IAEA Report on

Decommissioning and Remediation after a Nuclear Accident

International Experts Meeting
28 January–1 February 2013, Vienna, Austria

IAEA
International Atomic Energy Agency

IAEA REPORT ON DECOMMISSIONING AND REMEDIATION AFTER A NUCLEAR ACCIDENT

The following States are Members of the International Atomic Energy Agency:

AFGHANISTAN
ALBANIA
ALGERIA
ANGOLA
ARGENTINA
ARMENIA
AUSTRALIA
AUSTRIA
AZERBAIJAN
BAHRAIN
BANGLADESH
BELARUS
BELGIUM
BELIZE
BENIN
BOLIVIA
BOSNIA AND HERZEGOVINA
BOTSWANA
BRAZIL
BULGARIA
BURKINA FASO
BURUNDI
CAMBODIA
CAMEROON
CANADA
CENTRAL AFRICAN REPUBLIC
CHAD
CHILE
CHINA
COLOMBIA
CONGO
COSTA RICA
CÔTE D'IVOIRE
CROATIA
CUBA
CYPRUS
CZECH REPUBLIC
DEMOCRATIC REPUBLIC OF THE CONGO
DENMARK
DOMINICA
DOMINICAN REPUBLIC
ECUADOR
EGYPT
EL SALVADOR
ERITREA
ESTONIA
ETHIOPIA
FIJI
FINLAND
FRANCE
GABON
GEORGIA
GERMANY
GHANA
GREECE
GUATEMALA
HAITI
HOLY SEE
HONDURAS
HUNGARY
ICELAND
INDIA
INDONESIA
IRAN, ISLAMIC REPUBLIC OF
IRAQ
IRELAND
ISRAEL
ITALY
JAMAICA
JAPAN
JORDAN
KAZAKHSTAN
KENYA
KOREA, REPUBLIC OF
KUWAIT
KYRGYZSTAN
LAO PEOPLE'S DEMOCRATIC REPUBLIC
LATVIA
LEBANON
LESOTHO
LIBERIA
LIBYA
LIECHTENSTEIN
LITHUANIA
LUXEMBOURG
MADAGASCAR
MALAWI
MALAYSIA
MALI
MALTA
MARSHALL ISLANDS
MAURITANIA
MAURITIUS
MEXICO
MONACO
MONGOLIA
MONTENEGRO
MOROCCO
MOZAMBIQUE
MYANMAR
NAMIBIA
NEPAL
NETHERLANDS
NEW ZEALAND
NICARAGUA
NIGER
NIGERIA
NORWAY
OMAN
PAKISTAN
PALAU
PANAMA
PAPUA NEW GUINEA
PARAGUAY
PERU
PHILIPPINES
POLAND
PORTUGAL
QATAR
REPUBLIC OF MOLDOVA
ROMANIA
RUSSIAN FEDERATION
RWANDA
SAUDI ARABIA
SENEGAL
SERBIA
SEYCHELLES
SIERRA LEONE
SINGAPORE
SLOVAKIA
SLOVENIA
SOUTH AFRICA
SPAIN
SRI LANKA
SUDAN
SWAZILAND
SWEDEN
SWITZERLAND
SYRIAN ARAB REPUBLIC
TAJIKISTAN
THAILAND
THE FORMER YUGOSLAV REPUBLIC OF MACEDONIA
TOGO
TRINIDAD AND TOBAGO
TUNISIA
TURKEY
UGANDA
UKRAINE
UNITED ARAB EMIRATES
UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
UNITED REPUBLIC OF TANZANIA
UNITED STATES OF AMERICA
URUGUAY
UZBEKISTAN
VENEZUELA
VIETNAM
YEMEN
ZAMBIA
ZIMBABWE

The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world''.

IAEA REPORT ON DECOMMISSIONING AND REMEDIATION AFTER A NUCLEAR ACCIDENT

INTERNATIONAL EXPERTS MEETING
VIENNA, 28 JANUARY–1 FEBRUARY 2013

Organized in connection with the implementation of the IAEA Action Plan on Nuclear Safety

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2013

Marketing and Sales Unit, Publishing Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna, Austria
fax: +43 1 2600 29302
tel.: +43 1 2600 22417
email: sales.publications@iaea.org
http://www.iaea.org/books

Printed by the IAEA in Austria
September 2013
IAEA/IEM/4

FOREWORD

by Denis Flory
Deputy Director General
Department of Nuclear Safety and Security

In response to the accident at the Fukushima Daiichi nuclear power plant, IAEA Member States unanimously adopted the Action Plan on Nuclear Safety. Under this Action Plan, the IAEA Secretariat was asked to organize International Experts Meetings to analyse all relevant technical aspects and learn the lessons from the accident. The International Experts Meetings brought together leading experts from areas such as research, industry, regulatory control and safety assessment. These meetings have made it possible for experts to share the lessons learned from the accident and identify relevant best practices, and to ensure that both are widely disseminated.

This report on Decommissioning and Remediation after a Nuclear Accident is part of a series of reports covering all the topics dealt with in the International Experts Meetings. The reports draw on information provided in the meetings as well as on insights from other relevant IAEA activities and missions. It is possible that additional information and analysis related to the accident may become available in the future.

I am grateful to the participants of all the International Experts Meetings and to the members of the International Nuclear Safety Group (INSAG) for their valuable input.

I hope that this report will serve as a valuable reference for governments, technical experts, nuclear operators, the media and the general public, and that it will help strengthen nuclear safety.

EDITORIAL NOTE

CONTENTS

INSAG PERSPECTIVE

This IAEA report is a comprehensive summary of the many issues associated with decommissioning, waste management and remediation following the emergency phase of a severe accident. The report identifies the current gaps and possible approaches to address some of the complex issues associated with the technical, societal, environmental and economic aspects of this topic. While acknowledging the extensive technical and implementation challenges associated with these activities, our comments will focus on some of the key safety aspects of this topic, which we interpret to include any factors that could be a threat to health and well-being.

PREVENTION OF SEVERE ACCIDENTS

Although the prevention of severe accidents is not within the purview of this report, planning for managing the post-emergency phase of severe accidents should help sensitize Member States to the desirability of taking actions to prevent them in the first place. As demonstrated by the Fukushima accident, the remediation costs in terms of both economics and societal effects are extremely high. These costs may be avoided (at far lower cost) if sufficient attention is paid to accident prevention and mitigation. A key ingredient in this regard is a safety culture within national regulatory agencies and nuclear plant operators that challenges complacency and fosters questioning attitudes. A healthy safety culture would counter the temptation to ignore past accidents on the basis that they involve different sites, technologies, operators or regulatory systems and to assume that a severe accident “can’t happen here”.

REGULATORY CHALLENGES

The report’s comments on regulatory roles and responsibilities deserve particular attention. It is evident that the challenges in carrying out a decommissioning, waste management and remediation programme following a severe accident automatically become regulatory challenges. However, in general, regulations are established for operating facilities and not for the long term management of severe accidents. The transition of regulatory oversight to a post-emergency severe accident management programme will likely demand attention to some unique and difficult regulatory issues. Planning for the post-emergency phase of a severe accident should include regulatory planning.

The oversight expertise relating to nuclear safety is resident in the nuclear regulatory body. However, there may be multiple agencies that have responsibilities for the post-emergency phases of a severe accident, such as remediation of the surrounding areas. It is desirable that (i) the responsible agencies recognize and make use of the unique nuclear expertise held in the regulatory body (such as knowledge of the risks associated with radiation); (ii) that each agency's roles and responsibilities are clear; and (iii) that an effective coordination mechanism is in place.

It is not possible to determine the characteristics of the site and the affected surrounding areas following a severe accident in advance because every severe accident is likely to have unique consequences. In addition, the first priority during the course of an accident is mitigation (such as the use of sea water for cooling) and not the optimization of post-emergency activities. As a result of these facts, it is also not possible to define the detailed decontamination, decommissioning and remediation programmes that will need to be carried out. This is in contrast to experience with the ordinary decommissioning and waste management at nuclear power plants. As a result, regulatory approaches following an accident must be sufficiently flexible to deal with major uncertainties. The exercise of this flexibility requires the in depth technical understanding that should be present in the nuclear regulatory body.

One of the most difficult regulatory and policy issues is the question of how to apply dose criteria in the case of remediation. For example, the determination of the dose criteria that should guide the decisions as to whether people should be allowed to return to their homes is complicated by the observation that societal health effects will probably exceed those due to radiation for the population affected by the Fukushima Daiichi accident. The balance between health effects due to societal issues and those arising from radiation dose requires further discussion and consensus building by international experts.

DECOMMISSIONING AND WASTES

INSAG is in general agreement with the report's conclusions on decommissioning and waste management. We emphasize four important safety requirements for decommissioning and decontamination following a severe reactor accident:

(1) Stable states for the plant's structures, systems and components (SSCs) need to be established before, and maintained during, the decommissioning period. The establishment of a stable state is usually addressed initially during the emergency phase of the accident. However, stable configurations

for all the SSCs must be sufficiently robust so that they can be sustained throughout the decommissioning activities, which could continue for several decades. This may mean that the initial stable state of some SSCs will need to be enhanced before and during decommissioning.

(2) Materials need to be sufficiently characterized and the end states defined so that a decommissioning plan can be developed that deals comprehensively with the latent hazards. There are a large number of potential safety issues (radiological, chemical and physical) with respect to the handling of complicated mixtures of wastes in various states (gaseous, liquid and solid). Decommissioning plans cannot assume the nature of any of the waste until it is characterized, at least to the extent possible. An example of the importance of this was provided by the Three Mile Island accident; it was assumed that the fuel was mostly undamaged until an inspection revealed that much of the core was disrupted. It is important not to rush into planning or initiating decommissioning activities before the state of the SSCs is adequately characterized.

(3) Worker and public safety with respect to doses and other risks must be addressed thoroughly. Safety could be affected by external phenomena such as temperature, wild fire, wind, storms, flooding and earthquakes; by internal phenomena such as hydrogen explosions, fire, working in confined and poor visibility areas, and human error; and by the means for handling and transporting the waste. The safety principles for operating reactors, such as defence in depth and questioning attitudes, are equally applicable to a site undergoing decommissioning following a severe accident. There will undoubtedly be uncertainties and surprises, which mean programmes need to allow for continuous safety enhancements as events unfold and for conservative decision making by managers.

(4) Systems and/or regular inspections must be established for monitoring both radiation and the condition of the facilities. The recent collapse of the Chernobyl structure covering the turbine building is a reminder of the importance of monitoring and that monitoring will have to be maintained over a long time.

The wastes generated from decommissioning and remediation will be diverse in terms of physical and chemical composition, of radiation and chemical toxicity, and of volumes and physical location in the environment. As severe accident wastes will also be very different from the wastes from normal operations, current regulatory standards for waste may prove inappropriate. Moreover, wastes will likely be accumulated over several decades as the decommissioning and remediation programmes progress, and it is possible during this time that some of the disposal solutions proposed for the waste may prove to be unsuitable. We conclude that more work on severe accident wastes might be a useful future IAEA activity.

SOCIETAL ISSUES AND REMEDIATION

We note that while there is considerable worldwide expertise and experience that is relevant to the technical aspects of decommissioning, waste management and remediation, expertise on the associated societal issues appears to be much less developed internationally. These societal issues result from the psychological, economic, political, cultural and sociological changes that may occur as a result of a severe accident. For the post-emergency phase, the resolution of issues relating to remediation will likely be particularly difficult. Remediation is a complicated societal issue, partly because it can affect the fundamental lifestyle of many people over an extended period. ‘Societal remediation’ is an important part of any remediation programme and should be considered when developing plans for the post-emergency phase of a severe accident.

Effective communications can have a significant role in ameliorating societal issues and gaining public trust. It is clear from the Fukushima Daiichi experience that communications are needed in both the affected and non-affected areas surrounding the accident site. For the former, the anxiety levels based on such factors as fear, exclusion, helplessness, economic impacts and disruption need to be dealt with on an individual basis. For the latter, the removal of people to non-affected areas and integration into the local population involves many significant issues, such as the stigma associated with radiation, family separations and the hazing of children. There is a need to develop communication plans that target the non-affected areas to provide factual information and to sensitize the local population to the needs of the people moving into their area.

NEW ENTRANTS

The nuclear enterprise is continuing to evolve with many new entrant countries contemplating the development of nuclear power programmes. It is unlikely, however, that many new entrant countries will have either the infrastructure or the underlying knowledge base to deal with a severe accident by themselves. A new entrant country will need to identify and address any gaps that may exist and the IAEA should provide assistance and support in this effort.

There are a variety of potential factors that may affect an effective plan. For example, the local conditions in the new entrant country may be quite different from those in the country of the reference plant. In such cases, the new entrant country will have to rely on a body of knowledge from sources other than those that bear on the reference plant and its site.

Some new entrant countries may have dense populations near a proposed nuclear site. As a result, the impact of a severe accident on such matters as relocation, food supply and economics may be more difficult to address than in the country of the reference plant. In addition, a severe accident could impact neighbouring States, which may also lack sufficient infrastructure to deal with the event. For all these reasons, we feel that the IAEA needs to take the special needs of new entrant countries into consideration when developing future programmes on the topics covered in this report.

CONCLUSIONS AND RECOMMENDATIONS

INSAG agrees with the recommendations to strengthen the IAEA programme on remediation and, thereby, to assist Member States in developing remediation plans. This could include the development of strategies, methodologies for planning and implementation, standards, criteria and guidance for the various aspects of remediation. We also believe that the IAEA should foster international cooperation on remediation so that the lessons learned from past experience can be shared and further developed.

The report contains many useful suggestions for improvements in planning and readiness for the post-emergency phase of severe accidents. While it is not possible to comment on all of these suggestions, their implementation and sustainability will require an effective international mechanism for monitoring and assessment. Adapting an existing mechanism that is already being used extensively by Member States will ensure broad participation, thus helping to ensure success. The Convention on Nuclear Safety may be the most appropriate vehicle for this purpose. The Convention on Nuclear Safety periodic review meetings provide an opportunity for the peer review of all aspects of nuclear safety in Member States and they could be expanded to include the post-emergency phase of severe accidents.

The societal consequences of severe accidents are complex and long lasting and may be responsible for the most serious health effects associated with an accident. These consequences will depend on many local factors, such as culture, infrastructure, population and the economy. It is imperative that Member States include these factors in their remediation planning, taking into account the lessons learned from past experience. Decisions should take into account both societal and radiation risks, recognizing the challenge in achieving an appropriate balance of the two in addressing issues relating to the repopulation of affected areas.

New entrant countries will likely require international support in developing plans for the management of severe accidents, including those discussed in this report. It is recommended that the IAEA recognize the specific gaps that new entrants may encounter and develop appropriate guidance for addressing them.

1. INTRODUCTION

Following the accident at TEPCO's Fukushima Daiichi nuclear power plant (the Fukushima Daiichi accident), the IAEA Director General convened the IAEA Ministerial Conference on Nuclear Safety in June 2011 to direct the process of learning and acting upon lessons to strengthen nuclear safety, emergency preparedness and radiation protection of people and the environment worldwide. Subsequently, the Conference adopted a Ministerial Declaration on Nuclear Safety, which requested the Director General to prepare a draft Action Plan.[1] The draft Action Plan on Nuclear Safety (the Action Plan) was approved by the Board of Governors at its September 2011 meeting.[2] On 22 September 2011, the IAEA General Conference unanimously endorsed the Action Plan, the purpose of which is to define a programme of work to strengthen the global nuclear safety framework.

The Action Plan includes 12 main actions; one of the actions is focused on communication and information dissemination, and includes six sub-actions, one of which mandates the IAEA Secretariat to "organize international experts meetings to analyse all relevant technical aspects and learn the lessons from the Fukushima Daiichi nuclear power station accident".[3]

The IAEA Secretariat organized an International Experts Meeting (IEM) on Decommissioning and Remediation after a Nuclear Accident, held on 28 January–1 February 2013 at IAEA Headquarters in Vienna. The meeting was attended by over 200 experts and government officials from 40 Member States, regulatory bodies, utilities, technical support organizations, academic institutions, vendors, and research and development (R&D) organizations.

The broad objective of the IEM was to identify and analyse aspects of decommissioning and remediation, and to assist Member States to be better prepared for and to be better able to manage the consequences resulting from a nuclear accident based on lessons learned from past accidents. The IEM focused on the complex technical, societal, environmental and economic issues that need to be considered for decommissioning, remediation and radioactive waste management after a nuclear accident, specifically after the emergency exposure situation resulting from an accident has been declared ended. The IEM addressed the short term and long term issues for decommissioning of accident-damaged

---

[1] Declaration by the IAEA Ministerial Conference on Nuclear Safety in Vienna on 20 June 2011, INFCIRC/821, IAEA, Vienna (2011), para. 23.

[2] Draft IAEA Action Plan on Nuclear Safety, Report by the Director General, GOV/2011/59-GC(55)/14, IAEA, Vienna (2011).

