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ADVANCING IMPLEMENTATION OF NUCLEAR DECOMMISSIONING AND ENVIRONMENTAL REMEDIATION PROGRAMMES

POLICY SUPPORT DOCUMENT

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Cover photography: Re-filled Lichtenberg open pit (Courtesy WISMUT GmbH 2015)

FOREWORD

Significant progress has been achieved in recent years in terms of addressing the legacies from the early development of nuclear energy, including the decommissioning of redundant research and fuel cycle facilities, research reactors and power plants, and the remediation of sites affected by past uranium mining and processing operations. Some countries are moving forward with dealing with these legacies, and accordingly have built up appropriate technical resources and expertise, but many national programmes still face significant challenges.

Factors constraining progress in addressing legacies from the past remain. There is for that reason a need to better understand the global situation and to analyse the barriers impeding the implementation of decommissioning and environmental remediation programmes, with the aim of outlining actions that may improve current situations where progress is impaired. The International Atomic Energy Agency[1] launched the project 'CIDER'[2] in March 2013 in support of these objectives and with the support of other international organisations, particularly the European Commission and the European Bank for Reconstruction and Development.

The present document aims to support the development of adequate policies in IAEA Member States for decommissioning and environmental remediation, addressing in essence the following three fundamental questions:

- *What are the motivations for implementing decommissioning and environmental remediation?*
- *What are the main constraints hindering progress of decommissioning and environmental remediation programmes?*
- *What are the solutions for overcoming these constraints, taking account of experience from programmes under implementation?*

This document, prepared in close collaboration between the European Commission's Joint Research Centre and the IAEA, makes concise yet comprehensive proposals in answer to those questions, drawn from a survey and a more extensive analysis provided in the CIDER project report[3], which was elaborated by expert groups from IAEA Member States (see Appendix).

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[1] The IAEA is widely known as the world's 'Atoms for Peace' organization within the United Nations family. Set up in 1957 as the world's centre for cooperation in the nuclear field, the Agency works with its Member States and multiple partners worldwide to promote the safe, secure and peaceful use of nuclear technologies.

[2] CIDER Project or 'Constraints to Implementing Decommissioning and Environmental Remediation'.

[3] CIDER Project Baseline Report 'Advancing Implementation of Decommissioning and Environmental Remediation Programmes', IAEA Nuclear Energy Series Report NW-T-1.10, IAEA (2016). – see http://www-pub.iaea.org/books/IAEABooks/10993/Advancing-Implementation-of-Decommissioning-and-Environmental-Remediation-Programmes-CIDER-Project-Baseline-Report

See also related IAEA publication: Overcoming Barriers in the Implementation of Environmental Remediation Projects, NW-T.3.4, IAEA (2013). http://www-pub.iaea.org/books/IAEABooks/8960/Overcoming-Barriers-in-the-Implementation-of-Environmental-Remediation-Projects

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1. INTRODUCTION

1.1. HISTORICAL BACKGROUND

Managing the legacies from industrial development has been a challenge ever since the Second Industrial Revolution which began during the last half of the nineteenth century. Such legacies need to be viewed as resulting from technological developments that indisputably brought improvements to human living conditions. But these developments took place in circumstances in which the protection of the environment did not have the same importance as it does today. Although the Industrial Revolution resulted in many positive outcomes for society, there were also many negative consequences for the environment, including the depletion of natural resources, increased carbon emissions, general pollution and resulting human health problems. Many of these impacts were left to be addressed by succeeding generations.

During the past century, rapid industrialization and urbanization led to greatly increased utilization of natural resources, frequently resulting in pollution of the natural environment, diminished quality of life and increased environmental stress. The 1960s saw an increasing understanding of the effects of industrial projects on the environment, resources, raw materials and people and, allied to this, increasing political pressure for greater consideration of the potential environmental impacts. During the 1970s national legal regimes began to incorporate formal requirements for 'environmental impact assessment' (EIA) procedures, to be used as a tool for ensuring that environmental consequences were identified and managed. The United Nations Conference on the Environment in Stockholm in 1972 and subsequent conventions formalized environmental impact assessment requirements for industrial projects.

It is only in recent decades, particularly since the Brundtland Commission in 1987 and the subsequent United Nations Conference on Environment and Development in Rio de Janeiro in 1992 (the Rio Conference), that systematic consideration has been given to ensure that industrial developments are undertaken in such a way that undue burdens are not passed on to future generations. This idea is embodied in the 3rd Principle of the Rio Declarations: "The right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations"[4].

The origins of *nuclear activities* are linked to the development of atomic weapons during and following the Second World War and the very substantial research and test programmes that were associated with these activities. The 1950s marked the beginning of the civil nuclear industry, involving the development of nuclear reactors for the production of electricity as well as facilities for the production and treatment of the nuclear fuel. Increasing demand for fuel led to the growth of uranium mining projects, which has resulted in significant accumulations of residues containing naturally-occurring radioactive materials (NORM). The decades after the Second World War also saw an increase in the development of facilities for the production of radioisotopes for medical and industrial applications. These facilities and residual materials from the associated activities contributed to the legacy situations which now need to be addressed. During this period the approach taken by the nuclear industry to the environmental impact resulting from the industrial projects it was promoting was similar to the more general situation described above, i.e. environmental impacts of industrial developments were typically regarded as marginal elements

[4] Rio Declaration on Environment and Development, http://www.unep.org/Documents.Multilingual/Default.asp?documentid=78&articleid=1163

and decisions on the disposition of waste did not always adequately take into account the potential for contamination of soil and groundwater.

Since the 1980s, and in particular the Chernobyl accident in 1986, several countries decided to curtail or abandon their nuclear programmes due to public concerns about the safety of the nuclear power plants. Other factors also contributed to the decrease of the nuclear industry, particularly the slowing rate of electricity growth in developed countries, which influenced decisions about capacity additions throughout the electricity sector. Additionally, the high cost of building nuclear power plants and associated financing constraints resulted in significant problems for many developing countries to adopt this alternative energy resource. Research programmes associated with military applications of nuclear energy were also reduced in size following the ending of the Cold War at the end of the 1980s.

The coincident policy decisions towards the end of the 1980s to reduce reliance on nuclear energy for civilian and military purposes meant that many nuclear facilities established since the 1950s, including facilities for the extraction and conversion of uranium and fuel fabrication and reprocessing facilities, became redundant. The earliest nuclear installations, related to both military and civilian applications, reached the end of their original design lives and many were shut down. Simultaneously, many uranium mining and processing operations that were developed to sustain military programmes were terminated, leaving behind large areas of contaminated land. Many countries were therefore left with facilities requiring to be decommissioned and/or sites requiring to be remediated.

1.2. DECOMMISSIONING AND ENVIRONMENTAL REMEDIATION (D&ER)

'Decommissioning' of a nuclear facility means all technical and administrative actions leading to the release of the facility from regulatory control. In practice, decommissioning covers:

- the preliminary characterization of the facility;
- the preparation and authorisation (licensing) of the foreseen strategy and activities;
- the clean-up and decontamination works and the dismantling works;
- the segregation and packing of the radioactive and non-radioactive waste and
- the final radiological monitoring for release once all dismantling works have been terminated.

