Nuclear Operators (WANO) and other players

Following the tragic accident at the Chernobyl nuclear generating station, nuclear operators worldwide were determined to work together to ensure such an accident could never happen again. To this end, the first preliminary international working discussions which led to actual results were held on 5 and 6 October 1987 in Paris, where top officials from UNIPEDE (The International Union of Producers and Distributors of Electrical Energy), INPO (Institute of Nuclear Power Operation) based in the USA, and EDF (Electricité de France) met. These organizations represented more than one third of worldwide operators from 32 member states. The representatives agreed on preliminary forms of preparatory and executive committees and on another meeting to be held in Moscow. The principal idea behind the creation of the future world association was the exchange of experience derived from operating a nuclear power plant. The founding session of the WANO was held on 15 and 16 May 1989 in Moscow.

The sole aim of the WANO is to increase nuclear safety all over the world, in particular by means of information exchange and promulgating examples of good practice. The organization in no measure supplants the already functioning IAEA, which is mainly an international body at governmental level. The new non-governmental organization is basically without any political influences from individual governments including only representatives of the operators. The WANO includes representatives of practically all utilities operating nuclear reactors exclusively for peaceful purposes.

From the outset, the WANO clearly defined its basic membership principles as being non-profit making and with no commercial activities. Its basis lies in mutual support between members, with a voluntary free-of-charge information exchange so that everybody was provided straightaway with information important for the safe operation of nuclear facilities.

To meet these goals, the WANO created its own security code computer network called Nuclear Network, which today connects almost all nuclear power plants. The WANO set its main programmes:

- Operating Experience.
- Peer Reviews.
- Professional and Technical Development.
- Technical Support and Exchange.

Within the Nuclear Network, the WANO created internal support discussion groups including more than 200 experts in specialist areas. The WANO also established a set of operational and safety parameters of its own, which are accepted worldwide and enable a comparison of any reactor units of different types in different places at any one time all over the world.

An important and positive example of the WANO was the world's first peer review held by the WANO in February 1992 on the basis of an offer from the Hungarian nuclear power plant Paks. Also, for the first time, the WANO peer review took place in a nuclear fuel re-processing factory in May 2002 (SNS, 2006).

16.4.1 World Nuclear Association (WNA)

The World Nuclear Association is the international organization that promotes nuclear energy and supports the many companies that comprise the global nuclear industry (WNA, 2011).

WNA arose on the foundations of the Uranium Institute (UI), established in London in 1975 as a forum on the market for nuclear fuel. In 2001, spurred by the expanding prospects for nuclear power, the UI changed its name and mandated itself to build a wider membership and a greater diversity of activities. The goal was to develop a truly global organization geared to perform a full range of international roles to support the nuclear industry in fulfilling its enormous growth potential in the twenty-first century.

Since WNA's creation in 2001, the effort to build and diversify has borne fruit. WNA membership has expanded to encompass 1 virtually all world uranium mining, conversion, enrichment and fuel fabrication; 2 all reactor vendors; 3 major nuclear engineering, construction, and waste management companies; and

4 nearly 90% of world nuclear generation. Other WNA members provide international services in nuclear transport, law, insurance, brokerage, industry analysis and finance.

WNA will remain a work in progress. Its rapid growth reflects recognized value and represents a major advance in building toward universal industry membership. Today WNA serves its membership, and the world nuclear industry as a whole, through actions to:

- Provide a global forum for sharing knowledge and insight on evolving industry developments.
- Strengthen industry operational capabilities by advancing best practices internationally.
- Speak authoritatively for the nuclear industry in key international forums.
- Improve the international policy and public environment in which the industry operates.

An overarching WNA purpose is to foster interaction among top industry leaders to help shape the future of nuclear power. All WNA activities focus on objectives outside the scope of national associations, intergovernmental organizations and the industry's reactor safety organization, WANO (WNA, 2011).

16.4.2 European Commission

The European Atomic Energy Commission (EURATOM) is an international organization established in 1958 to form a common market for development of peaceful uses of atomic energy. A major incentive for the creation of EURATOM was to facilitate the establishment of a nuclear-energy industry on a European rather than a national scale. Other aims of the community were to coordinate research in atomic energy, to encourage the construction of nuclear power installations, to establish safety and health regulations, to encourage the free flow of information and the free movement of personnel and to establish a common market for trade in nuclear equipment and materials.

