IAEA TECDOC SERIES

IAEA-TECDOC-1826

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Management of Large Volumes of Waste Arising in a Nuclear or Radiological Emergency

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MANAGEMENT OF LARGE VOLUMES OF WASTE ARISING IN A NUCLEAR OR RADIOLOGICAL EMERGENCY

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INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2017

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Printed by the IAEA in Austria
October 2017

IAEA Library Cataloguing in Publication Data

Names: International Atomic Energy Agency.
Title: Management of large volumes of waste arising in a nuclear or radiological emergency / International Atomic Energy Agency.
Description: Vienna : International Atomic Energy Agency, 2017. | Series: IAEA TECDOC series, ISSN 1011–4289 ; no. 1826 | Includes bibliographical references.
Identifiers: IAEAL 17-01117 | ISBN 978–92–0–107417–1 (paperback : alk. paper)
Subjects: LCSH: Radioactive waste management. | Nuclear accidents. | Hazard mitigation. | Emergency management.

FOREWORD

After the accident at the Fukushima Daiichi nuclear power plant, in Japan in 2011, the IAEA Action Plan on Nuclear Safety was developed. Following its endorsement by Member States, various activities have been conducted to strengthen nuclear safety, emergency preparedness and protection of people and the environment. One such example is the work done by the Waste Safety Standards Committee, a standing body of senior representatives in the areas of waste safety that makes recommendations on the IAEA programme for the development, review and revision of safety standards and on activities to support the use and application of these standards. It reviewed existing IAEA safety standards on waste safety to explore possible implications of the Fukushima Daiichi accident and in light of the Action Plan. As a result, the recommendation was made to develop guidance material on the management of large amounts of contaminated waste resulting from remediation and on methods to accelerate the licensing process to ensure availability of treatment, storage and disposal facilities for the types and amounts of waste generated during an accident or as a result of remediation activities.

This publication, prepared based on the recommendation, focuses on waste management planning as a part of the overall emergency preparedness that needs to be established for such a nuclear or radiological emergency. This publication and the other IAEA publications referenced throughout will be useful to national planners and policy makers, facility and programme managers, and other professionals responsible for developing and implementing national plans and strategies to manage radioactive waste arising from nuclear or radiological emergencies.

The IAEA is grateful to all those involved in the preparation and review of this publication, in particular H. Grogan (United States of America). The IAEA officers responsible for this publication were Y. Kumano and A. Guskov of the Division of Radiation, Transport and Waste Safety.

CONTENTS

1. INTRODUCTION

This publication addresses the management of large volumes of radioactive waste arising ina nuclear or radiological emergency. In this publication, the term "waste" refers to materials that are contaminated by radionuclides and for which no further use is foreseen. Such waste includes waste arising from emergency response, recovery actions such as remediation of affected area, decommissioning of the affected facilities, and secondary waste arising from waste processing facilities.

The management of large volumes of waste will be one of many efforts to be dealt with to allow recovery of affected areas, to support return of evacuated or relocated populations and preparations for normal social and economic activities, and/or to mitigate additional environmental impacts. "Large" in this context is used in this document to mean that the volume of waste to be managed can quickly overwhelm existing capacities of the organizations that routinely address waste management issues, thereby elevating the management of these wastes to the level of a national or an international challenge if other countries are affected. Such situations may result from a nuclear or radiological emergency associated with a nuclear power plant (NPP), from a radiological emergency triggered by a nuclear security event (e.g. explosion of a radiological dispersal device) or any other nuclear or radiological emergency involving dispersal of radioactive material into the environment. Some of these emergency situations may happen in any country.

Although it is not possible to predict the exact nature and scale of any future nuclear or radiological emergencies that result in contamination of the environment, there are a number of aspects that can be anticipated. From consideration of these aspects, advanced planning and preparatory work can be undertaken that will significantly improve recovery efforts when needed.

Study of past recovery efforts indicates such future efforts will be directed toward restoration of resources to beneficial use by the population in the long term. Waste management is one aspect of recovery that cannot be planned in isolation from other recovery activities. The quantity and characteristics of the waste to be managed, the rate at which waste will be produced, and the length of time that waste management activities will continue depend on this context. Accordingly, guidance given in this document for management of large volumes of waste arising from a nuclear or radiological emergency is considered and presented in the context of the larger recovery effort.

It is often assumed that recovery activities follow the emergency phase, and that they are clearly separated in time (sequential). However, review of past experiences tells that some of recovery and waste management activities may start even during the emergency phase, The extent and timing of carrying out such activities during the emergency phase will depend on the nature of the emergency and the resulting consequences.

1.1. BACKGROUND

Several past emergencies and other activities involving dispersion of radioactivity in the environment have resulted in the production of large amounts of waste as the result of either the emergency or the subsequent remediation efforts undertaken in the affected areas. Such waste has to be managed in a manner to ensure safety both in the short and long term.

Experiences and lessons learned from past nuclear emergencies, including the Chernobyl NPP accident in Ukraine in 1986, and the Fukushima Daiichi NPP accident in Japan in 2011, demonstrated the importance of proper management of waste. This includes waste arising from the emergency itself, from various actions taken during the emergency response, and from the remediation activities. Past experience clearly shows that lack of preparation prior to an emergency complicates waste management. This experience also indicates that waste management following an emergency could be improved through acceleration of key steps in the decision making process including the safety demonstration and licensing procedures. Thus, the need for, and importance of, providing guidance on planning for the management of large quantities of waste following a nuclear or radiological emergency is highlighted.

In January 2014, the IAEA organized the International Expert Meeting on Decommissioning and Remediation after a Nuclear Accident highlighting the specific short term and long term issues that may need to be addressed during decommissioning of facilities and remediation of the off-site environment affected by a nuclear accident [1]. At this meeting, various issues on the management of large volumes of waste arising from a nuclear accident were discussed. This discussion led to the recognition of the crucial need for development of a strategy to support the recovery phase following an emergency.

1.2. OBJECTIVE

The objective of this publication is to provide guidance to Member States for the management of large amounts of waste generated from recovery efforts following a nuclear or radiological emergency. This document focuses on waste management planning as a part of overall emergency preparedness that needs to be established for such a nuclear or radiological emergency in line with IAEA Safety Standards such as Refs. [2] and [3]. Planning for waste management for a nuclear or radiological emergency, with flexibility to accommodate the inherent uncertainties, provides a mechanism to facilitate recovery and promote resilience in the impacted population. This document was developed based on evaluation of lessons learned from previous nuclear or radiological emergencies, along with considerations regarding the potential range of impacts from a potential future emergency. In addition, experiences on remediation and associated waste management for several legacy sites were also reviewed and taken into consideration in this document.

1.3. SCOPE

With the aim of providing a strategic overview and general guidance on waste management following an emergency, this guidance stresses the importance of preparedness in advance of any future emergency.

Scope of this publication includes:

- Identification of lessons learned from experiences from nuclear or radiological emergencies relevant to management of waste arising from emergency response and recovery efforts;
- Identification of the need for preplanning, before an emergency, for waste management as part of the overall emergency preparedness and in the context of larger recovery effort;
- Consideration on how to return to the normal waste management scheme (e.g. development of safety case by operators, authorization and oversight by regulators) as soon as practicable following an emergency.

Scope of this publication does not include:

- Detailed guidance (point-by-point instructions) for radioactive waste management planning for an emergency, given the inherent uncertainty of such events and the diverse contexts that may apply (i.e. geography, culture, licensing framework, and many other factors);
- Guidance regarding emergency preparedness and response; this is the function of other documents, such as IAEA Safety Standards GSR Part 7 [2], GS-G-2.1 [3] and GSG-2 [4]; rather, only waste management considerations in the context of nuclear or radiological emergency planning are addressed;
- Waste generated from normal decommissioning activities of the affected nuclear facilities;
- Guidance regarding management of waste arising from past practices that resulted in large contaminated areas (although lessons from cleanup of such past practices are considered in this publication).

1.4. RELATIONSHIP TO OTHER IAEA PUBLICATIONS

This publication is one of a series of companion reports prepared to support Member States' efforts to improve preparedness in relation to waste management following a nuclear or radiological emergency. This document is supported by two companion reports, which provide further technical basis to the arguments for predisposal management and disposal of waste as shown in Figure 1. This document also addresses environmental remediation and decommissioning of affected sites, focusing on those aspects that are relevant to waste generation and waste management activities.

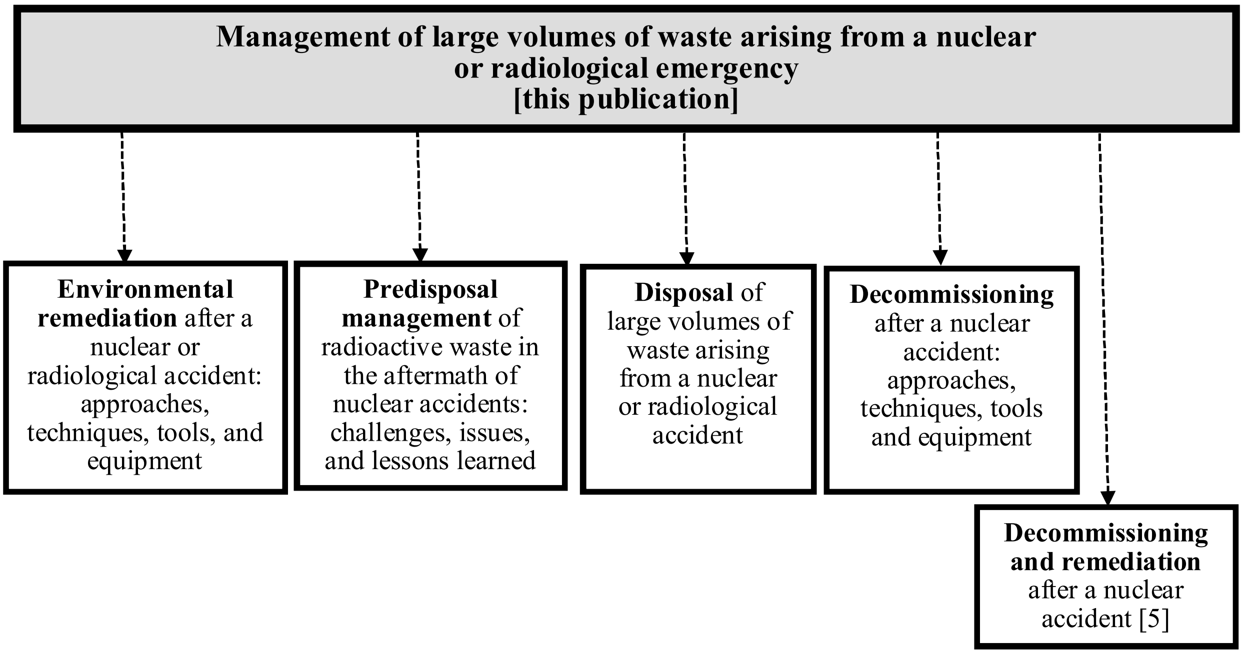

FIG. 1. Companion documents addressing management of waste following a nuclear or radiological emergency.

There are a number of publications related to the management of radioactive waste, such as Safety Requirements GSR Part 5 [6] and SSR-5 [7]. GSR Part 5 focuses on the management of radioactive waste prior to disposal, covering all the steps in the management of radioactive waste from its generation up to disposal, including processing, storage and transport. SSR-5 provides a set of requirements that must be met to ensure the long-term safety of disposal facilities in order to protect people and the environment. Though this document focuses not solely on radioactive waste, but also waste slightly contaminated by radionuclides as a result of a nuclear or radiological emergency, the principal goal to ensure the safety throughout the management of such waste remains the same. In addition to these Safety Requirements publications, there are a number of Safety Guides, which provide recommendations and guidance on how to comply with the safety requirements on radioactive waste management, such as Safety Guides GSG-3 [8], SSG-23 [9], and SSG-29 [10].

In addition to those Safety Standards related to radioactive waste management, the issue of need for the safe and effective management of waste arising from an emergency and emergency response actions is addressed as a part of General Safety Requirements publication on emergency preparedness and response, GSR Part 7 [2].

Furthermore, the IAEA is revising the Safety Guide WS-G-3.1, "Remediation Process for Areas Affected by Past Activities and Accidents" [11] that will also address issues involving management of large amounts of waste with relatively low concentrations of radionuclides that can be generated by remediation activities in greater detail, expanding on the current treatment of this subject in WS-G-3.1.

To supplement the descriptions in the Safety Standards mentioned above, this document focuses on lessons learned from experience with previous nuclear or radiological emergencies, along with considerations regarding the potential range of impacts that may result from a future emergency, and based on these, provides guidance for the management of large amounts of waste generated by an emergency.

The list of IAEA Safety Standards that were specially taken into account in this document is given below:

- *Predisposal Management of Radioactive Waste*, General Safety Requirements GSR Part 5 [6];
- *Disposal of Radioactive Waste*, Specific Safety Requirements SSR-5 [7];
- *The Safety Case and Safety Assessment for the Disposal of Radioactive Waste*, Specific Safety Guide SSG-23 [9];
- *The Safety Case and Safety Assessment for the Predisposal Management of Radioactive Waste*, General Safety Guide GSG-3 [8];
- *Preparedness and Response for a Nuclear or Radiological Emergency*, General Safety Requirements GSR Part 7 [2];
- *Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards*, General Safety Requirements GSR Part 3 [12];

1.5. • .INFORMATION CONSIDERED

In order to prepare this publication, a range of relevant past experiences was evaluated. This included the two major NPP accidents; the 1986 accident at the Chernobyl NPP in Ukraine, and the 2011 accident at the Fukushima Daiichi NPP in Japan, together with the 1957 accident at the Windscale site in the United Kingdom. The range of emergencies studied for this publication was not limited to NPP accidents alone. Other radiological emergencies can lead to the analogous challenges addressed in this publication and so the example of the Goiânia accident in 1987 was investigated. Finally, remediation of radiologically contaminated legacy sites, such as the Wismut uranium mine in Germany, nuclear production facilities in the United States of America, and the past nuclear test site at Maralinga in Australia, were considered. These remedial efforts provide useful insights and implications for waste management involving large volumes of waste, while sharing some key similarities to emergency situations.

A short summary of each event is provided below;

- The explosion on 26 April 1986 at the Chernobyl NPP, which is located 100 km from Kiev in Ukraine (at that time part of the USSR), and the consequent reactor fire, which lasted for 10 days, resulted in an unprecedented release of radioactive material from the nuclear reactor and adverse consequences for the public and the environment. The resulting contamination of the environment with radioactive material caused the evacuation of more than 100,000 people from the affected region during 1986 and the relocation, after 1986, of another 200,000 people from Belarus, the Russian Federation and Ukraine [12].

- The Fukushima Daiichi NPP accident occurred on 11 March 2011 which resulted in a meltdown of core material in three of the plant's six nuclear reactors. The failure occurred after the plant was hit by the tsunami triggered by the Great East Japan Earthquake; the plant released substantial amounts of radioactive materials to the atmosphere. No short-term radiation exposure fatalities were reported, in contrast to more than 15,000 deaths due to the earthquake and tsunami [14].

- The Windscale accident was caused by a fire on 10 October 1957. The accident occurred when the core of the Unit 1 nuclear reactor at Windscale, Cumberland (now Sellafield, Cumbria) caught fire, releasing substantial amounts of radioactive contamination into the atmosphere. The fire burned for three days with the result that radioactive material was released and deposited across parts of the United Kingdom and northern Europe [15].

- The Goiania accident is an example of a radiological emergency that did not arise from a NPP. On 13 September 1987, a shielded, strongly radioactive ^{137}Cs source (50.9 TBq, or 1375 Ci, at the time) was removed from its protective housing in a teletherapy machine in an abandoned clinic in Goiania, Brazil, and subsequently ruptured. Many people incurred large doses of radiation, due to both external and internal exposure. Four of the casualties ultimately died and 28 people suffered radiation burns. Residences and public places were contaminated. The decontamination necessitated the demolition of seven residences and various other buildings, and the removal of the topsoil from large areas. In total about 3500 m^3 of radioactive waste were generated [16].

- The German Wismut Remediation Project is an example for recovery of contaminated land. The Wismut uranium ore mines and processing facilities were constructed and operated in the former German Democratic Republic to provide uranium for the former Soviet Union's nuclear weapons programme. During more than 40 years of operation, minimal regard was given to environmental protection and public health. The remediation dealt with about 325 million m^3 of waste rock material (low grade uranium ore), about 160 million m^3 of radioactive tailings as well as large volumes of contaminated material from area cleanup and water treatment residues [17].

- The Hanford Site was a nuclear weapons materials production area in Washington State in the northwest United States and provides another example of recovery of contaminated land. The Hanford complex was first constructed during World War II to produce plutonium for nuclear weapons. The site was expanded and operated throughout the Cold War to meet national needs for nuclear weapons materials. This large complex at Hanford included nine production reactors along the Columbia River, uranium fuel fabrication facilities, and chemical separation facilities for the extraction of plutonium from fuel rods irradiated in the production reactors. The production mission ended in 1989. Since then the site has been the scene of a massive environmental remediation effort to address the environmental contamination that resulted from the weapons production mission. At present, the primary contamination concerns are for radioactive and chemical contamination of the subsurface environment (vadose zone and groundwater) and to treat and dispose of large volumes of stored radioactive and chemical waste [18].

- Maralinga was a site in Australia used by the United Kingdom for nuclear weapons testing and is an example of recovery of contaminated land. The United Kingdom conducted seven atmospheric nuclear weapons tests at this site in 1956 and 1957, which ranged in size from 1 to 27 kT. Additionally, over 600 "minor trials" dispersed long-lived radioactivity to the local environment in the form of natural and depleted uranium, plutonium and americium. The major trials left close-in contamination (fallout and neutron activation products), but no long-term hazard resulted. However, the hundreds of minor trials dispersed highly radioactive and long-lived contamination to the local environment, which was then ploughed to reduce its concentration by dispersal. Remediation of this contamination was a large effort for the Australian government [19], [20].

A summary of waste arising from these past events is provided in Appendix I.

1.6. STRUCTURE

Waste management following an emergency needs to be planned and implemented consistently with the overall protection strategy developed as part of emergency preparedness. The priority during the emergency is on stabilizing the situation and bringing it under control. Once stable conditions are achieved, the primary focus of activities will shift and the overall strategies towards achieving the agreed endpoints will need to be refined accordingly. Waste management is one aspect of recovery that cannot be planned in isolation from other recovery activities.

Underlining the interrelationship of waste management with various emergency actions and long-term recovery activities, this document proposes strategic planning on waste management in advance to any future emergencies.

Chapter 2 of this document examines anticipated impacts and challenges in relation to management of waste following an emergency. Chapter 3 identifies areas of preparatory activities in order to mitigate the significance of such challenges. Chapter 4 provide the conclusion of the discussion. Appendix I summarises major aspects of past nuclear or radiological emergencies investigated to identify lessons. Appendix II illustrates the summary of challenges identified in Chapter 2 and related preparatory actions proposed in Chapter 3. Furthermore, Annex I provides an example on how to undertake preplanning for waste management.

2. EXPECTED IMPACTS AND CHALLENGES

Experience from recovery following the Chernobyl NPP and Fukushima Daiichi NPP accidents, as well as from other remediation and recovery efforts, has shown that the issues for managing large volumes of waste following an emergency are diverse and numerous. The range of situations addressed in the areas affected by the Chernobyl NPP accident differed substantially from those in the regions affected by the Fukushima Daiichi NPP accident. One common issue was that large amounts of waste were generated very quickly. The sudden generation of those materials had diverse impacts that created many challenges related to waste management. Large in this context denotes that the volume of waste to be managed exceeds the capacity of the organizations that routinely address radioactive waste management issues, thereby elevating the management of these wastes to the level of a national or an international challenge if other countries are affected. In addition, the composition of waste involved will be much more heterogeneous and complex, compared to normal operational or decommissioning waste streams, likely including non-radioactive, but hazardous and organic, constituents. Thus, the challenge of large amounts of waste with complex composition is to be faced. Also, considering the diverse range of waste from the point of radioactive toxicity, more stringent safety considerations need to be given to waste with high radioactivity than slightly contaminated material, which may not even need to be managed at facilities specifically established for radioactive waste.

Because of the inherent lack of predictability, it is essential to prepare for the fact that any future nuclear or radiological emergency could differ significantly from previous ones, and in unanticipated ways. Nevertheless, past experience provides a basis to anticipate likely impacts and challenges, which are described in the following sections.