The end point may allow the facility to be re-used for other purposes or may result in the complete structural demolition of the facility (see scheme 'Nuclear Decommissioning – main steps' on next page 10).

The goal of *'environmental remediation'* is to reduce the radiation exposure from existing or potential contamination of land areas. This can be achieved through actions applied to the contamination itself, by reducing or by confining the source, or through the pathways for human and environmental exposure. Contaminated land can be found in the immediate vicinity of disused facilities and sites, but can also be result from advertent or inadvertent, larger scale dispersion to the environment of radiological materials or waste, or can be the consequence of past incidents or accidents involving radiological sources and installations (see analogue scheme 'Environmental Remediation – main steps' on page 12).

Consideration should be given to the long timeframes of D&ER projects. Even in those countries with the most advanced capabilities, the schedules are in general of the order of several decades.

1.3. ADDRESSING NUCLEAR LIABILITIES

On a global basis, it is estimated that there are over thirty thousand facilities that use radioactive material and that will require eventual decommissioning[5]. From an environmental remediation perspective there is no authoritative published estimate of the total amount of land that will require remediation; it appears that several hundreds to thousands of former nuclear weapons test sites are potentially contaminated and there exist large quantities of mill tailings (200 million tonnes in the United States alone)[6] and large areas of land contaminated due to radiological accidents (several thousand km^2) that require remediation. Decommissioning of disused nuclear installations may require substantial expenditures. By way of example, decommissioning cost estimates for a single nuclear power reactor range generally from 0.5 to 1 billion EUR. Expected costs can be much higher for some specific installations, e.g. the cost of decommissioning all facilities on the Sellafield site in the UK is expected to be in excess of 100 billion EUR. The costs are attributable to undertaking the D&ER activities, for the safe conservation of the site or installation and the waste and material management (including costs for material recycling or waste final disposal).

The legacies from past use of nuclear energy are often a state responsibility, e.g., in the case of state-owned infrastructure or military applications, in countries where uranium mining or electricity production is undertaken by state-owned organizations, or when the state takes over the legacies from former private companies. The cost of managing the legacy facilities or sites is charged to the annual state budget. In other cases, facilities may be owned by the private sector, e.g., commercial power reactors in countries where electricity production is not undertaken by the state. Funds are expected to be or are mandatory requested to be set aside by the operating organization to defray some or all of the cost of decommissioning the facility or remediating the site.

Political commitment is generally a major driving force for implementation of D&ER and, without this, significant progress is unlikely to occur. Part of the government's responsibility is to put in place the overall framework to address the nuclear liabilities from past activities. The overarching reasons *why* progress should be made in decommissioning and environmental remediation are developed in section 2 of this document.

1.4. CONSTRAINTS HINDERING PROGRESS OF D&ER PROGRAMMES

Experience shows that constraints of different types cause delays or impede D&ER programme implementation. A related survey conducted in 2012 by the IAEA among its Member States at the outset of the CIDER project highlighted the main 'barriers' hindering progress of programmes. These can be grouped as follows:

- absence of a national policy and an adequate legal and regulatory framework;
- lack of technology and enabling infrastructure;
- limited resources and lack of programme management expertise; and
- societal and stakeholder concerns.

Such barriers can be overcome, as demonstrated by the progress being achieved by those countries advancing D&ER projects. Sections 3 to 6 of this document provide general advice based on good practice developed from experience gained in these programmes and explain *how* the implementation of D&ER projects can be facilitated.

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[5] Status of the Decommissioning of Nuclear Facilities around the World, IAEA (2004) http://www-pub.iaea.org/MTCD/publications/PDF/Pub1201_web.pdf

[6] U.S. ENVIRONMENTAL PROTECTION AGENCY, Uranium Mill Tailings, USEPA, Washington (2014) http://www.epa.gov/radiation/docs/radwaste/402-k-94-001-umt.html,

Nuclear Decommissioning – main steps

Nuclear decommissioning encompasses several steps which are in principle sequential but which can in some circumstances overlap

Preparatory Phase

- Characterisation: inventory of the radioactivity present in the facility
- Lifecycle planning of decommissioning work
- Planning of staff and financial resources
- Safety assessment and Environmental impact assessment
- Authorisation process

Evacuation of residual spent nuclear fuel or other highly active material

- Evacuation of spent nuclear fuel to interim storage facility in view of deep geological disposal or reprocessing (recycling)

Decontamination

- Chemical or mechanical removal of radioactivity levels from the highest contaminated components

Dismantling equipment and infrastucture

- Removal of large metallic components and evacuation for cutting or off-site melting
- Removal of disused equipment and infrastructure (ducts, trays, pipes, cables, ..); substitution if necessary by small mobile units
- Segregation of waste, decontamination, cutting and packing

Release of the buildings

- Measurement of the residual building components (walls, floors, ceilings, ..)
- Decontamination where needed

Demolishing buildings (if not re-used)

- Demolishing of the building structures

Final release of the site

- Monitoring absence of contamination of the soil
- Decontamination if needed
- Release from regulatory control

Waste & Material Management

Most nuclear decommissioning steps generate waste and reusable materials; they are characterised and segregated in different categories, in view of their further treatment, packing and evacuation for recycling or disposal.

Usual management approaches are:

High & Intermediate Level waste
(less than 1% of total volume)