[3] Ibid., p. 5.

facilities, management of radioactive waste arising from a nuclear accident and remediation of the off-site environment.

The IEM consisted of four plenary sessions and eight parallel sessions dealing with decommissioning, remediation and waste management. The sessions focused on topics such as experience from past accidents, current challenges in decommissioning and remediation, and the management of radioactive waste and damaged fuel. Each of the sessions was summarized and an overall IEM Chairpersons' Summary was produced (Annex A).

Long term recovery following a nuclear accident aims to restore normal life to affected populations. The technical measures for recovery are aimed at ensuring radiation protection of the public in the long term. These technical measures centre on remediation, decommissioning and radioactive waste management. Typically, these activities are implemented over a period of decades. Plans for remediation, decommissioning and radioactive waste management require regulatory authorization before and control during their implementation, and they are usually derived from an overarching strategy that includes, for example, principles for clearance of radioactive materials and radioactive waste minimization.

Owing to the very long time frame for recovery[4] from a nuclear accident, this IEM also drew on experience and learning from previous nuclear and radiological accidents, as well as on experience gained from the management of nuclear legacy sites, much of which is applicable for post-accident situations.

The IAEA's Basic Safety Standards (BSS)[5] recognize three types of exposure situation to control public and occupational exposure to radiation, namely planned, emergency and existing exposure situations. After a large nuclear accident, residual activity may be present in the environment and cause radiation exposure of the public that may require further control and, if necessary, environmental remediation. The BSS provide requirements to ensure a smooth transition from an emergency exposure situation to an existing exposure situation. The responsible national authority has to take the decision for defining

---

[4] The IAEA Safety Glossary does not define 'recovery'. It is generally understood to be the process of return of affected populations to a state of normality after a disaster. In the present report, the term 'recovery' is used in a narrower sense: (i) it refers to the remedial, decommissioning and radioactive waste management activities taken in support of efforts to restore a state of normality for affected populations; (ii) it applies to both on-site and off-site activities; and (iii) it applies to activities implemented mostly during existing exposure situations.

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards — Interim Edition, IAEA Safety Standards Series No. GSR Part 3 (Interim), IAEA, Vienna (2011).

this transition. The IAEA Secretariat is undertaking activities to better define how this brief transition period should be managed.

1.1. BACKGROUND

Accidents at nuclear facilities have occurred infrequently. However, some of the severe nuclear accidents have had a major impact on the surrounding population and environment, and, in some cases, have had trans-boundary implications. The remediation of large areas of agricultural, residential and industrial land, and the decommissioning of highly contaminated and damaged structures are complex and very costly undertakings, and it may take decades until such activities are finished. Post-accident recovery requires a long term commitment to a complex and costly series of measures to protect people and the environment. The human, technical and financial resources required to address recovery present a significant challenge for affected Member States.

Recovery from nuclear accidents, such as Chernobyl, are far from complete and recovery actions to fully address the consequences of the Fukushima Daiichi accident will take decades to be fully implemented. The Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station Units 1–4 (the Fukushima Daiichi Decommissioning Roadmap) was developed by the Government of Japan and the TEPCO Council on Mid-and-Long-Term Response for Decommissioning, established in December 2011. The Fukushima Daiichi Decommissioning Roadmap envisages decommissioning occurring over a time span of 30–40 years. The lessons learned from post-accident recovery are drawn from experience that unfolds over a period of decades.

1.2. OBJECTIVES

The objective of this report is to highlight the lessons learned during the IEM on decommissioning, remediation and radioactive waste management in the light of the Fukushima Daiichi accident. The report also highlights lessons learned from previous nuclear and radiological accidents, and from the management of nuclear legacy sites. The central components of the report are the insights gained from presentations by keynote speakers, panellists and poster presenters, and from discussions and contributions by participants during the IEM. These insights are supplemented by experience from other relevant activities being carried out in the framework of the Action Plan.

This report summarizes the discussions and conclusions of the IEM, includes appreciable information on the recovery activities both on-site at the Fukushima Daiichi nuclear power plant and off-site in surrounding prefectures. The report also summarizes the discussions on progress made towards recovery in other Member States affected by accidents, and relevant experience from the management of nuclear legacy sites, and highlights lessons learned to date in the following key areas:

— Post-accident activities related to decommissioning, specifically activities carried out on a licensed site;
— Remediation of off-site areas affected by radionuclides;
— Strengthening capabilities for dealing with decommissioning and remediation after a nuclear accident.

Several lessons learned are elaborated in the main body of the report for each of these three major areas. Bringing together lessons learned to date and highlighting experience and best practice in this field, the report is expected to serve as a reference for experienced experts, government officials, operators of nuclear power plants and the public. The report represents an integral component of the implementation of the Action Plan by the Secretariat and will contribute to the ongoing efforts to strengthen this important area of safety.

2. POST-ACCIDENT ACTIVITIES RELATED TO ON-SITE DECOMMISSIONING

The terms ‘siting’, ‘design’, ‘construction’, ‘commissioning’, ‘operation’ and ‘decommissioning’ are normally used to delineate the six major stages of the lifetime of an authorized facility and of the associated licensing process. The term ‘decommissioning’ refers to the administrative and technical actions taken to allow the removal of some or all of the regulatory controls from a facility. Aspects of decommissioning have to be considered throughout the other five major stages. When an accident occurs at a nuclear facility, it will either be repaired and returned to operation or decommissioned. When damage is extensive, such as that caused by a severe accident, the decision is invariably to decommission the facility.

Decommissioning of nuclear facilities under normal circumstances follows a life cycle approach that is comprised of the following major steps:

— Facility design, for which current safety standards require that the future decommissioning of a facility be taken into account at the design stage.
— An initial decommissioning plan should be developed as part of the authorization process for operation of a new facility. The initial decommissioning plan is generally focused on technical feasibility and financial assurances for decommissioning.
— Periodic review and revision of the decommissioning plan should be carried out, as appropriate, throughout the lifetime of the facility.
— In decommissioning terminology, the time between final shutdown of a facility and the issuing of an authorization to decommission a facility is referred to as the 'transition period'[6], during which activities such as removal of nuclear fuel, post-operational clean out and characterization are carried out.
— Preparation of the final decommissioning plan begins prior to shutdown and will continue during the transition period. Among other things, the final decommissioning plan specifies the strategy, main phases and activities, and end point for decommissioning.
— When the regulator approves the final decommissioning plan, the decommissioning actions, such as decontamination, dismantling and demolition, can take place to achieve the decommissioning end state.
— When decommissioning actions are completed and accepted by the regulatory body, the facility is released from regulatory control, unless some regulatory restrictions remain through the modification of regulatory authorization.

When dealing with decommissioning of a facility that has been damaged by a nuclear accident, some of the above steps may need to be adapted to meet the challenges of the post-accident situation. The administrative and technical actions that need to be taken to allow the removal of some or all of the regulatory controls from a facility depend on the extent of the damage. Stabilization measures, removal of accident debris, decontamination measures and supplemental shielding are preparatory decommissioning actions.

The initial decommissioning plan produced prior to the accident needs to be modified according to the extent of the damage. For example, modifications to the decommissioning plan will be needed to implement the stabilization measures and the characterization plan, to remove damaged fuel, to update the

[6] The use of the term 'transition period' in decommissioning is different from and should not be confused with the notion of 'transition' from an emergency to an existing exposure situation.

decommissioning cost estimate and to manage large volumes of radioactive waste.

For clarification, some additional decommissioning terminology is provided below:

- ‘Stabilization’ refers to activities to achieve long term stable conditions in an accident-damaged facility. Intensive stabilization actions will have well defined milestones; however, some stabilization activities may continue throughout decommissioning.
- ‘Post-accident clean out’[7] includes activities such as the removal of contaminated debris and the removal of damaged fuel and fuel debris until the interim end state for post-accident clean out is achieved.
- The ‘interim end state’ for post-accident clean out could, for example, be when nuclear fuel and fuel element debris are removed, with the exception of small residual amounts that cannot be removed until systems and structures are disassembled/demolished. Some of the factors important to decisions for the interim end state of safe enclosure are addressed in Section 2.6.

Stabilization activities, post-accident clean out and the interim end state for decommissioning are all part of the preparations for final decommissioning and require regulatory authorization.

2.1. STRATEGIC PLANNING

Lessons Learned: Strategic planning for the phases of work following a nuclear accident needs to focus on and prioritize the use of limited resources, support decision making, inform all interested parties and consider near term priorities as well as long term issues. Strategic planning for post-accident clean out should begin early with the understanding that plans will be revised as further information and data are acquired, and unanticipated conditions are encountered.

As taken into account in the Fukushima Daiichi Decommissioning Roadmap, a strategy must be developed to identify the steps of post-accident

[7] This term is introduced to correspond with terminology used for decommissioning after normal shutdown (i.e. for non-accident facilities). When shutdown is under normal conditions, decommissioning preparations include a stage that is commonly referred to as ‘post-operational clean out’, where the bulk of the radioactive material, such as fuel and operational waste, is removed from the facility.

clean out, including key milestones, hold points and end points. The strategic plan that describes the decommissioning strategy will initially be conceptual in nature but will evolve in detail as progress is made and actual conditions are better known.

Strategic planning should consider long term issues, such as the final end state for decommissioning, and be integrated with regional and national planning, and the national waste management strategy. Short term needs may dictate that the level of detail for long term planning will initially be very general. However, this will become more specific as post-accident clean out progresses and as uncertainties are resolved or reduced.

Planning for final decommissioning can be deferred, but should begin well before the post-accident clean out is complete. Final decisions on decommissioning will influence how the post-accident clean out is carried out. The ultimate condition of the facilities and the site, that is, the final end state, can only be explicitly defined when sufficient progress has been made during post-accident clean out. In the interim, various end state options can be developed for the purposes of understanding the benefits and impacts of alternate decommissioning strategies and end states.

The Government of Japan invited the IAEA to conduct an international peer review[8] of the Fukushima Daiichi Decommissioning Roadmap. The objective of the peer review was to provide an independent assessment of the activities associated with the planning and implementation of decommissioning of the Fukushima Daiichi nuclear power plant, specifically:

— To improve the decommissioning planning and the implementation of pre-decommissioning activities at the Fukushima Daiichi nuclear power plant;
— To facilitate sharing, with the international community, of good practices and lessons learned for decommissioning operations after the accident that were identified during the review.

The review was organized in two steps. The objective of the first step, undertaken in April 2013, was to review the Fukushima Daiichi Decommissioning Roadmap, including the decommissioning strategy, and the planning and timing of decommissioning phases. Several specific short term issues and recent challenges were also examined, such as the current condition of the reactors, management of waste, protection of employees, and the structural integrity of

[8] Although the IEM took place before the peer review mission, the peer review report was published while this report was being written.

reactor buildings and other structures. The peer review concluded that relatively stable cooling of the fuel and fuel debris in the reactors and spent fuel pools has been achieved and is adequate to remove the decay heat. However, the review identified several challenges to achieve a sustainable situation over the period of the next 10–20 years. The review identified some additional measures to further enhance the monitoring processes and instruments for ensuring prompt identification and mitigation of events at the site, as well as to improve the communication of events to the authorities and the public. The IAEA team encouraged the Government of Japan and TEPCO to prepare to discuss the end state of the Fukushima Daiichi nuclear power plant decommissioning strategy, in close cooperation with other stakeholders.[9] The second step of the Fukushima Daiichi Decommissioning Roadmap review by the IAEA will be carried out later in 2013.

At the International Experts Meeting:

It was discussed that decommissioning challenges and, thus, decommissioning plans vary considerably for accident-damaged facilities as evidenced by experience at Windscale Pile 1 (United Kingdom)[10], the fuel reprocessing facility at Kyshtym[11] (Russian Federation)[12], Three Mile Island (TMI) Unit 2 (United States of America) and Chernobyl Unit 4 (Ukraine).

A number of principles for the decommissioning strategy and planning were discussed and highlighted as follows:

- Care should be taken to commit resources to support clear needs;
- R&D programmes should be focused on challenges that support specific decommissioning needs rather than technical novelty;

[9] Report of the IAEA International Peer Review Mission on Mid-and-Long-Term Roadmap Towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station Units 1–4.

[10] An accident occurred on 10 October 1957 when the core of Pile 1 at Windscale (now Sellafield), United Kingdom, caught fire, releasing significant quantities of radioactivity into the environment.

[11] The Kyshtym accident occurred on 29 September 1957 at the Mayak fuel reprocessing plant in the former USSR (now the Russian Federation), resulting in the release of large quantities of radioactivity to the environment.

[12] In this report, the Belorussian Soviet Socialist Republic, the Russian Soviet Federative Socialist Republic and the Ukrainian Soviet Socialist Republic (part of the USSR until 1991) are referred to by their present country names, Belarus, the Russian Federation and Ukraine, respectively.

— Flexibility and adaptability are essential for management at strategic, managerial and technical levels, and unnecessary complexity in all of these areas should be recognized and avoided;
— Organizational structures may change as progress is made with decommissioning and operational priorities change;
— Where possible, adapting proven technology is preferable to developing new approaches.

It was highlighted that the Fukushima Daiichi Decommissioning Roadmap defined the decommissioning work and set major milestones for on-site work and R&D projects in three phases at its inception. The three phases and the associated end states to be achieved support the following stated objectives:

(a) Phase 1: to commence fuel removal from spent fuel pools within 2 years.
(b) Phase 2: to commence fuel debris removal from reactor pressure vessels within 10 years.
(c) Phase 3: to terminate the decommissioning process within 30–40 years.

It was also noted that the reactor cores are being maintained at low temperature. In addition to maintaining power supplies and cooling, major challenges in the short term period are:

— Retrieval of spent fuel from spent fuel pools;
— Management and storage of accumulated water after treatment;
— Reduction of radiation levels;
— Improvement of the working environment.

Other near term challenges include the prevention of spread of contamination to local water-ways and to the ocean, and relevant decisions on remote technology options to access high radiation areas.

In the longer term, to achieve the Phase 2 objective within ten years, many issues and problems need to be solved well in advance. Three significant examples of these issues are: (i) preparation for fuel debris removal; (ii) treatment and disposal of radioactive waste; and (iii) development of remote control devices for fuel debris removal.

2.2. ESTABLISHING STABLE CONDITIONS

Lessons Learned: It is necessary to establish stable conditions for a facility prior to conducting operations necessary for removing damaged fuel and fuel debris.

The IEM came to the understanding that achieving stabilization objectives can take from months to years and maintaining them will require ongoing attention for an indeterminate period. Stabilization activities and related lessons include, but are not limited to, the following examples:

— Confinement of radioactivity and radioactive materials: When stabilization is achieved, additional release of radioactive materials into the environment must be managed as an authorized discharge throughout the course of post-accident clean out and until the decommissioning end state is achieved. In cases where the reactor building is significantly damaged, priority should be given to installing additional barriers to prevent radionuclide migration away from the source, such as enclosures, covers and engineered barriers.
— Cooling and venting: Cooling and venting are needed to achieve and maintain cold shutdown and, subsequently, to remove explosive gases to prevent further damage to the facility or the surrounding area that would result from excessive temperature or pressure.
— Criticality control: In the case of a core disruption accident, it is extremely important to prevent criticality. Criticality control should address the use of neutron poisons, such as boron, and other means. If neutron detection function is lost, it is essential that alternate means be put in place.
— Structural integrity: Buildings and structures damaged by the accident that are important for safety should be evaluated and reinforced, repaired or replaced, as necessary. The possibility of further degradation should also be addressed.
— Water management: The TMI and Fukushima Daiichi accidents created large quantities of water contaminated with fission products and fuel particles that had to be processed. Those dealing with stabilization and post-accident clean out must be prepared to commit significant resources for water management and to continue to do so through to the final states of post-accident clean out. Unauthorized off-site releases of water must be prevented.

The IEM further discussed the management of tritium-contaminated water as a special challenge. Liquid waste treatment systems are very effective at the removal of radionuclides such as caesium, strontium and the actinides. On the other hand, tritium contamination in water cannot be easily removed with any standard treatment system. Although tritium concentrations in water after treatment may be below allowable discharge limits, discharge of treated water has not always been implemented due to stakeholder concerns. At the Fukushima Daiichi nuclear power plant, it has been necessary to install on-site tanks to store the tritiated water resulting from the steady accumulation of treated cooling water due to groundwater ingress into the reactor cooling circuits.

At the International Experts Meeting:

Presentations described or referred to several cases of establishing stable conditions following an accident.

At TMI Unit 2, a means to provide cooling of the reactor core was needed to replace the circulation of the highly contaminated primary coolant through the normal decay heat removal system. This would have resulted in high radiation levels in the auxiliary building where human occupancy was needed for other functions. Cooling was accomplished through the steam generators instead of the normal decay heat removal system.

At Chernobyl, an enclosure for the accident-damaged unit was rapidly put in place (the ‘shelter’). Twenty seven years later, the ‘new safe confinement’ is being constructed to maintain stable conditions following degradation of the shelter.