Research has been undertaken at EURATOM's own Joint Research Centre (JRC), as well as under contract with various research bodies in member countries and under agreement with the countries and international organizations. JRC scientific institutes are located at Ispra (Italy), Karlsruhe (Germany), Petten (the Netherlands), Geel (Belgium) and Seville (Spain).

Beyond the frontiers of the former Soviet Union, most of the fallout from Chernobyl came down on European Union (EU) countries. They were also the nations outside the frontiers of the former Soviet Bloc that were most concerned about the possible consequence of defects in older model Soviet reactors and the sea dumping of high-level nuclear waste. For these reasons, the IAEA and the EU (through the European Commission) have worked more closely with each other in nuclear safety and nuclear waste management than they did in pre-Chernobyl

16.2 Dismantling the Soviet type research reactor Rossendorf, Germany.

years, particularly to enhance the safety of older Soviet reactors and to deal with the consequences of Chernobyl. Examples of projects where cooperation has taken place include: Ignalina NPP in Lithuania where two Soviet design RBMK-1500 reactors have been shut down; Sofia Research Reactor in Bulgaria undergoing partial dismantling and refurbishing; and Rossendorf Research Reactor (a Soviet design VVR-2) undergoing decommissioning in Germany. Figure 16.2 shows the dismantling of the Rossendorf reactor in progress.

Even though EURATOM has lost most of its significance as a promoter of nuclear energy in Western Europe, it still retains its safeguards functions.

16.4.3 International Commission on Radiological Protection (ICRP)

The ICRP is one of the few – and probably the most important – international organizations active in nuclear cooperation that predates the IAEA

The work of the ICRP assesses effects associated with exposure to ionizing radiation and thus helps to prevent cancer and other diseases, and protect the environment.

Since 1928, ICRP has developed, maintained and elaborated the International System of Radiological Protection used worldwide as the common basis for radiological protection standards, guidelines, programmes and practice.

ICRP has published more than 100 reports on all aspects of radiological protection. Most address a particular area within radiological protection, but a handful of publications, the so-called fundamental recommendations, describe the overall system of radiological protection. The International System of Radiological Protection has been developed by ICRP based on 1 the current understanding of the science of radiation exposures and effects, and 2 value judgements. These value judgements take into account societal expectations, ethics and experience gained in application of the system.

ICRP is an independent international organization with more than 200 volunteer members from approximately 30 countries across six continents. These members represent the leading scientists and policy makers in the field of radiological protection.

ICRP is funded through a number of ongoing contributions from organizations with an interest in radiological protection (ICRP, 2011).

16.5 Transfer of knowledge: education and training consortia

Expansion of nuclear power and other nuclear applications requires continuous nuclear knowledge transfer (this section is based on IAEA, 2006 and 2004). The IAEA and other international associations assist knowledge transfer and help link established centres of competence with centres of growth. This helps preserve knowledge for countries experiencing workforce ageing and attrition.

The IAEA provides guidance and offers on-site missions to member states to help maintain the necessary skill base, workforce levels and access to accumulated knowledge. It supports networks of educational institutions. Its International Nuclear Information System (INIS), with over 2 000 000 bibliographic records plus a unique collection of full text non-conventional literature, is the world’s leading information system on the peaceful uses of nuclear science and technology (IAEA, 2006).

The IAEA (2004) writes that:

> In many Member States, demographic and economic factors pose potentially difficult challenges to the continued safe and reliable operation and maintenance of nuclear power plants (NPPs). Many of the personnel currently operating and maintaining NPPs in Member States are reaching retirement eligibility. In most cases, these are the people who were responsible for the commissioning and initial operation of the plant, through which they learned a great deal about the plant design and operating characteristics. The younger age cohorts of many Member States are neither as large [as a group] nor as interested in working in NPPs as were their predecessors. And, the economic conditions in a number of Member States have resulted in workforce reductions in the nuclear industry and disruptions of traditional new worker hiring patterns. That, in turn, has negatively impacted the interest of potential new employees and the availability of relevant institution-based educational programmes.

> . . . The safe, reliable, and cost-effective operation of NPPs requires that personnel possess and maintain the requisite knowledge, skills, and attitudes to do their jobs properly. Such knowledge includes not only the technical competencies required by the nature of the technology and particular engineering designs, but also the 'softer' competencies associated with effective management, communication and team work. Traditional worker training programmes have addressed *explicit knowledge* that is contained in written documents, policies and procedures. However, *tacit knowledge* that is held in a person's mind has not typically been either captured or transferred in any formal manner. Rather, new workers have acquired such knowledge over time . . . through their working with those who already possess it. As those workers who are in possession of this *tacit knowledge* leave the workplace for retirement, the effective capture and transfer of that information becomes even more critical.