2.1. IMPACTS

It is anticipated that the following broad impacts will be foreseen to any future nuclear or radiological emergencies involving significant releases of radioactive material to the environment and the generation of large volumes of waste:

- **Health and safety impacts**: exposure of individuals in the affected area(s) as well as exposures associated with recovery from the emergency will be primary determinants of the range of recovery options and the time frame required for the recovery.;
- **Environmental impacts**: a large-scale release of radioactive materials to the environment will likely affect soil, vegetation (likely including agricultural products), water resources, and infrastructure;
- **Societal impacts**: displacement of the population, loss of homes and businesses, psychological shock, loss of trust, and stigma associated with the affected area and people, are some of the non-radiological impacts that can be anticipated;
- **Financial impacts**: cost associated with the loss of commodities and resources as well as costs of response and recovery efforts may be enormous.

Magnitude of the impacts will be significantly different for different emergency cases. For example, if an emergency at a NPP results in release of radioactive materials, the resulting impacts become far greater than an emergency without release of radioactive materials to the environment. Also, release of long-lived radionuclides will cause greater impacts than an emergency which only releases short-lived radionuclides. Uncertainty in all of these anticipated impacts, with regard to magnitude, extent, and nature, is acknowledged. The response to and recovery from an emergency will need to address all elements that contribute to these impacts. Therefore, as part of efforts for preparedness for a nuclear or radiological emergency, it is important to take into account waste management aspects when developing an overall protection strategy.

Review of experience with remediation of the legacy sites, Hanford Legacy Nuclear Production Site in the United States and Maralinga Legacy Nuclear Weapon Test Site in Australia, indicate that waste management programmes for widespread radioactive contamination are most successful when conducted within the context of an overall strategy for cleanup [19]. Those strategies include these elements:

(1) Characterization to quantify the amount (volume and radioactivity) and distribution of contamination to be remediated;

(2) Prioritization of remediation activities to protect critical resources, workers and the public;

(3) Remediation activities based on a well-developed set of end-states with defined time lines for reducing the extent of the contaminated area.

Even though the nature and scale of any future nuclear or radiological emergency cannot be predicted precisely, there are key aspects that can be anticipated. These key aspects are identified and considered in turn below and lay the foundation for identifying key components to prepare for waste management in case of an emergency.

2.1.1. Health and safety impacts

Contaminated areas that result from the release of radioactive materials to the environment can be expected to increase occupational and public exposures. Health and safety will be the primary focus during the recovery effort, therefore a method to quantify and manage these doses in a consistent, comprehensive manner in accordance with the respective exposure situation will need to be implemented. Exposures will need to be considered for the entire spectrum of waste management activities ranging from stabilization of situation (e.g. access to the facility) and remediation activities, to collection, storage, treatment and other waste processing activities and disposal.

> **Goiânia radiological accident example:** A shielded ^{137}Cs source was removed from its protective housing in a teletherapy machine in an abandoned clinic in Goiânia. The source capsule was subsequently ruptured, and the remnants of the source assembly were sold for scrap to a junkyard owner, who noticed that it glowed blue in the dark. People were fascinated and some grain-sized fragments of the source ended up in the homes of several families, and other fragments came to be dispersed to places throughout the city. By the

time the scale of the emergency was discovered, and countermeasures were taken, many people had incurred large doses of radiation due to both external and internal exposure. Four of the casualties ultimately died and 28 people suffered radiation burns. Residences and public places were contaminated. The decontamination necessitated the demolition of seven residences and various other buildings, and the removal of topsoil from large areas. In total, about 3500 cubic metres of radioactive waste were generated [21].

2.1.2. Environmental impacts

According to existing experience it can be anticipated that radioactive material will be dispersed in the environment following an unforeseen nuclear or radiological emergency. However, the nature and extent of the environmental contamination will depend on a wide variety of factors such as the type of the emergency that lead to the releases of radioactive material. For example, a much broader range of radionuclides including long-lived nuclides was released during the Chernobyl accident as compared to that of Fukushima Daiichi NPP, reflecting the absence of reactor containment and the dispersal of reactor core material from Chernobyl. Similarly, a much wider territory was impacted following the Chernobyl accident. However, small changes in conditions during these events could have resulted in different dispersion throughout the environment. For example, different meteorological conditions during the releases could have changed the resulting deposition footprint and thus impacted areas. Additionally, the time of year when the events occurred impacted the subsequent dispersal throughout the environment.

A nuclear or radiological emergency that results in widespread dispersal of radionuclides in the environment is likely to impact both soil and biota, which include vegetation, agricultural products, and livestock. Clearly, the exact nature of the impact will depend on many variables that relate to the characteristics of the release (radionuclide composition, chemical/physical form of the released material), the characteristics of the impacted environment itself (soil type, land use), the duration of the release, and the time of year it occurs. For example, the Fukushima Daiichi NPP accident occurred prior to the growing season and consequently the potential impact to agricultural products was minimized. Had the event happened later in the season, it may have resulted in contamination of very large volumes of agricultural products that would have needed to be treated as waste. Even so, there are enormous volumes of soil and vegetation that still require managing as waste. It is estimated that the stockpile of soil and other contaminated material generated from remediation activities after the accident will be approximately 16–22 million m^3 after the volume of plants and trees is reduced by incineration [14], [22].

A nuclear or radiological emergency may also impact surface water and groundwater. In the short term, this impact can result from direct deposition to surface water or from runoff across contaminated lands discharging to surface water. Depending on the specific characteristics of the emergency, the latter might also have a longer-term impact. There is also the potential for impacts to groundwater as the result of infiltration of longer-lived contaminants. The relative significance of these different pathways will depend on a host of factors including the geography and hydrogeology of the impacted area, the specific radionuclides of concern and the activity released.

A further consequence is the inevitability that property will be impacted. Important cultural resources (religious sites, national monuments, historic sites, etc.) and societal infrastructure (e.g. roads, railways, utility plants) may also be impacted. The restoration of such properties to beneficial use, to the extent possible, will be a primary endpoint to be determined, and achieved, in the recovery process, which will impact the amount of waste generated.

When considering strategies and plans for waste management, it is essential to have a good understanding of the characteristics of the different waste types. Characteristics include radionuclide activity and nature of species, concentration, chemical composition and physical properties. The environmental landscape that is contaminated by the emergency needs also to be considered when developing such strategies and plans. For nuclear emergencies involving releases of radioactive material to the environment, it can be anticipated that the dispersed contamination will include, at minimum, radiocaesium and radioiodine. Other radioactive constituents may also be dispersed in the environment depending on the nature of the emergency, but these constituents are the most common.

> **Fukushima Daiichi NPP emergency and Windscale nuclear production emergency example:** The radionuclide releases from the Windscale accident in 1957 and the Fukushima Daiichi NPP accident in 2011 have similarity. Both released predominantly radiocaesium and radioiodine. The main differences are that Fukushima Daiichi released a greater quantity of these radionuclides and that at Windscale fallout occurred across national borders mainly in North-West Europe [15], [23], [24], [25].

2.1.3. Societal impacts

The non-radiological consequences from the emergency among affected population may include stress, psychological shock, loss of homes, loss of trust, and stigma associated with impacted area and population etc. Evacuation and relocation for purposes of public protection during the emergency phase, and the lengthy exclusion of the public from the affected areas, can be expected to pose such impacts and to cause high public concern. Public interest and expectations regarding recovery, expressed through stakeholder participation in decision making, will influence the establishment of endpoints for recovery, and therefore the waste management objectives that support recovery. The extent of societal impacts of the Chernobyl and the Fukushima Daiichi NPP accident is noted in these examples:

> **Chernobyl NPP emergency example:** Following the Chernobyl accident, the decision on the evacuation of population from the Chernobyl NPP 30 km zone and some settlements beyond the bounds was made and in total 164 700 people were evacuated and resettled. The exclusion zone still remains in place, although the boundaries have been revised based on radiation levels. This area has largely reverted to forest [26].

> **Fukushima Daiichi NPP emergency example:** The number of population who remain evacuated as a result of the 2011 Great East Japan Earthquake and the Fukushima Daiichi NPP accident, including those who have evacuated voluntarily, was around 119 000 in January 2015, compared with a peak of around 164 000 in June 2012 [14]. By March 2015, approximately 1,900 deaths were reported in Fukushima Prefecture as cases related to the injury or evacuation conditions, though none of these were considered as the result

of radiological effects [27]. (Note that since Fukushima Daiichi NPP accident was caused by the natural disaster (earthquake and tsunami) which also destroyed and impacted the society, the above numbers include both impacts by the natural disaster and the NPP.)

2.1.4. Financial impacts

The financial impacts of a nuclear or radiological emergency are associated with loss of properties (shops, houses, industry, etc.) and resources (agricultural land, forest, cultural assets, infrastructure, recreational assets, etc.). There will be obvious immediate financial impacts during the emergency phase associated with emergency response actions. Less obvious but still consequential are the long-term financial impacts from the cost of recovery. Waste management will constitute both short- and long-term financial impacts of the recovery effort. As the recovery progresses and endpoints are identified (Section 2.2.4), the financial requirements to achieve desired endpoints and the valuation (economic as well as other valuation considerations such as cultural value) will need to be factored into the endpoint selection within the context of overall justification and optimization process. The financial cost associated with recovery, including waste management activities, can be significant and represent a long-term commitment of substantial national financial resources. The extent of financial impacts of past nuclear or radiological emergencies is noted below as examples:

Fukushima Daiichi NPP emergency example: According to the Ministry of Environment's cost estimate, it is projected that in five years from the accident (2011-1015), 3.3 trillion JPY will be spent for remediation of contaminated area outside the Fukushima Daiichi NPP and for waste management associated with the remediation [28].

Wismut uranium ore residues remediation example: The German project to remediate the Wismut uranium residues required an expenditure of 7,100 million Euros to achieve environmentally stable configuration for the uranium ore mining and processing residuals [17].

Maralinga legacy test site remediation example: Maralinga Legacy Test Site Remediation example: Cleanup of the Maralinga test site cost 108 million Australian dollars. This did not include additional costs paid to Aboriginal people for land alienation and settled claims with other individuals. In perpetuity maintenance of the Maralinga site costs the Australian government an additional 239,000 Australian dollars per annum [29], [30].

Hanford legacy production site remediation example: The latest estimated price for completion of the remainder of Hanford Site cleanup (to achieve the selected endpoints), including some post-cleanup oversight, is 110,200 million US dollars (present-day value) from 2015 to 2090 [31].

2.2. CHALLENGES

Regardless of the amount and composition of radioactive materials released to the environment, their presence will likely dictate the need for remediation for continued use of resources by the population. This remediation is likely to produce large volumes of waste of complex composition that will need to be managed, and which is very likely to exceed the capacity for normal waste management activities. If a nuclear or radiological emergency occurs as a result of, or in conjunction with, a natural disaster (such as earthquake and tsunami), both the volume and complexity of wastes generated will be that much greater.

There are a number of challenges that can be anticipated. These include:

- A very high level of concern from the public;
- Various technical difficulties associated with characterising and managing the waste;
- Capabilities of the existing decision making and regulatory framework (unless preplanning efforts have been made); and
- Establishing efficient, effective management and communication of information, data, and activities.

In addition to the challenges identified above, there are further challenges that are linked to the time frames following a nuclear or radiological emergency. These challenges are due to interdependencies of waste management activities from generation to disposal of waste and other response and recovery decisions that are made.

This section summarizes these challenges starting with those associated with the different time frames.

2.2.1. Time frames

The priority during emergency phase of a nuclear or radiological emergency is on stabilizing the situation and brining it under control and on protecting individuals. This presents the challenge that the resulting decisions may be less than ideal with regard to waste management. In the absence of adequate waste management planning as part of the overall emergency preparedness, quick decisions that impact future waste management are more likely to be made without careful consideration of their impact on the long-term safety of radioactive waste. Expedient decisions made early in the emergency response will likely need to be revisited and revised when transitioning to existing/planed exposure situation, as the situation allows.

The time frame for recovery following a nuclear or radiological emergency involving significant releases of radioactive material into the environment and resulting in long term public exposures due to residual radioactive material is likely to last for many years under an existing exposure situation. Accordingly, expectations regarding the recovery phase and waste management will need to be defined appropriately. It will be especially challenging to resist the urge to provide specific times when milestones for remediation will be met until a thorough understanding of the situation is achieved. Establishing a comprehensive understanding of the situation is necessary first in order to avoid setting unrealistic expectations for recovery and waste management activities. Then consideration on long time period for remediation and waste management activities following a nuclear or radiological emergency will be required. Even if the recovery could be completed effectively within relatively short time period (in months to years), the challenges related to waste management extend much longer and, in some circumstances will impact future generations. Thus, the issue of sustainability of waste management activities will be an issue.

An understandable misperception regarding time frames for the post-emergency situation is to consider emergency phase and the recovery phase as separate and distinct phases in time – that is, sequential. Review of past events demonstrates that this is not the case; the waste management activities are subject to considerable overlap in time as well as in geography with other activities carried out during the emergency phase, though waste management activities and other recovery activities will not to be expected to take place when actions are taken to regain control over the situation and to protect individuals (primarily during the urgent phase).

> **Chernobyl NPP emergency example** - Waste management activities (e.g. collection, storage and disposal of highly radioactive waste) commenced very early after the accident and continue more than a quarter century later. Radioactive Waste Disposal Storage and Radwaste Temporary Localization Site within the Exclusion Zone were created under extreme conditions in 1986 though these facilities do not comply with the effective normative requirements to facilities designed for radioactive waste [26].

> **Fukushima Daiichi NPP emergency example** - The government and Tokyo Electric Power Company (TEPCO) announced on 16 December 2011 that all the plants affected by the accident achieved the 'cold shutdown state'. This announcement officially brought the 'accident' phase of events at the Fukushima Daiichi NPP to a close [14]. However, activities to prevent further releases of radioactive material to the environment continued past this date. Waste management activities (e.g. collection of debris and water treatment) began even before this time [32].

Some additional considerations with regard to time frames are noted:

- Waste management resulting from various recovery actions needs to be conducted in a timely manner so that it does not delay the recovery further, but also in a manner that does not compromise the protection strategy.
- Regardless of the level of preparedness, decisions that impact waste management will commence almost immediately following an emergency.
- The nature and extent of contamination, and decisions regarding what radioactive material can and cannot be reused / recycled or released from control, restricts what endpoint is achievable in recovery, and in what time frame.

2.2.2. Challenges associated with public concern

A nuclear or radiological emergency will result in a high level of public concern. Public concern following a nuclear or radiological emergency will likely produce these challenges:

- Fear of radiological impacts;
- Desire to resume normal life as it existed prior to the emergency;
- Eroded trust and diminished credibility for decision-makers;

- Demand for open sharing of available, accurate and complete information in a timely manner with context;

- Demand for immediate actions resulting from evacuation and loss of properties, and to reduce health impacts.

Public perception regarding a nuclear or radiological emergency is more negative than that from any other type of disaster whether or not they are caused by natural or man-made factors. Consequently, the associated waste management issues are problematic – for example, in selecting locations for waste processing, storage, and disposal facilities.

> **Fukushima Daiichi NPP emergency example:** Disaster debris, such as damaged houses, from the Great East Japan Earthquake and associated tsunami, could not be dealt with by the affected municipalities alone because of the massive volumes of disaster-related waste. In order to manage the huge quantity of debris, the national government (Ministry of Environment (MOE)) called upon cross-jurisdictional approaches to make use of facilities outside the affected area [33]. However, due to nationwide concern that radioactive fallout from Fukushima Daiichi NPP accident may have contaminated this debris, substantial discussions were necessary between national and local government, and local populations. To mitigate public concern and to ensure protection of the public from additional exposures, MOE developed a guideline in August 2011 that described the safety strategy for cross-jurisdictional waste treatment, recycling of disaster debris, and safety assessment and monitoring procedures for incineration. Cross-jurisdictional waste management finally started in November 2011 in Tokyo and several other municipalities subsequently accepted this approach [34], [35].

A public desire will naturally arise to restore conditions to normal as quickly as possible, leading to a demand for immediate action.

In the case of a nuclear or radiological emergency, experience has shown that public trust in virtually everyone associated with the event (including nuclear engineers, regulators, decision makers, and associated technical experts) will be diminished as a consequence of the emergency. This is because, fairly or unfairly, such "experts" will be viewed as bearing some degree of responsibility for the emergency. The eroded trust will extend to waste management activities: thus, the challenge will be to gain public participation in, and acceptance of, waste management decisions.

Experience with numerous emergencies has demonstrated that there will be intense public demand for information regarding all emergency and recovery efforts including waste management activities. The demand will be for timely and open sharing of information, data, and context (including frank admission of what is uncertain or is not known yet). Any inability or unwillingness to provide comprehensive consistent data and information, along with context to enable the public to understand the impacts to themselves, others, and the environment, will erode trust further and thereby the ability to take actions to improve the situation.

Identification of contaminated zones in inhabited areas may induce a public expectation for decontamination activities, even in areas that are lightly contaminated. Meeting this expectation will result in generation of larger volumes of waste with low contamination that will need to be managed in compliance with safety regulations.

2.2.3. Technical challenges

Issues associated with the technical resources required for management of waste from a nuclear or radiological emergency will likely produce the following challenges:

- Waste characterization challenges that arise from large volumes, complex composition of wastes, diverse properties, lack of adequate procedures and instrumentation, and lack of radiation protection equipment;
- Lack of, or limited availability or capacity of, equipment and facilities for waste collection, processing, storage, transport and disposal;
- Difficulty of characterizing waste in areas with elevated radiation levels.

Waste characterization serves to provide information relevant to process control and assurance that the waste or waste package will meet the acceptance criteria for processing, storage, transport and disposal of waste [6]. Waste characterization information is essential for design and development of new waste management facilities, or adaptation of existing facilities (e.g. waste processing facilities, disposal facilities). Even normal operations with a predictable waste stream from managed processes require waste characterization information. The additional challenges for characterizing waste following an emergency will be:

- The large volume implies the need for considerable equipment to characterize and process the waste.
- The complex composition, or diverse properties of the waste, will make it very challenging to characterize. Lack of uniformity of the wastes may require additional time to acquire more measurements and samples.
- There may be a lack of adequate procedures and instrumentation in place to support characterization activities (at least initially).
- There may be a shortage of radiation protection equipment (and/or remote handling equipment) to enable the workforce to perform the characterization tasks safely (at least initially).

Similar problems can be expected concerning the limited availability or capacity of equipment and facilities for processing, storage, and disposal of waste. Also, technical limitations may be encountered in decontaminating some resources; for example, contaminated forests have proven challenging.

> **Chernobyl NPP emergency example:** Vast forested areas in Ukraine were contaminated following the emergency at the Chernobyl NPP in 1986. One area, since known as the "red forest", held an area where the trees were killed directly by the intense radiation field. These trees were cut down and buried to manage the radiation risk. However, much larger areas remain where living trees remain contaminated. Given the contamination, logging these trees for forest products is not desirable, and the radiation exposure for logging crews (whether to gather forest products or simply to decontaminate the area)

makes any action problematic. The potential for forest fires to return contamination to the atmosphere through combustion and uplift of particulate matter and smoke remains a serious concern. Consequently, forest fire suppression is one of key elements to mitigate this risk [26].

2.2.4. Endpoint identification

Issues associated with endpoint identification within the context of justification and optimisation of the recovery from a nuclear or radiological emergency will likely produce the following challenges:

- Developing a common understanding of the situation and a common objective (not everyone will want the same outcome) ;
- Building a dialogue regarding the potential options for recovery, as well as their interdependencies;
- Establishing trust of stakeholders, which is central to the identification and selection of accepted endpoints.

Ideally, recovery and waste management need to be implemented in accordance with defined endpoints. The term “endpoints” is used here to express the final configuration of the land area affected by the emergency and all that is contained within it such as buildings and structures. A holistic approach is necessary to develop sustainable waste management strategy considering the interdependencies of different waste management activities. For instance, the selected endpoint for a specific geographic area may be to clean it up to a certain level for unrestricted use by a certain date, while the endpoint for another area may be to dedicate it to permanent use as a radioactive waste disposal facility. The endpoint selected for the first area in this example (cleanup by a given date) would contribute directly to the volume of waste that needs to be disposed of, and hence the size of the disposal facility of the second area (the disposal facility). Identification and selection of endpoints will depend upon the specific context of the emergency and will require a systematic process that balance many considerations as well as input from numerous stakeholders. Achieving a common understanding of the situation (that is, of the nature and extent of environmental degradation resulting from the emergency) including understanding of financial resources required for possible alternative endpoints, will provide the basis for endpoint selection. Considerations will include the necessity of reducing risk to human health and environment (in present and future generations), financial requirements for recovery, financial and cultural value of the resources and property, as well as technical limitations to what is achievable in recovery. In general, stakeholder participation, including the affected population, in identifying, selecting, and accepting the endpoints is essential for achieving success. This participation will contribute to building trust between the parties involved in the recovery process and therefore the waste management activities required to achieve those endpoints.