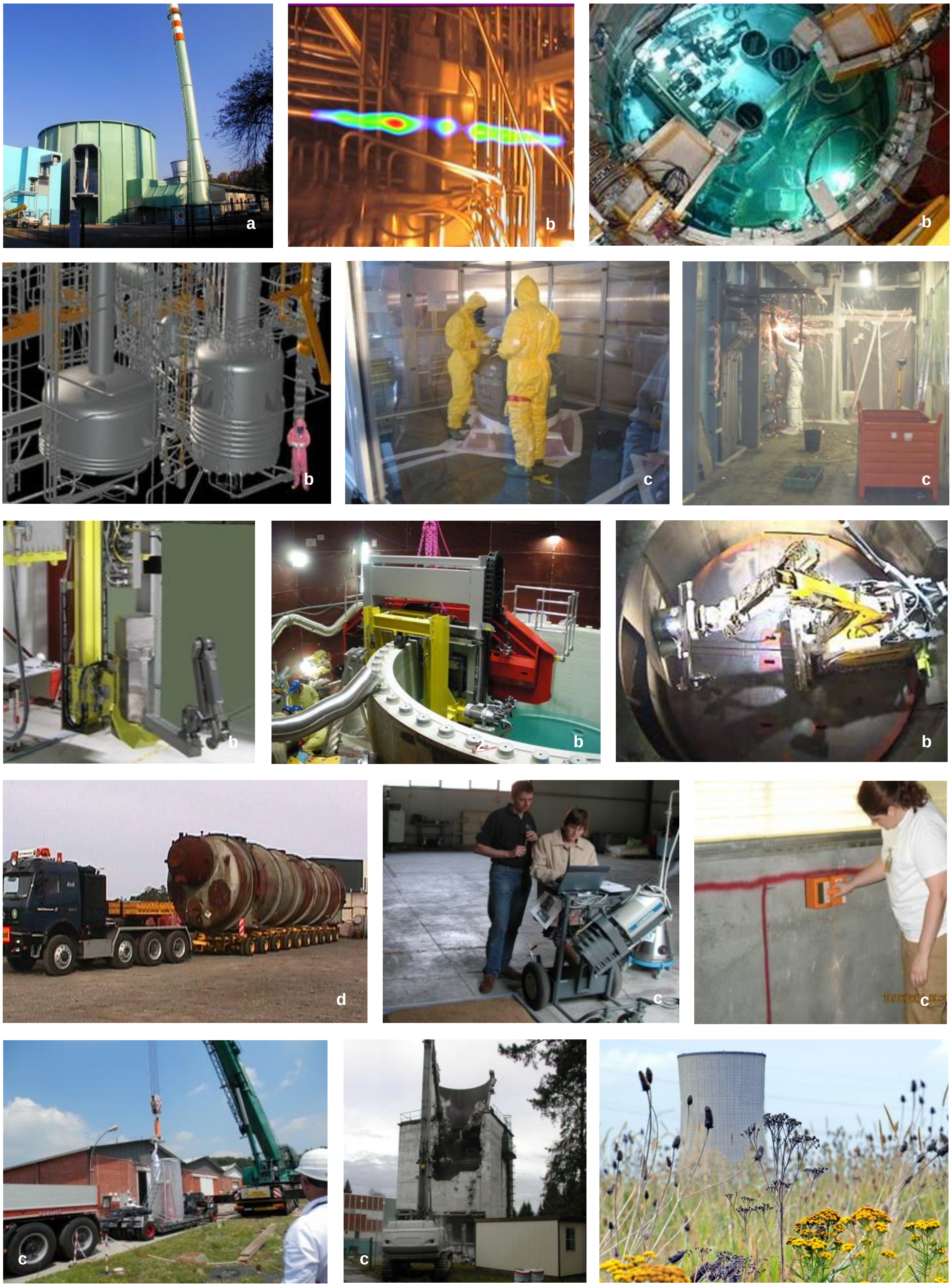
- Packing in specific hermetic/shielded containers
- Interim storage in view of later deep geological disposal

Low Level Waste
(approximately 10% of total volume)

- Off- or on-site conditioning (incineration, supercompaction, melting)
- Immobilisation in containers or drums (grouting or other)
- Interim storage/evacuation for final disposal

Very Low Level Waste and Clearable Material and Waste
(approximately 90% of total volume)

- If applicable: measurement for release of the material from radiological control (i.e. 'clearance')
- If not clearable: treatment, packing and evacuation for final disposal



[a] Ispra-1 reactor, Italy
[b] characterisation, assessment and robot remote handling activities of the CEA (courtesy CEA, France)
[c] dismantling works, clearance radiation measurements and evacuation transport (EC-JRC, Italy)
[d] transport of the Oskarshamn steam generator (courtesy Sudsvik, Sweden)

Environmental Remediation – main steps

Environmental Remediation is implemented stepwise, with a spectrum of potential remediation actions that will depend on the selected strategy

Preliminary phase – preparing the programme

- ❑ Conducting historical site assessment
- ❑ Assessment of the environmental impact from the contamination
- ❑ Select remediation criteria
- ❑ Consideration of the availability of competent staff and financial resources
- ❑ Consideration stakeholders' perception and possible response

Site Characterisation

- ❑ Determination of the characteristics, distribution and extent of radioactive constituents or contamination sources, mapping of other risk sources, as well as potential future releases, determination of potential transport pathways (ground or surface water, ..)
- ❑ Assessment of associated exposure risks to humans and the environment

Remediation strategy and planning of the activities

- ❑ Agreement on final objectives of the remediation work, in function of the acceptable residual exposure
- ❑ Establishment of remediation strategy and remediation plan
- ❑ Safety and environmental impact assessment, authorisation process

Implementing the remediation actions

In situ remediation

- ❖ *Containment* of the contaminants by surface caps (membranes, soil, ..), cutoff walls, bottom barriers, hydraulic control, ..
- ❖ *Stabilization* by encapsulation or compaction
- ❖ Physical, chemical or biological *in situ treatment*
- ❖ Methods to reduce plant uptake of contaminants to protect agriculture
- ❖ Natural attenuation (no technological remediation)

Material removal

- ❖ Removal of vegetation
- ❖ Removal of surface soil (by scraping, excavation, …)
- ❖ Removing contamination from hard (rock) surfaces

Ex situ treatment

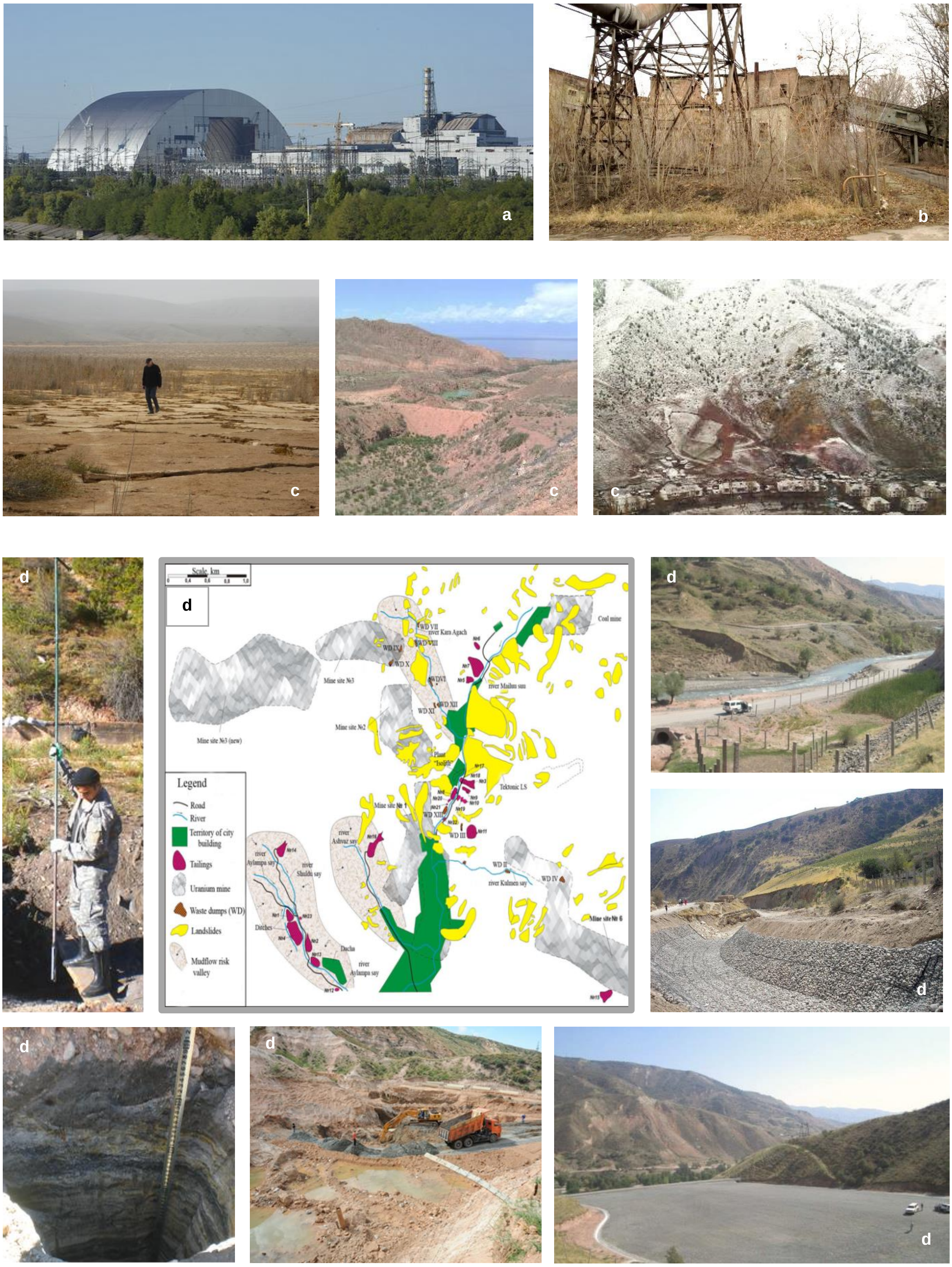
- ❖ Physical segregation, filtration
- ❖ Washing, leaching
- ❖ Incineration
- ❖ Chemical extraction
- ❖ Biological treatment (of organic components)