16.5.1 International networks

International networking can be considered a good practice. It has several beneficial effects. It facilitates sharing of information and good practices between the members; it provides an enabling environment to complement each other's possible lack of expertise in certain fields (not all expertise is available at every place), it ensures that the students get the information from the best professors or the best expert of the special subject. There are several large international networks: ENEN (Europe), ANENT (Asia) and WNU (worldwide). These are briefly described below.

The European Nuclear Engineering Network (ENEN) project was launched under the fifth framework European Commission programme in January 2002. The ENEN was given a more permanent character and legal status by the foundation of the ENEN Association. This association is located in France, in Saclay.

The main objective of the ENEN association is preservation and further development of expertise in nuclear fields by higher education and training. This objective should be realized through cooperation between universities, research organizations, regulatory bodies, the industry and other organizations involved in the application of nuclear science and ionizing radiation.

The Asian Network for Education in Nuclear Technology (ANENT) has been worked out as a highly effective web-based educational system to complement conventional knowledge transfer methods by networking teachers, students and their institution that are engaged or interested in the peaceful uses of nuclear technology and other applications.

ANENT is primarily aimed at Asia and the Pacific region, where huge economic growth is now under way and is expected to continue into the future, accompanied by rapidly increasing demand for energy. The demand cannot, and should not, be met by fossil fuels only. Fossil fuels are limited and increasingly expensive, and now they are thought to be the largest cause of global warming. Nuclear energy is expected to play an important role to close the widening gap between energy supply and demand.

Although some countries in Asia already have experiences of operating nuclear power programmes (NPPs) for decades, there are some potential newcomer countries to these programmes at the planning stage. Other countries are to maintain and expand the use of radiation and radioisotopes. Demand for excellent human resources is increasing in the field of nuclear technology in the region. At the same time, however, many countries are facing urgent issues of nuclear knowledge management such as ‘brain drain’, shortage of educational opportunities, resources and facilities. Thus the Asian region needs to develop a wide spectrum of nuclear education and training programmes for capacity and infrastructure building.

The basic concept was discussed and agreed upon at a consultancy meeting, which was held in July 2003 in Daejeon, Republic of Korea, in cooperation with the Korea Atomic Energy Research Institute (KAERI). On the basis of the basic agreement, the ANENT was established at the first coordination committee meeting, which was held in February 2004, in Kuala Lumpur, Malaysia. The participants agreed upon the initial Terms of Reference and an action plan for launching the ANENT (IAEA, 2011).

The World Nuclear University (WNU) is a global partnership committed to enhancing international education and leadership in the peaceful applications of nuclear science and technology. The central elements of the WNU partnership are:

- The global organizations of the nuclear industry: WNA and WANO.
- The intergovernmental nuclear agencies: IAEA and OECD-NEA.
- Leading institutions of nuclear learning in some 30 countries.

The WNU was inaugurated in 2003 in a London ceremony commemorating the 50th anniversary of President Eisenhower’s historic ‘Atoms for Peace’ initiative. Within the UN system, the WNU is recognized as a ‘Partnership for Sustainable Development’ by the UN Commission on Sustainable Development (CSD).

A non-profit corporation, the WNU pursues its educational and leadership building mission through programmes organized by the WNU Coordinating Centre (WNUCC) in London. These cooperative activities are designed to harness the strengths of partnership members in pursuit of shared purposes.

Operationally, the WNU is a public–private partnership. On the public side, the WNUCC’s multinational secretariat is composed mainly of nuclear professionals supplied by governments; the IAEA further assists with financial support for certain WNU activities. On the private side, the nuclear industry provides administrative, logistical and financial support via the WNA.

The prospect of a steady worldwide growth in the use of nuclear technology for power generation and in a diversity of sophisticated applications in medicine, agriculture and industry, points to the need for a greatly expanded global cadre of nuclear professionals in the twenty-first century. The role of the WNU partnership is to support this growth by (WNU, 2011):

- Strengthening education in nuclear science, engineering and law.
- Promoting public understanding of nuclear technology.
- Inspiring and strengthening the development of a new generation of leaders for the nuclear industry.