Zoning of land area is often considered during the emergency response and recovery efforts. This zoning will delineate areas that remain open for unrestricted use, areas that require remedial action to attain a selected land use objective (e.g. unrestricted use; limited industrial use), and areas that are potentially determined to be too contaminated to recover. The spatial extent of these zones can be expected to evolve as recovery progresses. That is, the “footprint” of contaminated areas is reduced progressively as a smaller area becomes devoted to waste management as other areas are recovered for beneficial use.

Hanford legacy production site remediation example: At the Hanford Site, endpoints for remediation were defined by first setting the following high level objectives determined based on public advice [18]:

- "Protect the Columbia River" – stop actual and future contamination of the Columbia River and its uses is viewed as a high priority.
- "Deal Realistically and Forcefully with Groundwater Contamination" – return groundwater to unrestricted use where possible. Restrict groundwater use where necessary, but apply treatment technologies and source removal to enable future use.
- "Use the Central Plateau Wisely for Waste Management" – to facilitate cleanup of the entire Hanford Site waste management needs to be concentrated in the Central Plateau. Minimize the amount of land devoted to, or contaminated by, waste management activities.

To meet these high level objectives, the following goals were established:

(1) Protect the Columbia River
(2) Restore groundwater to its beneficial use to protect human health, the environment, and the Columbia River;
(3) Cleanup River Corridor waste sites and facilities to:
   - Protect groundwater and the Columbia River;
   - Shrink the active cleanup footprint to the Central Plateau;
   - Support anticipated future land uses.
(4) Cleanup Central Plateau waste sites, tank farms, and facilities to:
   - Protect groundwater;
   - Minimize the footprint of areas requiring long-term waste management activities;
   - Support anticipated future land uses.
(5) Safely manage and transfer legacy materials scheduled for offsite disposition, including special nuclear material (including plutonium), spent nuclear fuel, transuranic waste, and immobilized high level waste;
(6) Consolidate waste processing, storage, and disposal operations on the Central Plateau;
(7) Develop and implement institutional controls and long-term stewardship activities that protect human health, the environment, and Hanford Site's unique cultural, historical and ecological resources after cleanup activities are completed.

To achieve these endpoints in an agreed timeline, milestones were established to achieve the final endpoint (FIG. 2).

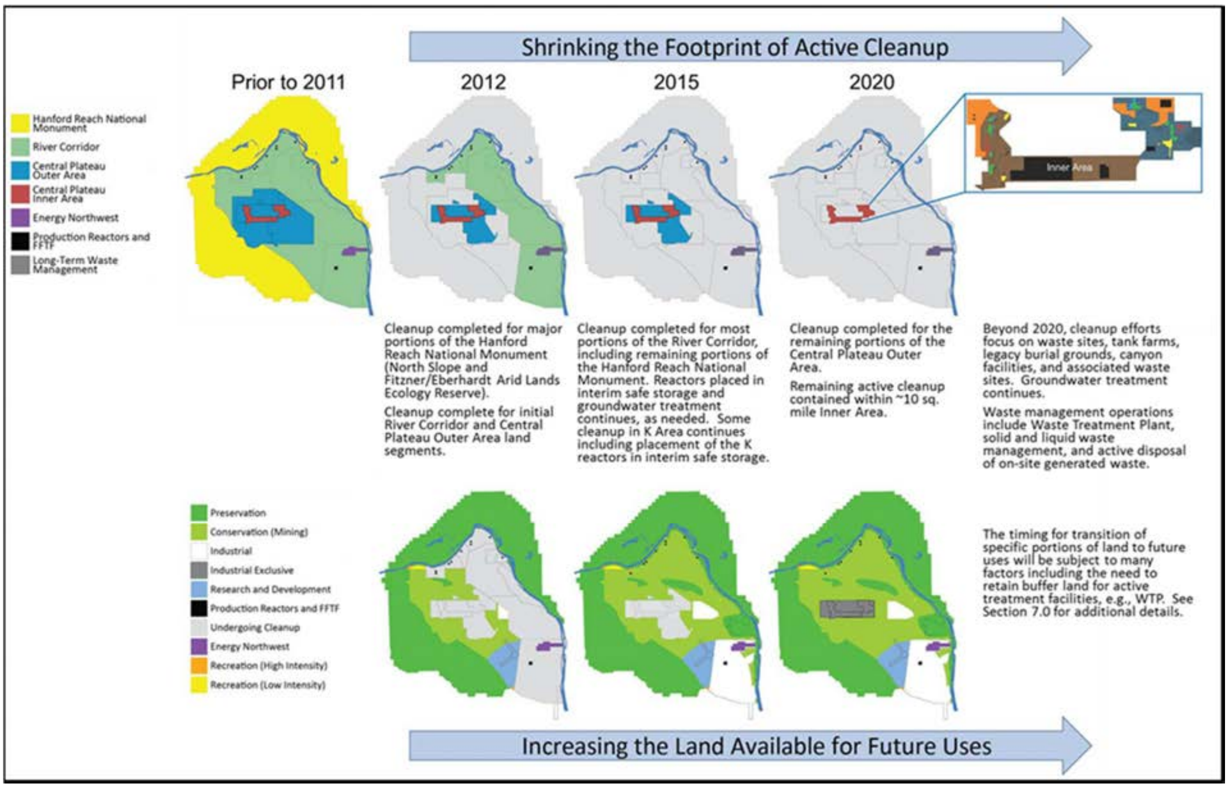

FIG. 2. Milestones for cleanup efforts of the Hanford Site. Reproduced courtesy of United States Department of Energy [18].

In the case of Chernobyl, an initial 30 km exclusion zone was established from where the population evacuated. This zoning was later modified once more after detailed mapping of the environmental contamination became available. This increased information resulted in expansion of the exclusion zone predominantly towards the north and northeast, and to a lesser extent to the west.

> **Chernobyl NPP emergency example:** After the Chernobyl accident, areas with ^{137}Cs contamination density:
>
> - Greater than 555 KBq/m^2 were set as Zones of Implicit (Mandatory) Resettlement;
> - From 185 kBq/m^2 to 555 kBq/m^2 were set as Zones of Guaranteed Voluntary Resettlement [26].

The current exclusion zone is likely to remain in effect for the foreseeable future because the contamination is comprised of a suite of long-lived actinides and the resources required to remediate this land outweigh the current need for recovery. Furthermore a wide range of spent fuel and radioactive waste management facilities are scheduled for construction in this zone.

In the case of Fukushima, a 20 km radius restriction zone was established around the NPPs which was later modified once detailed mapping of the environmental contamination became available.

Fukushima Daiichi NPP emergency example: Following the Fukushima Daiichi NPP accident, a restricted area of 20 km radius was defined during the emergency from where the population was evacuated. Similar to the Chernobyl accident, following more detailed mapping of the environmental contamination, the evacuation order was extended to cover those areas of the deposition footprint from the plume that exceeded a specified criterion. The deposition extended roughly northwest from the Fukushima Daiichi NPPs [14].

The introduction of distinct zones or areas will also likely be established for recovery as discussed in Section 2.2.3, and may have different waste management needs.

Chernobyl NPP emergency example: Different waste disposal needs arose for the guaranteed voluntary resettlement zone (e.g. the "Ripkinskyy" disposal site that was used to dispose of decontamination waste for areas where the population could return) than for the decontamination and onsite waste from the permanent exclusion zone (e.g. the "Buryakivka" disposal site) [26], [36].

Without well-defined endpoints, waste management activities are more likely to be inefficient or ineffective if the cleanup objectives are transient or undefined and will result in greater costs and time requirements. Where endpoints are well-defined but lack public acceptance, waste management activities are likely to incur similar risks.

Additional challenges are imposed if the endpoints require a long time to achieve (for example, several decades or longer), as discussed in Section 2.2.1 as part of time frame challenges.

2.2.5. Regulatory challenges

Issues associated with the regulatory framework and regulations for recovery from a nuclear or radiological emergency will likely produce the following challenges:

- Framework may not exist, or may not be applicable to the waste management activities following an emergency (e.g. lack of regulatory guidelines for using existing infrastructure);
- Overlapping/conflicting regulatory authority;
- Lengthy licensing process;
- Availability and applicability of clearance/exemption process;
- Political inertia;
- Limited availability of regulatory staff with sufficient expertise and skill to provide oversight for waste management activities;
- Difficulty integrating waste management regulation into the recovery effort.

Prime responsibility for ensuring safety of radioactive waste management facilities or activities is placed on generators of radioactive waste and operators of radioactive waste management facilities in the normal situations as is described in IAEA Safety Standards GSR Part 5 [6] and SSR-5 [7]. In addition, the government and the appointed regulatory body have a responsibility to ensure the safety of those activities through appropriate regulatory oversight. The existing regulatory framework for waste management has been largely devoted to the management of radioactive waste generated under normal operational conditions. Such wastes are characterized to establish the need for further treatment or conditioning, or its suitability for further handling, processing, storage or disposal before the licensing of those facilities and activities.

In contrast, waste generated by a nuclear or radiological emergency typically comprises a much larger volume that is distributed over a wide area but with relatively low radioactivity. Responsibility to deal with such waste might be placed to different organizations after emergencies, based on the country's emergency preparedness and response framework [2]. In many countries, the framework for regulating radioactive waste under normal operational conditions is likely to have been developed without consideration to the needs of waste management following an emergency. Indeed, review of past nuclear or radiological emergencies has shown that a regulatory framework developed for management of radioactive waste under normal operational conditions is often not applicable to waste management needs following an emergency.

Adding to this challenge, regulatory authority of multiple agencies may overlap, or even some of their regulations may be in contradiction. Where this is only discovered following an emergency, the time required to resolve such conflicts will present a major challenge to the timely execution of necessary waste management activities.

Fukushima Daiichi NPP emergency example:

The Fukushima Daiichi NPP accident led to a number of modifications of the nuclear safety regulatory authorities in Japan including those with responsibility for the regulation of radioactive waste management. Following the accident, the Japanese government established new legislation clearly defining responsibilities for off-site waste management since this aspect was not addressed in the national legal framework before the accident. The Ministry of Environment (MOE) was appointed as the responsible body to develop the necessary acts and to implement off-site remediation activities.

The Act on Special Measures concerning the Handling of Environmental Pollution by Radioactive Materials Discharged by the Nuclear Power Station Accident Associated with the Tohoku District – Off the Pacific Ocean Earthquake that Occurred on March 11, 2011 [37], [38] was established in August 2011 to promptly reduce the impacts of environmental pollution by instituting measures taken by interested parties: especially the national and local governments and the relevant licensee of NPP (i.e. Tokyo Electric Power Company). In accordance with the act, MOE developed basic principles and standards for remediation and contaminated off-site material including soil. Because no regulations previously existed for radioactive or contaminated waste arising from off-site activities, the MOE also defined new waste streams and provided guidelines on how to deal with each waste stream in the standard [39].

Hanford Legacy Production Site remediation example: Before the remedial effort could commence, it took significant time to find consensus between the U.S. Department of Energy (US DOE), as responsible party, and the U.S. Environmental Protection Agency and Washington State Department of Ecology, as joint regulators. These three agencies negotiated and agreed to the Hanford Federal Facility Agreement and Consent Order (commonly known as the Tri-Party Agreement). The purpose of this agreement is to achieve compliance with the U.S. Comprehensive Environmental Response Compensation and Liability Act (CERCLA) remedial action provisions and with the Resource Conservation and Recovery Act (RCRA) treatment, storage, and disposal unit regulations and corrective action provisions. More specifically, the Tri-Party Agreement 1) defines and ranks CERCLA and RCRA cleanup commitments, 2) establishes responsibilities, 3) provides a basis for budgeting, and 4) reflects a concerted goal of achieving full regulatory compliance and remediation with enforceable milestones in an aggressive manner. Lead regulatory authority over different elements of the cleanup was delegated to each agency, performed in consultation with the other agencies [40].

As mentioned above, there are notable differences in the characteristics and rate of generation of radioactive waste for normal operational conditions and from an emergency situation. Under normal operational conditions, a long regulatory process is widely accepted to provide the desired level of assurance of the safety of radioactive waste management activities and facilities. This is because safety is paramount, and typically time is available to provide this evaluation before waste is treated or disposed. In contrast, such a long licensing process might not be applicable for waste management following an emergency due to its time constraint. In such situations, different licensing approach might be necessary in order to implement waste management activities in timely manner without compromising the safety.

Where a large volume of waste is produced following a nuclear or radiological emergency, there may be immense benefit from being able to use clearance and exemption criteria to reduce the quantity of material that needs to be managed at facilities specially designed for radioactive waste. This will be challenging to accomplish where the regulatory framework does not include provisions for clearance and exemption, or if the framework includes clearance and exemption criteria that are inapplicable to the post-emergency situation.

Political inertia may hinder progress in recovery as well. For an emergency that produces a large volume of radioactive waste and contaminated material, recovery will be likely to require a national commitment to provide funding and resources supported by political decisions. Political inertia may also manifest itself in the reluctance to prepare for a nuclear or radiological emergency in advance, although such preparation is required in Requirement 15 of GSR Part 7 [2].

Another challenge that can be anticipated will be the limited availability of regulatory staff that possesses sufficient expertise and skill to provide the necessary oversight for waste management activities. Where budgets and planning are aimed at the normal operational situation, providing additional oversight to ensure safe and compliant waste management activities following an emergency will require enhancing the capacity of the country's regulatory function to meet this demand.

Finally, there will be a challenge presented by the difficulty of integrating all the various aspects of the recovery effort, including waste management.

2.2.6. Challenges on management of activities

Issues associated with the management of activities related to recovery from a nuclear or radiological emergency will likely produce the following challenges in addition to those faced in any complex project:

- Responding to prioritized goals of the emergency response requiring urgent decisions, while taking account of waste management aspects and needs of a longer-term waste management;

- The recovery from an emergency resulting in large volumes of waste exceeding the capabilities of existing waste management infrastructure and frameworks thus making integration of waste management activities within overall recovery difficult;

- Difficulties in establishing an effective management system that considers the evolving nature of the situation and the recovery in all aspects such as decision making in a timely manner, communication and information exchange, and for providing timely communication of status, decisions, and progress.

It is expected, and appropriate, that early in the emergency response, priority on making necessary decisions, and taking necessary protective and other response actions will be aimed at regaining control of the situation and protecting workers and the public. There are decisions that will need to be made in this time frame that may impact waste management, but because of the urgency of the situation, consideration may not be given to their long term consequences for waste management. However, there may be cases where better choices could be made with regard to waste management that do not impair the emergency response – but the urgency of the situation leaves these opportunities for improvement unconsidered. The challenge, then, is to keep waste management considerations in mind during this urgent time frame at the preparedness stage as one input to the overall processes for justification and optimization of the protection strategy for this period of time so as to reduce the negative impact on the waste management activities, as required in in Ref.[2].

Existing facilities and activities might be available to help manage radioactive waste following an emergency – but likely the challenges posed by the volume of the waste or by its complex composition will exceed the capacity of the existing system. In these cases, the challenge will be to evaluate expeditiously and upgrade the safety basis and capacity of such facilities, if possible, to help cope with the recovery needs.

Overall, the challenge will be to quickly establish an effective system to manage waste during the recovery that can facilitate timely decision making, coordinate performance of recovery work (including waste management), and communicate the project status, decisions, and progress toward endpoints with a frequency that meets stakeholder and public needs.

2.2.7. Challenges on information and data management

After an emergency, a lot of activities related to waste management need to be planned and implemented quickly. In situations with strong time pressure, these activities may need to be conducted without thorough consideration on the impact or interdependencies between subsequent waste management steps, which might lead to the loss of important data and information on waste or related activities. In such situations, issues associated with information and data management following a nuclear or radiological emergency will likely produce the following challenges:

- Identification of critical data to acquire for waste management purposes and their quality assurance requirements;
- Collection, review, and organization of the data;
- Retention of the data;
- Interpretation of the data to promote understanding;
- Prompt access to and dissemination of the data.

Data are the key to effective planning and performance of recovery and the participation of concerned parties. Because of the urgency (as discussed in Section 2.2.1), challenges will arise in shorter time frames in terms of identifying which data are critical to collect and retain, and in ensuring that consistent data collection occurs that meets quality assurance requirements. As discussed in Section 2.2.2, there will likely be intense public demand for timely, consistent information with context which will be challenging to provide. Because recovery, and therefore waste management, will be likely to occur over long period (as discussed in Section 2.2.1), long term data retention and accessibility also presents a significant challenge.

> **Chernobyl NPP emergency example:** The Radioactive Waste Burial Facility (RWBF) Buryakivka was designed shortly after the Chernobyl accident and constructed in 1987. Forced by the lack of more suitable storage and/or disposal options, disposal of waste with dose rates of up to 5 R/h (50 mSv/h) was permitted for a restricted period, even though the facility was not designed for this type of waste. Information on the characteristics of the disposed waste was not retained and presents a major challenge for assessing performance of the facility [26].
>
> In addition to Buryakivka, hundreds of interim storage facilities were created after the Chernobyl accident in 1986 – 1987. However, the inventories and characteristics of waste disposed in these facilities is not well known. As a result, significant efforts were required to reassess the safety of these facilities, including waste retrieval or reconstruction of facilities [41], [42].
>
> **Fukushima Daiichi NPP emergency example:** In order to facilitate waste management activities associated with contaminated material arising from off-site area, the Ministry of Environment prepared Waste Related Guidelines [43]. These guidelines were developed in order to provide a concrete and simple explanation of the laws and regulations as well as concrete methods on the investigation, storage, collection, transport and disposal of waste polluted by radioactive materials caused by the accident, to parties such as waste generators and parties who conduct waste treatment, including municipalities, etc. This document also provides guidelines on data collection and record keeping associated with waste arising from remediation or other activities.

2.2.8. Challenges on management of workforce and financial resources

Issues associated with the workforce and financial resources for the recovery from a nuclear or radiological emergency will likely produce the following challenges:

- Limited availability of technical experts;
- Limited availability of a trained workforce;
- Finite availability of financial resources.

The limited availability of specialized expertise and a trained workforce will pose key challenges for waste management. These human resources will be needed urgently during recovery to plan, implement, and perform waste management activities. These activities will include characterizing, segregating, and treating/processing, transporting and storing waste, as well as designing, licensing, constructing, and operating waste management facilities. Further activities will be related to disposing of waste.

As noted in Section 2.1.4, recovery and waste management for an emergency involving significant contamination of the environment with radioactive material will require considerable financial expenditures to accomplish the necessary recovery work. A key challenge will be obtaining the necessary financial resources. Thus, some mechanisms for securing some part of the necessary funding could be discussed and adopted prior to a nuclear or radiological emergency in order to ease the decision making process.

3. PREPARATION FOR EXPECTED WASTE MANAGEMENT CHALLENGES

Experience shows that recovering from a nuclear or radiological emergency is likely to require massive efforts and will differ significantly depending on the nature of the emergency and the national, local and site-specific circumstances. Nevertheless, there are several key aspects about an emergency that can be anticipated and used to provide the basis for preparedness and in doing so to facilitate recovery.

Experience also shows that recovery activities tend to be highly complex because of many interrelated aspects to recovery. Endpoints based on the future land use will need to be determined based upon the geography (e.g. agricultural land, forest or residential area) and population of the impacted areas. Furthermore, endpoint and recovery time frames will be influenced by contamination levels, the associated hazards to public health and the environment, and the availability of resources needed to accomplish the goals determined for those elements. Therefore, establishing clear decision making processes that involve affected populations and other stakeholders is important to facilitate recovery.

As time passes from the onset of an emergency, issues related to waste management will be recognized as central to affecting the progress of the recovery. Since waste generation is unavoidable during the massive recovery activities, it is important to recognize that waste management needs to be integral to the recovery process.

Based on this recognition, this chapter describes preparatory activities to be taken as part of overall emergency preparedness that would help reduce some of the difficulties in recovery and associated waste management activities in the aftermath of an emergency, which are categorized into 9 topics. Appendix II summarizes the relationship of challenges identified in Chapter 2 and proposed reparatory actions, which is addressed in the following sections.