Waste treatment and disposal

- ❑ Solidification with cements, polymers, fixing agents or vitrification
- ❑ Packing in suitable disposal containers
- ❑ Transport and disposal of large waste volumes on adequate site:
  - ❖ Mined out quarries, former mines
  - ❖ Underground caverns
  - ❖ Natural basins
  - ❖ Specially dug trenches, pits
  - ❖ Mounds

Restricted or Unrestricted Release of the site

- ❑ Monitoring of contamination and effectiveness of the remediation
- ❑ Release of the site for restricted or unrestricted use
- ❑ Implementation of an institutional control programme



[a] Chernobyl new confinement, Ukraine

[b] site of the former Pridneprovskiy chemical plant, Ukraine

[b] former uranium extraction sites, Central Asia, Kyrgyzstan and Tajikistan

[c] characterization and environmental remediation works in Kyrgyzstan

2. MAIN DRIVERS FOR IMPLEMENTING D&ER PROGRAMMES

There are four principal reasons why states should progress with decommissioning and remediation liabilities: (1) respect of ethical principles, (2) societal confidence in the nuclear sector, (3) economic benefit and (4) compliance with international agreements.

2.1. RESPECT OF ETHICAL PRINCIPLES

Liabilities from the earlier developments of nuclear energy may result over the short or long term in unacceptable health, safety and security risks to workers and the general public and in increased risks to the environment. Achieving equity between generations requires that the generation which incurs the liabilities selects technologies and strategies which minimize the resource and risk burdens for future generations. Although it is unavoidable that each generation passes a mixture of burdens and benefits to succeeding generations, such actions are more acceptable if future generations' freedom of choice is not unduly restricted. Accordingly, liabilities should be managed in such a way that potential future impacts are kept at a level that is acceptable both economically and in terms of safety.

Consideration must be also given to the possibility that radiologically-contaminated facilities and sites can give rise to consequences which go beyond health risks from exposure to radiation, e.g. psychological effects. As experience from Chernobyl has demonstrated, serious consequences may result both from accidents and from the subsequent remediation measures[7].

2.2. SOCIETAL CONFIDENCE IN THE NUCLEAR SECTOR

Timely planning and implementation of D&ER projects for disused commercial nuclear facilities may increase societal confidence in the capability of the governments and the nuclear sector to deal with the long-term consequences of nuclear power and facilitate public acceptance of future nuclear power development or new projects. Conversely, retaining shutdown facilities for many years with no decision, plan, or active effort to address decontamination and decommissioning will adversely impact public perception and attitudes.

2.3. ECONOMIC BENEFITS

Complementary to ethical and societal considerations, there are indeed important economic reasons for early implementation of D&ER programmes. Investment in D&ER can be good for the local economy. Such activities may lead to increased job opportunities, spur development of new businesses and facilitate sector growth. From the perspective of the site owner, D&ER may result in increased property values and provide potential redevelopment opportunities. Implementing D&ER at disused facilities or sites can be a significant driver for increased industry and business in the area local to the site.

Conversely, delaying D&ER projects may be costly due to potential degradation of structures, spread of contamination, loss of institutional knowledge, and uncertainty of future impacts on factors that will influence remediation efforts, such as availability and cost of waste management services and availability of a trained workforce to conduct D&ER activities.

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[7] OUGHTON, D.H., 'Social and ethical issues in environmental remediation projects', Journal of Environmental Radioactivity 119 (2013)

2.4. COMPLIANCE WITH INTERNATIONAL AGREEMENTS

The international community has recognized that number of environmental issues represent a global concern: the trans-boundary impact on neighbouring countries that may occur as a result of historical operations, has led to the necessity for countries to enter into arrangements to address aspects of off-site contaminant migration. Such cooperative arrangements serve to improve the protection of the environment and the health of the individuals living in these areas. In addition, they may assist building trust between people of neighbouring countries.

In this context of management arrangements, the 'Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management'[8] requires contracting parties take the appropriate steps to ensure the safety of the related processes, including also the decommissioning of the nuclear facilities.

3. NATIONAL POLICY AND LEGAL & REGULATORY FRAMEWORK

Policy and the legal & regulatory frameworks provide a significant catalyst and are often the main driver for action. Experience suggests that, where such frameworks are absent or ineffective and, as a result, the mandate of the regulatory authority is unclear, the motivation for facility owners to initiate D&ER is low and ongoing projects do not have a well- established end point. As a result, efforts and expenditures are likely to be ineffective, and there is a strong potential for the projects to be delayed or unsuccessful.

3.1. DEFINING A NATIONAL POLICY

Defining a national policy provides an essential basis for D&ER programmes, establishing core objectives and providing visible evidence of national intent in relation to managing a perceived hazardous situation. The formulation of a national policy will encourage the establishment of a legal framework and associated regulation for ensuring coherent and consistent approaches to decommissioning and environmental remediation. It will also support continuity in the necessary developments and in the related investments, and continuity of knowledge and competence. Where applicable, depending on the country's governmental system, regional or local governments may also develop a policy in accordance with the national policy and within the scope of their authority.

The policy will not only be based on technical and organisational factors, but will also consider political aspects in general, and public engagement issues in particular, and should for this reason be widely shared. Experience has indeed shown that a good communication of the policy will further facilitate public dialogue and involvement in later stages of the implementation of projects.