At the Fukushima Daiichi nuclear power plant, remote technology may help to find and repair water leak points from the reactor buildings. If that cannot be done, it will be necessary to find other options to gain access to the damaged fuel and fuel debris. In the interim, water that leaks into the turbine halls is being recycled back to the containment to provide cooling.

2.3. CHARACTERIZATION

Lessons Learned: Characterization is key to technical decision making, planning, engineering and conduct of activities. Obtaining information and data regarding actual conditions and characteristics is essential for post-accident clean out and for proper planning for final decommissioning. It should be recognized that available knowledge cannot always be complete and more information would always be useful. However, the key requirement is the availability of sufficient and reliable information with which to make sound judgements and decisions.

Each accident will present challenges that will require adaptation of existing technologies to conduct characterization for post-accident clean out and preparations for final decommissioning, particularly for the recovery of damaged fuel. A major focus of characterization will be to better determine the condition and configuration of the damaged nuclear fuel and fuel element debris.

An important aspect of information management is collecting and disseminating technical data in a manner that is suitable for the needs of those who will plan and implement decommissioning, radioactive waste management and remediation. Analysts who evaluate such data should consult with the end users of such data.

Characterization of damaged structures, systems and components (SSCs) important to safety will require customized and novel/innovative technical solutions. In many cases, remote technology will be needed to characterize areas with high radiation dose rates and/or areas where personnel access is impossible. Many of the applications of remote technology will need to be customized to the specific circumstances and each adaptation or development can be a time-consuming and expensive undertaking.

At the International Experts Meeting:

Although characterization was not explicitly presented as a stand-alone topic, the above lesson learned was addressed throughout the IEM. It was included in the sessions related to planning, radioactive waste management and damaged fuel management. Two presentations highlighted characterization issues that are of particular concern for damaged fuel:

— Studies of the once molten Chernobyl fuel (called Chernobyl ‘lava’) evaluated how its properties changed with time; understanding these changes is important for any future handling of the material.
— At TMI Unit 2, the hardness and other physical properties of the re-solidified molten core was needed to design the drill bits that were subsequently used to break up the mass of fuel debris.

2.4. DAMAGED FUEL AND FUEL DEBRIS MANAGEMENT

Lessons Learned: Each fuel damage accident is different and, consequently, the characteristics of the damaged fuel and fuel debris are unique. Thus, each fuel retrieval project is different and has its own specific challenges. Neither precedents from past accidents nor accident simulation will enable accurate prediction of the condition of damaged fuel that has yet to be characterized visually and physically.

Nuclear fuel, once placed into operation, will have very high levels of radioactivity contained in a complex matrix. Its physical configuration within a reactor core is mechanically complicated for reasons of structural strength and thermal stability during operations and for handling during its insertion into and removal from the reactor core. Fuel overheating and melting may destroy the structural integrity of the fuel. As a result, removing damaged fuel and fuel debris is one of the most challenging aspects of post-accident clean out.

Planning and design for a damaged fuel removal campaign must address all relevant issues associated with fuel removal. This includes issues associated with retrieval, packaging, storage and long term management, all of which need to be addressed in an integrated manner. This integrated manner must include considerations, such as worker health and safety, physical removal, tools and equipment, containers, measuring and monitoring removed materials and debris, interim on-site storage, and material packaging and transport.

Past accidents have resulted in significant differences in the degree of damage to reactor cores. Experience from the TMI and Chernobyl accidents has provided a knowledge base that has proved to be of benefit for post-accident clean out activities at the Fukushima Daiichi nuclear power plant. The collection of data and knowledge management from post-accident clean out at the Fukushima Daiichi nuclear power plant will add to this knowledge base.

At the International Experts Meeting:

It was noted that for severe accidents some of the damaged fuel may migrate into reactor systems and into the reactor building. In the case of the Chernobyl accident, about 3.5% of the fuel was disbursed outside of the reactor building. A primary technical challenge is to characterize the location, configuration and composition of the damaged material; this information is needed before detailed plans for its removal can be designed and implemented. While modelling/simulation may provide an indication about the extent of fuel damage and how the damaged fuel may have migrated, it is not a substitute for visual confirmation.

At the Paks nuclear power plant (Hungary), an accident occurred in a fuel cleaning vessel that led to severe damage of fuel assemblies due to overheating. As a consequence, significant contamination of the reactor hall occurred. Subsequently, during the three year period in which removal of the damaged fuel was completed, extensive decontamination was also carried out and the reactor was returned to normal operation. In the case of TMI Unit 2, damaged fuel retrieval began around five years after the accident and was completed in a period of about ten years. At Chernobyl Unit 4 and Windscale Pile 1, retrieval of damaged fuel remains to be accomplished. At the Fukushima Daiichi nuclear power plant, the current plan is to begin the retrieval of molten fuel in about ten years and it may take a further decade or more to accomplish.

Damaged nuclear fuel and fuel debris will likely introduce a new waste stream into the national waste management strategy. The design of containers for this material should minimize impediments to future handling and transport of the material, as well as its future disposal. The selection of treatment and processing options for this material, as well as the final disposal pathway for it will need to be assessed.

Although each case of retrieval and management of fuel debris is substantially different, the following important points were highlighted by the experts:

— Characterization of damaged fuel and fuel debris is essential before planning any retrieval/intervention (this includes visual confirmation of the location and configuration of such material);
— Adequate shielding, ventilation and lighting are essential to provide safe conditions for workers;
— To the degree possible, tools need to be simple, reliable and adaptable to provide flexibility to deal with the unexpected;
— Hostile conditions will require the use of remote handling technologies and tools, but implementing remote technological approaches can become a relatively complex undertaking;
— The use of full scale mock-ups for testing of tools, validation of processes and training of workers is essential;
— Appropriate containers are needed for transfer and storage of fuel debris, and transport if required.

After retrieval, the options for fuel debris could include interim storage on-site or off-site, as well as processing for long term storage and disposal.

2.5. WASTE MANAGEMENT DURING POST-ACCIDENT CLEAN OUT

Lessons Learned: Wastes generated from a nuclear accident will have their own specific physical, chemical and radiological characteristics, posing special challenges for conditioning, packaging, storage, transport and disposal. It is likely that there will be large volumes of such waste following an accident. Close interaction is essential between all those involved in the entire sequence of waste management, from designing the processes needed for waste conditioning through to establishing waste acceptance criteria for disposal.

In the past, many types of radioactive waste from accidents have been managed and treatment methods are available for most accident-damaged fuel. However, any accident will need to address specific management and technical challenges. Large volumes of solid waste are created during post-accident clean out which have medium to high radioactivity levels and with wide variations in physical and chemical characteristics. The presence of organic matter, putrescible material and soil in these waste arisings can present additional challenges. New facilities will be needed to condition, package, store and prepare waste for transport to storage or disposal facilities.

Technology development will be required on a case by case basis to adapt existing treatment and handling systems to manage the waste arising from an accident. These can include, for example, systems for volume reduction, stabilization and packaging. As with any waste management system, selection must be based on safety, technological and economic factors.

At the International Experts Meeting:

It was highlighted that for the Fukushima Daiichi nuclear power plant the waste management strategy has to address several complex water management challenges. These include the reactor coolant, complexities caused by sea water injected for cooling and the intrusion of groundwater into the facilities. The difficulty of identifying and sealing the water leakage path from the reactors and containment, and the ingress of groundwater into the damaged units has led to the need to process and treat large volumes of cooling water. An ever increasing number of tanks are being used for storing water that has passed through treatment systems for purification. Significant storage is also required for vessels containing the zeolite media used for water treatment. On-site enclosures have also been created to store the debris created by the tsunami that was subsequently contaminated during the accident.

For any post-accident situation, such as the situation at the Fukushima Daiichi nuclear power plant, a specific radioactive waste management strategy is needed to guide on-site radioactive waste management. The waste management strategy should include not only long term storage but also, to the extent possible, the reuse and recycling of materials. Early estimates of future waste arisings by waste quantity and category are important for long term planning and need to be updated periodically. Close coordination is required between those responsible for on-site waste management plans and activities, and those who manage storage and disposal facilities that serve national needs. This coordination is indispensable for addressing technical constraints for waste conditioning and subsequent disposal of the waste arisings from accident sites.

Examples of waste management challenges following the Fukushima Daiichi accident are:

— Availability of the means to sample and categorize on-site tsunami debris and contaminated trees that have been felled;

— Conditioning of wastes containing chlorides to minimize corrosion, and finding disposal options for waste containing chloride products;
— Sampling of caesium-loaded zeolite from the inside of adsorption columns;
— Identifying and measuring the radionuclides that are important for safety evaluations;
— Establishing ways to systematize and prioritize a great variety of wastes for processing and disposal.

Establishing an integrated waste management strategy is a key issue for successful decommissioning. Many unexpected challenges will arise and flexible programme management is indispensable.

After the Chernobyl accident, there was a need to quickly collect and store locally huge amounts of radioactive waste of different types generated during the post-accident clean out. Such wastes included fragments of the reactor core, reactor structures thrown out by the explosion, fragments of the plant structures, debris generated as a result of demolition of buildings in the villages located around the plant, contaminated equipment, tools and vehicles, parts of metal structures, concrete debris and soil removed from large areas. Many 'collection points' and temporary storage facilities were established during the emergency response phase, some of them without any physical barriers between the waste and the environment. There was a significant effort to segregate the waste according to the material and its origin, but due to the time pressure and the very large amounts of materials, extensive waste characterization and segregation of these materials was not possible.

The exclusion zone, established around the Chernobyl nuclear power plant after the accident, limits the public's access to the heavily contaminated areas and to the stored radioactive waste. Consequently, there has not been an urgent need to relocate the waste from the points of initial collection and storage. During the years that followed the accident, a strategic decision evolved to use the already contaminated exclusion zone as an area to host a number of new waste management facilities and to serve as a waste management complex for the entire country. This approach reduces the efforts and costs for complete remediation of the large contaminated zone, eliminates the need for transport and disposal of all of the waste from the exclusion zone to a non-contaminated location outside of the exclusion zone and prevents the creation of an additional radiation burden to the population in the vicinity of such a new location.

An important R&D issue related to waste management is the development of waste processing and disposal capacities. The overall strategy for R&D should address waste form specifications, compliance of waste forms with present and future disposal facilities, and the development of safety regulations and technical standards based on the results of these R&D activities.

2.6. FINAL DECOMMISSIONING FOLLOWING POST-ACCIDENT CLEAN OUT

Lessons Learned: Final decommissioning activities of the damaged facility may not begin until decades after an accident. It is, therefore, important to ensure that a system of inspection and surveillance is established to monitor and maintain the long term performance of SSCs important to safety until decommissioning is completed.

None of the facilities at which the three major nuclear accidents with fuel damage took place that preceded the Fukushima Daiichi accident, Windscale Pile 1 (United Kingdom), TMI Unit 2 (USA) and Chernobyl Unit 4 (Ukraine), have entered into final decommissioning. Deferral of decommissioning has been used to obtain the benefit from advances in technology, resolve long term waste disposal issues, prepare final decommissioning plans and obtain financial resources. Deferred decommissioning can also lead to a reduction in occupational exposures from radioactive decay and allow the establishment of methods to reduce waste volumes.

Experience with degradation of shut down facilities and the recent roof collapse at the Chernobyl turbine building highlight the importance of ensuring safe storage of an accident-damaged facility.

Measures should be taken to minimize multiple interim waste storage sites because in the future, some, if not all, are likely to require decommissioning and remediation.

For large decommissioning projects, the strategy of ‘in situ decommissioning’ (referred to as ‘entombment’ in IAEA publications[13]) could be considered an appropriate decommissioning strategy.

At the International Experts Meeting:

The experts described the current status of accident-affected facilities and legacy facilities, and their expected or achieved end states. These end states range from the expectation of decommissioning to a greenfield site (TMI Unit 2), to safe enclosure of facilities for an indeterminate time (Windscale Pile 1 and Chernobyl Unit 4), to entombment of facilities (US Department of Energy legacy reactors).

[13] INTERNATIONAL ATOMIC ENERGY AGENCY, Decommissioning of Facilities Using Radioactive Material, IAEA Safety Standards Series No. WS-R-5, IAEA, Vienna (2006).

The decommissioning end state for the Fukushima Daiichi nuclear power plant will not be determined until post-accident clean out is well under way. In addition to the need of finding out the actual conditions of materials and areas that cannot be currently accessed, final disposition will also be dependent on future decisions regarding waste disposal.

3. REMEDIATION

3.1. OBJECTIVES OF REMEDIATION

Lessons Learned: The objectives of remediation after nuclear accidents need to be broadened to ensure that radiological effects, as well as physical, mental and social well-being[14] are appropriately taken into account. International guidance should be further developed to reflect a wide remit for the objectives of remediation which, in addition to reducing public exposures, includes economic and social perspectives, such as maintaining public trust in the safety of food and commodities.

The IAEA Safety Glossary[15] defines 'remediation' as: "[a]ny measures that may be carried out to reduce the radiation exposure from existing contamination of land areas through actions applied to the contamination itself (the source) or to the exposure pathways to humans".

Thus, remediation, if used in a narrow sense, is about reducing exposures through actions directed at the source and/or through actions directed at the exposure pathway. Environmental remediation is often considered to have the goal of returning a site to the conditions that prevailed before the contamination. In practice, however, this is often not feasible, especially if large areas are affected.

---

[14] "Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity." Preamble to the Constitution of the World Health Organization as adopted by the International Health Conference, New York, 19–22 June, 1946; signed on 22 July 1946 by the representatives of 61 States (Official Records of the World Health Organization, No. 2, p. 100) and entered into force on 7 April 1948.

[15] INTERNATIONAL ATOMIC ENERGY AGENCY, IAEA Safety Glossary: Terminology Used in Nuclear Safety and Radiation Protection, 2007 Edition, IAEA, Vienna (2007).

The BSS contain recommendations on remediation which are relevant for existing exposure situations following a nuclear accident. This requires, among other things, that the responsible persons or organizations prepare a remedial action plan, supported by a safety assessment, to be submitted to the regulatory body or other relevant authority for approval. The remedial action plan is aimed at the timely and progressive reduction of the radiation risks and eventually, if possible, to the removal of restrictions on use of, or access to, the area.

Remedial actions aimed at the reduction of exposures to the public are subject to justification and optimization. Thus, any action has to be justified, so that remedial actions should do more good than harm. Any additional dose received by individuals as a result of remedial actions should be justified on the basis of the resulting net benefit, including consideration of the consequent reduction of the annual dose.

Remediation is an activity where the close interaction of the relevant stakeholders is of particular significance. The objectives of remediation encompass more than reducing radiation doses to humans. The notion of 'health' has been broadened to include aspects other than direct effects of radiation, noting that health is not defined as the absence of disease by the World Health Organization, but rather as a state of physical, mental and social well-being. An objective of remediation, from this perspective, is the return to normal life and livelihoods.

Remedial actions should ideally be commensurate with risks and are expected to yield sufficient benefits to individuals and to society (including the reduction in radiation detriment) that outweigh the cost of such actions and any harm or damage caused by the actions. In practice, the balance between the perceived benefits of averting radiation dose and the cost varies after different accidents in different parts of the world in different decades. The costs of averting small doses in some affected areas after different accidents have been high. These costs have been justified by addressing wider objectives such as the need to ensure the continued acceptance by consumers of agricultural produce or other social and cultural issues.

In response to a request made by the Government of Japan, the IAEA dispatched a fact-finding mission[16] to support the remediation of large contaminated areas off-site of the Fukushima Daiichi nuclear power plant. The mission focused on the provision of assistance related plans to remediate large areas contaminated as a result of the Fukushima Daiichi accident. The

[16] Final Report of the International Mission on Remediation of Large Contaminated Areas Off-site the Fukushima Dai-ichi NPP, NE/NEFW/2011, 15 November 2011.

remediation related strategies, plans and activities were also reviewed, and the findings were shared with the international community to broadly disseminate lessons learned. The mission included an assessment of the information provided, open discussions with the relevant institutions in Japan and visits to the affected areas, including several demonstration sites used to test and assess various remediation methods.

At the International Experts Meeting:

The experts noted that while emergency preparedness and response have been given proper attention by the IAEA, preparedness for remediation following an accident requires more attention. They considered that improved guidance could be developed for remediation based on the lessons learned from the different remediation cases experienced to date.

There is a need to find the appropriate balance between a ‘technical’ (or numerical) approach and a ‘social’ approach for making decisions on remediation actions. It was proposed that further guidance on integrating and optimizing both approaches be developed.

The experts noted the evidence from the presentations of the extensive work underway in the environs of the Fukushima Daiichi nuclear power plant on evaluating remediation techniques and R&D for their improvement.

The importance of economic activity and livelihood in setting remediation objectives was emphasized. For example, the objectives of remediation for a community, based on the recovery goals of the Fukushima Prefecture, are to:

— Guarantee the safety of residents and the security of property;
— Regenerate and revitalize primary industry;
— Become a hub for future economic activities;
— Promote the use of local resources and skills, e.g. in tourism and crafts.