3.1. ROLES & RESPONSIBILITIES

Experience has shown the importance of pre-defined roles and responsibilities for emergency response and recovery activities, including waste management activities, and of coordination as required in Ref.[2]. This aspect will be highly dependent on the country, region, cultural traits, political system, and regulatory framework, among other things. It is also widely acknowledged that a single body (e.g. a NPP operator) cannot tackle the whole spectrum of recovery actions; hence, government involvement is inevitable.

> **Chernobyl NPP emergency and Fukushima Daiichi NPP emergency examples:** Both in Ukraine and Japan, major organizational changes and new roles related to remediation and associated waste management were required soon after the accidents. These formed the basis of a national framework to move proactively towards recovery [26], [38].

As is required in GSR Part 1 [44] and GSR Part 7 [2], it is the responsibility of the national government to make provisions for an effective framework for safety and to ensure the roles and responsibilities for preparedness and response to a nuclear or radiological emergency are clarified. It is also necessary to coordinate and ensure consistency among the emergency arrangements of the various response organizations, operating organizations and the regulatory body at local, regional and national levels. For a nuclear emergency associated with nuclear facilities such as NPPs, coordination between onsite and offsite waste management activities throughout the recovery would be advantageous to facilitate effective and efficient implementation of waste management.

> **Fukushima Daiichi NPP emergency example:** Offsite waste is managed by Japan's Ministry of Environment, whereas onsite waste is managed by TEPCO (as NPP operator) and Nuclear Regulation Authority (NRA) (as regulator); because these waste areas are managed and regulated independently, this created additional challenges [45].

In order to facilitate timely actions regarding waste management, it is important that the roles and responsibilities of government (local, regional and national) and government agencies are established prior to an emergency, which include:

- Management of the planning and implementation of overall recovery and waste management activities at the appropriate level of government, and coordination between all levels of government;
- Taking control and ownership of damaged plant from operators and off-site contaminated land from property owners, and to provide compensation, if this is needed to advance recovery;
- Providing financial and technical support to waste management;

- Procedure for reassigning existing internal resources to streamline and expedite waste management activities, and identification of additional capacity if required;
- Keeping the public informed through strategic messaging and working with all other stakeholders to provide timely information on waste management activities.

  Finnish example: Finland began to consider the potential need to manage very large volumes of waste after a nuclear or radiological emergency as a result of training and planning exercises such as INEX 3[1]. The regulatory authority STUK issued a report in 2008 that recommended waste management be incorporated into emergency planning, and that existing national and regional waste disposal plans recognize the potential impacts of emergency situations. The report further recommended that contracts contain clauses that could be invoked in emergency situations and that monitoring and waste registries be established [46].

National government can facilitate recovery and waste management activities in urban and rural communities by establishing the framework and social infrastructure necessary to engage the appropriate department and agency capabilities to support local recovery efforts. This could include leveraging the necessary resources to rehabilitate communities. In addition, mechanisms for securing some part of the funding needed for waste management activities related to an emergency could be discussed and adopted prior to an emergency in order to ease the decision making process.

In many cases, the role of stakeholders, especially the population living in contaminated territories, has been acknowledged as a key factor for success in recovery programmes. Even with the best efforts, the national government will not be able to tackle the whole range of waste management activities needed in recovery. This is all the more challenging when time is limited and the affected territories are wide and geographically various. As a matter of fact, local governments are more connected to local population needs, and questions, and this close connection helps in setting the goal for waste management in the recovery efforts.

The efforts of local government are often targeted at residents' everyday life in a recovery situation. Experience has shown that recovery can be performed relatively smoothly when local people are able to remain in a territory affected by the emergency so long as it is demonstrated to be sustainable in the long term. The benefits of this sustainability not only relate to health issues but also economic prosperity, social relationships, public service, cultural assets, psychological aspects, etc. For this reason accurately understanding the fears, needs and priorities of local residents is paramount during recovery. Even so, this understanding may not be enough: efficiency in the waste management programmes also depends on trust between actors (see Section 3.9). A clear and shared vision of roles and responsibilities, from national government to the individuals, therefore needs to be anticipated as a key milestone to be achieved, should a nuclear emergency occur.

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[1] The INEX series of international nuclear emergency exercises, organized under the OECD Nuclear Energy Agency's (NEA) Working Party on Nuclear Emergency Matters (WPNEM), have proven successful in testing, investigating and improving national and international response arrangements for nuclear accidents and radiological emergencies. The INEX-3 series of consequence management exercises was established to help NEA member countries better manage their response in the latter phases of a nuclear emergency and took place in 2005-2006.

In summary, in order to address the impacts of a future nuclear or radiological emergency in a targeted way, the following preparatory actions can be taken:

- Define roles and responsibilities for all parties that will be involved in the recovery, including those carrying out waste management;
- Designation of a leading authority would provide important advantages.

3.2. ADAPTIVE STRATEGIES FOR WASTE MANAGEMENT

As described above, efforts for preparedness made in advance of an emergency will help facilitate recovery. However, before beginning detailed preplanning, it would be beneficial for Member States to consider the overall strategy to be pursued for managing waste resulting from a nuclear or radiological emergency. While ensuring safe disposal is the ultimate objective, it is important to understand the many steps involved in the overall waste management process, how they may depend upon one another, and how the availability of technical, financial, and regulatory resources can affect the timing of the different steps. This understanding is useful for identifying areas that need to be emphasized in preplanning.

Strategies are developed by organizations charged with achieving recovery objectives. Initial actions taken upon declaration of the emergency and those based on the early monitoring and mapping efforts are commonly aimed at prompt protection of the population (e.g. evacuation, relocation, etc.) rather than long term recovery. By necessity, some decisions needs to be made quickly in order to protect the population and to regain control of the situation. Such decisions may not be optimal with regard to the long term management of waste, but necessary to meet the immediate objective of mitigating the consequences of a nuclear or radiological emergency and protecting individuals. As the emphasis shifts from emergency response to long term recovery, the primary focus of activities will change and the overall strategies towards achieving the agreed endpoints will need to be refined accordingly.

Protection strategy and recovery actions will likely include several of these elements:

- Land zoning to delineate areas that remain open to unrestricted use, areas that require remedial action, and areas too contaminated to allow access (noting that such zoning can change as recovery progresses, including prioritization of recovery activities);
- Restrictions on use of agricultural products and natural resources from affected areas, and the transport of people and materials into and out of the affected areas;
- Use of decontamination technologies for agricultural, industrial, residential, and natural areas;
- Natural attenuation through radionuclide decay and weathering effects;
- Lifestyle modifications to further reduce exposures.

The combination of elements selected in the strategies has direct implications for the production of waste that needs to be managed.

Chernobyl NPP emergency example: Norway was the country outside the former Soviet Union that experienced the greatest contamination. The most important radionuclides for agricultural products were ^{134}Cs and ^{137}Cs. In 1986, 10% of lamb and mutton (2,300 tons), and 27% of reindeer meat (545 tons) was classified as not fit for human consumption because it contained above 600 Bq kg^{-1} and 6000 Bq kg^{-1}, respectively. Most of this meat was used as feed for fur animals and the most contaminated meat was destroyed [47].

In Germany, about 5,000 metric tons of milk powder (so-called whey) contaminated with ^{134}Cs and ^{137}Cs was banned from use in the food industry and/or as feed for animals. The political decision was made to decontaminate the milk powder and a facility was constructed and operated in the northern part of Germany for this sole purpose. The decontamination process yielded 44 m^3 of radioactive waste, i.e. immobilized ion exchange resins, with an activity of about $8{,}0 \times 10^9$ Bq, that was disposed of in the Morsleben disposal facility [48].

Therefore, when developing the protection strategies, it is important to consider waste management aspects as well. Also, strategies and plans need to be flexible so that they can be adjusted to accommodate changes in recovery activities and the overall strategies towards achieving the agreed endpoints.

When preplanning the waste management aspects in relation to the strategy for recovery, one key issue is how to predetermine the appropriate time frame for waste management in recovery plans.

For example, if a Member State determines that it has the necessary resources, experience, and infrastructure, it may choose to adopt a strategy leading to relatively rapid disposal. In such a case, preplanning of waste management would place greater emphasis on those aspects of disposal, such as: one or more disposal facility concepts, standard licensing review procedures, identification of capacity of existing waste management facilities that could safely be adapted or expanded, or identification of potentially suitable regions for siting of new facilities. For preplanning such aspects, the use of postulated scenarios of a nuclear or radiological emergency in accordance with GSR Part 7 [2] and the identification of possible recovery activities could be a basis for developing a generic strategy for recovery actions after an emergency.

On the other hand, a Member State may determine to store waste until a decision of disposal site or releasing of material from regulatory control is made by satisfying all of its internal concerns related to siting, construction, and licensing. In such a case, preplanning would place greater emphasis on interim management sites or facilities. Preplanning for interim management (e.g. storage and processing) would ideally address topics such as location criteria, construction standards, and operational practices. In addition, the level of preparatory activity will also depend on the size of national programme for which emergency planning is necessary, as well as the national waste management strategy. Some Member States may decide to prepare or even to pre-authorize basic design of waste management facilities, while other Member States may not.

In any case, it is important to recognize that any plans prepared ahead of time will need to be modified to the actual situation.

Figure 3 illustrates various aspects to be considered in preplanning the management of waste arising from an emergency. The strategy for these needs to include objective-driven endpoints and recovery time frames that will be identified for the contaminated area taking into account the waste involved and the related threats to public health and environment. Every recovery action relies on the availability of appropriate resources (financial, human and other) to accomplish the chosen objectives.

French CODIPRA doctrine example: French approach: In 2005, at the request of the French Government, the national directorate for nuclear safety and radiation protection (DGSNR), which has since become the nuclear safety authority (ASN), established a steering committee for the management of the post-accident phase of a nuclear accident (CODIRPA). This committee involved the wide range of stakeholders affected by post-accident management, such as public authorities, operators, associations, experts, etc. The work of CODIRPA focused on four guiding principles to manage a post-emergency situation: preplanning activities; justification and optimization to reduce public exposures; and stakeholder input to the decision making process. A spatial zoning of the territory based on environmental contamination levels is employed for planning purposes and waste management is recognized as an important theme.

CODIRPA defines a waste management scheme that considers waste streams and endpoints. A distinction is made between actions to be carried out in the days and weeks following the emergency (collection, packaging, transport, buffer storage), and other actions that are to be carried out over longer time-spans (waste processing, storage). The close relationship between decontamination methods, waste volumes and waste streams is recognized. Waste management close to the location of the emergency is a principle applied by CODIRPA and is aimed at limiting the transfer of contaminated materials beyond the contaminated territory. However, CODIRPA also envisages the use of preexisting facilities for the management of contaminated waste. The selected management solutions – especially those, which concern contaminated waste – need to be sufficiently versatile to allow the gradual transition from temporary solutions to a long term solution [49].

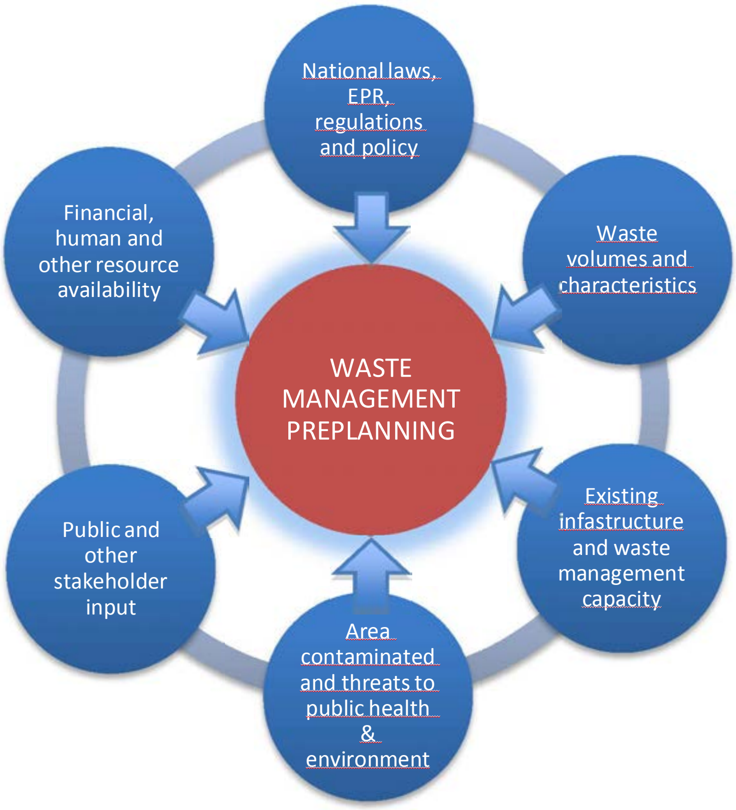

FIG. 3. Key inputs for preplanning activities relevant to waste management following an emergency.

Further details regarding development of a preplan are given in ANNEX I, together with an example.

In sum, in order to facilitate prompt recovery actions without adversely affecting associated waste management activities, following preparatory actions can be taken:

- Preplanning of waste management activities to facilitate their prompt implementation. It is beneficial to consider overall protection strategy before conducting detailed preplanning activities;
- Preplanning of waste management activities based on applicable national laws, regulations and policies in the overall framework of the national emergency preparedness and response;
- Significance of the elements illustrated in Figure 4 may differ in each emergency; however, preplanning adopting flexible, step-wise approach will help identifying national capacities to deal with the situation and possible needs to build additional capacity after the emergency.

3.3. WASTE MINIMIZATION

Remedial activities following an emergency result in the generation of large volumes of contaminated materials of complex composition. When selecting a waste minimization strategy in remedial action, this may be accomplished through:

- Minimize the amount of waste through a balanced selection of cleanup criteria;
- Minimize the amount of waste through selection of remediation techniques;
- Optimize possibilities for reuse, recycling, and/or disposal to non-radioactive waste management facilities (which may require a clearance/exemption process);
- Use volume reduction technologies (incineration, compaction, evaporation, etc.).

The selected endpoints for remediation will have a direct impact on the volume and characteristics of waste that needs to be managed. For example, cleaning areas with very low levels of contamination to background concentrations could result in enormous volumes of low-activity waste. Hence, it is important to consider the waste management consequences in conjunction with other criteria when selecting endpoints for recovery. A hierarchy of waste management decisions exist which will determine the volume and characteristics of the waste to be managed (see Figure 4).

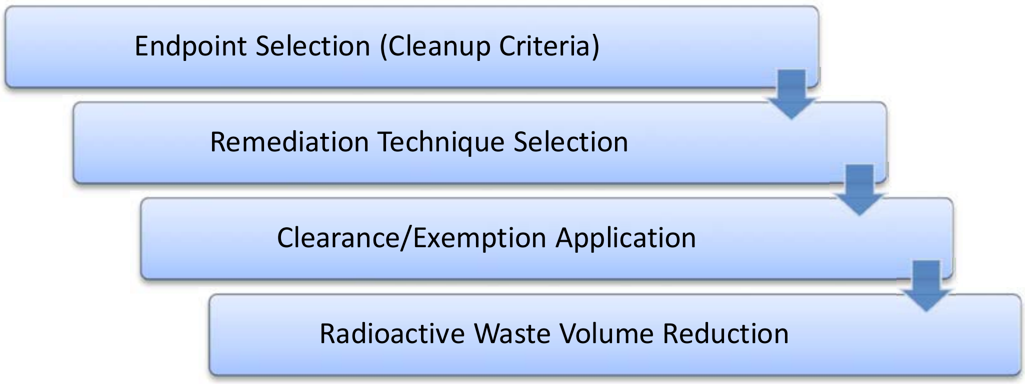

FIG. 4. Hierarchy for waste minimization approach.

The chosen remediation techniques selected will impact the volume and type of waste to be managed. Careful selection of remediation techniques can reduce the volume of waste requiring disposal. For example, various cleaning and abrasive methods can be used to remove surface contamination from metal and concrete debris, allowing the conditioned material to be released from regulatory control. Where possible, liquid decontamination methods is better to be avoided if there is no suitable system for handling contaminated water, and to avoid the risks of leaks and spills. In some cases, deep tillage (inverting the topsoil to move the surface deposition of contamination into the subsurface) may be a technique to consider if future agricultural use of the land is not intended. Also, various soil washing and related screening systems have been used to treat lightly contaminated soils. By managing the contamination "in place" in this manner, vast volumes of contaminated soil may not require management as radioactive waste.

Once waste is generated, waste volume reduction through incineration, compaction, evaporation, or other means needs to be sought as the next step. The safe and timely application of such waste reduction process can be achieved by utilizing existing infrastructure. Therefore, preplanning for provision or adaptation of existing infrastructure to accomplish this is advisable. Further discussion on adaptation of existing infrastructure is given in Section 3.5.

Clearance and exemption concepts are also measures that can be used to reduce the amount of waste that needs to be managed as radioactive waste. In general, a material that is contaminated below a clearance level does not present a significant radiological hazard and does not need to be controlled under radiological safety regulatory regime. Although it may still be subject to control under conventional waste regulations, application of clearance and exemption schemes will also allow disposal of cleared/exempted waste in non-radioactive waste disposal facilities.

Some countries have a regulatory framework that allows for clearance or exemption of radioactive material. In a recovery environment, however, such regulatory frameworks may not be applicable simply because they were designed for authorized practices in normal situations.

> **Fukushima Daiichi NPP emergency example:** A clearance system exists and has been utilized for nuclear reactors. Three months after the Fukushima Daiichi NPP accident, the Japanese Nuclear Safety Commission issued advice concerning its application for recycling of offsite waste [50].

For countries that lack clearance/exemption of radioactive material in their regulatory framework, consideration could be given to the benefits of including such criteria in their regulations to support recovery as discussed in Section 3.4.

Related to clearance and exemption is the concept of reuse and recycling of wastes. These concepts are used widely in normal situations, where some materials can be repurposed within radiological facilities to avoid waste generation while gaining beneficial use of the materials. Some examples of reuse /recycling could be: the use of fly ash from low-level waste incineration or slightly contaminated concrete debris in road construction or in construction of cementitious facilities for waste storage or disposal.

> **Fukushima Daiichi NPP emergency example:** The Ministry of Environment proposed controlled recycling of disaster waste in Fukushima Prefecture in December 27, 2011 [51]. Furthermore, a document describing basic principles related to recycling of construction by products was issued by the Government of Japan in October 25, 2013 which applies to public works in Fukushima Prefecture [52]. The document describes basic principles as well as guidelines including contamination levels suitable for recycling, background level, protection of workers and public from additional exposure.

In sum, in order to reduce the amount of waste that needs to be treated as radioactive waste, the following preplanning actions can be taken:

- If clearance and exemption thresholds, and techniques used to demonstrate compliance with these thresholds, are already present in regulations, evaluate their applicability in the context of recovery. If a regulatory path for consideration of reusing and/or recycling of materials produced during recovery activities does not yet exist, consider including one in the regulatory framework [53].

- Investigate potential alternatives for waste volume reduction through in-place management of contamination and discuss these alternatives with relevant stakeholders (e.g. companies to be engaged in future for roads constructions may volunteer to take the fly ash and use it).

3.4. REGULATORY FRAMEWORK AND PROCESS

As is described in IAEA Safety Requirements GSR Part 1 and GSR Part 5, the regulatory body appointed within the national legal and regulatory framework is responsible for establishing or adopting regulations and guides to specify the principles, requirements and associated criteria for safety [44]. The regulatory body is responsible for establishing regulatory requirements specific to the management of radioactive waste, on the basis of national policy and legislation [6], which is usually developed for waste management during normal practices without consideration of potential impacts on waste management following an emergency.

Although the safety objectives and the fundamental safety principles established in SF-1 [54] are fully applicable to waste management activities for both normal operations and after an emergency, the regulatory framework and regulations appropriate to those situations might require adjustment due to the reasons mentioned in Chapter 2.

Past experience has shown that recovery action including waste management could be delayed or poorly performed because of the inadequacies of the regulatory framework and regulations that are applied to such activities after emergency. In some cases, activities related to waste management may be necessary before the regulatory framework and regulations are developed or revised to cope with the situation and oversight of these activities. Quick recovery of appropriate regulatory oversight is critical to rebuild public trust and to ensure long term safety of activities.

In order to be well prepared for potential changes to the regulatory framework and regulations, it is beneficial to consider the following provisions including:

- Measures to initiate recovery and waste management activities in a timely manner without compromising safety;
- Identification of facilities and activities (e.g. segregation, storage, transportation) for waste management that could receive accelerated regulatory approval during recovery action;
- Development of a licensing process for waste management including clarity on what decisions and activities need formal approval by a regulator before they can be implemented, and which do not (e.g. disposal usually requires prior authorization but packaging waste for interim storage may or may not);
- Measures to ensure safety and radiation protection of the workforce involved in recovery action;

- Measures to ensure waste characterization is performed promptly and is compatible with the long term safety.