3.2. ESTABLISHING A LEGISLATIVE & REGULATORY FRAMEWORK

The legislation and regulations with respect to D&ER can be 'dedicated' or 'embedded' in more wide-ranging national energy (or nuclear energy) or environmental (in case of remediation)

[8] Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, INFCIRC/546, IAEA (1997)
https://www.iaea.org/publications/documents/conventions/joint-convention-safety-spent-fuel-management-and-safety-radioactive-waste

legislation and regulations. The requirements can be established at various levels: in an act, decree, or licence, or even in a guidance document or standard. This will vary from country to country and depends on the national legislative context. Regulatory systems can be either prescriptive, performance based or goal setting.

The legal & regulatory framework should be sufficiently comprehensive[9,10]; provisions should be made to address:

- the definition of adequate criteria for the whole process;
- identification of roles and responsibility of entities dealing with D&ER;
- creation of an inventory of liabilities;
- granting of licenses or authorizations ;
- development of a waste management system;
- estimation of costs and development of funding mechanisms;
- communication and facilitating stakeholder engagement;
- oversight of D&ER programmes.

Establishing a complete and coherent set of D&ER legislation, regulations, standards and guidelines, or amending the framework accordingly will create a clear basis and as such stimulate the implementation of D&ER activities.

The existing framework should be reviewed in accordance with international standards and good practices[11].

3.3. IDENTIFICATION OF ROLES AND RESPONSIBILITIES

Roles and responsibilities of entities dealing with D&ER should be clearly assigned in the national legal and regulatory framework in such a way that there will be no duplication or void.

- The role of the *governments* is to develop a policy and establish the effective legal and regulatory framework for the implementation of D&ER. For the specific case of contaminated land, they should ensure that existing exposure situations are identified and evaluated to determine which occupational exposures and public exposures are of concern from the perspective of radiation protection. They should require the regulatory body or other relevant authority to ensure that remedial actions and protective actions are justified, that protection

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[9] A practical example of regulatory framework can be found in the European Directive for the responsible and safe management of spent fuel and radioactive waste (Directive 2011/70/Euratom) which requires that each country of the European Union establishes and implements a 'national programme', for turning its national policy into practical actions and solutions
http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32011L0070&from=EN

[10] IAEA Safety Standards:

- General Safety Requirements (GSR) Part 1, Governmental, Legal and Regulatory Framework for Safety, IAEA (2010), http://www-pub.iaea.org/MTCD/publications/PDF/Pub1465_web.pdf
- General Safety Requirements (GSR) Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, IAEA (2014), http://www-pub.iaea.org/MTCD/publications/PDF/Pub1578_web-57265295.pdf
- General Safety Requirements (GSR) Part 6, Decommissioning of Facilities, IAEA (2014), http://www-pub.iaea.org/MTCD/publications/PDF/Pub1652web-83896570.pdf

[11] In this sense the IAEA has developed the Integrated Regulatory Review Service (IRRS) which is designed (by performing review missions) to strengthen and enhance the effectiveness of the national regulatory infrastructure of States for nuclear, radiation, radioactive waste and transport safety and security of radioactive sources.
http://www-ns.iaea.org/reviews/rs-reviews.asp

and safety is optimized and that appropriate post-remediation control measures and waste management strategies are put in place.

- The main role of *regulatory authorities* is to ensure safety, environmental protection and security in compliance with legal and regulatory requirements. In practice, they have the responsibility for issuing authorization or licenses for D&ER activities and monitoring these activities by performing regular inspections and enforcement actions where necessary. Additionally they can have a mandate concerning communication with other governmental authorities and conducting public consultation regarding direct effects of risks and D&ER activities on population and land-use.

  An effective regulatory authority should be independent and have the necessary enforcement power. The experience shows that substantial changes in organization, funding, staff, and training may be required if a regulatory body that is accustomed only to overseeing small-scale radiation protection problems (e.g. radiological sources, the medical sector) is at a certain stage faced with large scale D&ER projects. Adequate resources should be provided to ensure the necessary competence.

- The *facility operators or owners* shall, in accordance with national regulations, provide a D&ER plan including the relevant technical data to the regulatory authority for authorization before implementation. Accordingly, the licensed operators or other responsible parties will manage the D&ER programme in compliance with the regulatory requirements and will be responsible for safety, environmental protection and security during the entire D&ER process and will report on this to the regulatory authorities. In legacy situations where the government has taken direct control, these responsibilities are undertaken by a relevant state agency.

In addition to the above entities, consideration should be made to address roles and responsibilities of other institutions directly or indirectly involved in D&ER programmes, including waste management organisations, industrial safety and environmental authorities, and public support services.

3.4. ADOPTION OF AN AFFORDABLE AND GRADED APPROACH

With the strategies to overcome the D&ER constraints, the extent of the efforts and resources put in place by a particular state should be commensurate with the liability that is faced.

Different factors influence what is required in practice: the number and size of the liabilities, their diversity and complexity and the associated level of risk. If the relevant liabilities are not large or complex, or have analogous or almost identical characteristics, the legal and regulatory framework, and the capacity of the state relating to the preparation, implementation, and oversight of D&ER should be of commensurate complexity. As the size and diversity of the liabilities increase, more complete legal and regulatory frameworks are necessary and additional capacities of the different players in the process must be considered. In this case, a greater effort is also needed to ensure for a long term the financial provisions and a capable workforce, skilful in the techniques and methodologies both from the side of the implementers and in the side of the oversight organization.

Although the exchange of experience among different countries is encouraged, caution should be taken not to choose and apply any model without tailoring it to the specifics of the particular case. The components should be adequate to cope with the specific needs of a country.

Synopsis section 3

NATIONAL POLICY AND LEGAL ANG REGULATORY FRAMEWORK
➢ Implement national decommissioning and environmental remediation policies; where applicable, define a regional or local policy ➢ Communicate the national and/or regional policy
➢ Ensure a sufficiently comprehensive legal & regulatory framework ➢ Review and amend the legislation, regulations and framework in accordance with international standards and good practices
➢ Assign clear roles and responsibilities of the government(s), regulatory authorities and owners and operators in such a way that there will be no duplication or void ➢ Ensure independence of the regulatory authority as well as adequate resources, considering the increased scale linked to decommissioning and environmental remediation projects ➢ Address also the roles and responsibilities of other institutions directly or indirectly involved in D&ER programmes
➢ Based on international experiences, adopt an overall approach which is commensurate with the extent and complexity of the liabilities ➢ Taylor international experiences to the specificities of the country

4. TECHNOLOGY AND ENABLING INFRASTRUCTURE

Decommissioning projects require the use of specific *technologies* for safe decontamination and dismantling, waste collection, treatment, characterisation and disposal, radiation measurement and laboratory analysis. In addition, for environmental remediation, technology selection may need to address site characterization and monitoring, hydrogeological modelling, cover design, soil decontamination and water treatment. Although most technologies now exist to perform all typical D&ER activities, in countries with less advanced programmes in D&ER there is often a *lack of accessibility* to a required technology due to missing information or limited experience to use the technology. An *adequate infrastructure* to support the effective use of the technologies, including water supply, electricity, roads, transportation systems, workforce accommodation and security for the site, is also often missing.