16.5.2 International cooperation

Besides ‘networking’ (Section 16.5.1), international (bi- or multilateral) cooperation managed by individual organizations is also good practice. Several examples (only a fraction of the worldwide total) can be mentioned:

- AREVA is developing collaboration with many universities worldwide for R&D programmes and training and education activities. AREVA is involved in the newly created master's degree in nuclear energy in Paris as well as in the European Nuclear Energy Leadership Academy. The AREVA University also has a network of correspondents and collaboration in Germany (TUM, KIT), North America (MIT, Stanford and Harvard) South Africa (NWU), Latin America, China and India.

  In 2008 AREVA and Paris University la Sorbonne launched a master's degree in project management that was attended by 20 young executives from South African organizations. Similar cooperation may be contemplated in other countries willing to develop their management capabilities in the energy field.
- Drawing on France’s experience in building and operating the country’s reactors, as well as its position as the world’s leading constructor of nuclear reactors, the French government decided to set up the France International Nuclear Agency (AFNI) to allow countries interested in acquiring or developing nuclear energy to benefit from this experience.

  The Agency is part of the French Atomic Energy Commission (CEA). Its main purpose is to help foreign governments prepare the institutional, human and technical conditions required for setting up a civilian nuclear programme that meets all requirements relating to safety, security, non-proliferation and environmental protection for present and future generations. It offers its support to all countries planning to develop nuclear energy for civilian purposes within the context of intergovernmental cooperation.
- The Department of Nuclear Engineering at the University of California at Berkeley has annually hosted the Asia-Pacific Forum dealing with current nuclear issues. In 2008, the topic was integration of safety, security and sustainability of nuclear technology. In 2009, the forum covered nuclear technology, safeguards and nuclear forensics. Overseas participants have included experts and leaders from industry (AREVA), universities (University of Tokyo, Tokyo Institute of Technology, Tsinghua University and Shanghai

University), and international organizations (JAEC, JAEA, KAIST, KAERI, CRIEPI and IAEA). The forums have provided students an excellent opportunity to interact with individuals from the international nuclear community.
- The Massachusetts Institute of Technology (MIT), International Science and Technology Initiative (MISTI) facilitates summer internships around the globe. With support from the Centre for Advanced Nuclear Energy Studies, approximately ten students have been placed at research centres in countries including Japan (TEPCO and Toshiba), France (CEA and AREVA) and Germany (Karlsruhe Energy Centre), and at the IAEA. In addition, since 2005 agreements have been in place to hold joint symposia on nuclear technology that have included students from the Tokyo Institute of Technology, Ecole Polytechnique and the University of Sao Paolo along with students from MIT.
- Since 1996, the Department of Nuclear Engineering at Texas A&M University has collaborated with the Moscow Engineering Physics Institute (MEPhI) and the Obninsk Institute for Nuclear Power Engineering (INPE) in the Russian Academic Programme in Nuclear and International Security (RAP-NIS). The programme has developed new curricula and programmes in nuclear materials safe management, radiation protection of man and the environment, decommissioning and decontamination of facilities in the nuclear fuel cycle, and nuclear non-proliferation. In addition to joint research projects and annual meetings involving faculty members from all three universities, a key part of RAP-NIS is the Foreign Field Experience (FFE). In this activity, students from A&M, MEPhI and INPE join together for a week-long series of lectures, visits and tours of a broad range of nuclear facilities. FFE events have taken place in the USA, France, Belgium and Switzerland. This gives students an opportunity to observe modern standards and practices, and build enduring professional networks.

16.6 Lessons learned and challenges

Given the predominant role the IAEA has in international nuclear cooperation, the following observations mainly reflect some experiences of the IAEA (this section is based on IAEA sources including IAEA, 1997 and 2008). However, it is felt that lessons learned and issues described below are also applicable to organizations dealing with diverse environments on a global scale: organizations having a regional scope should have comparatively fewer problems. Given its particular nature, the nuclear safeguards sector is not discussed below.

16.6.1 Nuclear techniques

In Fischer's *History of the International Atomic Energy Agency* (IAEA, 1997), the author gives a good overview of the IAEA's involvement in recent nuclear techniques:

> The IAEA has helped its members, and particularly the developing Member States, to make use of nuclear techniques – applications of radiation and radioisotopes – to a far greater extent than was foreseen in the Statute, which . . . does not explicitly mention these applications of nuclear energy. The IAEA and FAO have pioneered the international use of isotope hydrology and of certain applications of nuclear science in agriculture and food processing. The IAEA's Co-ordinated Research Programmes (CRP) . . . offer a novel way for developing countries to cooperate with each other and to 'twin' with leading laboratories in the industrialized nations in undertaking research on problems of special interest to the developing countries.