3.2. APPLICATION OF REFERENCE LEVELS AND STANDARDS

Lessons Learned: There is a need for transparency in the derivation and implementation of subsidiary reference levels of activity in food and commodities to facilitate the public’s and experts’ understanding. Further international technical and practical guidance should be developed to support the existing international standards. In particular, clear guidance in support of the implementation of the standards and on reference levels in specific situations should be developed, including a review of associated food and commodity reference levels applied during remediation to provide a consistent and coherent message.

The International Commission on Radiological Protection (ICRP) has published recommendations[17] for the protection of people in emergency exposure situations and guidance[18] on the protection of people living in long term contaminated areas after a nuclear accident or a radiation emergency. The ICRP recommends that a reference level to guide optimization in existing exposure situations should be selected within a range of annual doses of 1–20 mSv to members of the public, and that can be amended as necessary during the course of remediation.

The BSS provide reference levels for the control of exposure of the public in existing (post-accident) situations. All reasonable steps should be taken to prevent doses remaining above the reference levels, typically expressed as an annual effective dose to the representative person[19], in the range of 1–20 mSv. The actual value adopted for the reference level will depend on the prevailing circumstances for the exposures under consideration, including the feasibility of controlling the exposure situation and experience in managing similar situations in the past.

The BSS provide recommendations on criteria for guiding remediation operations such as:

- — Optimization of the form, scale and duration of remedial actions;
- — Priority to those population groups for whom the dose exceeds the reference level;
- — Taking all reasonable steps to prevent doses remaining above the reference levels.

Reference levels applied for remediation of contaminated areas are generally set not higher than 5 mSv/a. However, there are cases where a restrictive reference level of 1 mSv/a is used to guide remediation. Often, this level is confused with the annual dose limit for exposure of the public from all human-made sources in a planned exposure situation.

---

[17] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, The 2007 Recommendations of the International Commission on Radiological Protection, Publication 103, Elsevier (2007).

[18] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Application of the Commission’s Recommendations to the Protection of People Living in Long-term Contaminated Areas After a Nuclear Accident or a Radiation Emergency, Publication 111, Elsevier (2009).

[19] “An individual receiving a dose that is representative of the doses to the more highly exposed individuals in the population” (BSS, see footnote 5).

Usually, doses are calculated based on very conservative assumptions for a representative person as specified in the BSS. Even if the expected exposure levels are below the reference levels set by the regulatory body, all measures taken are subject to optimization to ensure that all exposures are controlled to levels that are as low as reasonably achievable, economic, societal and environmental factors being taken into account. In choosing the optimized remediation option, the radiological impacts on people and the environment should be considered together with non-radiological impacts. The costs of the transport and management of radioactive waste, the radiation exposure of, and health risks to, the workers managing the waste, and any subsequent public exposure associated with its disposal should all be taken into account. Most attention is directed at population groups with the highest exposure, in particular those for whom residual doses exceed the reference level.

The application of dose criteria in practice is a complex task, since the radiological end point — the annual effective dose to the representative person — is the result of the interaction of various factors such as the radionuclides involved, the environmental conditions, land use and living habits. Estimates derived from modelling alone are associated with large uncertainty; however, linking the available environmental monitoring results to the models will increase the reliability of the results. Consideration of radiation exposure provides scientifically based judgements, and the generic reference levels in the BSS can be taken into account when national authorities are setting situation specific reference levels. Subsidiary reference levels, such as measurable ambient radiation levels and/or radionuclide activity concentrations in various environmental media, foodstuffs and feed for agricultural animals, are more suitable for practical application as they are specific to the accident and are derived using appropriate models with event specific parameters.

However, the meaning of such subsidiary reference levels, commonly termed ‘benchmark’ values, may not be easily communicated to the public. A particular problem may arise due to the lack of harmonization in some of the benchmark values between international organizations and different countries. This underlines the need for clarity in the derivation and transparency in the implementation of these values to allow the public and experts to understand how benchmark values are derived and applied.

At the International Experts Meeting:

The experts discussed the international practices and standards for decommissioning and remediation after a nuclear accident, and reported on the feedback of their application.

Conventions[20] and international standards[21] already exist; however, experience shows that there is a need for clear, quantitative international guidance for remediating contaminated territories, disposing of contaminated debris and rubble, or controlling contaminated consumer products. The guidance should be based on radiological protection principles, i.e. justification, optimization and limitation, and should take into account objective issues, such as radiation exposure and the costs of remediation, and appropriately address subjective issues, including public perception, anxiety and political pressure. The guidance should also facilitate communication with the public.

The experts described the challenges of a transition from an emergency exposure situation to an existing exposure situation and of remediation, and noted that being prepared to respond to an emergency does not imply being prepared for remediation activities. Clarity of roles and responsibilities during this transition is essential and was identified as a current weakness. There was considerable discussion about the need to facilitate the prompt return of affected areas to normal conditions.

In determining remediation end points, the experts highlighted the importance of involving all stakeholders in the decision making process.

The international standards established for managing existing exposure situations were discussed; it was proposed that they should be elaborated to address the various different existing exposure situations that can occur, for example, for remediation in the period after an emergency situation has been declared ended.

There was a general understanding that the numerical basis for standards is important for defining the appropriate level of dose for action.

The Japanese standards for remediation following the Fukushima Daiichi accident were presented. These standards follow the ICRP recommendations and guidance to determine the remediation strategy for contaminated areas. This led to the development of the following remediation policy for different affected areas where doses were likely to be less than 20 mSv/a, 20–50 mSv/a and greater than 50 mSv/a.

---

[20] Convention on Nuclear Safety, INFCIRC/449, IAEA, Vienna (1994); Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, INFCIRC/546, IAEA, Vienna (1997); Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency, INFCIRC/336, IAEA, Vienna (1986); Convention on Early Notification of a Nuclear Accident, INFCIRC/335, IAEA, Vienna (1986).

[21] The BSS (see footnote 5); JOINT FAO/WHO FOOD STANDARDS PROGRAMME, CODEX ALIMENTARIUS COMMISSION, Codex General Standard for Contaminants and Toxins in Foods, Schedule 1 — Radionuclides, CODEX STAN 193-1995, CAC, Rome (2006).

For those areas where doses are less than 20 mSv/a, the aim is to reduce radiation dose of resident adults and children by 50 and 60%, respectively, for two years from August 2011. This will be achieved through radioactive decay, natural attenuation and decontamination. The long term target is to achieve an additional annual exposure level of 1 mSv/a or less. For those areas where the dose ranges from 20 to 50 mSv/a, the aim is to reduce the dose in residential areas and farmland to less than 20 mSv/a as soon as possible. For those areas where the dose is likely to be greater than 50 mSv/a, demonstration projects will be implemented and the lessons learned will be reflected in future remediation policy.

There is a need for clarification and a better understanding of the different international standards for radioactivity in consumer products (food, drinking water and other commodities). Some confusion that exists among national authorities and the public and the relevant international organizations needs to be resolved.

3.3. CHARACTERIZATION AND MONITORING OF THE ENVIRONMENT

Lessons Learned: While public exposures from external radiation are well correlated with radionuclide deposition densities, exposures from inhalation and ingestion vary significantly with time and location, depending on environmental characteristics. For long term remediation, key environmental factors leading to variation in public exposure require characterization to develop an appropriate and responsive remediation strategy. Improved guidance is needed on characterization and monitoring which is specific to remediation for existing exposure situations.

One of the main objectives of environmental characterization and monitoring is to provide a careful evaluation of farming, food distribution and forestry/fishing systems in order to provide a sound assessment of public exposures. Monitoring also provides information on the efficiency of implementation of the adopted remediation strategies. Monitoring is essential because:

- There is often considerable environmental variation in radionuclide deposition densities and activity concentrations in environmental materials;
- It provides information on the effectiveness of remediation actions;
- It identifies constraints on possible remediation options;
- It provides reassurance for stakeholders and people living in contaminated areas that the remediation approach is effective.

The monitoring strategy needs to be regularly re-evaluated to ensure the ongoing protection of people with the highest exposures. The re-evaluation can also take account of changes in the environment and respond to changing social considerations.

Characterization and monitoring provide critical input into the development of appropriate remediation strategies for the recovery phase and to enable decisions to be made at local and regional levels. In existing situations, the radiation impact is mainly driven by a few, usually long lived, 'key' radionuclides. Decisions on the appropriate remediation strategies were dominated by, for example, the levels of: ^{90}Sr at Kyshtym (Russian Federation); ^{137}Cs at Chernobyl (Ukraine), Goiânia (Brazil) and Fukushima (Japan); and $^{239/240}$Pu at Palomares (Spain) and Maralinga (Australia).

Monitoring equipment, methodologies and logistics associated with the determination of radionuclide activity concentrations of both humans and environmental samples should be identified, provided and certified at the pre-implementation step of remediation. The provision of in situ monitoring equipment for foodstuffs and whole body measurements at local monitoring stations for communities in contaminated areas is highly desirable.

As soil and sediments are natural 'sinks' for some radionuclides, the activity concentrations of radionuclides in these environmental compartments are one of the most important criteria that need to be identified to guide the need for remediation. However, experience after the Chernobyl accident showed that it is essential to also characterize the contaminated area with regard to its environmental and agricultural conditions, and to predict radiation doses using site specific information, as areas leading to relatively high long term doses are not necessarily the ones which are most contaminated.

Experience after both the Chernobyl and Fukushima Daiichi accidents showed that certain foodstuffs were relatively highly contaminated, and that there was little or no previous knowledge of the importance of some of these products. It is, therefore, essential to measure radionuclide activity concentrations in all components of the food chain. For long lived radionuclides, the need to monitor some environmental compartments may persist over many years as was observed after the Kyshtym and Chernobyl accidents.

At the International Experts Meeting:

The experts discussed that decisions on environmental remediation of the inhabited and/or economically active area and optimization of the remediation programme should be preceded by site and exposure scenario characterization. The radiological characteristics of contaminated areas should be compared with the subsidiary reference levels to identify and prioritize the areas requiring remediation.

Environmental radiation conditions should be monitored at the planning and implementation stages, and following the completion of remediation. Monitoring and characterization should include:

- — Space and time resolution for measurements and sampling;
- — Ecosystem characterization (soil type, vegetation, etc.);
- — Soil monitoring (in situ measurements, depth distribution, etc.);
- — Atmospheric monitoring (air concentrations, aerosol size, etc.);
- — Water body monitoring (water, sediments, fish, etc.);
- — Agricultural foods and commodities (vegetable and animal);
- — Semi-natural foods (game, wild fungi and berries, etc.);
- — Supplementary information (demography, dwelling types, food rations, etc.);
- — Recording and reporting of monitoring data.

The monitoring scheme should be commensurate with the heterogeneity of the deposition of radionuclides in contaminated areas and the scale of local remediation actions.

After the Chernobyl accident, radiocaesium uptake from sandy and highly organic soil in some affected areas in both the former USSR and western European countries continued to be relatively high for decades, requiring continuing remediation and monitoring. In many areas contaminated by the Fukushima Daiichi accident, the radiocaesium remains in the upper soil layers and is relatively immobile, so there is currently a low transfer of radiocaesium to crops due to the prevailing soil types.

The application of geographical information systems linked with radioecological models to compile and analyse diverse radiological, environmental and social information is useful for guiding and evaluating remediation.

3.4. DOSE ASSESSMENT

Lessons Learned: Inadequate attention to temporal and spatial variation in the environmental behaviour of deposited radionuclides can lead to estimates of dose which are inaccurate and may overlook areas or pathways causing higher doses. There is a need to continuously improve dose assessment models using site specific information gathered during characterization and monitoring, and taking account of recent scientific progress.

Decisions on environmental remediation of currently or potentially inhabited and/or economically active areas with elevated radiation levels should be based on an assessment of the radiation doses for the people living in these areas. The assessment should be based on:

- Data from environmental monitoring of radionuclides from the site including whole body measurements;
- Characterization of the situation specific exposure scenario;
- The predicted annual effective dose of the representative person residing in the area of interest, if prescribed by the regulatory body.

Account needs to be taken of the inherent variability in the environmental pathways of radionuclides in contaminated ecosystems and the uncertainty of model predictions. There are numerous international, regional and national radioecological models that can be used for estimating spatial and temporal variation in both external and internal doses.

To account for the uncertainties arising from the variability of environmental conditions and living habits, models are often intentionally designed to provide conservative results. Such uncertainties can be reduced significantly if whole body measurements of residents in contaminated areas are adequately linked to the model predictions.

At the International Experts Meeting:

Environmental decision support systems developed in Belarus, the Russian Federation and Ukraine, as well as in western Europe after the Chernobyl accident, were presented. These systems combine assessment models with geographical information systems to manage and prioritize data and visualize the situation. They also allow variation in parameter values to be explored and uncertainty quantification to be undertaken. The aim of these systems is to estimate major human exposure pathways, taking into account spatial and temporal variation in aspects such as ecosystem characteristics, population lifestyle, age–gender and social structure, dwelling types and dietary habits. Dose assessments based on such tools provide essential input for enhancing the optimization of remediation.

3.5. EVALUATING MANAGEMENT OPTIONS FOR REMEDIATION

Lessons Learned: A large number of different available remediation options have been evaluated with respect to a wide variety of different technical, environmental and social factors. Currently, the information used to evaluate management options is largely based on experience from European conditions and societies, and needs to be reviewed to take into account the experience of remediation in Japan and elsewhere**.**

A wide range of management options for remediation have been developed, tested and implemented at legacy sites and in areas contaminated by nuclear accidents, notably in response to the Palomares, Kyshtym and Chernobyl accidents. These experiences have enabled the development of a wide range of technically effective remediation actions. The management options are largely, but not exclusively, designed to reduce the ingestion dose from the consumption of contaminated food and drinking water, the external dose from contaminated surfaces, and the inhalation dose from resuspended material.

A purely technical solution to remediation is generally inappropriate, since it fails to take into account the many other relevant issues which determine whether it is suitable, technically feasible, efficient and cost effective for the target area. Thus, a wider perspective has been adopted on the selection of suitable remedial actions for a contaminated area. Technical effectiveness in reducing doses is important, but it is only one of many criteria that need to be considered when identifying appropriate management options to use in a remediation strategy. Information on available management options has been compiled in data sheets and in many scientific publications and international recommendations, which enable users to critically evaluate whether they are suitable for areas requiring remediation. Many factors can influence the implementation, the impact and consequence of the use of various management options. These factors include the location and timing, effectiveness, technical feasibility, economic cost, legislation, waste disposal and environmental issues.

Management options used in a remediation strategy should contribute to a sustainable approach promoting agriculture and commerce, and also enable social and cultural activities to continue in the affected areas. Such positive social and economic outcomes can act as important additional benefits of remediation, in addition to dose reduction.

Decontamination by removal of radionuclides from surfaces and soil is an important part of remediation for areas affected by nuclear accidents. There is extensive experience of decontamination of radioactively contaminated legacy sites. Many of the techniques developed for these sites are directly applicable to nuclear accidents. While these techniques can be readily applied for small inhabited areas, their use for large areas of contaminated agricultural land raises significant challenges regarding waste disposal and the associated costs.

After the Kyshtym accident, top soil removal was largely conducted in inhabited areas, but was also carried out on the relatively small, highly contaminated parts of agricultural land within the Eastern Ural radioactive trace.

Many other remedial options were also used on agricultural land, largely to reduce radiostrontium transfer to crops and milk. After the Chernobyl accident, top soil was removed from inhabited areas but not from agricultural land because of the enormous logistical efforts and the waste disposal costs, and the many efficient remediation management options which were developed to reduce the radiocaesium activity concentrations in food from these areas. For instance, ploughing of soil was used extensively to submerge or dilute the contaminated top soil after the Kyshtym and Chernobyl accidents; modified fertilization of soil can significantly reduce uptake by crops.

After the Fukushima Daiichi accident, a key initial and ongoing focus of the remediation strategy in Japan has been a range of decontamination techniques, including high pressure water cleaning and top soil removal, to reduce external radiation doses. Top soil removal has focused largely on inhabited areas (including farmsteads) and some top soil removal has occurred on agricultural land. Different ploughing methods are being used increasingly with time to ensure minimal radiocaesium contamination of foodstuffs. Decontamination has been, and is being, conducted in urban areas and farmsteads in the 'intensive contamination survey' area. Soil removal is part of the designated special measures to ensure that the additional external dose does not exceed 1 mSv/a. The storage and disposal of waste generated through these activities is the key challenge associated with top soil removal in contaminated areas. In Japan, much of the removed top soil is being stored in temporary storage sites.

Top soil removal of agricultural land provides an example of how different features of a management option can be valued differently in different countries and for different accidents. Balancing the high logistical requirement and waste disposal costs against the achievable averted dose, the economic value of agricultural land, its availability and the strong attachment of the local communities to their land may lead to different results.

The compilations[22] on management options for remediation of contaminated environments are freely available and were used after the Fukushima Daiichi accident. These compilations are largely based on experience from Europe after the Chernobyl accident. Some of the relevant data sheets have been translated into Japanese and adapted for local conditions.