The absence of *waste and material management and processing* routes, although in general not sufficient to prevent to initiate D&ER projects, is generally a major constraint. In particular, the lack of an appropriate repository can influence the choice of strategy (e.g. deferred dismantling) and will complicate the programme. In the case of site remediation lack of disposal options may inhibit the overall implementation of the project or result in an accumulation of waste in temporary facilities.

4.1. IMPLEMENTING D&ER TECHNOLOGIES AND RELATED INFRASTRUCTURE

Specific technological solutions should be evaluated for each site. There is no single recommended approach for the D&ER of a particular site; the path forward depends on the situation then applying at the site, the risks, the envisaged end state and future use of the site, as well as the available resources. Many countries have already dealt successfully with D&ER for different types of facilities and sites under diverse conditions. Therefore, taking benefit from these *experiences*, a useful approach to executing D&ER would be to select and apply appropriate proven technologies. Technologies in widespread use for D&ER, including their advantages and disadvantages, are presented from various IAEA documents and other public sources [12,13,14].

A decision can also be taken to develop *proper technology* together with the building of national capacity or to develop *new technology*, for specific purposes, and will depend on the availability of the technology, the national infrastructure, funding, human resources and experience.

The identification and implementation of the necessary and available *infrastructure* is linked to the choice of the technology. Consideration should be given that if the infrastructure is absent, the use of mobile systems especially for short/medium term activities may be an alternative. Even after a D&ER project is completed, it might be necessary to maintain some infrastructure in order to fulfil *long-term* monitoring requirements.

4.2. IMPLEMENTING WASTE AND MATERIAL PROCESSING INFRASTRUCTURE

It is necessary to prepare a *waste and material management plan* for all types of materials generated as a result of D&ER activities. The plan should be based on the characterization of the installations or sites and on their expected end-state. The plan should address the possible disposition or recycling pathways for waste and re-usable materials and define the options for segregation, characterization, decontamination, packing and transport.

Appropriate *infrastructure* is necessary for waste treatment, conditioning, transporting and storage. This can be organized at national or regional level (typically in countries with a large nuclear industry) or at the level of the site. Here also use of mobile systems or relying on external sites can be an alternative.

Preferably a national or regional final *waste disposal repository* should be made operational in order to close the waste disposal route. In many countries where a permanent waste repository is not yet available, temporary waste storage facilities are implemented, at national level or on-site.

Linked to the final repository, *'waste acceptance criteria'* have to be fixed for the conditioned and immobilized waste packages. In the case there is no repository established, the waste acceptance criteria have to be anticipated (forecasted) to allow facilities to progress with waste treatment and conditioning activities.

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[12] State of the Art Technology for Decontamination and Dismantling of Nuclear Facilities, Technical Report Series No. 395, IAEA (1999) http://www-pub.iaea.org/mtcd/publications/pdf/trs395_scr/d395_part1_scr.pdf

[13] Decommissioning of Research reactors: Evolution, State of the Art, Open Issues, Technical Report Series No. 446, IAEA (2006) http://www-pub.iaea.org/MTCD/publications/PDF/TRS446_web.pdf

[14] Federal Remediation Technologies Roundtable (FRTR, U.S.): Remediation Technologies Screening Matrix and Reference Guide https://frtr.gov/matrix2/section1/toc.html

Synopsis section 4

TECHNOLOGY AND ENABLING INFRASTRUCTURE
➢ Assess alternative technological solutions for each site, based on international experiences ➢ Undertake the development of proper or new technology if more appropriate ➢ Identify the necessary and available infrastructure (fixed or mobile) to enable projects ➢ Ensure infrastructure for long-term purposes
➢ Elaborate a waste and material management plan for all type of expected materials generated ➢ Implement waste treatment and storage infrastructure at national, regional or site level ➢ Implement a final waste disposal repository ➢ Define waste acceptance criteria

5. RESOURCES AND PROGRAMME MANAGEMENT EXPERTISE

Although there is an overall economic benefit from undertaking D&ER at an early stage, implementation generally requires significant *financial resources*. Lack of funding may result from owners or state authorities not taking appropriate actions in the past to accrue the necessary decommissioning and remediation funds, poor management of available funds, or redirecting reserved funds to address other demands.

The availability of *qualified and experienced human resources* is even more critical to support D&ER projects. In general, the nuclear sector faces difficulties in recruiting personnel with the required competencies. In cases when D&ER follows directly from the shutdown of a facility or site, there are obvious reasons to maintain the operational staff employed, but experience shows an important *cultural change* which is not facilitating the transition (different mind-set, different nature of the work) even if appropriate training is provided. In cases of legacy sites that have on the contrary been in a state of long-term shutdown or abandoned, the lack of *historical knowledge* (e.g. characterization data, unknown risks present in the installation) is an obstacle in initiating D&ER projects and can debouch into safety issues.

The complexity and variety of most of the D&ER projects require that a national programme is set up. The programme will facilitate the definition and optimisation of strategies and the identification of resources, gaps and critical issues that require to be addressed.

5.1. ENSURING FUNDING

The ultimate responsibility for nuclear legacies rests within the state, as reaffirmed by the Joint Convention. Thus, the primary source of financing should be ensured within the country (from public or private funding sources), which in certain cases could be complemented with international resources. It is also essential that the generation that benefits from a nuclear activity establish arrangements for the appropriate funding that will ensure safe D&ER activities, even if performed by future generations.

Primary Sources of Funding

Funding must, at a minimum, comply with the criteria of the *'polluter pays'* principle (which enhances the responsibility of the operator and does not provoke imbalances for free competition), *'sufficiency'* (the funds must be enough to complete the D&ER tasks), *'availability'* (the funds must be available at the appropriate times), and *'transparency'* (the funds must be used only for D&ER, and their management must be clear, auditable, and transparent). Generally, a legal framework is established to ensure and enforce these requirements.

Three main types of funding models have proved effective and are in use in different countries: direct funding from government, internal segregated or non-segregated funds, and external segregated funds:

- *Funding from government* applies when the facility is owned by the state, which is the case for many research reactors and legacy sites. The established mechanism will either pay the costs from the state annual budget, or the state may contribute to accumulate a decommissioning fund over time.

- In the *internal segregated or non-segregated funds*, the operating organizations are responsible for amassing and managing the financial resources. The segregated model refers to have a separated fund from the operating organization budget, whereas the non-segregated model means that the funds are integrated with the normal budget of the operator. The management of these funds are usually subject to very specific and strict rules to ensure an adequate management and full transparency (i.e. that the funds are used only for D&ER activities).

- In the *external segregated fund* model, the funds are managed externally by a private or public entity, and can be centralized (i.e. to fund all the D&ER activities of a country), or dedicated to each operator.

There are several options to raise the necessary funds. This can be done by annual payment during the operational life of the facility, a prepayment before start up, setting aside a fraction of the revenues from the commercial activity of the facility, or paying a levy (or tax) of the benefits of the commercial activity of the operator.

A thorough analysis of the options, requirements, and risks as described above is needed together with the characteristics and nature of the D&ER projects to be funded, in order to select the most convenient funding arrangement for a particular country.