A CRP is a mechanism whereby a dozen or more institutes from as many member states join a common R&D theme and pursue related activities, and share results.

The IAEA's final report of a coordinated research project from 2004 to 2008, *Innovative and Adaptive Technologies in Decommissioning of Nuclear Facilities* (IAEA, 2008), provides a full summary of the modes of international cooperation in the areas of decommissioning and cleanup:

> There are three modes of international cooperation that can be utilized in this domain. The first is through bilateral arrangements between countries and/or organizations. The second is cooperation on a regional level and the third is through the activities of international organizations. The latter form of cooperation, with emphasis on information and technology exchange, including joint research and development and demonstration projects, has been very successful in the decommissioning area. Coordinated Research Projects are the typical mechanisms for implementing such a strategy. Cooperation of this nature has many benefits and is practical for several reasons. First, it makes good economic sense to share and learn from each other's experiences and compare future strategies. The resulting benefit is that it prevents duplication of efforts. A second point worth mentioning is that projects initiated by any or all of the international organizations tend to be considered more credible and therefore generate more financial support. Third, joint projects create a support network and a system of formal and informal peer reviews. This external review process enhances and adds technical credibility and validity to national approaches and methodologies. And finally, cooperation and exchange of information are required and used by countries as a means of checking their own progress – a means of calibration. . . . [A] CRP is also a means for participating institutions to establish bilateral or multilateral contacts bound to bear fruit independently of and extending beyond the CRP framework.

16.6.2 Nuclear safety

Regarding nuclear safety, Fischer's *History of the International Atomic Energy Agency* (IAEA, 1997) states that:

> The Statute foresaw that the IAEA would have a standard setting role in nuclear safety, in consultation or collaboration with the United Nations and the relevant specialized agencies. The standards would be obligatory in the IAEA's own operations and in all cases where the IAEA was directly involved as a supplier, supervisor or controller. If Agency projects had become the main vehicle for obtaining nuclear supplies, as the negotiators of the Statue had expected, such projects would have led to the application of mandatory IAEA safety standards to most of the world's peaceful nuclear activities outside a few supplier States. This did not happen and IAEA safety standards remained mandatory only in the relatively few Agency projects approved by the Board of Governors and in a larger number of technical cooperation projects.
>
> In another direction, however, the IAEA has gone a good deal further in promoting nuclear safety than the Statute foresaw, for instance in negotiating binding conventions on
>
> - early warning in the event of a nuclear accident,
> - availability of emergency assistance,
> - safety of land based nuclear power plants,
> - safe disposal of nuclear waste,
> - protecting nuclear material against criminal acts, and providing for liability for nuclear damage.

16.6.3 Technical cooperation

Regarding technical cooperation, Fischer goes on to write:

> . . . technical assistance or cooperation has evolved over the years from a programme designed chiefly to support the then nascent nuclear energy establishments of the developing countries to one that has been able to provide direct and tangible benefits to major sectors of the national economy. It has moved from a programme of unrelated projects drawn up chiefly by the recipient government to one that focuses on a more limited number of projects, often backed up by the IAEA's support of research and by the work of the IAEA's laboratories.

As a challenge often faced by IAEA TC projects, it should be noted that a TC-recipient country should take full responsibility to achieve the objectives of the project. The IAEA can help, but it cannot and should not take over.

The following reflects the experience of the IAEA and other international organizations involved in nuclear cooperation.

Firstly, the resources needed (both human and financial) to cope with the challenges to implementation of nuclear programmes may be large. Clearly, these resources may not be equally available in different nations, that is some countries are more prepared to face the costs of nuclear programmes than others, as appropriate mechanisms (technical and economic) are essential to implement large-scale projects. Whenever resources are not available, implementation delays can be a long-lasting problem in some countries.