There are inevitable changes with time in infrastructure, the economic situation and cultural perspectives of society. This means that some remediation options and lessons learned from the recovery phase of accidents which occurred decades before may have less relevance in present day circumstances.

---

[22] EURANOS: European Approach to Nuclear and Radiological Emergency Management and Rehabilitation Strategies,
http://www.euranos.fzk.de/index.php?action=euranos&title=objectives

At the International Experts Meeting:

It was noted that experience with legacy sites has shown that it is best to utilize existing proven technology and commercial ‘off the shelf’ equipment wherever possible to facilitate the implementation of remediation and to reduce the associated costs and risks.

The importance of focusing on technologies, which often change over time, and the need to encourage innovation, was emphasized. For example, for the rural population around the Chernobyl nuclear power plant, radiocaesium contributed to the external and internal dose. Agricultural remedial options were the most efficient in reducing dose, averting 30–40% of the collective internal dose to the affected population. One of the most effective options was a drastic modification of agricultural practices of pasture land which involved deep ploughing, reseeding, drainage and fertilization to compensate for the low nutrient status of the land. Top soil removal was not a preferred long term remediation option for agricultural land.

Legislation was enacted in Japan in August 2011 and fully entered into force in January 2012 promoting decontamination which varies with dose rates. In the ‘special decontamination’ area, covering 11 municipalities in the (former) restricted zone and planned evacuation zone, decontamination is implemented by the national Government. In the intensive contamination survey area, 101 municipalities (as of January 2013)[23] were designated where the external dose rate is higher than 0.23 μSv/h in air (equivalent to over 1 mSv/a through external exposure pathways, assuming indoor and outdoor occupancy). Decontamination is being implemented by each municipality and supported financially and technically by the national Government. A roadmap has been produced to guide decontamination actions.

In pilot projects, technologies have been developed and tested for forests, farmland, buildings and roads in the restricted and planned evacuation areas in the Fukushima Prefecture. The majority of the effort involved manual washing and removal of contaminated material using conventional technology. Methods were also tested that might improve decontamination while decreasing waste volume.

There has been extensive testing of different decontamination methods in Japan and associated demonstration projects. These methods are being implemented in many municipalities. Experience gained from large scale decontamination will enhance currently available knowledge of the use of these techniques specifically for existing situations after accidents.

---

[23] At the time of publication of this report (September 2013), the number of designated municipalities was 100.

In Japan, an assessment of effectiveness, efficiency and cost has provided the basis for prioritization of decontamination techniques, including those which do not involve removal of top soil. Techniques using agricultural machinery have been adopted according to the specific contamination levels.

The ability to reduce dose rates varied in different areas around the Fukushima Daiichi nuclear power plant. Estimated annual dose could be reduced to less than 20 mSv/a for areas with 20–30 mSv/a but not for those exceeding 40 mSv/a before decontamination.

Interim storage facilities are being secured for soil and waste generated in the Fukushima Prefecture, with a target to commence operations in 2015. Final disposal of waste outside of the Fukushima Prefecture is planned to occur within 30 years. Several potential sites for the survey of the interim storage facilities have been identified.

3.6. DEVELOPING AND IMPLEMENTING REMEDIATION STRATEGIES

Lessons Learned: In response to the Chernobyl accident, international remediation guidance was produced on developing and implementing remediation strategies. The Fukushima Daiichi accident, for which such guidance was used, showed that suitable, generally applicable state of the art tools to facilitate decision making for remediation should be reviewed so that better accident specific remediation planning can be undertaken.

Remedial actions aiming at the reduction of exposures to the public are subject to the application of the three radiation protection principles: justification of practice, optimization of protection and limitation of individual doses for remediation workers. One challenge is, therefore, to identify features of different potential management options which allow a remediation strategy to be derived that complies with each of these three criteria.

A large number of management options (more than a hundred) are available which can be used in remediation. Decision makers need guidance on selecting appropriate options for remediation. The key factors which need to be considered include the deposited radionuclide(s) and levels of deposition, the ecosystems affected and how they are used, timescales for implementation, technical, environmental and social constraints, and acceptability.

The selection of management options used in a remediation strategy should be optimized in a manner which takes into account the particular circumstances of an accident. Recent experience has demonstrated that the choices of management options made in eastern and western Europe after the Chernobyl accident differed within and between countries. Moreover, some accidents are not purely radiological. They may be combined with the spread of hazardous chemicals, or, as in the case of the Fukushima Daiichi accident, the consequences of the devastation caused by the earthquake and tsunami.

In the past, decisions on which remediation options to use were largely based on a cost–benefit analysis. However, the focus has now moved to the multi-attribute analysis approach which provides a broader view, since factors such as the preferences of the inhabitants of affected areas are incorporated. The challenge is to reach a situation specific balance between different actions addressing various consequences in a holistic manner, to achieve acceptably low dose rates, optimal health and environmental protection while maintaining economic activity.

At the International Experts Meeting:

The discussions among experts highlighted the importance of forward planning at the start of the remediation process and the strengthening of relevant international guidance. It was also noted that current provisions concerning remediation in the BSS could be complemented with further guidelines. Information on remediation strategies in the IAEA's Technical Reports Series No. 475[24] was considered a good example. A systematic decision making process for remediation is needed, particularly due to the uncertainty of the roles of the main actors, including regulators.

Remediation should not be considered as decontamination only — the use of other methods could be more beneficial and relevant for protecting the food chain. Accidents are unique with their own set of characteristics. Each remediation strategy has to be adopted taking into account the radionuclides involved, the contamination levels, the affected ecosystems, cultural and social perspectives, and the value and availability of land.

Assessment tools to guide decision making on remediation have been developed and could find broader application. Further development of complementary tools was considered valuable and purposeful.

The experts identified the need to find the appropriate balance regarding the 'technical' and 'social' approaches for remediation measures, and recommended assessing the possibility to develop guidance for Member States on how to combine both approaches in an optimal manner. Lessons already learned from remediation activities applied following major accidents and on nuclear

[24] INTERNATIONAL ATOMIC ENERGY AGENCY, Guidelines for Remediation Strategies to Reduce the Radiological Consequences of Environmental Contamination, Technical Reports Series No. 475, IAEA, Vienna (2012).

legacy sites should be further scrutinized to develop standards of remediation preparedness and to identify key issues and best practices.

In addition to the direct radiological consequences, there have been many other impacts on both humans and the economy, which means that the remediation strategy needs to address a wide range of different issues. This is reflected in the priorities for revitalizing the Fukushima Prefecture which include living with peace of mind, working in people's hometown, rebuilding towns and re-connecting people.

Experience was presented from the CODIRPA[25] initiative to develop policy elements for post-accident management in the event of a nuclear accident and to identify the main protective actions for the post-accident phase.

The experts considered that improved guidance is needed on the practical aspects of decision making in remediation planning, such as how to decide whether it is better to leave contamination in place versus reducing radiation doses by removing soil, trees or draining lakes, and how to communicate with residents on when it is safe to return home.

4. STRENGTHENING CAPABILITIES FOR DECOMMISSIONING AND REMEDIATION AFTER A NUCLEAR ACCIDENT

4.1. NATIONAL RESPONSIBILITIES

Lessons Learned: All accident experiences have shown that it would have been beneficial to have prepared national plans for decommissioning and remediation in advance. Competent authorities should initially develop generic decommissioning and remediation plans that should be readily adaptable to specific situations.

The post-accident phase of a nuclear accident involves the interaction of numerous national organizations with the on-site and off-site services, with local and central authorities both playing a major role. Analysis and discussion of past events have revealed that the division of responsibilities between different parties and the framework for cooperation is often unclear, to the potential detriment

[25] FRENCH NUCLEAR SAFETY AUTHORITY, Policy Elements for Post-accident Management in the Event of Nuclear Accident: Steering Committee for the Management of the Post-accident Phase of a Nuclear Accident (CODIRPA), 5 October 2012.

of the efficiency and effectiveness of actions taken in all phases. Even small uncertainties or discrepancies between the roles and responsibilities among the different parties may lead to decisions that are not well considered, taken too late and, in the worst case, are counterproductive to the achievement of protection goals.

Under normal conditions, these interactions are exercised — but rarely at the scale required to administer very large and catastrophic accidents, or the combined effects of a nuclear accident with a large scale natural event such as the devastating earthquake and tsunami in Japan in 2011. Governments have the responsibility for establishing the necessary arrangements to enable the transition from accident response to the long term recovery phase.

National frameworks, generic protocols or implementation plans for remediation, waste management and decommissioning should be developed. Such frameworks should be designed to ensure the return of the affected areas effectively and efficiently. They need to consider technical planning and financial resources, decision making and optimization strategies, stakeholder input, and the availability and accessibility of physical and human resources.

At the International Experts Meeting:

The experts discussed national responsibilities in the context of decommissioning and remediation following a nuclear accident, and of legacy sites. In several presentations and in the subsequent discussions, the need for national authorities to develop a preliminary plan and arrangements for decommissioning and remediation in advance of an accident was stressed, while recognizing that each accident is unique and that plans cannot, therefore, be very detailed.

There is a need for decommissioning and radioactive waste management strategies to be integrated into such plans. The accurate estimation of future waste generation is important for long term planning, and the national waste management strategy may need to be adapted or modified in order to accommodate alternative strategies for managing large volumes of materials resulting from decommissioning and remediation.

Throughout all phases, close communication between the teams responsible for decommissioning and radioactive waste management is essential. The importance of forward planning was highlighted, and many experts indicated that international guidance should be strengthened in this regard.

Preparedness for emergencies does not mean adequate preparedness for remediation activities. The decision making process during the transition from accident management to remediation appears to be a weak link, particularly due to the uncertainty of the roles of the main actors, including regulatory authorities.

In some cases, this process may require that national authorities be prepared to make organizational and structural adaptations according to the circumstances.

Following the Kyshtym accident in 1957, the Mayak Production Association enterprise established an emergency centre to deal with the accident's consequences. The emergency centre consisted of senior management and experts representing the Mayak Production Association and the Ministry of Machinery Engineering. The development of radiation and sanitary standards, as well as monitoring of public health was carried out by the USSR Ministry of Health, with the engagement of local sanitation and medical establishments.

In 1989, the US Department of Energy established the Office of Environmental Management to solve technically challenging risks posed by the decommissioning and remediation of large nuclear legacy sites. The regulators involved in the Office of Environmental Management's programme are the US Environmental Protection Agency, the Department of Transportation and the state environmental and health regulatory agencies.

To cope with radioactive contamination after the Fukushima Daiichi accident, the Government of Japan enacted special legislation in August 2011, which came fully into force in January 2012. Based on this legislation, the Japanese national Government, namely the Ministry of the Environment, directly deals with decontamination within the special decontamination area. Within the intensive contamination survey area, decontamination has been, and will be, conducted by municipal governments, with expenses covered through subsidies from the national Government. The national Government provides financial and technical support. Aiming at smooth and effective implementation of decontamination work, the Fukushima Office for Environmental Restoration was opened in the City of Fukushima in January 2012.

The Government of Japan and the TEPCO Council on Mid-to-Long-Term Response for Decommissioning, which is addressing on-site decommissioning, developed and issued the Fukushima Daiichi Decommissioning Roadmap on 21 December 2011. This Roadmap was subsequently revised and reissued on 30 July 2012 and again in June 2013.

4.2. REGULATORY CONSIDERATIONS FOR POST-ACCIDENT SITUATIONS

Lessons Learned: The national regulatory system should take into account, as much as possible, all circumstances which may arise during the post-accident phase to provide for effective decision making. In the event of an accident, an adaptive, risk-informed approach could also be applied in conjunction with other methodologies for more effective regulatory decision making.

In the event of an accident, most Member States are not well prepared for the remediation, decommissioning and radioactive waste management challenges that may arise. This applies equally well to regulatory authorities as to those tasked with the implementation of long term recovery measures. Each accident will present a unique set of challenges. The multiple regulatory authorities that are drawn into recovery-related activities would, under normal circumstances, not be engaged to the extent that accident recovery requires. The degree of communication, coordination and cooperation required among a broad spectrum of authorities needs to be emphasized.

Unless there has been a specific need in the past, most regulatory authorities are not prepared for the complexities of remediation and decommissioning of accident-damaged facilities. In fact, remediation may not be within the regulatory framework of many Member States. Issues that present special regulatory challenges are those such as site characterization, clearance of materials containing radionuclides, providing guidance for the development of remediation plans and long term institutional control of sites that remain under regulatory control.

At the International Experts Meeting:

There was discussion that regulatory authorities should be prepared to adapt to potential post-accident situations in the way they interpret regulations and by being proactive with regard to situation specific problems. It was suggested that regulators be prepared to not only advise, but also to challenge government decision making if necessary. The regulator’s role in decision making for decommissioning and remediation is critical. Regulatory authorities will be called upon to advise governments on complex policy issues, such as responsibilities for funding of remediation, stakeholder involvement and long term institutional controls. It was recognized that regulatory authorities have a key influence on the implementation of these activities.

In taking decisions or advising on them, authorities need to be transparent and consider the broader societal balance of risks and benefits of a course of action, including the imposition of burdens on future generations. The strict interpretation of regulatory standards was discussed and it was considered that, in some instances, a more flexible approach could be used by the regulator, while still ensuring safety and that erring too much on the side of caution may not always be conducive to optimization of radiation protection.

It was recognized that existing national regulatory standards and criteria may not be adequate to deal with new situations and that new legislation may need to be enacted to help with recovery. In the case of Chernobyl, it was found that existing legislation was inadequate to deal with the waste arising from the accident, which, in turn, hampered the development of solutions for managing large quantities of lower activity wastes. For example, waste classifications existing prior to the accident did not have sufficient scope to encompass the diversity of radioactive wastes that arose after the accident.

The Chernobyl and Fukushima Daiichi accidents revealed regulatory inconsistencies when trying to deal with waste of a similar activity and nature which arose off-site and on-site. Disposition was hampered because regulations for waste classification required the wastes to be dealt with differently. A more adaptive approach to the interpretation of the regulations would allow safe and more cost effective approaches to be implemented.

The determination of disposal routes for radioactive wastes arising from accidents can be a challenge because their characteristics are different from those of conventional waste, and criteria for acceptance of accident-derived wastes at existing disposal facilities are not something that would have been foreseen. It was suggested that regulatory review of safety cases developed specifically for such waste streams would help to achieve safe and cost effective disposal solutions.

Decommissioning of accident-damaged facilities is, from all perspectives, a very complex undertaking. It was suggested that identification and promotion of good practices for decommissioning of such challenging facilities should be on the international agenda.

It was noted that after resettlement of evacuated areas, the public has a role in the implementation of optimization measures for radiation protection. Such optimization measures can be facilitated by regulatory authorities, for example, by setting up local forums to provide information and training. Regulatory authorities will also have an important role in long term radiation monitoring. Regulatory preparedness for long term recovery was identified as an area for strengthening in several presentations at the IEM.

Legacy sites are sites that typically suffer from deteriorated engineered structures, an operational history that was poorly documented, had poor regulatory supervision in the past and a shortage of funds to carry out remedial actions. Hence, from a technical point of view, there are appreciable parallels with post-accident situations. Experience with regulation of legacy sites that have radiological contamination, such as complex R&D sites and legacy uranium production sites, offers knowledge that is transferrable to post-accident situations. In the long term, accident sites become managed and regulated much as a legacy site would.

4.3. NATIONAL WASTE MANAGEMENT STRATEGY

Lessons learned: The existing long term radioactive waste management policy and strategy may be severely challenged in the event of an accident. Measures should be taken to consider how these challenges can be met through pre-planning, taking account of sustainability principles and the experience of previous accidents and comparable legacy situations.

It was emphasized that all Member States having a nuclear programme or having to deal with radioactive waste should establish a policy and strategy for radioactive waste management. A well defined governmental, legal and regulatory framework, with clear allocation of responsibilities and appropriate human and financial resources, is a prerequisite for implementation of a comprehensive radioactive waste management strategy. A comprehensive radioactive waste management strategy will cover characterization, segregation, treatment, conditioning, storage and disposal of radioactive waste.

A nuclear accident can affect many, if not all, aspects of the radioactive waste management strategy that was established prior to an accident. The volume of lower activity wastes to be managed may increase by several orders of magnitude, depending on the decommissioning and remediation strategies adopted. Higher activity wastes may be generated by damaged fuel, fuel element debris and liquid waste arisings that are highly contaminated. These present special challenges for the radioactive waste management strategy.

Existing storage and disposal capacity will likely be insufficient to accommodate the larger volumes of radioactive waste generated by an accident. Storage and disposal capacity will be created either by the development of new facilities or by the expansion of existing or planned facilities. This, in turn, implies additional activities for site selection, site characterization, facility design, regulatory approvals and construction. Alternatively, end state options for some damaged nuclear facilities may need to be re-evaluated and modified, taking into consideration options such as in situ decommissioning and in situ remediation.