As discussed later in Section 3.5, preplanning for initial waste management activities (e.g. collection, segregation) will help resume normal waste management procedures more quickly following an emergency, possibly even in the emergency phase. Pre-licensing of such facilities and activities, or having established a dialogue between regulator and implementer on this topic, will be beneficial in order to mitigate some of the detrimental consequences that can arise from lack of consideration of the longer-term consequences on waste management.

As part of the preplanning, it is important to consider the impact that large volumes of waste of complex composition, arising within the public domain will have, and the need to manage this waste safely, efficiently and effectively. This requires recognizing the potential for such a situation to exist, how it might be accommodated, if at all, within the current regulatory and waste management framework, and evaluating how this would be addressed. Careful consideration of existing regulations is advisable to identify any obvious impediments to recovery and waste management activities, as well as to identify any inconsistencies in the management of similarly contaminated materials from different sources.

Considering the huge volume, time constraint and other factors described earlier, introduction of clearance and exemption schemes is beneficial to minimize the quantity of material requiring management as radioactive waste [12]. The government or regulatory body need to determine which practices or sources within practices are to be exempted from some or all of the safety requirements. The way in which these determined values need to be incorporated into national regulatory requirements will depend on the particular regulatory approach adopted. One approach may be to use these levels in the definition of the scope of the regulations. Another approach may be to use the levels to define radioactive material for the purposes of the regulations. The regulatory body shall approve which sources, including materials and objects, within notified practices or authorized practices may be cleared from regulatory control. Verification of the values of those sources needs to be based on a procedure that is acceptable to the regulatory body, by prior approval or on application [12], [55] . The exact threshold used for clearance and exemption scheme might not be set up in advance of an emergency due to lack of actual information about the waste. Nevertheless, it is beneficial to consider as part of preplanning how the concept of clearance and exemption can be utilized for waste management after an emergency, though it might also need to consider changing options for clearance on the basis of actual circumstances.

The option of unconditional clearance requires taking into account all possible exposure pathways in the derivation of the clearance levels, irrespectively of how that material is used. Alternatively, if the unconditional clearance is not feasible or efficient in some circumstances, conditional clearance might become an option. In this case, only limited exposure routes and materials have to be considered when deriving the clearance levels, in which site specific data and purpose of release can be introduced in the calculations [53], [56].

In summary, in order to ensure effective and safe waste management following an emergency, the following provisions for regulatory actions can be taken:

- Evaluate applicability of existing regulatory framework and regulations for waste management after an emergency. It may be decided that a different regulatory framework needs to be developed that allows for more rapid decision making.
- Determine waste management facilities and activities which need to be notified or authorized and develop a licencing process for them that is prompt but does not compromise long term safety –one expected solution could be done by pre-licensing of standardized facility design.
- Consider enhancing the competency and capacity for regulation in relation to waste management following an emergency.

3.5. APPROACH TO SAFETY

In the field of radioactive waste management, development of a safety case is an internationally accepted and widely used concept for safety demonstration of waste management facilities and activities as described in references such as IAEA Safety Requirements GSR Part 5 and SSR-5 [6], [7].

The safety case is the collection of scientific, technical, administrative and managerial arguments and evidence in support of the safety of a waste management facility or activity, covering the suitability of the site and location and the design, construction and operation of the facility, the assessment of radiation risks and assurance of the adequacy and quality of all of the safety related work associated with the facility or activity. The safety case and supporting safety assessment provide the basis for demonstration of safety and for licensing. They will evolve with the development of the facility or activity, and will assist and guide decisions on siting, location, design and operations. The safety case will also be the main basis on which dialogue with interested parties will be conducted and on which confidence in the safety of the facility or activity will be developed [8].

Those functions of the safety case are also very important to demonstrate the safety of the waste management facilities and activities following an emergency. However, evaluation of past emergencies indicates that frequently tension exists between the need for urgent decision making to reduce radiological risk and the extent of safety demonstration that occurs before and while the action is taken. During the emergency, mitigation of immediate consequences of radiological contamination is the highest priority. Some waste management challenges inevitably arise during the emergency phase and some arise during the recovery. The solution to this challenge may need to be reached without waiting for development and authorization of a full-scale safety demonstration considering protection of present human health and the environment, and economic and political factors.

Past experience shows the needs of staging including temporary storage of waste generated soon in an emergency.

> **Chernobyl and Fukushima Daiichi NPP emergency examples:** After both the Chernobyl and the Fukushima Daiichi NPP accidents, conceptual designs for storage sites were urgently sought, while recognizing the wide variety of “facilities” (mostly temporary

storage sites: trenches, open-air lots, holes…) that arose out of necessity from day one [1], [26].

Even though the time available for developing such temporary storage facilities may be limited, their longer term (years to decades) safety has not be overlooked because of the uncertainty about the time required to return to a normal waste management situation. This is because experience demonstrates that some storage sites or de facto “disposal” sites may remain in use for much longer period than initially anticipated.

Chernobyl NPP emergency example: Storage points which were constructed soon after the accident with the intention of short-term storage have still been used after 25 years since the accident [26].

The length of time required to develop a safety case for normal waste management facilities presents an added challenge especially given the anticipated time constraints. Consequently, it is advantageous that some activities are performed as part of preplanning including: clarification of site selection/exclusion criteria suitable for such facilities and developing conceptual designs. Ideally, a pre-designed concept would be developed, supported by a regulatory framework suitable for the post-emergency situation.

During the development process of pre-designed facilities, the concept of the safety case may be applied. By developing a generic or preliminary safety case in advance, the normal waste management process can be adapted after an emergency occurs, based on the real inventory and other detailed information, thus accelerating licensing and authorization without compromising the safety objective.

Since the volume of waste arising from an emergency could overwhelm the existing capacity of radioactive waste management facilities, utilization of existing infrastructure for the purpose of volume reduction (e.g. incineration) and others will be useful. If the national strategy considers utilization of existing infrastructure which is not originally designed for the purpose of dealing with radioactive material, it is inevitable to evaluate the safety of such activities (utilization of existing infrastructures) and take necessary measures to improve the safety. Such evaluation could be done as part of preparedness.

Some Member States may already have existing disposal facilities supported by a safety case that can be adapted to manage waste arising from an emergency. Others may need to develop disposal facilities. In either case, comprehensive guidance for development of the safety case for disposal is provided by the IAEA [7], [9], [10], [57]. It is anticipated that the safety case of disposal facilities can be developed under the customary deliberative and measured approach applicable to the normal situation. That is to say, the safety case for disposal will not need to be developed with the same urgency as predisposal, especially if the Member States select deferred disposal as the national strategy.

In summary, though the methodology for safety demonstration and its validation and authorization scheme may differ from normal waste management activities, many preparatory actions can be taken in order to realize waste management activities with sufficient level of safety even after an emergency.

French CODIPRA doctrine example: CODIRPA applies the principle of management "closest to the source" in order to limit the transport of waste, to reduce the extent of contamination, so that the location of storage facilities, Incineration and possibly repositories shall be provided inside the Zone of Protection of Population (ZPP), where the population is still there. On the other hand, CODIRPA envisages the use of facilities existing prior the accident for the management of contaminated waste. With this in mind, CODIRPA considers appropriate to study the regulatory instruments which allow the implementation of the actions of remediation as for example the quick licensing of waste management facilities without following the usual procedures, the requisition of facilities or of personnel. The facilities would be, in case of an emergency, designed or adapted in order to be able to process contaminated waste [49].

3.6. WASTE MANAGEMENT FACILITIES AND ACTIVITIES

Management of waste covers all the steps from its generation up to disposal, including processing (pretreatment, treatment and conditioning), storage, transport and disposal. Among the various steps of waste management, waste collection, segregation and packaging for temporary storage are the first waste management activities observed during emergency and recovery, which can be defined as staging in this document. Due to the sudden nature of waste generation after an emergency, the staging is considered as one of crucial step for early waste management activities, which has a role to initiate waste management activities in timely manner without affecting the other prioritized activities to deal with the emergency.

Following the initial step, waste will need to be further processed based on appropriate consideration of the characteristics of the waste and of the demands imposed by the different steps in its management. Throughout these different steps of waste management, characterization needs to be performed in stepwise manner to enhance the understanding of the characteristics of the waste.

FIG. 5 represents simplified steps for management of waste arising from a nuclear or radiological emergency. Note that in the actual situations, some steps such as storage and transport will be performed several times (e.g. storage after processing, transport before and after staging). In the following subsections, activities and consideration at each step of those typical waste management activities are described.

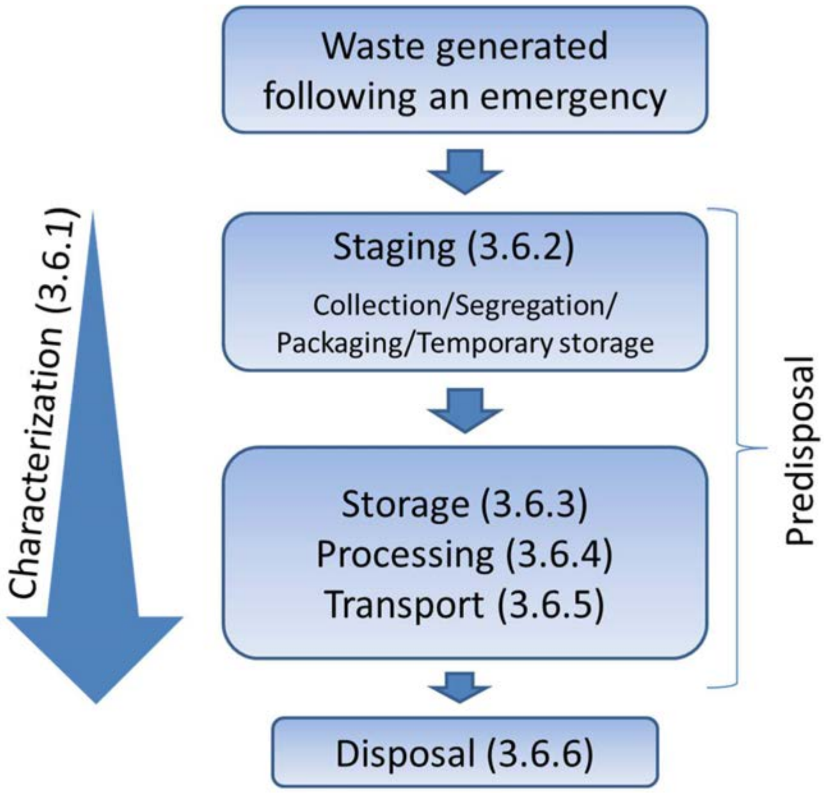

FIG. 5. Simplified representation of steps for management of waste arising from a nuclear or radiological emergency.

3.6.1. Waste characterization and segregation

Waste management requirements during recovery will be highly correlated with the decontamination measures that are taken, and the various cleanup and decommissioning activities. However, the objectives for decontamination and waste management are somewhat different: for decontamination, methods to reduce radionuclide concentrations to acceptable levels are identified; for the latter, methods for managing and disposing of the wastes are identified. Waste management plans are set up in order to gather, segregate, condition, transport, store and eventually dispose waste, thus establishing management plan for different waste streams. In order to develop appropriate plans that ensure worker and public safety, waste characterization remains crucial. However, experience shows that it will be challenging to allocate sufficient skilled personnel to plan and implement proper waste characterization early after an emergency because waste management will not be the primary objective at that time, and most experienced personnel may be engaged with other emergency response activities. Hence, preplanning for waste characterization in a general manner would help to identify the essential characterization work required for large quantities of waste and segregation before further waste management steps.

In general, waste characterization provides the basis for defining appropriate waste streams and for making decisions about appropriate waste management steps. Segregating the waste into different streams is a pre-requisite to conduct following waste management activities (i.e. processing, conditioning, and disposal) in an effective and targeted way.

There are alternative approaches that may be selected for waste management which will determine the extent of waste characterization necessary during the early stage of waste management.

If the estimated total volume of waste is relatively small or if sufficient resources are available, comprehensive waste characterization could be performed during staging and support subsequent waste management activities.

However, in many cases it will not be reasonable to assume that sufficient resources are available to conduct full scale characterization of wastes from the early phase. For example, laboratory capacity may be limited and may be dedicated to sampling of air, water, and soil to support safety decisions and verify that remediation goals are being achieved. In such cases, waste characterization will focus on ensuring proper waste segregation and short-term storage. Field screening techniques may be sufficient for this initial level of characterization. Then as resources become available, more detailed waste characterization will be necessary to define appropriate waste streams and develop the necessary waste management facilities such as treatment facilities. Later, when a disposal facility is planned, comprehensive information on waste characterization such as radionuclide inventories, chemical components and waste forms, will be required to assess the long term safety of the disposal facility.

Waste characterization and segregation are very important for establishing an effective waste management strategy. The following points show how closely interconnected this topic is:

- Information on the characteristics and properties of the wastes allows for the classification of different waste streams.
- Information on the characteristics of the different waste streams is required to make decisions on how to deal with them, e.g. segregation plans, selection of appropriate waste processing techniques, design considerations for storage and disposal facilities.
- How waste streams are segregated will determine what, if any, further processing is required, which in turn determine packaging requirements, and storage and disposal needs. All these factors impact facility requirements, both short and long term, and costs.
- Selection of decontamination methods or availability of opportunities for reuse / recycling of specific waste constituents will directly impact the volume and characteristics of the waste streams to be managed.
- Waste characterization information will be essential for developing a safety case and performing safety assessments for waste management facilities.

To ensure that the wastes are characterized appropriately by the later phase of recovery, there will need to be early guidelines developed for the differentiation and segregation of large volumes of waste. Especially during the early phase of an emergency, providing guidance on "To Know What To Do" and "To Know What Not To Do" will be beneficial to workers and people who need to deal with waste. During the urgent phase of an emergency, little, if any, actual handing of waste will take place. However, preparations for appropriate handling and review of preplanning considerations could be started. Following this period, waste management activities need to be initiated which will lead to further characterization and decisions regarding appropriate management (e.g. reuse/recycling, safe release from regulatory control (clearance), radioactive waste processing, storage and disposal). During this phase, much consideration and care needs to be given to “What Not To Do” in order to avoid improper waste management steps which might cause difficulties with respect to future processing, transport, storage and disposal. As time passes, it becomes increasingly important to address and implement “What To Do”.

Development of such guidance prior to an emergency as part of preplanning is beneficial to facilitate appropriate waste management activities in a timely manner (“To Know What To Do”). Conversely, lack of any preplanning can lead to inappropriate decisions, mixing of incompatible wastes, unnecessary or insufficient remediation activities, leading to potentially inadequate processing, storage, and/or disposal facilities, thus resulting in further erosion of public trust (“To Know What Not To Do”).

> **French CODIPRA doctrine example:** The management of waste, products and contaminated land in a post-accident situation is a theme covered by CODIRPA, which identifies the waste which could be produced in post-accident situations and defines the management systems for the waste (waste streams and endpoints). CODIRPA has identified a number of actions to be taken (collection, packaging, transport, buffer storage) which need to be carried out ideally in the days and weeks following the accident and other actions that are to be carried out in the time-span ranging from a few months to a few years (waste processing, storage) [49].

Proper handling of waste from early in the emergency based on such guidelines will enable targeted handling and processing of solid and liquid waste, which will definitely facilitate all subsequent steps up to the envisaged endpoints. Then as a next step, more detailed waste characterization needs to be conducted to gradually gain understanding of waste and establish appropriate waste streams.

In summary, in order to initiate waste segregation and characterization promptly after an emergency, the following preparatory actions can be taken:

- Give special attention to the development of a waste categorization system for waste arising from emergencies;
- Develop/identify methodologies for rapid characterization to support waste segregation of large volumes from early phase, and plan for supply of the necessary equipment and instrumentation (e.g. Ref. [58]);
- Develop guidance on waste handling in early stages (e.g. waste segregation, early waste characterization) (“To Know What To Do” and “To Know What Not To Do”).

3.6.2. Staging

From early days after the onset of emergency, it is crucial to consolidate waste in collection locations where it does not hinder emergency response or recovery activities.

In this document, staging is defined as an intermediate stage where collected waste is brought for segregation, temporary storage including packaging and may also be used for characterization. There may be several staging sites distributed throughout the contaminated area. Proper staging early in the emergency will help conducting subsequent waste management activities in a more effective and efficient manner. A full-scale staging facility (or area) could provide following main attributes:

- Ensure that all wastes entering the staging facility are under appropriate management controls, which may not be the case for wastes outside of the staging area.

- Sufficient size to allow segregation by waste type to facilitate characterization and avoid the mixing of incompatible materials. Collected waste needs to be segregated on the basis of radiological, chemical and physical properties as a preliminary waste characterization. This will facilitate temporary storage and help avoid the mixing of incompatible materials.

- Arrangements to store the material received and create records to be maintained under a quality management system. In order to demonstrate safety, it is essential to collect and maintain records on radiological, chemical and physical properties (e.g. volume, surface dose rate) of the waste from the earliest phases of waste management.

- Durable containers to hold bulk materials (e.g. concrete or metal boxes, reinforced fabric bags, suitable plastic containers), surrounding by curbing with drainage systems to control potential releases. These containers need to be selected in order to avoid dispersion of waste and minimize additional exposure of workers and public. Installation of drainage systems and other monitoring systems to easily monitor uncontrolled release of wastes need to be considered.
- Concrete or other low permeability hard surfaces on which to place the containers need to be considered. This protects underlying soils from unexpected dispersion of waste or contamination due to deterioration of containers.

- Security fencing and surveillance measures to prevent uncontrolled receipt of waste and unauthorized entry by members of the public need to be considered. Staging areas will not necessarily be developed within the site boundary of an existing nuclear facility, therefore security measures may need to be considered.

- Trained radiological safety and security personnel to perform activities (e.g. segregation of waste based on gamma dose rates, supervision of all activities including labelling of waste within segregation, recording of waste within packaging, accepting packaged waste, surveillance of temporary storage, managing personnel dosimetry programmes, etc.).

Staging needs to be started even before assessing the longer-term impact on the activities or recovering, considering the interdependencies between the early stage of waste management (staging etc.) and the subsequent step. Therefore, it is beneficial to conduct preplanning for the attributes mentioned above which especially, are taken note of: clarifying potential sites for staging and identifying the appropriate types of containers for waste and how to acquire and distribute these containers in a timely manner. Those preplanning with interaction with regulatory authority and implementer will further facilitate activities in an emergency. In the case where transport of waste from one staging site to another is necessary, safe transport of such waste will also need to be considered as well (see Section 3.6.5).

Clarifying potential sites for staging in preplanning may be possible.

> **U.S. radiological emergency preparedness planning exercises example:** Liberty RadEx drill was organized by US-EPA in April 2010 involving federal, state, local agencies and private citizens. During the exercise, potential locations for collecting contaminated material were identified in consultation with Community Advisory Panel [59], [60].

For waste arising from an emergency not related to nuclear fuel cycle facilities, locations for implementation of the general staging could include private airports, military installations and similar controlled access settings with the applicable large scale area of low permeability hard surface including concrete surfaces.

However, considering the inherent uncertainties on the geographic distribution of contamination, as well as the characteristics and quantity of these wastes, it may not be reasonable to identify specific staging area. Moreover, land use in recovery action will be addressed to need be flexible in accordance with the overall strategies towards achieving the agreed endpoints (see Section 3.2). In such circumstances, a zoning approach can be utilized in recovery to identify potential staging sites efficiently and with confidence in the safety of those locations. Below gives an example of the site selection process using a geographic information system (GIS).

As the first step of site selection, the first GIS layer would distinguish between areas where the temporary storage facilities could be safety located on a safety performance basis. While this first GIS layer would identify zones suitable for the facilities, additional GIS layers would be needed to identify, for example, exclusion zones for culturally sensitive locations, key natural resource preservation, demographically important locations, and other exclusions. The number, and nature, of these additional exclusion zone layers would differ for different nations, cultures, locations and details of the specific event.

Such a GIS construct would provide a preparedness tool for radioactive waste management in recovery. This tool will provide the means to rapidly identify the locations of suitable waste management facilities with confidence in the safety margin of the generic design and facilitate the decision making process for site-selection.

Another important part of preplanning is waste packaging. If planning includes matching durability of waste containers and temporary storage systems to the expected time (with an appropriate safety margin to account for uncertainty in storage time), much effort, exposure and expense for recovery action might be reduced because of avoiding the need to repackage waste considering the long term waste management. Certain plastic containers, for example, would be subject to embrittlement and cracking under long term sun exposure or other weathering conditions. Therefore, prior consideration on appropriate waste container types and its procurement method will help prompt start of the normal waste management.