Secondly, it is clear that the availability of resources will not be the sole constraint in the implementation of nuclear programmes. Several other factors will need to be factored into the overall approach to produce satisfactory results. However, it is important to recognize that without appropriate financial resources very little can be done beyond preliminary planning. Due attention should be given to the institutional arrangements that need to be in place in countries so that effective results can be obtained from the support given by international organizations. The difference between market economies and transitional economies plays a significant role. In summary major factors hindering effective international nuclear cooperation include:

- Programme costs and limited capacities of national budgets.
- Inadequate knowledge of data and insufficient study of issues related risks.
- Public perception of radiological and non-radiological risks.
- Inadequate legislation and imperfect regulations.
- Shortage of modern equipment.
- Lack of overarching national priorities (e.g. energy plans, environmental remediation targets).
- Cultural differences (e.g. language barriers, traditions, decision making processes) that may make it difficult to ‘digest’ international assistance.

16.7 Future trends

Recent developments and current challenges in nuclear energy, nuclear applications, nuclear safety and security, and nuclear verification were the themes of IAEA Director General Mohamed ElBaradei’s General Conference opening speech delivered at the IAEA 51st General Conference – 17 September 2007.

He spoke of the importance of international cooperation in these areas, stressing the significance of values such as dialogue and multilateralism. The ‘Atoms for Peace’ ideal remains central to the agency’s vision.

Over the years, international nuclear cooperation has evolved from a programme designed mainly to stimulate the growth of nuclear energy centres of the developing countries to one that has been able to provide direct and tangible benefits to major sectors of the national economies. To this end, the focus has changed from the exchange and exporting of technologies to inclusion of aspects such as capacity building and the upgrading of the national infrastructure, the involvement of local stakeholders and international donors, and support of financial institutions (e.g. the European Bank for Reconstruction and Development, EBRD) that could concretely help in targeted, large-scale activities. This trend is expected to continue for the foreseeable future.

16.8 Sources of further information

EUROPA 2011, European Commission, International Cooperation for Lasting Solutions http://ec.europa.eu/research/iscp/index.cfm (accessed on 13 December 2012).

Government Offices of Sweden, 2011, Foreign Policy and International Cooperation, www.regeringen.se/sb/d/2094 (accessed on 13 December 2012).

IAEA, www.iaea.org (accessed on 13 December 2012).

IFNEC, 2011, International Framework For Nuclear Energy Cooperation, www.ifnec.org (accessed on 13 December 2012).

Monken Fernandes, H., Santamaria Recio, M., Forsstrom, H., Carson, P.M., 2011, International Cooperation and Support in Environmental Remediation – Is There Any Room for Improvement? Journal of Environmental Radioactivity, 19 September 2011.

Programme for Promoting Nuclear Non-Proliferation (PPNN) 2000, Briefing Book Vol 1, Sixth Edition 2000 by E. Bailey, R. Guthrie, D. Howlett and J. Simpson, Chapter 8 www.ppnn.soton.ac.uk/bb1/Bb1Chap8.pdf (accessed on 13 December 2012).

16.9 References

IAEA, 1997, Fischer, D., History of the International Atomic Energy Agency – The First Forty Years, IAEA, Vienna.

IAEA, 2002, Building a sustainable future, IAEA, Vienna.

IAEA, 2004, The Nuclear Power Industry's Ageing Workforce: Transfer of Knowledge to the Next Generation, IAEA-TECDOC-1399, IAEA, Vienna.

IAEA, 2006, Nuclear energy and the IAEA: Fostering the efficient and safe use of nuclear power, IAEA, Vienna.

IAEA, 2007, The Path Ahead – Moving Further Onward 51st IAEA General Conference, September 2007 www.IAEA.org (accessed 13 December 2012).

IAEA, 2008, Innovative and Adaptive Technologies in Decommissioning of Nuclear Facilities, IAEA-TECDOC-1602, IAEA, Vienna.

IAEA, 2011a, Status and Trends in Nuclear Education, Nuclear Energy Series NG-T-6.1, IAEA, Vienna.

IAEA, 2011b, IAEA Primer: Maximizing the contribution of nuclear technology to society while verifying its peaceful use, IAEA, Vienna.

ICRP, www.icrp.org (accessed on 13 December 2012).

OECD-NEA, 2010, Radioactive waste management and decommissioning at the NEA, 2010 http://www.oecd-nea.org/rwm/documents/RWM_Flyer_April_2010.pdf (accessed on 13 December 2012).

NEA, 2011, www.oecd-nea.org/nea (accessed on 13 December 2012).

SNS 2006, Slovak Nuclear Society, Atoms in Slovakia, 2006.

WNA, 2011, www.world-nuclear.org/about.html (accessed on 13 December 2012).

WNU, 2011, www.world-nuclear-university.org (accessed on 13 December 2012).

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