Advance consideration should be given to what might be done with regard to the radioactive waste policy and strategy in the event of an accident. It was noted that this should, at least, include the following:

— The adequacy of existing waste management strategies to deal with post-accident situations.
— The identification of potential sites for the disposal of large quantities of very low level waste and low level waste.

— The development of sustainable, integrated waste management strategies taking a holistic view of the disposition of waste arisings both on-site and off-site, and taking account of the interdependencies between all waste management steps including reuse and recycling.
— The development of 'generic' designs and 'generic' safety cases for the different types of facility (e.g. storage, disposal) that might be needed in the case of an accident for dealing with damaged fuel and other waste forms which might arise. This would accelerate the final design, construction and licensing of facilities for safe management of radioactive waste in the event of an accident.

At the International Experts Meeting:

While the IEM had a specific session dealing with the management of radioactive waste and damaged fuel, waste management strategy was also touched upon in other sessions.

Discussions highlighted the importance of planning for waste disposition if an accident were to occur. Advance planning provides time for a more thorough and careful consideration of issues that might arise. Furthermore, advance planning for what might be called a 'national post-accident management and recovery plan' should cover both what should be done and what should not be done. Such plans would not necessarily fit an actual post-accident situation, but would be a useful starting point. Understanding what might happen and planning for this eventuality may help alleviate some of the problems encountered in previous accidents.

In response to the Chernobyl and Fukushima Daiichi accidents, the national Governments took ultimate responsibility for establishing long term decommissioning and waste management strategies. The involvement of the local governments of the affected communities, the public and the regulatory authorities was also highlighted. In some Member States, plans have been drawn up to consider long term governance of radioactive waste based on the participation of the affected communities and development of sustainable waste management solutions. Caution should be exercised in the early days of recovery planning, so as not to rule out options that might be viable later.

The principle of 'beginning with the end in mind' was highlighted in the cases of the TMI, Chernobyl and Fukushima Daiichi accidents. In terms of immediate treatment of waste, a number of presentations noted the importance of having final disposal in mind when choosing among waste forms. At the Fukushima Daiichi site, reuse and recycling of materials is being considered as a means to implement waste minimization.

Examples were given of the significant problems of dealing with damaged fuel from the accidents at Windscale, Chernobyl, Fukushima and TMI. These situations pose long term management challenges that even in the case of Windscale, which happened over 50 years ago, have not yet been resolved. The chemical and physical complexities of both lower and higher activity waste forms are such that it is important to ensure that they are in passively safe forms acceptable for both storage and disposal.

The need for an integrated approach to waste management was emphasized by several speakers. In the case of the Fukushima Daiichi accident, identifying specific waste management strategies and having effective communication between teams in charge of different steps of radioactive waste management was seen as a key issue. Such communication helps to ensure the proper consideration of interdependencies and to facilitate the management of any secondary waste that might arise. Estimates of radioactive waste inventories should be established as early as possible to assist with the development of radioactive waste management strategies.

Following the Fukushima Daiichi accident, guidelines were produced for waste management and remediation which take account of long term requirements. In considering the availability of existing disposal routes, or utilizing existing facilities, it should be recognized that waste arisings from accidents may also contain non-radiological contaminants, such as heavy metals and toxic organics, in greater amounts than under normal situations.

The very large quantities of lower activity wastes resulting from accidents were also an issue of discussion at the IEM. Remediation may help return affected areas to normal conditions, or as near normal as possible, but new challenges will arise due to the large volumes of waste arising from remedial activites. The generation of large volumes of lower activity wastes from remediation has been a specific feature of the Chernobyl and Fukushima Daiichi accidents, as well as legacy site programmes. Each situation has required the development of new sites for storage and disposal of waste. In the case of Chernobyl, some of these sites are now considered unsuitable for disposal and new disposal solutions have to be found. In siting of new facilities to accommodate large volumes of waste, it was suggested that measures should be taken to avoid the creation of too many waste storage and disposal sites.

The financial implications of unplanned termination of a facility due to an accident are that previous cost estimates may no longer be valid to ensure the availability of decommissioning funding. Sources of decommissioning funds remain an unsolved issue in several countries. While financial challenges should not compromise public and worker safety, unnecessary expensive solutions should be avoided. Several examples were given where, with stakeholder agreement, in situ decommissioning (entombment) and on-site disposal had taken place, which demonstrated significant cost savings. It was suggested that case studies should be developed for accident or legacy situations to apply cost–benefit analysis and to compare alternative solutions.

IAEA staff informed the IEM participants that some of the issues highlighted above were already under consideration; in particular, a publication is being developed which will address waste management strategies and the development of generic safety cases for the disposal of large amounts of low activity waste.

4.4. STAKEHOLDER INVOLVEMENT

Lessons Learned: Stakeholder participation is essential throughout recovery for ensuring the sustainability of decisions, including the selection of decommissioning end states, waste disposal site selection, remediation targets and objectives, and implementation of remedial actions. Experience from past accidents and legacy situations has shown that decisions taken and solutions derived with stakeholder involvement are the ones most likely to succeed.

The role of stakeholders in the approval and successful implementation of projects that affect the community was discussed and widely acknowledged. Successful stakeholder involvement requires the identification of roles, transparency between parties, and the development of trust and respect, all in the interest of achieving the best outcome from a particular project. This is true in the case of recovery operations following a nuclear accident and at a legacy site.

The successful implementation of decommissioning and remediation activities requires the involvement of the affected parties in the community. The circumstances following a nuclear accident cause confusion and anxiety in the population, and the actions necessary to achieve recovery may be met with resistance from those affected. It is only by having the trust of the public that progress can be made. The importance of trust for a constructive stakeholder interaction cannot be overestimated and should be established through interactions between operators and stakeholders during routine meetings in the operational phase of the facility.

The siting process for new facilities for managing accident wastes, for example, would require stakeholder engagement and acceptance, noting that some of the new sites may be outside of the affected area or local government boundary. Such stakeholder involvement in decision making also applies to the determination of decommissioning strategies and end states for affected/damaged facilities. In these contexts, stakeholder interaction featured throughout the sessions. It was acknowledged that stakeholders were in it ‘for the long haul’, over decades and possibly much longer.

Stakeholder involvement is, therefore, essential at the early stage of the planning and during the implementation, with the aim of succeeding by establishing and maintaining trust. Stakeholder communication plans should be established at national, regional and local levels, especially concerning the return to ‘normal’ and ‘safe’ conditions. In the event of an accident, having had good relations with stakeholders prior to the accident is certain to be beneficial. During the emergency response, there is little time for interaction with stakeholders; however, in the transition to an existing exposure situation and later, when decommissioning and remediation are being planned and implemented, interaction with stakeholders becomes essential. Success will be limited, or projects will be seriously delayed, discontinued or undergo unnecessary reorientation if the stakeholder interaction is not carried out properly.

Engagement with stakeholders in decommissioning and remediation projects may have to continue for extended periods of time. Stakeholder interaction is not a substitute for the need for the decision maker, such as the national government, local municipalities or the nuclear power plant operators, to take responsible actions when necessary. Thus, the roles of different parties involved in a stakeholder interaction need to be clearly defined.

At the International Experts Meeting:

A number of examples of remediation projects were discussed at the IEM in which the successful outcome had been supported by a constructive stakeholder interaction. Such examples provide valuable experience to be implemented in future projects.

The role of stakeholders was recognized as being important for recovery planning and implementation, but it was noted that there is a danger in placing too much reliance on the stakeholder interaction process. Therefore, the primary role of the scientific community and the regulatory authorities in setting standards must be retained.

The experts addressed the problem of obtaining the trust of stakeholders. The trust which is necessary in the aftermath of an accident must have been obtained before the accident occurred by regular and continuous interactions between operators, the authorities and stakeholders.

Experience with past accidents indicates that when it comes to the potential harm from radiation, the public wants to be confident that they understand ‘how safe is safe’. The experts discussed the problems inherent in reaching a definition of what would constitute ‘safe’ in a radiation protection context. However, in view of the perceived importance of the subject in accident situations, the international organizations were urged to try to develop such a definition as an aid for communicating with the public.

The meaning of ‘normal’ living conditions or ‘normality’ or ‘a liveable environment’ after an accident was also discussed. These are important issues for the public and warrant further consideration by relevant expert groups.

The concept of ‘sustainable decisions’ was also discussed and it was explained that cleanup actions can take years, even generations, to complete and will be very costly. Consequently, there is a need for society to understand and accept the long term commitment to pursue difficult, expensive work.

4.5. KNOWLEDGE MANAGEMENT

Lessons Learned: The completion of decommissioning and remediation after an accident can take decades. Experience has shown that knowledge gained from post-accident remediation and decommissioning, and legacy site management should be recorded, catalogued, easily retrievable, and made available to an international audience. An international coordinated approach is needed to protect against loss of knowledge over long periods and to ensure that the information, knowledge and lessons learned can be readily accessed and applied to future events.

A large body of knowledge exists concerning nuclear accidents, recovery from accidents, legacy sites, and decommissioning and remediation of accident and legacy sites. Although previous experience and lessons learned have been presented in many scientific and technical venues, the information is not catalogued in a way that enables easy access. It is necessary to extract the value from a large volume of data and information. To profit from this body of knowledge, it must be shared and must serve as a foundation for collaboration.

The knowledge and information must also be available for periods of decades or more. None of the facilities at which the three major nuclear accidents with fuel damage took place that preceded the Fukushima Daiichi accident, Windscale Pile 1 (United Kingdom), TMI Unit 2 (USA) and Chernobyl Unit 4 (Ukraine), have entered into final decommissioning. Recovery actions from the Chernobyl accident of 1986 are ongoing, and the present version of the Fukushima Daiichi Decommissioning Roadmap anticipates a 30–40 year decommissioning period. The potential for loss of information and human expertise would further add to the cost of decommissioning.

At present, experience with evaluating and applying various remediation actions is largely confined to countries that have utilized them for a limited range of existing conditions such as legacy sites or nuclear accident response. Suitable mechanisms are needed to effectively distribute remediation knowledge and experience more widely, and to facilitate assistance when and where it is needed.

At the International Experts Meeting:

The following points were highlighted:

- The technical support needed in the remediation phases differs from that in the emergency phase and currently it is a challenge to source such expertise and experience.
- A clearing house for recognized experts and for prequalified firms in the area of remediation would be useful.
- Worker involvement in all phases of planning and implementing a remediation strategy can help ensure success. Workers have a unique perspective on remediation and are a good source of ideas for solutions to problems. They can also provide a key interface with local communities and residents, and help to communicate the nature of the problem.

Experts from around the world presented lessons learned, technical challenges and successes, and experiences in responding to accident and legacy situations. It was discussed that efforts to encourage programmes for sharing information are important for ensuring accessibility and transparency to the public and interested stakeholders. Access to such a programme for sharing knowledge is also important for newcomer countries, taking into account cultural differences.

The experts also noted that while nuclear decommissioning is becoming a mature activity, it is not yet undertaken on a wide scale. Thus far, decommissioning projects have been facility specific or site specific. Furthermore, decommissioning and remediation are commercially oriented, and this may inhibit the sharing of technical knowledge and experience. Thus, international cooperation on different aspects of decommissioning and remediation of nuclear accident and legacy sites should continue and should be strengthened. The experts identified the need for greater international cooperation through the sharing of technical resources including knowledge and people.

There were also discussions concerning how information on available remediation methodologies and techniques could be compiled to facilitate their implementation globally. Ready access to such information would be especially useful for countries not having a sufficient infrastructure to support the necessary technology, but where the legitimate use of radiation may have caused legacies that might need to be addressed and remediated.

The need to archive information collected during and after an accident was also discussed as an essential action. Access to such an archive is important for learning, training purposes and for public information purposes.

Long term preservation of information and knowledge is essential because it documents, for future generations, the basis for end state decisions, the final conditions at the site and the need for appropriate long term stewardship actions.

Knowledge management systems in various countries for capturing 'lessons learned' were discussed; however, the experts noted that such systems needed to be visible and linked in some manner, so as to be available to the international community. Even within a country, in a number of cases, systems are not adequately or at all linked.

The IAEA Report on Reactor and Spent Fuel Safety in the Light of the Accident at the Fukushima Daiichi Nuclear Power Plant, from the IEM of 19–22 March 2012, identified a lesson learned concerning the need for an international coordinated approach to "efficiently manage and perform the R&D required to implement measures to improve safety and severe accident knowledge, and to obtain and disseminate data and information from the Fukushima Daiichi accident". This highlights the general need for knowledge management across other related disciplines.

4.6. CAPACITY BUILDING

Lessons Learned: Nuclear accident and legacy facility recovery actions are long and costly efforts. There is a need to mobilize sufficient and competent personnel globally, along with complementary resources, for extended periods of time. Capacity to effectively meet these needs must be developed and maintained.

The IAEA defines capacity building as a systematic and integrated approach that includes education and training, human resource development, knowledge management and knowledge networks to develop and continuously improve the governmental, organizational and individual competencies and capabilities necessary for achieving a safe, secure and sustainable nuclear power programme.

At the International Experts Meeting:

Member States that are dealing with accident recovery and legacy situations highlighted the need for ongoing capacity building. Some recovery projects have been ongoing since the 1950s. Maintaining a stable and skilled workforce was highlighted as a particular challenge, especially for 'disembarking' countries.

Experts noted that expertise is lost when projects are stopped and restarted, adding to the time and cost to eventually complete a project.

The need for sustained capacity building was emphasized in the presentations, in particular the need to increase staffing throughout the system in response to an accident.

5. CONCLUSIONS

This report of the IEM on Decommissioning and Remediation after a Nuclear Accident summarizes key lessons learned in the area of decommissioning, remediation and waste management following an accident and from legacy situations. These lessons learned, drawn from international experience, incorporate the evolving understanding of the Fukushima Daiichi accident. They take into consideration insights gained from the IEM and some additional sources of information.

While there have fortunately been few accidents, their consequences demand that forethought be given to how the impacts of a potential accident may be dealt with. Throughout the IEM, the need to develop a strategy in advance to support the recovery phase of a potential accident was recognized as crucial. Competent authorities should develop decommissioning, remediation and waste management plans to elaborate such a strategy. In doing so, it should be recognized that the planning cannot be prescriptive and should be readily adaptable. In several countries, preparedness for long term recovery is not sufficient; in some, it is non-existent.

To be effective, this advance planning (i.e. preparedness for long term recovery) should include an appropriate level of stakeholder participation. Residents of potentially impacted areas and other stakeholders should have the opportunity to provide their input to the advance planning process. Early involvement of stakeholders will help develop trust among competent authorities, operators and interested parties. In the case of the potentially affected public, this will also provide an opportunity for them to develop an understanding of radiological concepts and the question of ‘what is safe’. This process could be supported through international cooperation, for example, by creating a group modelled along the lines of the OECD/NEA Forum on Stakeholder Confidence[26].

[26] http://www.oecd-nea.org/fsc/

A severe accident will challenge even well established national waste management programmes and plans. Preparedness for long term recovery provides an opportunity to consider a full range of potential decommissioning end states, waste management and remediation options. This planning should take account of sustainability principles, the balance of risks and benefits, and experience from previous accidents.

When accident events directly affect the public, decisions on remediation approaches need to be made with the involvement of those most impacted. Similarly, the involvement of the accident site workforce and local community representatives in developing recovery approaches has been shown to be beneficial. The process of planning, which involves both stakeholders and experts for decommissioning, remediation and radioactive waste management, has the benefit of developing relationships and an understanding of the complexities of recovery following an accident. Discussion, analysis and relationship building during planning are important and will help to clarify roles and responsibilities among the parties.

During post-accident recovery, decisions have to be made based on available but often incomplete information. The key issue is to obtain sufficient, relevant and reliable data with which to make those decisions. Thus, appropriate characterization and monitoring programmes are needed.

Remediation decisions will be made taking account of a range of radiological safety considerations, environmental factors, and societal and cultural norms and expectations. This emphasizes the need to ensure that a full range of remediation options is considered, as well as an understanding that the same solution may not be applicable to all circumstances.

Experience shows that actions to recover from an accident, as well as legacy situations, will take decades to complete. Once an accident occurs, international and national mobilization of personnel and equipment will be needed for an extended duration. Training and knowledge transfer will be part of the process. Sustaining this effort for decades is challenging.

The regulatory regime must be prepared to be adaptable and to include a risk-informed approach in decision making. The broader societal benefits and ability to apply a specific course of action may, in some instances, take precedence over strict application of numerical standards or criteria.

An international coordinated approach is needed to ensure that the information, knowledge and lessons learned from post-accident recovery, and also management of legacy sites, can be readily accessed and applied to future events.

The IEM addressed activities that, in many cases, have not yet begun (e.g. reactor dismantling) or are still ongoing (e.g. off-site remediation). There is still much to be learned and shared. Based on experience from previous accidents, the development of a full set of lessons learned from the various aspects of recovery will take several decades. The participants at the meeting agreed that the IAEA should consider reconvening a similar IEM in around two years and that information collected should be periodically evaluated for incorporation into the IAEA's safety standards and technical reports.