Potential Complementary Funding Sources

The involvement of international funding institutions can provide access to international expertise and international best practice. Their involvement can also lead enhanced credibility in terms of increased openness and involvement by local communities in environmental remediation activities.

Some of the major international funding organizations currently active in financing D&ER projects are:

- the *European Bank for Reconstruction and Development and Nuclear Safety* (EBRD)[15], founded in 1991 and involved in international assistance in the area of nuclear safety since its inception as many of its countries of operation inherited a burdensome nuclear legacy from Soviet times;

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[15] European Bank for Reconstruction and Development, EBRD http://www.ebrd.com/nuclear-safety.html

- the *Instrument for Nuclear Safety Co-operation* (INSC)[16] of the *European Commission* which finances measures to support a higher level of nuclear safety, radiation protection, and the application of efficient and effective safeguards of nuclear materials in third countries;

- the *North Atlantic Treaty Organisation* (NATO) which has developed a number of partnership tools and mechanisms to enable individual Allies and partners to support security and defence-related projects (including D&ER of former military sites);

- the *United Nations Development Programme* (UNDP) working with local governments to meet development challenges and develop local capacity; the *IAEA-Technical cooperation* helps IAEA Member States to build, strengthen and maintain capacities in the safe, peaceful and secure use of nuclear technology in support of sustainable socioeconomic development.

Funding can be also provided through *Government to Government* (G to G) cooperation agreements, example being the cooperation programme between USA and Iraq during the period from 2008-2013 (to engage D&ER activities which include training the staff, the delivery of equipment and instrumentation and providing advice for the different stages of the D&ER planning).

5.2. ENSURING KNOWLEDGE, SKILLS AND COMPETENCIES

The usual significant time-scales of D&ER processes require also a specific attention to the *long-term* strategic planning of staffing and training needs.

Undertaking D&ER activities should start with engaging and retaining staff resources of the existing operating organizations. Their knowledge of the design and operational history is essential. However and as mentioned above the new organizational *culture* required is different from that for operation of such facilities and sites. Operation is essentially a process based on a reasonably standard routine and training can easily be planned and tested. In D&ER projects, the nature of tasks is constantly changing and as a result more flexibility is required to adapt to unexpected situations. Staff will have to be re-trained accordingly. Management will have a key role in maintaining people's spirit and commitment towards an end goal which is very different to those of an operational facility.

New skills and competencies are needed, including project management, commercial and cost management, planning, monitoring of progress and reporting, risk management, and interface management with authorities, as well as knowledge of foreign languages. In conjunction with utilizing existing staff, supplementing the project team with internal new staff or external *outsourced* professional staff will speed up the development of an efficient D&ER organization.

Attention should be paid to the fact that activities and possibilities for careers in nuclear D&ER are often perceived negatively, or at least not considered as attractive. Despite this negative perception, experience shows that working in D&ER can offer many perspectives for career development, providing many technological challenges within an overall objective of restoring a safe environment. Promotion of these activities particularly among young professionals should therefore be pursued.[17]

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[16] Instrument for Nuclear Safety Cooperation, multiannual indicative programme 2014-2017 https://ec.europa.eu/europeaid/instrument-nuclear-safety-cooperation-multiannual-indicative-programme-2014-2017_en

[17] Education and Training in Nuclear Decommissioning, European Commission, ISBN 978-92-79-51836-2 (2015)

Independently of the long term planning of staffing and training, a management system must be also put in place to guarantee the *preservation of the knowledge* of the facility and its historical records and to ensure the knowledge transfer to future workforces. The International Atomic Energy Agency (IAEA) is currently providing expertise in this area.[18]

5.3. PROGRAMME MANAGEMENT

A *national programme* is necessarily founded on an inventory of all relevant information needed to perform a sound risk assessment, to prioritize and define an optimal strategy, to assess the cost of alternatives for decommissioning and environmental remediation and to ensure the necessary funding. Information should be collected and maintained centrally by an organization nominated to undertake that role.

A *risk assessment* for each of the facilities and sites as part of the inventory will be a fundamental component used for comparison and prioritization later. The assessments should take into account the risks to public health and to the environment resulting from the current status of the facilities or sites: status of conservation, stability of the containment and structures, waste characteristics (volume, physico-chemical and radiological properties), size of the affected area or volume of water affected, and leakages or other incidents that may have occurred. The assessment should also consider the consequences of potential accidents, e.g those provoked by extreme external events (earthquakes, floods, extreme rain, landslides, etc.). Essential factors are the proximity to surface or underground water courses and the population that could be impacted in the vicinity.

Countries with large numbers of contaminated installations and sites should define a *prioritization scheme* of the projects in line with the national policy. This scheme will rely on the status of installations and sites and the related risks, but also on other factors reflecting the national context, e.g. the availability of resources and expertise, the political implications of adopting a specific strategy in the context of the country's international relationships. For instance, priority might be given to the development of a national skills and knowledge base by initially undertaking non-complex projects before undertaking those of greater complexity. Another option may be to allocate higher priority to projects carrying risks that could lead to trans-boundary consequences.

When developing a programme, consideration should be given to adopting a *lifecycle approach*, from the beginning through to completion (which can be over a long term), including dealing with any required post-project remediation. This will facilitate the identification of gaps in technology, infrastructure and resources and will minimize the potential for delays and for unsuccessful project execution and completion.

The overall implementation process will however gain efficiency if there is, over the lifecycle, a *stepwise adaptation* of the measures and the regulatory oversight. Flexibility will allow to adequately account for the changing nature of the installation or site, the different hazards and risks, and to appropriately use resources that are commensurate with the activities.

The typically large uncertainties and potential for drawbacks during execution of the programme will be minimized by the development of a *programme risk register* with mitigation strategies. Risk-informed decision-making is central to all aspects of D&ER activities[19].

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[18] See IAEA Nuclear Knowledge Management (NKM) Services:
https://www.iaea.org/nuclearenergy/nuclearknowledge/NKM-Services/index.html

[19] The DRiMa project (International Project on Decommissioning Risk Management) provides recommendations on the application of risk management methodology to decommissioning projects.

Performing periodic *independent reviews* will provide expert opinion on programmes or activities relating to D&ER, taking account of international good practices, and thereby assisting countries to improve their performances. In this sense IAEA Member States may invite independent peer review missions such as those undertaken through the IAEA's ARTEMIS review service.[20] Such reviews contribute also to increased national and international confidence in the approaches and activities of the state or organization and in such a way also to an improved public acceptability of national programmes. Obviously peer review missions will only be effective in countries where policies exist and where programmes are in a process of implementation.