3.6.3. Storage

Storage facilities will be required for waste management following an emergency. Therefore development of preparatory plans for the design and development of storage facilities will allow waste management following an emergency to proceed according to more normal waste management practices much sooner than otherwise. These designs will need to recognize that the storage facilities may be utilized for long periods of time until disposal facilities are available. This is especially the case when a strategy that defers disposal is selected as described in Section 3.2.

The consequences of long storage periods and uncertainties regarding the amounts of waste to be accommodated may also require developing facilities with the flexibility to increase storage capacity. Since the quantity and characteristics of the waste to be managed are inherently unpredictable, a preliminary storage design that is modular and scalable would offer advantages. A modular design can be used in one or more places to support the specific needs of waste management, and enables efficient development of a scalable safety case. A scalable design permits sizing the facility to meet waste management requirements once waste characteristics and quantities are identified.

Preliminary designs for storage facilities can be developed in advance of any potential nuclear or radiological emergency as generic designs that conform to national requirements. At least two design criteria need to be considered: containment and dose-limitation. Preparing more than one generic design based on different design criteria would allow the broad range of potential waste characteristics to be managed.

Storage can serve different functions. It can be used to store waste that contains short-lived radionuclides to decay to a level at which it can be released from regulatory control (clearance), or authorized for discharge, recycling and reuse. Storage can also be used to collect and accumulate a sufficient amount of radioactive waste prior to its transfer to another facility for treatment and conditioning. It is important to determine the value of a storage option depending on waste characteristics.

If there are only shorter-lived radionuclides (e.g. ^{90}Sr, ^{134}Cs, and ^{137}Cs) in the waste with relatively low concentration, then a long term storage facility that can safely contain these contaminants up to a level at which the radioactive waste can be released (a decay storage approach) may be a preferred option instead of going for disposal as radioactive waste.

3.6.4. Processing

Knowledge and experience exists concerning the processing and disposal of very large volumes of decommissioning waste in the nuclear sector, as well as building and other structural demolition debris, municipal solid waste, hazardous chemical waste, uranium mill tailings and other mining waste in a manner protective for the public and the environment. Much of this knowledge and experience involves processing and disposal of large waste amounts of bulk, unpackaged waste using near-surface landfills. For special issues, e.g. effective monitoring systems or awareness of radiation issues among scrap metal dealers, much experience has also been obtained.

In case of a nuclear or radiological emergency, a broad distribution of radionuclides dispersed within various bulk wastes (e.g. in soil, vegetation, building material and debris) is to be expected from various generation points. Thus, it is advantageous to utilize portable/modular waste processing units that can be transported for use.

Also, the utilization of existing infrastructure can be an option to meet urgent needs for risk reduction. Due to the likely prevalence of high volume, low radioactivity level waste, it is advantageous to consider to what extent municipal solid waste processing facilities and landfills (as well as nuclear installations for radioactive waste conditioning) could be used.

Relying upon existing facilities for waste management in a recovery context is often considered a practical, or expedient, measure. Such facilities may include incinerators, landfill disposal, transportation resources, garbage collection facilities, and water treatment plants (sewage system). Broadly speaking, relying on existing infrastructure provides a pragmatic approach to quick recovery, by making use of existing industries (especially transportation and civil engineering industries) and skills. These industries can be instrumental in establishing decontamination plans.

In order to manage large volumes of contaminated organic material, incineration seems particularly to be of advantage. Nevertheless, the use of incinerators requires the fulfillment of various conditions and pre-requisites. The incinerator design needs to include features to protect the public from discharges of radioactivity. To avoid spreading of radionuclides the incinerator needs to be equipped with appropriate filters and scrubbers to avoid discharging radionuclides to the atmosphere. Ashes are to be collected and monitored for radioactivity content before dispatch to disposal. With respect to the Fukushima Daiichi NPP accident, the option to use incinerators has been subject to comprehensive investigations and discussions [45].

Nevertheless, such facilities can only be used to the extent they allow processing of slightly contaminated material and waste. The work performed and experiences gathered clearly demonstrate that large amounts of such material and waste can successfully be managed in this way. This encompasses especially the combustion of contaminated organic material in municipal incinerators as well as the disposal of resulting ashes in municipal landfills. Thus, possible access to such facilities could help to mitigate the large volume waste.

However, adapting conventional facilities so that radioactive materials can be processed safely is not always straightforward. Issues related to ensuring worker safety and evaluating basic safety functions such as containment, are likely to arise during the recovery activities. It needs to be recognized that utilization of conventional facilities may cause generation of secondary waste as well as waste generated from the decommissioning of such facilities.

> **Fukushima Daiichi NPP emergency example:** Where existing infrastructure for municipal solid waste were used to treat slightly or potentially contaminated materials (e.g. municipal incinerators and waste landfills), the process of obtaining the agreement of municipalities to use conventional incinerators to reduce the volume of off-site contaminated material has proved to be difficult [14], [39].

Therefore, as part of an anticipation programme, a basic plan for adapting and/or upgrading existing infrastructure would ease the whole process of recovery and equip people to tackle the issues they will face.

3.6.5. Transport

Since waste management may be conducted in various facilities and locations, transport of waste arising from the staging will be necessary, even during an emergency, where existing regulations for the transport of radioactive material [61] might not be fully met due to the time constraint and lack of resources. For such transport, the complex and diverse characteristics of waste may require a variety of transport casks and transport methods, some of which might not be used in routine transport of radioactive materials. Therefore, in order to ensure safety of workers and populations, it is beneficial to identify possible transport modes based on existing infrastructures, transport containers providing sufficient shielding and confinement, as well as the applicable safety requirements and guidance for such situations as part of preplanning.

> **Fukushima Daiichi NPP emergency example:** The Act on Special Measures [37], [38] and associated regulations were established by the Ministry of Environment (MOE) following the accident and address requirements for transport of decontaminated waste and other contaminated material. To supplement these regulations, MOE eventually developed guidelines on decontamination and waste management. The guidelines also provided practical guidelines for safety measures during transport with the purpose of 1) preventing dispersion of radioactive materials during transport and handling and 2) protecting the public from additional exposure caused by transport. [43], [62]. Furthermore, in advance of commissioning interim storage facilities, the basic plan for transport of contaminated soil to the facilities was developed by the MOE in Nov. 2014 [63].

Further details on preplanning for transport are provided in the companion report (see Figure 1).

3.6.6. Disposal

Disposal activities will take place over a longer time frame, allowing a return to normal waste management practices. By the time most materials are shipped for disposal, much of the uncertainty regarding the nature and extent of the recovery and the waste streams involved will have been resolved based on data obtained by waste characterization. In essence, this document considers that disposal of waste following a nuclear or radiological emergency will not differ significantly from other, more normal radioactive waste disposal activities. Sufficient time to select site and assess the safety for disposal in the existing regulatory framework will generally be available. The primary difference will be in terms the potentially very large volumes and much more heterogeneous characteristics of the waste to be managed, as well as the additional regulatory and operational challenges involved in safely disposing waste arising from the emergency. Preparing the safety case may also present quality management challenges related to data reliability. In order to develop a disposal facility after an emergency, experience in developing radioactive waste disposal facilities can be utilized [7], [9], [10], [57]. In addition, one of the companion reports (see Figure 1) provides additional consideration for disposal of waste arising from an emergency.

3.6.7. Summary

There are multiple steps in the waste management process and the interactions between them need to be recognized (GSR Part 5 [6] Requirement 6 for interdependencies). Furthermore, following an emergency, issues associated with time frames will increase the challenges identified in 2.2.1. In order to better harmonize these steps and while developing facilities in a timely manner, the following preparatory actions can be taken:

- Develop a methodology for site selection or develop site selection/exclusion criteria;
- Develop a range of conceptual designs for potential waste management facilities (e.g. containers and general design for staging, modular type storage facility, mobile treatment facilities);
- Develop regulatory framework as necessary to support expedited licensing of waste management facilities following an emergency;
- Consider how to upgrade or utilize existing infrastructure to support waste management.

It is important to note that such preplanning needs to be conducted in line with the national strategy for waste management as discussed in Section 3.2, involving regulatory authorities for establishing common understanding on adaptable safety standards.

3.7. WORKFORCE AND EXPERTISE

Following an emergency, waste management activities may need to be conducted by organizations or personnel who are not involved with radioactive waste management in normal situations. Also, some waste management activities might require additional expertise as compared to normal situations. For example, for characterization of waste caused by an emergency, some radionuclides might be selected as key radionuclides that are not common for radioactive waste from routine operations. In such a case, it becomes necessary to improve the skill or even develop techniques to measure such uncommon radionuclides. Once an emergency occurs, the availability of a sufficient number of suitably qualified personnel to perform recovery and waste management activities will impact timely and appropriate implementation. Therefore, a plan for upgrading the skills of the existing workforce and identifying and allowing for new kinds of tasks to be undertaken in the field (such as waste characterization, measurement, radiation protection) is recommended to be developed in advance to an emergency. It is beneficial to investigate what types of expertise are missing in the organization and to explore the options to enlarge that capacity as part of overall emergency preparedness. Such arrangements will include both selection of personnel and their training to ensure that the personnel selected would have the requisite knowledge, skills and abilities to perform their assigned functions during, and subsequent to, a nuclear or radiological emergency.

> **Windscale nuclear production emergency example:** Following the fire at the Windscale Works and release of radioactivity to the environment, an extensive environmental survey was conducted which lead to the restriction of milk consumption etc. A report published in 1958 summarized the organisational and technical experience,

including:

"In an incident of this type there is a need for a rapid increase in both monitoring and analytical facilities. Provided that the local survey and analytical resources can rapidly be augmented, it is unnecessary to have always available on every site sufficient personnel and equipment to carry out the comprehensive survey which is needed following the accident. The team available on the spot needs to be of sufficient strength to provide a quick estimate of all possible hazards within a period of a few hours. Close prior co-ordination between establishments allows the building up of the team with additional trained personnel and suitable instruments" [64].

A review of the expertise and capabilities that exist within a country will allow gaps to be identified. In some cases existing multilateral arrangements may contain provisions of assistance in an emergency and be considered sufficient; alternatively, new bilateral or multilateral arrangements (e.g. Assistance Convention, agreements with other countries etc.) may be considered necessary [65], [66].

Training exercises or drills based on hypothetical emergency scenarios provide a sound mechanism for identifying both workforce and information management requirements. Exercises also allow the plans and systems to be tested and refined on the basis of lessons learned.

In addition, considering the societal impact addressed in Section 2.1.3, establishment of a reliable information management system that allows ready access to data will be important to regain trust of stakeholders. These systems need to be developed and tested as part of the preparatory actions and to the extent possible integrated into systems that are in everyday use so that they are familiar to users.

In sum, in order to initiate and conduct activities related to waste management in a timely and appropriate manner after an emergency, the following preparatory actions can be taken:

- Integrate longer-term waste management considerations with emergency response efforts in the overall emergency preparedness in terms of staffing, qualification and training. This needs to include upgrading workforce skills and capabilities including special training regarding both new procedures and processes and those who may serve as first responders.
- Identify relevant areas of technical expertise that will be needed, depending on nature and scale of potential emergency.
- Develop and maintain roster of technical experts, suitable emergency workers, and companies with a trained workforce. Consider placing contracts in advance to facilitate access to private-sector assets.
- Consider the mobility and availability of trained workforce resources.
- Establish systematic and effective training programmes, including arrangements for continuing refresher training on an appropriate schedule.
- Perform considerations about how additional staff can be recruited on short-term basis and the training and instructions to be given for their intended duties, initially and periodically.

- Plan for providing reassurance of safety of adapted/upgraded infrastructure used for waste management to the workforce and population in transparent manner.

3.8. DATA MANAGEMENT AND COMMUNICATION

As mentioned in previous sections, it is important to consider the interdependency among various steps in the waste management process. Activities conducted during the early steps in waste management (such as waste segregation and treatment) might have a negative impact on the safety in later phase (such as storage and disposal). Following an emergency, the challenging situation will further increase the complexity of management of data acquired in various steps of waste management (see also Section 2.2.7). Nevertheless, there will be multiple sources of data during emergency response and recovery activities that will be important to waste management. Therefore, integrated data collection, organization, and preservation are important for the decision making process and implementing strategies for recovery and waste management. Uncoordinated data management leads to duplicative effort, inefficiencies, lost information, and poor communication. Data collected without quality management can also complicate safety case development for disposal purposes. Decisions on waste management that support recovery objectives will be based on reliably collected data, as well as stakeholder understanding of these data

> **Hanford legacy nuclear production site remediation example:** At the Hanford Site in the United States, an extensive data collection programme guides recovery efforts. For example, groundwater contamination is monitored through an extensive well network for hydraulic heads and contaminant concentration levels, and the results reported to regulators and the public through an annual groundwater monitoring report that is available on the internet in an interactive format (e.g. Ref. [67]). As waste sites are remediated, soil is sampled at the point where excavation ends and analysed to provide a record of "cleanup verification" data. Excavated soil, as well as decommissioning and decontamination materials that are shipped to waste management facilities are sampled to provide estimates of disposal inventory. All of these data are maintained in a site-managed, openly accessible environmental database system to support numerous needs [68].

The adequate preparation for collection and retention of data as part of preparedness is recognized as essential [2], [3]. However, ensuring this happens with regard to waste management during an emergency has proven challenging. Review of past experiences revealed that collection and retention of data which are needed for waste management tends to be overlooked in the early phase of an emergency. Consequently, there was a loss of critical information for subsequent waste management activities.

> **Chernobyl NPP emergency example:** The exact location of temporary storage sites quickly built during the emergency, as well as the characteristics of waste disposed during the emergency response, was either not collected or not retained (e.g. the characteristics of waste disposed in the first ten disposal cells at Buryakivka are largely unknown)[36], [41].

Therefore, it is beneficial to consider developing a data management system for waste as part of preparedness planning as well considering effective system to collect and maintain a sufficient amount of essential data. Further technical information on necessary data for the development of predisposal and disposal facilities is given in companion reports (see Figure 1).

In conclusion, in order to avoid loss of important information and/or inefficient data management efforts after an emergency, the following preparatory actions can be taken:

- Definition of roles and responsibilities for establishment and maintenance of a data management system;
- Establishment of an integrated data management system to expedite collection, retention, and reporting of data critical to emergency response and waste management activities, thereby enabling data management activities to begin promptly;
- Identification of applicable quality management requirements for data collection and data management systems;
- Development of a communications plan to effectively share data and interpretations on waste management planning, operations, waste characterization, technology, monitoring, and progress toward endpoints;
- Establishment of an information management system to allow data for waste management activities for the recovery to be accessed by local government and other stakeholders. The system needs to be developed ahead of time and used in training exercises so that users are familiar with it and improvements can be made based on experience gained from exercises;
- Identification of all organizations that need to be involved at the preparedness stage; periodical re-evaluation of the plans to ensure those resources are available when needed;
- Identification of data necessary to be collected during each step of waste management, considering the needs for developing subsequent facilities such as storage and disposal.

3.9. BUILDING TRUST

The importance of maintaining public trust and understanding in emergency preparedness and response is well recognized [2], [3]. However, experience has shown that public trust associated with a nuclear or radiological emergency, including nuclear engineers, regulators, decision makers, and associated technical experts, will be greatly diminished as mentioned in Section 2.2.2. Therefore, it is important to consider methods for proactively engaging stakeholders before an emergency in order to establish trust. This could help avoid losing trust and credibility after an emergency.

Experience shows that waste management decisions need to be clearly, carefully and thoroughly explained and discussed across the spectrum of stakeholders during the recovery phase. Such discussions can have a tremendous impact on the efficiency of eventual decisions regarding waste management in the recovery process, especially their scientific soundness, and on the inevitable need to optimize use of limited resources. Local community leader or facilitator can serve a valuable role in this process. In this context, a local community leader or facilitator is defined as someone who is trusted by both the public impacted by the waste management decisions and by the organizations that manage and regulate the waste. They can interface with stakeholders translating individual concerns into general opinions. Examples of the effectiveness of such an approach have been seen in communities impacted by the Fukushima Daiichi NPP accident where facilitators have been a constant presence, living close to or within the impacted population. They can also have a role to play in communities surrounding nuclear facilities where no event has occurred and can foster trust. If the country already has a certain extent of waste management programme for radioactive waste arising from routine operations, such existing waste management programme would already have a process for involving stakeholders. Maintaining and enhancing such a process is another way to enhance the relationship with stakeholders.

Among the desirable provisions that may be chosen prior to a nuclear or radiological emergency to foster trust, education is arguably the most important. Without a fundamental understanding of radiation and the nature of the contamination and associated radiological health risks, it will be difficult for the public to participate in an informed decision making process. Therefore, it is very important to provide the population with a basic education on radioactivity and risks. Ideally, it becomes part of a national initiative to cope with a potential nuclear or radiological emergency by involving and preparing the population as much as possible through education.

Also, self-help protective actions such as monitoring become important for residents to identify those areas where remediation is necessary or certain countermeasures are appropriate. Therefore, it is beneficial if training on self-help protective actions is included as a part of educational programme.

Participation of the population in every major decision during recovery and waste management helps to ensure the sustainability of these decisions, though it has to be emphasized that such participation of the population doesn't reduce the responsibility and importance of relevant authorities for making timely decisions.

> **Fukushima Daiichi NPP emergency example:** Ministry of Environment (MOE) and Fukushima Prefecture jointly established the Decontamination Information Plaza in January 2012. The plaza provides an opportunity for people to learn in an interactive way, not only about the remediation projects being undertaken, but also about the principles of radiation protection, background radioactivity and how radioactive materials are used in daily life. Information is provided through websites and pamphlets, and a telephone hotline is available to provide answers to technical and health-related questions. Individuals have the opportunity to talk to medical and technical experts about the remediation works [69].
>
> Date city is one of the municipalities which conducted decontamination with active involvement of public from early phase. By the end of 2012, public hearings in relation to the municipality's decontamination plan had been organized more than 200 times since July 2011. Five Decontamination Support Centres were established in October 2011, whose activities include consultation on radiation protection and decontamination, publication of newsletters to introduce latest topics on decontamination etc. Those

activities enhanced understanding of the public and facilitated remediation activities in the city [70].

U.S. Liberty RadEx drill Example: The Liberty RadEx drill was organized by US-EPA in April 2010 to practice and test federal, state, and local assessment and cleanup capabilities in the aftermath of a dirty bomb, “a radiological dispersion device incident,” in an urban environment. More than 1,000 participants, representing federal, state, and local agencies, as well as private citizens and companies, were involved. Field drills and training exercises took place around Philadelphia for three days. During the Liberty RadEx exercise, participants were provided opportunity to enhance understanding on emergency response and other associated activities, supported by EPA scientists and engineers [59], [60], [71].

U.S. Waste Management Workshop example: The Wide Area Recovery and Resiliency Program (WARRP) Waste Management workshop, hosted by the Department of Homeland Security (DHS), was a two-day workshop, held in Denver, Colorado, in March, 2012. The workshop involved representatives from federal, state, and local agencies with the aim to advance the planning of federal, state, and local officials in the area of waste management (segregation, temporary storage, transportation, processing, and disposal) following a chemical, biological, or radiological (CBR) wide-area emergency in the Denver, Colorado, urban area. The objectives of the workshop included [72]:

- Understanding the importance of preparedness for waste management;
- Identifying the significant issues and exploring efforts underway to address the priority issues.

In summary, in order to avoid complete loss of public trust after an emergency, the following preparatory actions can be taken:

- Involve relevant stakeholders from the preparedness stage;
- Develop mechanisms for stakeholder participation in response and recovery;
- Consider the value of local community leaders or facilitators in stakeholder participation;
- Develop a strategy for communication with the public and education in long term.

4. CONCLUSION

This TECDOC considers the management of large volumes of radioactive waste arising in a nuclear or radiological emergency with widespread environmental impacts that may extend beyond national borders. The word “large” in this context indicates that the volume of waste to be managed exceeds the capabilities of the organizations that routinely address waste management issues, thereby elevating their management to a national challenge. In some cases, an emergency may also cause international challenges, in particular where other countries are affected. The word “waste” in this context encompasses the range of slightly contaminated material up to radioactive waste with high activity values.