Annex A

CHAIRPERSON’S SUMMARY[1]

International Experts Meeting on Decommissioning and Remediation after a Nuclear Accident
28 January–1 February 2013, Vienna

BACKGROUND

History has clearly demonstrated, and it has repeated itself in the events and aftermath of March 2011, that a major nuclear accident, just as any other major accident, not only affects public health and the environment, but, in addition, causes a wide range of direct and indirect effects. These include evacuation and relocation; social unrest; indirect health effects related to anxiety, radiological stigma and symptoms of a post-traumatic nature; as well as effects on property, the economy, public policy and politics. All of these factors influence the setting of targets for decommissioning and remediation; this is often an iterative process involving consideration of the legal framework, finances, processes, methodology and technology. Importantly, decommissioning and remediation are carried out in close interaction with stakeholders, with the public (affected by both the accident and the recovery from its consequences) playing an important part.

Today, we have substantial knowledge about the impact of major nuclear accidents as well as a wealth of experience — good and sometimes less so — from a range of decommissioning and remediation projects following nuclear accidents. There are also a number of lessons to be learned from decommissioning and remediation of other legacy sites that did not originate from nuclear accidents but where the problems encountered are of a similar nature. Experiences have been discussed, over the years, in many forums, including a number of IAEA initiatives and UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) reviews of scientific information on health and environmental effects of accidents and legacy sites of a comparable nature.

It is timely to discuss this knowledge in relation to the Fukushima Daiichi accident, to provide guidance to future actions aimed at strengthening our

[1] The opinions expressed in this Summary — and any recommendations made — are those of the Chairperson and do not necessarily represent the views of the IAEA, its Member States or other cooperating organizations.

understanding of the exposure situation, and our ability to successfully carry out decommissioning of facilities and environmental remediation after a nuclear accident.

THIS INTERNATIONAL EXPERTS MEETING

This is the fourth in a series of International Experts Meetings (IEMs) organized under the IAEA Action Plan on Nuclear Safety. The preceding three meetings dealt with the subjects of reactor and spent fuel safety; enhancing transparency and communication effectiveness; and protection against extreme earthquakes and tsunamis, all of them in the light of, and building on the experience from, the accident at the Fukushima Daiichi nuclear power plant. This week, approximately 200 experts from close to 40 countries plus several international organizations, had the opportunity to discuss a variety of issues related to decommissioning and remediation after a nuclear accident, again taking stock of experiences from the accident at the Fukushima Daiichi nuclear power plant.

The IEM responds directly to the IAEA Action Plan on Nuclear Safety, which, under the umbrella of "protection of people and the environment from ionizing radiation", calls for actions to "ensure the on-going protection of people and the environment from ionizing radiation following a nuclear emergency." For further actions relevant to this and other action items, please consult the Action Plan Dashboard available on the IAEA's web site. The meeting held eight separate sessions, covering the following subject matter:

- Decommissioning, environmental remediation and associated waste management challenges resulting from nuclear and radiological accidents;
- Review of experience and strategic lessons learned from past accidents and legacy situations;
- Challenges in decommissioning and remediation;
- Management of radioactive waste and damaged fuel;
- Decommissioning standards and technologies;
- Improving national and international cooperation for managing the post-accident phase of nuclear and radiological accidents.

As for previous IEMs, the IAEA will publish a report with presentational material on an accompanying CD-ROM. The report will incorporate the session chairs' review of the discussions of the different topics. In this Chairperson's Summary, I make some general observations and remarks in relation to cross-cutting issues and suggest how they can be captured in recommendations for future work. This Summary will also form part of the final report.

THE CRUCIAL ROLE OF PLANNING FOR POST-ACCIDENT SITUATIONS

Planning of any activity requires the consideration of potential accidents; the activities should be planned so that such accidents do not occur, and if they occur, planning should aim at containment of radioactivity and for mitigating the consequences should any radioactivity be released in any form. This is recognized in the IAEA's Fundamental Safety Principles[2] in which Principle 8 states that "[a]ll practical efforts must be made to prevent and mitigate nuclear or radiation accidents."

Radiation protection considers three exposure situations, namely 'planned exposure situations', 'emergency exposure situations' and 'existing exposure situations', as laid out in the 2007 Recommendations of the International Commission on Radiological Protection[3] and the IAEA's Basic Safety Standards[4] (BSS). One of the main purposes of planning is to prevent the exposure situation from turning into an emergency exposure situation and/or an existing exposure situation. Nevertheless, such transitions occur. Accidents happen and are mostly related to human factors such as incomplete information or knowledge, difficulties in interpreting information, lack of implementation of procedures, negligence or deliberate override of operational limits. Additionally, operations may be carried out, or may have been carried out, with limited prior consideration of future needs for decommissioning and remediation, or within accepted safety limits but still resulting in on-site and/or off-site contamination that needs to be addressed in decommissioning and environmental remediation.

There is no reason to believe that accidents will not happen in the future, leading to future actions related to recovery activities such as decommissioning and remediation. Before an accident, planning should identify and establish appropriate procedures to handle acute consequences and bring the situations under control in a manner that reduces, to the extent practicable and possible,

---

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Fundamental Safety Principles, IAEA Safety Standards Series No. SF-1, IAEA, Vienna (2006).

[3] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, The 2007 Recommendations of the International Commission on Radiological Protection, Publication 103, Elsevier (2007).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards — Interim Edition, IAEA Safety Standards Series No. GSR Part 3 (Interim), IAEA, Vienna (2011).

the long term consequences that will turn into legacy. If such a legacy occurs, or already exists, a system to deal with it, which includes decommissioning and remediation, must be available.

The discussions held at the IEM highlighted the importance of forward planning and that international guidance can be strengthened in this regard. The meeting discussed the feasibility of generic ‘protocols’ that would guide post-accident recovery work. Particularly, with regard to remediation, a recommendation can be formulated as follows: *The IAEA should strengthen its programme on remediation after a nuclear accident to assist Member States to facilitate the return of affected areas to normal conditions.*

The definition of what is ‘normal’ may vary and requires due consideration of a number of factors, which include, but are not limited to:

- Division of responsibilities, including the role of government, the regulatory framework and financial provisions;
- Approaches to involving stakeholders;
- Approaches to defining targets and end states;
- Methods and technology;
- Development of a generic fuel and waste management programme, including classification of waste, predisposal management and conditioning, storage and disposal.

These factors are briefly discussed below.

Division of responsibilities — a national framework

The acute phase of a nuclear accident involves the interaction of numerous organizations with the on-site and off-site rescue service, local and central authorities playing a major role. Normally, this interaction is frequently exercised — but rarely at the scale required to administer very large and catastrophic accidents, or the combined effects of a nuclear accident with a large scale natural event such as the Great East-Japan Earthquake and Tsunami in 2011. This may potentially lead to actions that inadvertently cause future problems in the recovery phase, e.g. for decommissioning and remediation. There may be a need to look into specific aspects of the acute management of large scale accidents from this perspective; however, this was not strictly within the scope of this IEM.

However, analysis and discussion of past events have revealed that, also in the recovery phase, the division of responsibilities between different parties, and the framework for operation, has been unclear, to the detriment of the efficiency and effectiveness of actions taken in the recovery phase. Even small shortcomings may lead to insufficiently informed decisions, taken too late and, in the worst case (although in reality probably rarely), counterproductive to the achievement of protection goals. It is, therefore, essential that there are not any ambiguities in the division of responsibilities between the parties engaged in the recovery.

For the really large accident with major and long term consequences, the government has a central responsibility; the necessary actions may be beyond the resources (financial and others) of the operators or any other organization, irrespective of financial arrangements such as insurances. IAEA Safety Standards Series publications, e.g. Governmental, Legal and Regulatory Framework for Safety[5], provide an outline of an overarching structure.

Interaction with stakeholders

The role of stakeholder interaction that is built on identification of roles, transparency, trust and respect, and that supports the achievement of the best outcome under the existing circumstances, is widely acknowledged; however, it should also be recognized that stakeholder interaction is not a substitute for the need for decision makers to take responsible actions when necessary, either this is government, local municipalities, operators or any other body with such responsibilities. Thus, the roles of different parties involved in a stakeholder interaction need to be clearly defined.

The importance of trust for a constructive stakeholder interaction cannot be overestimated. Trust will not be achieved if potential events (such as accidents) have not been identified and clearly communicated in the planning phase — and it subsequently turns out that such an event takes place.

Other issues are:

— Timing of interaction: Stakeholder interaction should be prominent in the pre-accident establishment of response mechanisms at the time when an activity is planned (those that are affected by policy should have a say in it), and in defining generic targets for decommissioning and remediation. In the acute phase following an accident, there is little if any room for interaction; however, in the transition to an existing exposure situation and later when decommissioning and remediation are planned and implemented, it becomes prominent. Success will be limited or projects will be seriously delayed, discontinued or undergo unnecessary reorientation, and will

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Governmental, Legal and Regulatory Framework for Safety, IAEA Safety Standards Series No. GSR Part 1, IAEA, Vienna (2010).

not create an outcome that can be largely embraced by the population, if stakeholder interaction is not carried out correctly.

— Sustainability of interaction: Anyone who engages with stakeholders in decommissioning and remediation projects has to be prepared to be in it for the long haul. Projects last years to decades, and may approach a century. A strong presence, consistency, transparency and a clear message contribute to trust, which will be built with time if carried out well.

A number of remediation projects were discussed, where the successful outcome had been supported by a constructive stakeholder interaction. Such examples provide valuable experience to be implemented in future projects.

Setting objectives and targets for remediation

A very important element of this IEM was the discussions that were held in a number of sessions and that, in one way or another, related to the objectives and targets (and end states) of decommissioning and remediation. Remediation is, if used in a narrow sense, about reducing exposures, through actions directed at the source and/or through actions directed at the exposure pathway, which, in extreme cases, leads to evacuation. Targets for dose reduction can be formulated and expressed as dose targets using agreed reference levels as guidance. Targets can also be defined for decommissioning, for example, in terms of the desired end state.

The International Commission on Radiological Protection and the BSS recommend that a reference level to guide optimization in an existing exposure situation should be selected within a range of annual doses of 1–20 mSv to members of the public, and can be adjusted as necessary during the course of remediation. The discussions revealed that reference levels or dose reduction targets were generally set within this range, not higher than 5 mSv and in most cases at 1 mSv, i.e. aligned with the annual dose limit for exposure of the public from all human-made sources in a planned exposure situation. These are almost exclusively calculated doses based on certain cautiously conservative assumptions. At least in the case of the Chernobyl accident, direct monitoring shows that actual exposures were usually well below such calculated doses.

Consideration of radiation exposure is indispensable as it provides scientifically based and, in a sense, objective benchmarks against which progress can be assessed. However, the meaning of these benchmarks may not be easily communicated to the public and a particular problem is the inconsistency in other ‘numbers’, e.g. activity restrictions on drinking water, foodstuffs and commodities, that are designed to assist in keeping within dose targets. There is a strong message from the IEM that a lesson learned from Fukushima is that these numbers should be reviewed to provide a consistent message. The IAEA would be well placed to lead this work, in collaboration with other bodies, e.g. the Food and Agriculture Organization of the United Nations and the World Health Organization (WHO).

The objective of remediation may be expressed differently depending on who is asked, and this is an area where the interaction with stakeholders is of particular significance. The notion of ‘health’ needs to be broadened to include other than direct effects of radiation, noting that health is not defined as the absence of a disease but, by WHO, as a state of “physical, mental and social well-being”. Experts may deal with doses and risks, and health issues in an objective fashion, but also experts would tell their children not to eat the ice cream they dropped on the floor, not because the risk associated with eating it has been assessed but because of a vague notion of it being ‘dirty’. Such non-quantifiable issues are close to human nature and closer to the heart; the questions that need to be answered are: “Can I drink this water?”, “Can my children go to school here?” and “Can I eat my home-grown vegetables?”. The objective of remediation, when discussed in this way, is the resettlement of people and a return to normal life and livelihoods.

For a community, the objective may be described as follows, which is based on the recovery goals of the Fukushima Prefecture:

— To guarantee the safety and security of residents;
— To regenerate and revitalize primary industry;
— To become a hub of leading industries;
— To promote the use of local resources and skills, e.g. tourism and crafts.

It was repeatedly pointed out that accidents are unique with their own set of characteristics.

Remediation may, in some instances, be complicated further by the fact that some accidents may occur against a backdrop of already high levels of discharges and off-site impact. Also, some accidents are not purely radiological; they may be combined with the spread of hazardous chemicals or, as in the case of Fukushima, the consequences of the nuclear accident occurs on top of the far-ranging devastation caused by an earthquake and tsunami. The challenge is to reach a balance between different actions addressing various consequences of such combined accidents, in order to achieve optimized health and environmental protection.

Thus, the formulation of objectives and targets is a complex process, based on fundamental concepts of radiation protection and an understanding of radiation risks, an understanding of health issues in general, and iterations with stakeholders to achieve the optimal outcome under the local circumstances.

The formulation and agreement on objectives would be facilitated by improved ability to communicate 'what is safe'. A recommendation for future work can be formulated as follows: *The accident at the Fukushima Daiichi nuclear power plant has highlighted the concern of people to be assured of their safety. The international community should strive to develop a practical definition of 'safe' as an aid for communicating with the public.*

Methods and technology

The IEM provided participants with an update on methodologies and technology. A number of presentations were made by Japanese colleagues, providing participants with very clear examples of important issues to address in terms of methodologies and techniques, the approach to resolving the issues and successful implementation. The importance of relying on proven technology and innovative use was emphasized. Furthermore, it was noted that decommissioning and remediation has developed into an 'industry' which generates innovations to satisfy the needs of the customers for cost effective methodologies and techniques. Participants from industry provided very useful information from this rapidly evolving field.

It is noteworthy that the 'customers' — in a broad sense — are not only corporations or governments. Web-based tools to assist the public, e.g. house owners, have been developed and made accessible.

The IAEA could have a role in keeping a record of the available methodologies and techniques, to facilitate their implementation globally, which includes countries with insufficient infrastructure to support the necessary technology, but where the legitimate use of radiation may have caused legacies that need to be addressed and remediated. Furthermore, the IAEA may consider the feasibility of dispatching a team of international experts providing early advice on the preparations for long term recovery actions.

Management of damaged fuel and radioactive waste

Examples discussed during the IEM pointed to the very significant problems encountered when dealing with the damaged fuel and radioactive waste generated by an accident, and subsequent decommissioning and remediation. Problems are encountered in both the high activity and low activity end of the spectrum:

— Damaged fuel poses particular problems as it retains its basic radiological hazard whereas the matrix has been damaged to an extent that makes it unsuitable for conventional management;

— Large volumes of very low level waste may be generated during remediation, where the volume of the waste presents a challenge for its management.

The sequence and timing of defueling and removal of damaged fuel are important to consider when planning for the decommissioning of accident-damaged reactors since, for example, the properties of the damaged fuel change over time.

While these problems would not be encountered in normal operation, they can be foreseen as a result of an accident and should, thus, be addressed in the planning stage. This can be accomplished by the development of generic methods captured by 'generic safety cases and supporting safety assessments', which cover the categorization, conditioning, storage and ultimate disposal of the waste, as well as criteria for clearance. The safety case(s) need to address the peculiarities of waste generated from an accident and need to give consideration to the end state of decommissioning.

With regard to waste management strategies, a recommendation can be suggested as follows: *The IAEA should assist Member States with the development of end states and decommissioning strategies for decommissioning of accident-damaged facilities.*

With particular reference to the large volumes of — often — low activity waste from existing exposure situations, a recommendation can be suggested as follows: *Large volumes of radioactive waste and materials with residual amounts of radionuclides are present in many countries. The IAEA should review its guidance on the management of these wastes and materials, with a view to ensuring their practical application after a nuclear accident.*

CONCLUDING REMARKS

While the knowledge base for decommissioning and remediation activities is sound, the IEM identified aspects where there is room for improvement. It is important that these issues are addressed by the nuclear safety and radiation protection community, either through amendments of instruments such as conventions, new instruments, IAEA General Conference Resolutions, improved guidance, improved sharing of knowledge and experience, strengthened review services for planning of remediation, or any other action or a combination thereof. The IAEA has a vital role in driving this process under the terms of the Action Plan on Nuclear Safety.

Detailed conclusions regarding the status and future work in specific areas will be included in the final report. As for this Summary, the following suggested recommendations for future IAEA activities, broadly related to action 10 of the Action Plan, have been identified:

(a) *The IAEA should strengthen its programme on remediation after a nuclear accident to assist Member States to facilitate the return of affected areas to normal conditions.*
(b) *The accident at the Fukushima Daiichi nuclear power plant has highlighted the concern of people to be assured of their safety. The international community should strive to develop a practical definition of 'safe' as an aid for communicating with the public.*
(c) *The IAEA should assist Member States with the development of end states and decommissioning strategies for decommissioning of accident-damaged facilities.*
(d) *Large volumes of radioactive waste and materials with residual amounts of radionuclides are present in many countries. The IAEA should review its guidance on the management of these wastes and materials, with a view to ensuring their practical application after a nuclear accident.*

The participants and contributors to the discussions are thanked for making their thoughts and expertise available to all, and for their engagement and constructiveness in the discussions.