Synopsis section 5

RESOURCES AND PROGRAMME MANAGEMENT
➢ Estimate costs, based on inventory and strategies ➢ Establish within the country the appropriate funding mechanism, as primary source of funding ➢ Assess possible complementary international funding sources if necessary
➢ Plan over the long-term staffing and training needs ➢ For facilities moving from operation to decommissioning, adapt human resources management to deal with the (cultural) changes ➢ Define strategy for recruitments and outsourcing ➢ Pay attention to stimulate interest of the young generation for careers in D&ER ➢ Ensure long-term preservation of knowledge of the site characteristics and historical records
➢ Establish a national inventory of liabilities ➢ Perform a risk assessment of facilities and sites which are part of the inventory ➢ Define a prioritization scheme for the future activities ➢ Develop strategies, considering the whole lifecycle of the projects ➢ Consider a stepwise adaptation of measures over the lifecycle of the projects ➢ Develop a programme risk register with mitigating strategies ➢ Assess progresses of the programme by independent reviews

[20] IAEA ARTEMIS or Integrated Review Service for Radioactive Waste and Spent Fuel Management, Decommissioning and Remediation) https://www.iaea.org/artemis/

6. SOCIETAL ISSUES

Less attention was paid in the past to informing public about the objectives and implementation strategies for D&ER projects and this has led, in many circumstances, to a general lack of trust of activities associated with the nuclear fuel cycle, including back-end activities. Stakeholder opinion and expectations are important elements of the decision-making process for D&ER projects and inadequate communication/engagement can represent a significant challenge to implementation.

Typical constraints encountered are:

- limited *technical knowledge* of the general public related to nuclear and radiological concepts and particularly a limited understanding of the objectives of D&ER programmes;
- concerns regarding the need to *store the waste on site*, adopting of a NIMBY mind set ('not in my backyard'), despite the D&ER projects have the objective to improve public and environmental safety;
- the presence of groups or individuals who are *against* the use of nuclear power on principle and link D&ER to this, and/or who may be opposed to be engaged in any communication process or have a specific agenda that is antagonistic to the aims of D&ER.

Other constraints can complicate the communication process:

- limited *budget* to cover all stakeholders demands;
- stakeholders making demands which are in *contradiction* with other stakeholder groups;
- past negative experiences of stakeholders, causing significant levels of *pessimism* regarding the likelihood that issues arising can be addressed in a satisfactory way.

Consideration should be also given that D&ER projects can be long lasting activities spreads over several years or even decades and *changes* of administrative procedures of the legal framework may happen and can affect previous arrangements. The stakeholders themselves may also change, with new people coming to live in the impacted areas.

6.1. ANALYSING THE SOCIAL AND ECONOMIC ENVIRONMENT

In a practical way and as a first step, an *analysis* of the social and economic environment should be done. This includes an identification of the level of knowledge and understanding related to D&ER activities, of the perception of risk, the interests, concerns, demands among the different stakeholder groups and possible opponents.

This can be done by conducting public opinion surveys, interviews with opinion leaders, discussions, interaction with local educational institutions, etc. It is useful also to collect positive and negative experiences from previous related projects, causes of success or failure, pitfalls and difficulties.

6.2. DEVELOPING AND IMPLEMENTING A STRATEGY FOR ENGAGEMENT

Experiences have shown that D&ER activities tend to be more effective if communication and stakeholder involvement is planned at an early stage. Good communication of the policy and related strategies will establish trust, cooperation and understanding between different interested parties in later D&ER projects. Involvement of impacted or interested persons can prevent fear-driven reactions, a potentially damaging public response, or the creation of undue expectations.

After having analysed the social and economic environment, target groups can be defined for developing a focused awareness raising *strategy*. Possible approaches are:

- the creation of public information centres, information campaigns or websites;
- events providing on-site visits to the facility to be decommissioned or the site to be remediated or sharing international experience;
- the creation of dedicated committees or councils to share visions and concerns as a forum for public dialogue;
- the development of educational programmes to improve the knowledge and understanding;
- if multiple or even contradictory concerns arise, sharing of concerns and agreement on a formal method of decision aid which can help to prioritize demands;
- in the case of strong opposition, the involvement of a facilitator agreed by all parties to open dialogue.

Trust between implementers and stakeholders will be enhanced by *integrating* together with the environmental also social, economic and even cultural concerns of the community.

Clear information should be provided from the beginning on the *financial resources* made available for the D&ER project, with the budget margins to address reasonable stakeholder proposals. Regular information on the budget expenditures should be provided to acquaint stakeholders on the progresses.

Changes of the strategy over the duration of a project should be clearly identified and motivated. Keeping promises, admitting uncertainties and justifying the decisions taken is important for developing a responsible relationship.

The fundamental goal of stakeholder involvement is to facilitate a consensus between the public, the project owner, and the regulatory agency on an acceptable D&ER approach. It should be borne in mind that the biggest challenge may often be to gain consensus between stakeholders with a range of different technical and social backgrounds. What can be obtained is 'informed consent', i.e., the willingness of those initially sceptical to agree upon a course of action, based on information provided and assessed over the course of the decision-making process. The approach will make decisions more robust towards the long term realisation of the project.

Synopsis section 6

SOCIETAL ISSUES

- ➢ Communicate and involve stakeholders at an early stage
- ➢ Analyse as a first step the social and economic environment of the projects
- ➢ Develop an awareness raising strategy, several approaches are possible
- ➢ Plan engagement in an integrated way (environment, social, economic, cultural)
- ➢ Inform stakeholders also on budgetary resources and margins
- ➢ Identify and communicate changes in the strategy

7. CONCLUSION

Dealing with the legacies from past nuclear and non-nuclear activities is an issue of increasing global concern. Principles of social justice and intergenerational equity provide a fundamental justification for why countries and utilities should undertake early decommissioning of disused nuclear facilities and environmental remediation of radioactively-contaminated sites.

It is evident that significant barriers hinder progress towards the implementation of decommissioning and environmental remediation programmes. These may be linked to the absence or weakness of national policy and associated legal and regulatory frameworks, insufficient access to appropriate technology and enabling infrastructure, a lack of technical and human resources and inadequate consideration of stakeholder involvement and political challenges.

Much can be learned through the detailed analysis of these constraints, which may be country- or site-specific, and by the international sharing of experiences and best practices in decommissioning and environmental remediation. In this sense the present document proposes a number of major strategic steps that help to overcome the barriers and thereby facilitate better implementation of programmes.

Progressing with decommissioning and environmental remediation programmes and avoiding delays in their implementation will, if managed correctly, yield economic gains for the concerned state and region. It will also ensure compliance with international agreements established to address the environmental impacts of historical activities undertaken during the early phase of the nuclear era and improve societal confidence in the long term sustainability of future technological choices.

APPENDIX

ADVANCING IMPLEMENTATION OF NUCLEAR DECOMMISSIONING AND ENVIRONMENTAL REMEDIATION PROGRAMMES

– CONSULTED AND INVOLVED EXPERTS –

This document is a synthesis of the baseline report of the IAEA CIDER project[2], which was developed by three main working groups, comprising of representatives from different IAEA Member States, addressing: (1) Policy, Legislative, Regulatory and Financial Framework; (2) Technology and Infrastructure; and (3) Social and Stakeholder Issues. The working groups were chaired/co-chaired by: (1) Mr. Reno Alamysah and Mr. Stewart Carey-Hodges; (2) Mr. Alexandre Oliveira and Ms. Sarah Roberts and (3) Mr. Petro Chernov/Ms. Katerina Konstantinova and Mr. Sebastian Schneider, respectively.

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