A review of past nuclear or radiological emergencies has been undertaken, including those following: the Chernobyl Accident and the Fukushima Daiichi Accident, and some key observations were made:

- Waste management following an emergency has not always received appropriate attention from the outset after an emergency. Decisions made and actions taken immediately after an emergency focus primarily on stabilising conditions at the emergency site;
- Large emergencies create large volumes of heterogeneous waste;
- Emergency workers have limited guidance on how to initiate targeted waste management activities; in the absence of clear guidance, some actions have been taken that have led to serious consequences for subsequent waste management; and
- Existing guidance is generally developed only for normal operations and is usually not directly applicable to an emergency situation.

In light of these observations, it would be advantageous to prepare for waste management following a nuclear or radiological emergency. Preplanning refers to the actions and plans that can be established before any emergency occurs that will allow recovery to proceed more efficiently. Preparation in the form of preplanning is essential and the plans to be provided needs to be flexible enough to be adapted to the specific emergency and its consequences. Preplanning is based upon recognizing those aspects related to waste management that can be established and designed ahead of time as part of overall emergency preparedness, and those aspects that cannot be predetermined in an absolute sense because of the inherent uncertainty and unpredictability of a future emergency.

Such preplanning is in accordance with Requirement 15 related to waste management in GSR Part 7 on emergency preparedness and response [2]. Preplanning of waste management in recovery need to be made consistent with and integrated with normal waste management in order to implement:

- Environmental remediation that identifies opportunities and employs techniques to avoid producing large volumes of contaminated waste unnecessarily;
- The siting, licensing, construction etc. of waste management facilities and activities which may be required in a timely manner.

Preplanning is not a one off event, but plans will need periodic review and updating to reflect changing data and circumstances. During preplanning, there exist a number of aspects that would benefit from consideration. Examples of such preplanning items are given in Annex I addressing some important considerations that may be applied in a future emergency. These include but are not limited to:

- Safety is essential when planning and undertaking waste management activities.
- The lead authority will need to be identified, and all relevant organisations, roles and responsibilities clearly defined.
- All waste management planning and handling activities need to take full account of the very large volumes of waste that will be generated in an emergency and subsequent recovery and need to recognize that such waste is likely of heterogeneous composition and unlike conventional radioactive wastes.
- The endpoints for environmental remediation need to be defined taking into account the amount and type of wastes that would be generated.
- Quality management systems and record keeping need to be applied to all aspects of environmental remediation including remedial action and waste management.
- Practical steps need to be taken whenever possible to minimize waste volumes up to disposal.
- When segregating wastes, waste type (*radioactive* or *exempt*) and radiological, chemical and/or physical properties of wastes is significant.
- Robust staging will allow the initial waste management and emergency response activities to be decoupled from the subsequent regular waste management meeting national policy and strategy.
- Disposal facilities will not need to be developed with the same urgency as predisposal facilities.

In the urgent phase immediately after an emergency, most activities will be focused on ensuring safety and protecting individuals. This is likely to involve some movement of debris and waste but not for the primary reason of waste management. All subsequent handling of waste need to be done in the context of waste management and following the requirementss established in the preplanning.

Finally, the involvement of a wide range of interested parties during the preplanning activities is likely to result in a more efficient strategy within the larger recovery effort.

APPENDIX I. OVERVIEW OF SELECTED NUCLEAR OR RADIOLOGICAL EMERGENCIES AND LEGACY REMEDIAL EFFORTS

TABLE I.1. OVERVIEW OF SELECTED NUCLEAR OR RADIOLOGICAL EMERGENCIES AND LEGACY REMEDIAL EFFORTS

Characteristic	Chernobyl NPP Accident	Fukushima Daiichi NPP Accident	Windscale Nuclear Materials Production Facility Accident	Goiânia Radiological Accident	Wismut Uranium Ore Residues Remediation	Hanford Site Legacy Production Facility Remediation	Maralinga Legacy Nuclear Weapons Test Site Remediation
Root Cause	Inadvertent explosions of core during emergency shutdown of reactor whilst undergoing power failure experiment	A major earthquake and tsunami event that exceeded the NPP design basis	A fire in the reactor pile	Negligent source management	Waste management decisions regarding mill tailings and cleanup waste	Waste management decisions (during production era)	Weapons testing
Radiological composition of the released contamination	A wide spectrum of radionuclides that included volatile, semi-volatile, and refractory elements. This accident involved the explosions of a reactor core, with the result that part of nuclear fuel constituents were released directly to the environment	Primarily noble gases and volatile elements. Mostly shorter-lived isotopes (half-lives ≤ 30 years); of these isotopes, ^{134}Cs and ^{137}Cs caused the greatest environmental concern [73]	The principal fission product released was ^{131}I. Smaller quantities of other fission products suchas ^{137}Cs and ^{210}Po were also released. [23], [64], [74]	^{137}Cs from radiotherapy equipment	Residues from uranium ore mining and processing from five mines and two processing sites	Uranium from manufacture of fuel rods; numerous fission and activation products and hazardous chemical products from reactor operations as well as waste products chemical separation of plutonium from reactor fuel	Dispersed long-lived radioactivity comprised of natural and depleted uranium, plutonium, and americium

TABLE I.1. OVERVIEW OF SELECTED NUCLEAR OR RADIOLOGICAL EMERGENCIES AND LEGACY REMEDIAL EFFORTS (cont.)

(cont.)

Characteristic	Chernobyl NPP Accident	Fukushima Daiichi NPP Accident	Windscale Nuclear Materials Production Facility Accident	Goiânia Radiological Accident	Wismut Uranium Ore Residues Remediation	Hanford Site Legacy Production Facility Remediation	Maralinga Legacy Nuclear Weapons Test Site Remediation
Waste characteristics	Fragments of reactor core and portions/fragments of reactor structures thrown out by the explosions; upper soil layer removal from a large area; timber (the "Red Forest"); fragments and debris from structures and generated as a result of demolishing the buildings in nearby villages; contaminated equipment; fragments of metal structures, concrete and various debris; other material	Offsite waste included soil and solid wastes (grass, leaves, branches, surface sediments etc., which are mostly bio degradable and combustible) (primarily ^{134}Cs and ^{137}Cs) On-site waste includes contaminated debris (wood, concrete, metal), contaminated water etc. containing various radionuclides including alpha emitters	Soil contaminated by surface deposition of atmospheric release of reactor fire combustion products	Human-transported source material (^{137}Cs) spreads contamination to many individuals and locations	Waste rock piles and tailings sludge containing low-grade uranium ore (^{238}U decay chain); solid waste and water treatment residues resulting from cleanup	Soil, structures, and groundwater contaminated with fission and activation products (as well as chemically toxic materials)	Soil contaminated with long-lived radioactive material ranging in size from inhalable dust to collectible fragments

TABLE I.1. OVERVIEW OF SELECTED NUCLEAR OR RADIOLOGICAL EMERGENCIES AND LEGACY REMEDIAL EFFORTS (cont.)

Characteristic	Chernobyl NPP Accident	Fukushima Daiichi NPP Accident	Windscale Nuclear Materials Production Facility Accident	Goiânia Radiological Accident	Wismut Uranium Ore Residues Remediation	Hanford Site Legacy Production Facility Remediation	Maralinga Legacy Nuclear Weapons Test Site Remediation
Spatial distribution of the contamination	About 30,000 km^2 had contamination >185 $kBq{\cdot}m^{-2}$ and about 190,000 km^2 had contamination densities > 37 $kBq{\cdot}m^{-2}$ [75] The Chernobyl NPP accident resulted in contamination of large areas not only within Ukraine, Belarus and Russia, as well as many other countries in Europe.	About 1,400km^2 had contamination >185 $kBqm^{-2}$ and about 5,200 km^2 had contamination densities >37 $kBqm^{-2}$ [75] More than 80% of the atmospherically-released Radionuclides are estimated to have gone offshore from Fukushima, followed by deposition in the Pacific Ocean.	Surface deposition throughout most of the United Kingdom and partly to northwest Europe [74]	There was no atmospheric dispersal; contamination was spread through human action to numerous locations in Goiânia as well as to locations in other nearby cites	Contaminated surface area of about 40 km^2[17]	Primarily subsurface at present, with approximately 520 km^2 of contaminated groundwater	120 km^2 of soil contaminated by nuclear weapons testing [29]

TABLE I.1. OVERVIEW OF SELECTED NUCLEAR OR RADIOLOGICAL EMERGENCIES AND LEGACY REMEDIAL EFFORTS (cont.)

Characteristic	Chernobyl NPP Accident	Fukushima Daiichi NPP Accident	Windscale Nuclear Materials Production Facility Accident	Goiânia Radiological Accident	Wismut Uranium Ore Residues Remediation	Hanford Site Legacy Production Facility Remediation	Maralinga Legacy Nuclear Weapons Test Site Remediation
Amount of waste	As of 2010 total amount of RAW in the Exclusion Zone (excluding the Shelter Object) is about 2,800,000 m^3. Overall activity of radioactive substances on natural sites of the Exclusion Zone is above 8.50E+15 Bq. [26]	The amount of soil and waste generated from decontamination in Fukushima Prefecture is estimated to be 16–22 million m3 after volume reduction (incineration) (as of October, 2013) [14], [22].	Milk from about 500 km^2 of nearby countryside was destroyed [15], [64]	3400 m^3 of waste, containing 46 TBq of activity in urban environments	325 million m^3 of waste rock material, and 160 million m^3 of tailings sludge originating from mining and processing; 865,000 m^3 debris/concrete, 14.5 million m^3 contaminated soil/waste rock, 200,000 metric tonnes of scrap metal originating from cleanup and water treatment residues; all located in densely populated areas [76]	200,000 m^3 of high level radioactive waste; 710,000 m^3 of solid radioactive waste	263,000 m^3 of contaminated soil was disposed to a large near-surface trench [29]

TABLE I.1. OVERVIEW OF SELECTED NUCLEAR OR RADIOLOGICAL EMERGENCIES AND LEGACY REMEDIAL EFFORTS (cont.)

Characteristic	Chernobyl NPP Accident	Fukushima Daiichi NPP Accident	Windscale Nuclear Materials Production Facility Accident	Goiânia Radiological Accident	Wismut Uranium Ore Residues Remediation	Hanford Site Legacy Production Facility Remediation	Maralinga Legacy Nuclear Weapons Test Site Remediation
Approaches used for waste management	Decontamination facilities Temporary localisation Low-level disposal of decontamination waste in areas outside the exclusion zone in low-level waste disposal trenches (e.g. Ripkinskyy) High level on-site waste disposal inside the Shelter Object, covered with upper layer of soil and other materials.	National government aims as a long term goal to reduce individual additional exposure dose to 1mSv/y or less by not only decontamination but also appropriate management comprehensively with monitoring survey, safety management of food, and health exams.	Mitigation by restriction on agricultural product use; collection and disposal of contaminated milk.	Source material encased in concrete and removed; contamination located by aerial survey; hot spots removed and placed in drums; contaminated structures demolished and removed; contaminated topsoil removed; contaminated materials from junk yards and paper recycling company removed. Waste packages placed in temporary storage, then disposed in two waste disposal facilities.	Relocation of rock piles, draining of tailing ponds, and *in situ* remediation by covering (in-place waste management).	Restricted access to control human exposure; treat, storage, and disposal of waste segregated by characteristics: high level waste destined for a geologic repository, while low-level waste is being disposed in large near-surface disposal facilities with leachate-collection systems that will eventually be closed with infiltration-limiting covers;	A zoned approach was adopted where some areas were managed to discourage use and thereby reduce exposure; soil and particle removal was done for higher contamination areas and disposed in near-surface disposal facilities.

TABLE I.1. OVERVIEW OF SELECTED NUCLEAR OR RADIOLOGICAL EMERGENCIES AND LEGACY REMEDIAL EFFORTS (cont.)

Characteristic	Chernobyl NPP Accident	Fukushima Daiichi NPP Accident	Windscale Nuclear Materials Production Facility Accident	Goiânia Radiological Accident	Wismut Uranium Ore Residues Remediation	Hanford Site Legacy Production Facility Remediation	Maralinga Legacy Nuclear Weapons Test Site Remediation
	High level off-site storage facilities that are located within the exclusion zone (e.g. Pidlisniy, III Stage of Chernobyl NPP) Low- and intermediate-level off-site waste disposal facilities (e.g. Buryakivka)	Waste segregated by activity density (Bq/kg or Bq/m^3), origin of waste and type of waste (decontamination soil, combustible waste etc.)				Pump-and-treat and other systems for remediating contaminated groundwater.	
Resources affected	Proximate area; agricultural land; forest, cities & villages displaced; some industrial impacts Distant regions; agricultural land and forest resources impact (agricultural lands were about one-third of the contaminated territory; this contamination of agricultural and semi-natural lands led to significant human exposures via foodstuffs)	Restriction/loss of land and industrial uses in the Prefecture, Significant population displacement reduced tourism to Japan, loss of forest, fishing, and ocean uses	Primarily agricultural (pastoral) resources that were contaminated for a relatively short time due to short half-live of the radionuclides released	Homes, businesses, recycle materials contaminated	Agricultural land and forests impacted; some industrial impact	Groundwater, surface water, river sediments and biota impacted; loss of land use for several decades for most areas during remediation, and permanently for a 20 km^2 core zone that will be set aside for long term waste management	Land sought for return to aboriginal peoples for traditional lifestyle use

APPENDIX II. INTEGRATED SUMMARY OF CHALLENGES, CONSEQUENCES, AND PREPARATORY ACTIONS

TABLE II.1. INTEGRATED SUMMARY OF CHALLENGES, CONSEQUENCES, AND PREPARATORY ACTIONS

Challenges (Section 2.2)	Consequences	Preparation Actions (Section 3)
Time frames (Section 2.2.1) • The priority during urgent phase of the emergency response will be on stabilizing the situation to prevent further radioactive releases, and on rescuing and protecting public and workers. This presents the challenge that the resulting decisions may be less than ideal with regard to waste management issues and principles.	Early decisions are likely to be made with little consideration for waste management impacts and related costs.	Develop some guidance for waste management (e.g. waste segregation, early waste characterization) to be included in emergency preparedness planning (Section 3.6). Include waste management considerations in emergency planning (Section 3.5, 3.6, 3.7) to facilitate rapid provision of equipment for waste collection and storage and early waste characterization in emergency preparedness planning.
• Emergency response and waste management activities are often not sequential.	Decisions affecting waste management will evolve as the emergency is stabilized.	Adopt an adaptive decision process (Section 3.1, 3.2) to cope with an evolving situation during recovery.
	Difficulty in establishing a *sustainable* waste management system for long periods.	Adopt an adaptive decision process (Section3.1, 3.2) to cope with an evolving situation during recovery.

TABLE II.1. INTEGRATED SUMMARY OF CHALLENGES, CONSEQUENCES, AND PREPARATORY ACTIONS (cont.)

Challenges (Section 2.2)	Consequences	Preparation Actions (Section 3)
	Data that are important for waste management from early in the emergency can be lost, never collected, or of limited use due to quality management problems.	Include plans for a data management system in emergency preparedness plans (Section3.8). Consider establishing, or improving, an integrated data management system for all emergency response and recovery data to meet the needs for collecting, sharing, updating, retaining, and interpreting data (Section 3.8). Identify data necessary to be collected during each step of waste management, considering the needs for developing subsequent facilities such as storage and disposal. Define data quality objectives describing what type of data, how much data, and what quality of data are necessary for decision making. (Section 3.8).
Public Concern (Section 2.2.2) • Fear of radiological impacts; • Desire to resume normal life; • Eroded trust and diminished credibility for decision making after an emergency (as result of the shock);	Scepticism towards those who plan, approve, and manage the recovery effort, limiting the ability to achieve consensus on actions to be taken (e.g. use of existing waste management facilities, selecting locations for new waste management facilities).	Develop a preplanning framework and develop related skills to provide for: • Stakeholder participation (Section 3.9); • Use of local community leader or facilitator (Section 3.9); • An effective communication programme (Sections 3.8 and 3.9).
• Demand for open sharing of available, accurate and timely information in a timely manner with context.	Public may emphasize social and financial factors; waste management may not be considered as an important issue.	Develop a preplanning framework for waste management to speed recovery and take into account social and financial factors (Section 3.2).

TABLE II.1. INTEGRATED SUMMARY OF CHALLENGES, CONSEQUENCES, AND PREPARATORY ACTIONS (cont.)

Challenges (Section 2.2)	Consequences	Preparation Actions (Section 3)
	Reduced credibility of responsible persons and experts decreases ability to act in a timely or effective manner.	Involve both stakeholders and regulators during preplanning to gain understanding and for better oversights after an emergency (3.4, 3.5, 3.6).
		Identify data requirements for waste management in the recovery (Section 3.8)
		Build trust (Section 3.9).
	Demand for latest information has consequences for information management (see Information Management, below).	Establish or improve an integrated data management for all emergency response and recovery data – to meet needs for collecting, sharing, updating, retention, and interpretation of data (Section 3.8).
	Demand for immediate action has consequences leading to inadequate planning and implementation of recovery.	Identify areas where decisions regarding response actions can be made prior to an emergency (Section 3.1).

TABLE II.1. INTEGRATED SUMMARY OF CHALLENGES, CONSEQUENCES, AND PREPARATORY ACTIONS (cont.)

Challenges (Section 2.2)	Consequences	Preparation Actions (Section 3)
Technical Resources (Section2.2.3) • Waste characterization challenges that arise from large volume, diverse properties, lack of adequate procedures and instrumentation, and lack of radiation protection equipment;	Inability to properly characterize, and hence to segregate, waste streams; without proper characterization, data (inventory) needed for facility design and safety case development will be incomplete.	Develop/identify techniques for rapid characterization to support waste segregation of large volumes during the emergency response phase, and plan for supply of the necessary equipment and instrumentation; determine whether initial decisions can be made using field screening techniques. (Sections 3.6.1, 3.7).
• Lack of, or limited availability or capacity of, equipment and facilities for processing, storage, transport and disposal; • Difficulty of characterizing waste in areas with elevated radiation levels; • Limited availability of technology for decontaminating some areas (e.g. contaminated forest);	It will be necessary to choose between managing unsegregated waste or performing waste segregation later (either option will incur greater costs than managing waste that was segregated at collection).	Develop/identify a strategy for characterising large volumes of heterogeneous radioactive waste to support long term waste management (Sections 3.3, 3.5).
• Limited availability of laboratory capacity for analysis of waste samples for characterization; • Difficulty in empowering local population with training and tools to support risk evaluation and remedial action.	Lack of adequate equipment and facilities will hinder and delay recovery and waste management.	Prepare pre-designed equipment and facilities, or pre-licensing of generic designs for radioactive waste management, involving regulators for review (Section 3.6). Develop/identify methodologies for rapid characterization to support waste segregation of large volumes from early phase (Section 3.6.1). Include in emergency preparedness planning a strategy for safely upgrading existing infrastructure to meet waste management needs (Section 3.6). Plan for providing reassurance to the workforce and population of safety of adapted/upgraded infrastructure used for waste management (Section 3.7).
	Alternatives to decontamination will need to be considered for certain areas.	Investigate potential alternatives for waste volume reduction through in-place management of contamination (Section 3.3).

TABLE II.1. INTEGRATED SUMMARY OF CHALLENGES, CONSEQUENCES, AND PREPARATORY ACTIONS (cont.)

Challenges (Section 2.2)	Consequences	Preparation Actions (Section 3)
	Inefficiency of "top-down" measures.	Plan for both education/training on radiological risks in areas located nearby nuclear power stations and local institutions devoted to gather priorities from the population in a post accidental situation and enhance relationships between the population and the government. (Section 3.9).
Endpoint Identification (Section2.2.4) • Developing a common understanding of the situation;	Time and planning are needed to develop a common understanding of the situation.	Pre-plan a process for identification and selection of endpoints to guide recovery and waste management activities based on clear allocation of responsibility (Section 3.1, 3.2).
• Building a dialogue regarding the potential options in the context of overall justification and optimisation, as well as their interdependencies;		Plan for adaptive strategies (Section 3.2). Establish or improve process for stakeholder participation (Section 3.9).
• Establishing trust of stakeholders, which is central to the identification and selection of accepted endpoints.	Delays in obtaining and using data delay the process of identifying endpoints, and thus delay waste management activities.	Establish or improve an integrated data management and communication system (Section 3.8).
	Time to re-establish trust will delay the process of identifying endpoints, and thus delay waste management activities.	Recover oversight function early by considering possible changes of regulatory framework and regulations, by means of preauthorization of generic designs etc. (Section 3.4, 3.6). Establish or improve process for stakeholder participation (Section 3.9).

TABLE II.1. INTEGRATED SUMMARY OF CHALLENGES, CONSEQUENCES, AND PREPARATORY ACTIONS (cont.)