Carl-Magnus Larsson
1 February 2013

Annex B

CONTENTS OF THE ATTACHED CD-ROM

The following papers and presentations from the International Experts Meeting on Decommissioning and Remediation after a Nuclear Accident are available on the attached CD-ROM.

RELATED DOCUMENTS

Programme of the International Experts Meeting on Decommissioning and Remediation after a Nuclear Accident

Chairperson's Summary
C.-M. Larsson
Australian Radiation Protection and Nuclear Safety Agency, AUSTRALIA

PRESENTATIONS

Session I (Monday): Decommissioning, Environmental Remediation and Associated Waste Management Challenges Resulting from Nuclear and Radiological Accidents

Opening Remarks
D. Flory
Deputy Director General and Head of the Department of Nuclear Safety and Security, International Atomic Energy Agency (IAEA)

Opening Remarks
A. Bychkov
Deputy Director General and Head of the Department of Nuclear Energy, International Atomic Energy Agency (IAEA)

Keynote presentations

Overview of the DOE-EM Environmental Legacy: Current Status and Long-term Strategies for Decommissioning and Environmental Restoration
M. Gilbertson and D. Huizenga
United States Department of Energy, USA

The Long-term Strategy for Remediation
H. Nishiyama
Fukushima Decontamination Promotion Team, Ministry of the Environment, JAPAN

The Mid-to-Long Term Strategy for the Decommissioning of Fukushima Daiichi NPP
H. Nakanishi
Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry, JAPAN

Regulatory Challenges Relevant to Decommissioning and Remediation
O. Mykolaichuk
State Nuclear Regulatory Inspectorate of Ukraine, UKRAINE

IAEA Action Plan on Nuclear Safety
G. Caruso
International Atomic Energy Agency (IAEA)

Programme and Perspectives on Post-accident Decommissioning and Remediation
T. Lazo
OECD Nuclear Energy Agency (OECD/NEA)

Session II (Tuesday): Review of Experience and Strategic Lessons Learned from Past Accidents or Legacy Situations

TMI-2 Recovery Project: Critical Lessons
J. DeVine
Consultant, USA

Decommissioning Preparations for the Accident-damaged Pile 1 Reactor at Windscale, UK
M. Cross
Nuvia Ltd, UK

Remediation of Chernobyl NPP Site
V. Kholosha and V. Seyda
State Agency of Ukraine for Exclusion Zone Management and Chernobyl Nuclear Power Plant, UKRAINE

Experience in Eliminating the Consequences of the 1957 Accident at the Mayak Production Association
G.Sh. Batorshin and Y.G. Mokrov
Mayak Production Association, RUSSIAN FEDERATION

Experience and Strategic Lessons Learned from Decommissioning and Remediation of Large Nuclear Legacy Sites
M. Gilbertson
Office of Environmental Management, US Department of Energy, USA

Session III: Parallel Sessions (Tuesday) — Challenges in Decommissioning and Remediation

Parallel Session III-A: Remediation Challenges and Determination of End States

Regulatory Framework for Remediation
L. Ramos
Nuclear Safety Council, SPAIN

Site and Exposure Scenario Characterization and Assessment of Radiological Impacts
M. Balonov
St. Petersburg Research Institute of Radiation Hygiene, RUSSIAN FEDERATION

Experience with In-situ Decommissioning as a Remediation End Point
H. Belencan
US Department of Energy, USA

Recovery Handbooks: Their Application and Future Development
R. Duarte-Davidson, A. Nisbet, S. Watson and S. Wyke-Sanders
Health Protection Agency, UK

Decision Making for Late-phase Recovery from Nuclear or Radiological Incidents
S.Y. Chen (National Council on Radiation Protection and Measurements, USA) *and A. Nisbet* (Health Protection Agency, UK)

Oral Presentations of Posters

Evaluation of Redistribution Effects of Cs by Wild Fire in Evacuation Area after Accident at Fukushima Daiichi Nuclear Power Site
T. Ichiki, M. Kato, S. Tsuchino and N. Yamada
Japan Nuclear Energy Safety Organization, JAPAN

Investigation of Secondary Off-site Radiological Effect due to Living Activities after Fukushima Accident
S. Hara, M. Kato and N. Yamada
Japan Nuclear Energy Safety Organization, JAPAN

Cleanup of Farmland Contaminated by the Fukushima Nuclear Accident
K. Miyahara and S. Nakayama
Japan Atomic Energy Agency, JAPAN

Prior Estimation of Dose Reduction as a Result of Decontamination in Fukushima Pilot Project
K. Akasaka, K. Miyahara, S. Nakayama, M. Okumura and H. Takase
Japan Atomic Energy Agency and Quintessa Limited K.K., JAPAN

International Cooperation on Regulatory Supervision of Legacies Arising from Nuclear Accidents
M. Bush (Energy Resources of Australia Ltd, AUSTRALIA), *R. Edge* (International Atomic Energy Agency), *M. Kiselev* (Federal Medical and Biological Agency, RUSSIAN FEDERATION), *K. McConnell* (Nuclear Regulatory Commission, USA), *A. Persinko* (Nuclear Regulatory Commission, USA) *and M.K. Sneve* (Norwegian Radiation Protection Authority, NORWAY)

Fundamental Consideration on Reference Levels in Radiological Protection for Implementation of Practical Off-site Remediation
T. Fujita, T. Hattori and D. Sugiyama
Central Research Institute of Electric Power Industry, JAPAN

Chernobyl Cooling Pond Remediation Strategy
A. Antropov (Chernobyl Nuclear Power Plant), *D. Bugay* (Institute of Geological Sciences), *G. Laptev* (Ukrainian Hydromet Institute), *V. Kanivets* (Ukrainian Hydromet Institute), *V. Kashparov* (Ukrainian Institute of Agricultural Radiology), *O. Voitsekhovych* (Ukrainian Hydromet Institute) *and M. Zheleznyak* (Institute of Problems of Mathematical Machines and Systems)
UKRAINE

Parallel Session III-B: Challenges in Planning and Implementation of Decommissioning

Developing Post-accident Decommissioning and Remediation Implementation Plans
L. Barrett
L. Barrett Consulting LLC, USA

Organizational and Managerial Aspects of Decommissioning after an Accident
M. Božik and P. Gerhart
JAVYS Plc, SLOVAKIA

Development and Application of Equipment and Tools for Intervention after an Accident
M. Chevallier
Groupe INTRA, FRANCE

U.S. NRC Regulatory Process for Decommissioning and Actions Related to Damaged Facilities after Accident
L. Camper
Nuclear Regulatory Commission, USA

Oral Presentations of Posters

Selection of Fuel-debris Properties Required for Defueling Work at Post Severe Accident
H. Higuchi, H. Ikeuchi, N. Kaji, T. Kitagaki, K. Koizumi, R. Wakui, T. Washiya and K. Yano
Japan Atomic Energy Agency, JAPAN

Strategy of a Back-end of Nuclear Energy in the Slovak Republic and Financing of Decommissioning of NPP A1
V. Slugeň
National Nuclear Fund and Slovak University of Technology, SLOVAKIA

Transformation of the Object Shelter into an Ecologically Safe System — Arrangement of the New Safe Confinement Arch Assembly Platform for the Shelter Object
T. Sushko
State Nuclear Regulatory Inspectorate of Ukraine, UKRAINE

National Framework for Decommissioning and Environmental Remediation following a Nuclear Accident
V. Paloor
Atomic Energy Regulatory Board, INDIA

R&D Back-ups for Operation of the Highly Contaminated Water Treatment System in Fukushima Daiichi Nuclear Power Station
G. Bonhomme (Kurion), *M.S. Denton* (Kurion), *T. Hijikata* (Central Research Institute of Electric Power Industry), *K. Inagaki* (Central Research Institute of Electric Power Industry), *K. Ishikawa* (Tokyo Electric Power Company), *R. Keenan* (Kurion), *T. Koyama* (Central Research Institute of Electric Power Industry), *S. Ono* (Tokyo Electric Power Company), *J. Raymont* (Kurion), *S. Suzuki* (Tokyo Electric Power Company), *T. Tsukada* (Central Research Institute of Electric Power Industry) *and K. Uozumi* (Central Research Institute of Electric Power Industry)
JAPAN and USA

Safe Storage of Zeolite Adsorbents Used for Treatment of Accident-generated Water at Fukushima Daiichi Power Station
M. Denton (Kurion), *H. Fukushima* (Hokkaido University), *W. Ji* (Hokkaido University), *Y. Kamiji* (Japan Atomic Energy Agency), *C. Kato* (Japan Atomic Energy Agency), *K. Morita* (Japan Atomic Energy Agency), *R. Nagaishi* (Japan Atomic Energy Agency), *K. Nishihara* (Japan Atomic Energy Agency), *Y. Okagaki* (Utsunomiya University), *S. Sato* (Hokkaido University), *A. Terada* (Japan Atomic Energy Agency), *Y. Tsubata* (Japan Atomic Energy Agency) *and I. Yamagishi* (Japan Atomic Energy Agency)
JAPAN and USA

Decommissioning a Post-nuclear Accident in Canada
S. Oue
Canadian Nuclear Safety Commission, CANADA

Session IV: Parallel Sessions (Wednesday) — Challenges in Decommissioning and Remediation (cont.)

Parallel Session IV-A: Case Studies for Remediation

Current Issue on Remediation in Fukushima and Creation of Newborn Fukushima
T. Inoue
Fukushima Prefecture, JAPAN

The Human Dimension of Remediation after a Nuclear Accident: From Experience to ICRP Recommendations
J. Lochard
International Commission on Radiological Protection (ICRP)

Remediation in Areas Affected by the Chernobyl Accident
I. Bogdevitch, S. Fesenko, V. Kashparov and N. Sanzharova
The Institute for Soil Science and Agrochemistry of the National Academy of Sciences of Belarus, BELARUS

Overview of the Results of Fukushima Decontamination Pilot Projects
K. Miyahara, S. Nakayama and T. Tokizawa
Japan Atomic Energy Agency, JAPAN

Remediation Following the Goiânia Accident
E. Amaral
Consultant, BRAZIL

Remediation after the Palomares Accident: Scientific and Social Aspects
C. Sancho Llerandi
Research Centre for Energy, Environment and Technology, SPAIN

Radiation Protection Strategies for Ensuring Radiation Safety of the Population of the East-Urals Radioactive Trace
A.V. Akleyev, S.S. Andreyev, M.F. Kiselev and O.Y. Volosov
Federal Medical and Biological Agency of Russia, RUSSIAN FEDERATION

Parallel Session IV-B: Challenges in Planning and Implementation of Decommissioning (cont.)

Establishment of Interim Facilities On Site during the Stabilization/Cleanup Phase: Chernobyl Experience
V.V. Tokarevsky
Institute for Chernobyl Problems, UKRAINE

Radiological Characterization of Accident-damaged Facilities and Sites
Y. Desnoyers and D. Dubot
French Alternative Energies and Atomic Energiy Commission, FRANCE

Demolition and Removal of Structures Damaged or Contaminated as a Result of the Fukushima Accident
S. Suzuki
Tokyo Electric Power Company, JAPAN

Global Experience with Implementation of Clearance
J. Feinhals
DMT GmbH & Co. KG, GERMANY

Decommissioning and Remediation after a Nuclear Accident, 3 Case Studies
S. Slater
Sellafield Ltd, UK

Session V: Parallel Sessions (Wednesday) — Management of Radioactive Waste and Damaged Fuel

Parallel Session V-A: Generation and Management of Materials and Waste

The Waste Management Strategy and the Licensing Process prior to and after a Nuclear Accident
P. Brennecke
Consultant, GERMANY

Management of Radioactive Waste Resulting from Remediation Efforts in the United States of America
H. Belencan (US Department of Energy) *and R. Seitz* (Savannah River National Laboratory), USA

Management of Large Waste Volumes of Solid Waste in Ukraine
T. Kilochytska
State Nuclear Regulatory Inspectorate of Ukraine, UKRAINE

Experience from the WISMUT Project with the Management of Large Volumes of Radioactive Residues
M. Paul
Wismut GmbH, GERMANY

Panel Discussion: Strategy, Planning and Licensing of Facilities and Activities for RWM
S. Suzuki
Tokyo Electric Power Company, JAPAN

Parallel Session V-B: Fuel Retrieval and Management of Fuel Element Debris

Management of Damaged Fuel and Fuel Debris Resulting from Severe Reactor Core Melt Accident
S. Bourg
French Alternative Energies and Atomic Energiy Commission, FRANCE

Defueling TMI-2
R. Green
Exelon Corporation, USA

Challenges for Removal of Damaged Fuel and Debris
C. Negin
Project Enhancement Corporation, USA

Material Study of Chernobyl “Lava” and “Hot” Particles
B. Burakov
V.G. Khlopin Radium Institute, RUSSIAN FEDERATION

Session VI: Parallel Sessions (Thursday) — Decommissioning and Remediation Standards and Technologies

Parallel Session VI-A: Decommissioning and Remediation Standards and their Application

Japan: Standard for Remediation
H. Nishiyama
Ministry of the Environment, JAPAN

Understanding the Long-term Implications of Severe Radiological Accidents (Including Infrastructure and Resource Needs)
W. Weiss
United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)

Remediation of Contaminated Lands: The Maralinga Lessons
G. Williams
Australian Radiation Protection and Nuclear Safety Agency, AUSTRALIA

The International Safety Regime for Decommissioning and Remediation after a Nuclear Accident: Lessons and Challenges from Fukushima
A.J. González
Nuclear Regulatory Authority, ARGENTINA

Parallel Session VI-B: Perspectives of Engineering and Technology Companies in Managing Complex Decommissioning and Remediation Projects

Environmental Remediation in Fukushima Prefecture
H. Kawamura
Obayashi Corporation, JAPAN

Efforts for the Restoration at Fukushima Daiichi Nuclear Power Plants
O. Maekawa
Toshiba Corporation, JAPAN

Lessons Learned: AREVA's Experience in Japan, March to July 2011
B. Adhemar
AREVA, FRANCE

Lessons Learned from Decontamination and Decommissioning Projects
R. Kury
CH2M Hill, USA

Session VII (Thursday): Improving National and International Cooperation for Managing the Post-accident Phase of Nuclear and Radiological Accidents

International Conventions and Their Application to Remediation and Decommissioning after a Nuclear Accident — Is the Current System Adequate?
N. Pelzer
University of Göttingen, GERMANY

Involvement of Interested Parties in Decision-making on Decommissioning, Remediation Strategies and Site End States
A. Bergmans
University of Antwerp, BELGIUM

Development of a National Doctrine for the Post-Accident Phase of a Nuclear Accident
J.-L. Lachaume
French Nuclear Safety Authority, FRANCE

Long-term Knowledge and Information Management Following Severe Accidents
F. Adachi (International Atomic Energy Agency (IAEA)), *T. Anayama* (Tokyo Electric Power Company), *K. Itabashi* (Japan Atomic Energy Agency), *S. Iwata* (The Graduate School of Project Design), *T. Karseka* (International Atomic Energy Agency (IAEA)), *H. Nakajima* (Japan Atomic Energy Agency), *T. Ohba* (National Diet Library), *A. Omoto* (Tokyo Institute of Technology) *and S. Takizawa* (Tokyo Electric Power Company)
JAPAN

Panel Discussion: Fostering Greater International Cooperation in Preparing for and Responding to Large Accidents Including Sharing of Technical Resources (Knowledge and People), Need for an International Advisory Panel — Opening Statement
N. Pelzer
University of Göttingen, GERMANY

Session VIII (Friday): Closing Session

Presentation of Summaries of Sessions I–VII

Sessions III-A and IV-A: Summary of Findings and Recommendations
O. Mykolaichuk and I. Salati

Sessions III-B and IV-B: Summary of Findings and Recommendations
E.G. Kudryavtsev

Session V-A: Summary of Findings and Recommendations
W. Blommaert and Cheng Hui Ma

Session V-A: Generation and Management of Materials and Waste: Summary Report
W. Blommaert and Cheng Hui Ma

Session V-B: Summary of Findings and Recommendations
S. Chande and J.-L. Lachaume

Session V-B: Fuel Retrieval and Management of Fuel Element Debris: Summary Report
S. Chande and J.-L. Lachaume

Session VI-A: Summary of Findings and Recommendations
C. Clement and T. Kirchner

Session VI-A: Decommission and Remediation Standards and Their Application: Summary Report
C. Clement

Session VI-B: Perspectives of Engineering and Technology Companies in Managing Complex Decommissioning and Remediation Projects: Summary
M. Gilbertson

Session VII: Summary of Findings and Recommendations
F. Besnus and T. Inoue

13-23271