Challenges (Section 2.2)	Consequences	Preparation Actions (Section 3)
Regulatory Framework (Section2.2.5) • Framework may either not exist, or may not be applicable to the post-emergency situation. • Overlapping/conflicting regulatory authority. • Lengthy licensing process. • Availability and applicability of clearance/exemption process. • Political inertia. • Limited availability of regulator staff with sufficient expertise and skill to provide oversight to waste management activities. • Difficulty integrating the recovery effort.	Overlapping/conflicting regulatory authority can delay progress while roles and responsibilities are resolved.	Designate roles & responsibilities (Section 3.1).
	The regulatory framework may need to be revised to enable recovery and waste management activities to proceed, causing delays.	Evaluate and revise regulatory framework for waste management in the context of recovery (accelerated licensing process (Section3.4)).
	Without an expedited licensing process for waste management as part of recovery, licensing of waste management facilities may be delayed or circumvented.	Plan for waste management facilities that needs to be developed in early phase of accident management (Section 3.6).
	Options for waste management may be limited by absence or inapplicability of clearance/exemption process.	Consider establishment or relevance of clearance/exemption process for waste management in recovery) (Section3.3, 3.4).
	Progress would be hindered by limited availability of regulatory oversight.	Regulatory agency emergency preparedness planning will need to include provision for ramping up competency and capacity for regulatory oversight and decision making (Section 3.4). Consider how to authorize and oversee waste management activities in prompt manner without compromising long term safety – this could be done by setting minimal regulatory criteria on siting and designing facilities, or by means of pre-licensing of standardized facility design, for example. (Section 3.4, 3.6).
	Uncoordinated action.	Designate roles & responsibilities (Section 3.1).

TABLE II.1. INTEGRATED SUMMARY OF CHALLENGES, CONSEQUENCES, AND PREPARATORY ACTIONS (cont.)

Challenges (Section 2.2)	Consequences	Preparation Actions (Section 3)
Management of Activities (Section 2.2.6)		
• Responding to demand for urgent action. • Longer-term waste management needs to be considered during the emergency response, despite the fact that stabilization of the situation and dose reduction to workers and the public are the highest priorities.	The demand for urgent action can be expected to force some actions to be undertaken without adequate planning for waste management.	Plan for an effective data management and communication programme (Section 3.8). Expand emergency preparedness planning to integrate longer-term waste management considerations with emergency response efforts (Section 3.6, 3.7). Plan for developing facilities and procuring equipment necessary for early waste collections and prepare guidelines for workers who need to deal with waste from early phase (Section 3.6, 3.7).
• The recovery from an emergency resulting in large volumes of radioactive waste will pose challenges beyond the capabilities of existing waste management infrastructure and frameworks: making integration of waste management with recovery difficult.	During the emergency response, it will be necessary to make decisions to mitigate releases; such decisions may result in detrimental impacts with regard to waste management.	Develop basic national strategies for recovery taking into account impact for waste (Section 3.2).
• Establish an effective management system for developing an understanding of the evolving situation, for making decisions in a timely manner, and for providing timely communication of status, decisions, and progress.		

TABLE II.1. INTEGRATED SUMMARY OF CHALLENGES, CONSEQUENCES, AND PREPARATORY ACTIONS (cont.)

Challenges (Section 2.2)	Consequences	Preparation Actions (Section 3)
	Time is required to adapt waste management systems to the post-emergency situation.	Establish roles and responsibilities in advance (Section 3.1). Pre-plan a process for identification and selection of endpoints to guide recovery, and waste management, activities (Section 3.2). Plan for adaptive strategies (Section 3.2). Plan for developing facilities and procuring equipment necessary for early waste collections and prepare guidelines for workers who need to deal with waste from early phase (Section 3.6).
Information Management (Section2.2.7) • Identification of critical data to acquire for waste management purposes and quality assurance requirements for those data; • Collection, review, and organization of these data; • Retention of these data; • Interpretation of these data to promote understanding; • Prompt access to and dissemination of these data.	Lost time in establishing data management system(s). High potential for decision making without all the relevant information. Loss of credibility and trust. High potential for multiple, fragmented data management systems. High potential for lost data, especially early in the emergency response and recovery. Difficulty in sharing and accessing data . Negative impact on disposal safety case development.	Define roles & responsibilities (Section 3.1). Include plans for a data management system in emergency preparedness plans (Section 3.8). Identify and determine data requirements for waste management in the recovery and quality assurance expectations (Section 3.8). Consider establishing, or improving, an integrated data management system for all emergency response and recovery data to meet the needs for collecting, sharing, updating, retaining, and interpreting data. (Section 3.8).

TABLE II.1. INTEGRATED SUMMARY OF CHALLENGES, CONSEQUENCES, AND PREPARATORY ACTIONS (cont.)

Challenges (Section 2.2)	Consequences	Preparation Actions (Section 3)
Workforce and Financial Resources (Section2.2.8) • Limited availability of technical experts for timely response; • Limited availability of a trained workforce for timely response; • Finite financial resources available.	Work will be prioritized according to available resources and timelines to achieve objectives limited by availability.	Identify relevant areas of technical expertise that will be needed, depending on nature and scale of potential emergencies (Section 3.7).
	Workforce training will be needed.	Develop and maintain roster of technical experts and companies with a trained workforce (Section 3.7). Include in emergency preparedness planning a strategy for upgrading workforce skills and capabilities (Section 3.7).
	Provision of funding for waste management will have to be addressed.	*Funding provision is beyond the scope of this document; no* <u>*technical*</u> *recommendation can be offered, but consideration on funding is described in Section 3.1.*

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ANNEX I. HOW PREPLANNING MAY BE UNDERTAKEN

Experience of past nuclear or radiological emergencies shows the necessity to be prepared for major unanticipated events that can lead to the need to management of very large volumes of waste and material contaminated by the emergency [I-1].

The objective of this Annex is to introduce a preplanning process and to develop a preplan that would enable an early response and allow best accident waste management practices to be applied.

I-1. MAIN STEPS FOR PREPLANNING

The main steps to allow preplanning to be undertaken are as follows:

- Define who is responsible for developing the preplan
  - Usually would be allocated by Government to appropriate ministry or agency, but is country specific.
  - Key point is that same organisation or institution needs to be accountable for the delivery of the preplan (reference material: GSR Part 7 [2] Requirement 15 for emergency preparedness and response (EPR), and GSR Part 5 [6] and SSR-5 [7] for radioactive waste management).
  - Ensure integration with overall EPR (not standalone).

- Define role and responsibilities – authority
  - Government retains overall responsibility but delegates to lead authority as a coordinating mechanism.
  - Lead authority has to set out the scope and process for developing the preplan.
  - Identify all other organisations involved in preplanning (including authorities, waste generators / operators, other stakeholders and interested parties) and specify roles.

- Develop basis for preplanning

  As the starting point of preplanning suitable to the country, it is important to understand the national situation such as:
  - The number and types of nuclear facilities, radiation sources in a country;
  - The status of the facilities (operational, decommissioning etc.);
  - Locations of facilities and nature of their surrounding environment (rural, urban, coastal etc.);
  - Proximity to national borders;
  - Outcomes of hazard assessment carried out consistent with Ref. [2].

  It is effective to perform preplanning based around scenario exercises. The scenarios need to consider low probability, high consequence events – using worse case assumptions – to assess the potential nature and spread of contamination. Note that Fukushima Daiichi NP accident indicates that it is not appropriate to screen out scenarios on the basis of assumed likelihood.

- Perform preplanning and review
  The preplanning process then needs to ensure that the waste management response is adequate to handle the consequences of the scenarios considered. Example of items included in preplanning is given in the next section.

  It is also important to give consideration on undertaking an exercise to test the efficiency of the preplan and its implementation, followed by revision to the preplan if necessary afterwards. In any event, the preplan needs to be updated to reflect changing circumstances at regular periods to maintain the plan as deliverable.

  For nuclear facilities, there will be existing emergency response plans, though these may not address waste management sufficiently. Since waste management is an activity linked with various mitigatory and protective actions, it is advisable to develop preplanning addressed in this subsection as an integrated part of the whole emergency response plans.

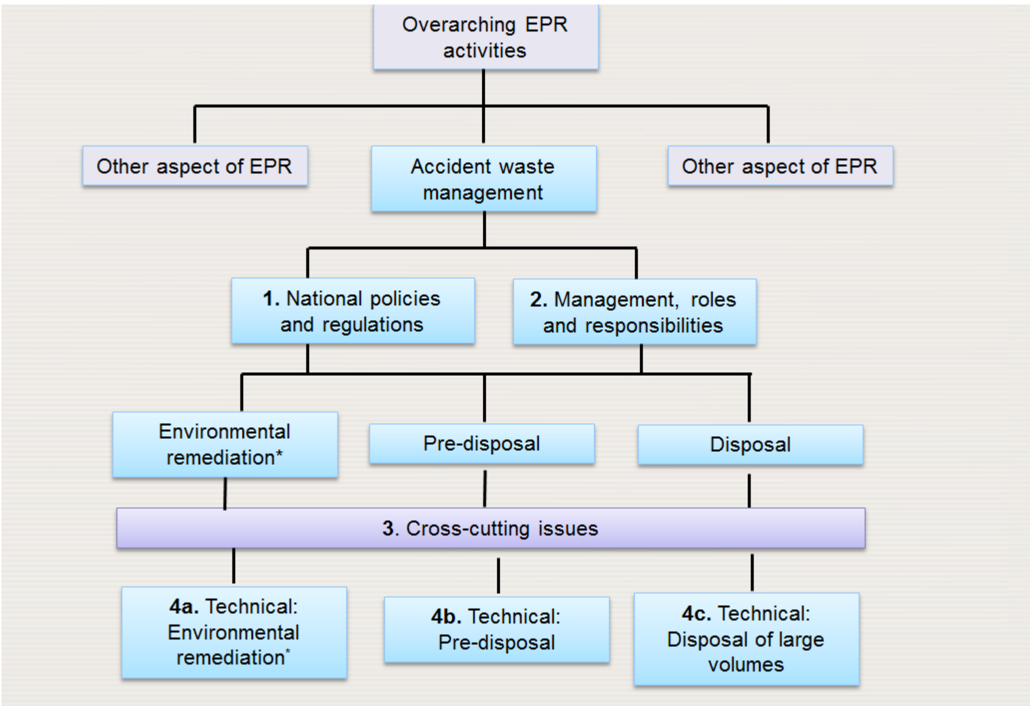
  For countries that do not have nuclear facilities and do not have border countries with nuclear facilities, then a smaller proportionate preplanning process for waste management might be undertaken. This will need to address scenarios based on (i) accidents involving radioisotopes and radiation sources, and (ii) possible malicious actions.

I-2. OUTLINE FOR A PREPLAN FOR ACCIDENT WASTE MANAGEMENT

Outline for structure of the waste management preplan

This example consists of 4-level structures as shown in Figure A-1:

(1) National policy and regulations;
(2) Management, roles and responsibilities;
(3) Cross cutting issues (for environmental remediation, predisposal activities and disposal) considering technical and other aspects;
(4) Technical level for each of environmental remediation, predisposal activities and disposal.



*Note: With respect to environmental remediation, the preplanning process discussed here is only in relation to those aspects that are relevant to waste generation and waste management activities.
EPR - emergency preparedness and response

FIG. I-1. Structure of preplanning.

I-2.1. National policy and regulations

The preplanning process needs to address the following, taking account of the national situation:

- Key principles and policy statements (a policy statement would usually follow consideration on principles);
- Regulations and safety levels;
- Note this needs to cover all aspects of waste management including environmental remediation, predisposal and disposal.

I-2.1.1. Key considerations and policy statements

The preplanning process needs to address the following aspects, taking account of the national situation:

- Application of same safety criteria as normal operations for workers and public (different criteria could be applied with appropriate justification);
- Environmental remediation end-points (and possible end uses);
- Preferred timing for disposal (accelerated or deferred);
- Use of conditional and unconditional clearance and exemption (and quantitative values e.g. bulk activity, v. radionuclide specific levels v. risk);
- Reuse and recycling of cleared wastes;

- Other environmental remediation and predisposal aspects addressed in companion reports (see Figure 1 in Section 1.4).

I-2.1.2. Regulations and safety targets

Regulations and safety targets need to be developed to reflect the key principles and policy decisions.
These may address:
- Assessing whether all existing regulations and guidance are appropriate.
- Identifying new regulations and requirements (including safety targets) that would need to be developed for waste management following an emergency.
- Specify measures including dose restrictions for exposure of workers/ emergency workers managing waste after the emergency (early in the response they will need to be designated and protected as emergency workers).
- Specify minimum cleanup criteria and safety targets applicable to the chosen end-point and end use.
- If clearance and exemption scheme is present in the country, consider if the system is applicable to the situation following an emergency.
- Specify minimum post-closure performance criteria for disposal facilities (dose, risk and complementary).
- Other environmental remediation and predisposal aspects addressed in companion reports (see Figure 1 in Section 1.4).

I-2.2. Management, roles and responsibilities

The preplanning process needs to address the following, taking account of the national situation:
- Roles and responsibilities of all key organisations and institutions;
- Resource planning and associated activities.

I-2.2.1. Define roles and responsibilities

Identify the lead authority for implementing the overall waste management preplan in the event of an emergency (note may not be same as authority that developed it – but having the same authority responsible for both would likely lead to more effective implementation):
- Identify overall lead organisation and / or individual, i.e. the coordinating mechanism;
- Identify leads for the main waste management stages of environmental remediation, predisposal and disposal (covering both technical and project management);
- Identify other organisations that will be involved in waste management activities (both hands on and desk based);

- Define roles, responsibilities and chains of command (including local parties, police, home guard etc. not just technical groups);
- Defining roles and responsibilities also needs to address integration with the overarching EPR management.

I-2.2.2. Resource planning and funding mechanism

- Recognize that emergency response and waste management is expensive, so rapid allocation of new budgets will be required.
- This will need to cover both the emergency phase and longer term waste management and disposal activities.
- Identify and maintain list of competent and experienced organisations (public and private, and international) to support the waste management activities.
- Establish appropriate contract mechanisms in advance.

I-2.3. Cross cutting issues

Cross cutting issues are those that are applicable to all stages in accident waste management, and so need to be considered in advance in a coherent manner to meet all requirements. These may cover:

- Technical aspects (for waste management organisations);
- Regulatory aspects (for decision making authorities);
- Management tools and procedures;
- Societal issues and stakeholder involvement.

I-2.3.1. Cross-cutting technical aspects

- Perform gap analysis to evaluate existing waste management infrastructure, tools, methods etc. that will be needed to implement Government policy in the event of an emergency (based on the scenarios considered).
- Propose new work needed to address any identified gaps, this may include research and development, to improve existing capability or develop new approaches.
- Examples of the aspects to be considered in the gap analysis could include:
  - Characterization methods and tools for wastes arising from an emergency (radiological, physical, chemical, biological);
  - Approaches for deriving waste inventories on the basis of calculation and characterization (both wastes collected and predicted arising from future environmental remediation);
  - Procedures for quality management and controls on waste characterization and other related data (e.g. provide confidence that waste acceptance criteria are met at disposal);

– Data collection, data management, databases for all purposes needed to support waste management (note this is wider than just for the inventory);
– Waste tracking and records to handle many locations, shipments, packages and types of waste from "cradle to grave".

I-2.3.2. Cross-cutting regulatory aspects

Potentially, the granting of permits and authorizations to undertake waste management activities could be the rate limiting step. The preplanning process may consider:

- Agreeing approaches for prompt licensing of waste management facilities, with respect to the prerequisites of the licence application (including pre-licensing of general designs);
- Capacity, capability and authority of the regulators to make prompt decisions to allow recovery and waste management to proceed;
- Improving interactions between regulatory and other decision making bodies when there are cross-cutting responsibilities (e.g. environmental and nuclear);
- For the purpose of waste volume reduction, consider how to adopt clearance/exemption scheme into the situation following an emergency.

I-2.3.3. Cross-cutting management tools and procedures

This will be an important area for the overall recovery following an emergency. However, for waste management aspects this is limited to a few topics such as:

- Consideration that because waste management is long term, it is likely that a new waste management organisation will need to be established or existing organisation will need to be expanded and this will require additional personnel and contractors etc.
- Suitably qualified and experienced personnel for undertaking waste management activities may be in short supply.
- Training and evaluating staff competence in waste management.
- Rapid updating and reporting mechanism on waste volumes and characteristics.

I-2.3.4. Cross-cutting societal issues and stakeholder involvement

This will be an important area for the overall accident recovery, however for waste management aspects this is limited to a few topics such as:

- Decisions on site end-states, end use and associated cleanup criteria;
- Approach to cleanup programme, zoning and "shrinking the footprint" (contaminated area);
- Siting of new staging areas, waste management, interim stores and disposal facilities;
- Timing of disposal programme (accelerated or deferred).

I-2.4. Technical level

The preplanning process would need to consider all technical aspects of waste management activities associated with each of the main phases:

- Environmental remediation;
- Predisposal;
- Disposal.

I-2.4.1. These technical level preplans are likely to be based on scenarios that take account of possible accident events, their location and consequences. This may be done at a national level or at a local level. At a local level, the preplans would address waste management in the early phase after an accident but would likely consider longer term decisions on waste disposal in a more limited way – those aspects would more likely be addressed at a national level. Environmental remediation

- Perform gap analysis to evaluate the capability and capacity of environmental remediation methods and services with respect to the waste management aspects (e.g. methods to develop rapid, field based monitoring devices), and also for other tools, methods etc. that will be needed to implement Government environmental remediation policy in the event of an accident (based on the scenarios considered).
- Identify possible tools and contractors to undertake rapid surveys, large soil scanning and sorting, etc.
- Address other environmental remediation aspects addressed in companion report (see Figure 1 in Section 1.4).

I-2.4.2. Predisposal

- Perform gap analysis to evaluate the capability and capacity of existing predisposal infrastructure (e.g. volume reduction, segregation, conditioning, storage facilities), and also for other tools, methods etc. that will be needed to implement Government predisposal policy in the event of an accident (based on the scenarios considered) [I-2].
- Identify possible methods, tools and contractors to facilitate rapid characterization of large volumes of bulk waste (e.g. to application of clearance and exemption, support segregation and sentencing decisions etc.).
- Identify possible staging areas.
- Perform steps to accelerate licensing process for waste management facilities (e.g. conditioning and storage). These steps may include agreeing a pro-forma license pack.
- Address other predisposal aspects addressed in companion report (see Figure. 1 in Section 1.4).

I-2.4.3. Disposal

There are many technical issues that will need to be considered with respect to planning and implementing disposal of accident wastes [I-3]. The gap analysis discussed below will be the primary means for identifying all of the aspects the preplanning will need to address:

- Perform gap analysis to evaluate the capability and capacity of existing disposal infrastructure, and also for other tools, methods etc. that will be needed to implement Government disposal policy in the event of an accident (based on the scenarios considered).
- Propose new work needed to address any identified gaps, this may include research and development, to improve existing disposal capability or develop new approaches.
- Estimate possible waste inventories for postulated emergencies that reflect the national situation (taking account of the numbers, types and locations of nuclear facilities and users of radioisotopes and radiation sources).
- The estimation of inventory needs to include likely spread (plume) of contamination, mobility of contaminants in the environment, volume and characteristics of contaminated materials (e.g. soils, trees, buildings etc.).
- Consider the development of modular and scalable designs for disposal of accident wastes that may enable rapid licensing and be implemented quickly.
- Evaluate the possibility for the transfer of existing licensed disposal facility designs to allow the rapid implementation and licensing of new facilities for accident wastes – noting that if the waste types, facility designs and locations of proposed new facilities are similar to the respective existing facilities, then their safety performance would also be expected to be similar.
- Address other disposal aspects addressed in companion report (see Figure 1 in Section 1.4).

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[I-1] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL CIVIL AVIATION ORGANIZATION, INTERNATIONAL LABOUR ORGANIZATION, INTERNATIONAL MARITIME ORGANIZATION, INTERPOL, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, PREPARATORY COMMISSION FOR THE COMPREHENSIVE NUCLEAR-TEST-BAN TREATY ORGANIZATION, UNITED NATIONS ENVIRONMENT PROGRAMME, UNITED NATIONS OFFICE FOR THE COORDINATION OF HUMANITARIAN AFFAIRS, WORLD HEALTH ORGANIZATION, WORLD METEOROLOGICAL ORGANIZATION, Preparedness and Response for a Nuclear or Radiological Emergency, IAEA Safety Standards Series No. GSR Part 7, IAEA, Vienna (2015).

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ISBN 978–92–0–107417–1
ISSN 1011–4289