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Retrieval and Conditioning of Solid Radioactive Waste from Old Facilities

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RETRIEVAL AND CONDITIONING OF SOLID RADIOACTIVE WASTE FROM OLD FACILITIES

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FOREWORD

Safety requirements for the storage and disposal of radioactive waste, as well as the technological capabilities for radioactive waste processing and disposal, have advanced substantially over the past two decades. Safety requirements and capabilities in the early years of nuclear technology development were significantly lower than today's standards, because of less knowledge and experience of radioactive waste management. Consequently, the quality of old waste forms and the safety of old waste disposal and storage facilities do not always meet modern requirements for quality and safety. To improve the status and conditions of such old facilities and waste, several countries are now upgrading old repositories or storage facilities for radioactive waste by retrieving the stored or disposed waste.

Practical experience with retrieval and reconditioning of old radioactive waste has shown that this is a complex and complicated task. Management of waste retrieval projects requires special attention, careful planning, specific preparation and appropriate implementation. A review of the available information, and an analysis of the existing experience with the planning and implementation of such projects, are essential for ensuring safety, minimizing costs and ensuring a quality end product for subsequent storage or disposal.

Recognizing the importance of this subject area for Member States, the IAEA initiated this technical report to identify, analyse and document methodologies and technologies for retrieval and reconditioning of radioactive waste from inadequate storage or disposal facilities that do not meet current standards. This report defines the most common situations when retrieval of old waste is needed. It also outlines generic procedures and methodologies for planning and implementation of the retrieval and reconditioning project. The annexes provide examples of waste retrieval projects.

The initial draft of this report was prepared and revised at two Consultants Meetings and a Technical Meeting held in 2004–2005. The IAEA is grateful to all those who participated in this work. The IAEA officer responsible for this report was V. Efremenkov of the Division of Nuclear Fuel Cycle and Waste Technology.

EDITORIAL NOTE

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

In the early days of the nuclear era, a production oriented approach dominated. Most efforts focused on the development of nuclear reactor technologies and their application in related fields. Management of the resulting radioactive waste was not considered a significant problem. While some countries had already developed and implemented permanent disposal repositories for some waste types (primarily low level waste (LLW)), other countries placed radioactive waste into on-site or off-site storage facilities. The intention was to retrieve and process such stored waste only at the end of the facility life as part of dismantling and decommissioning activities.

The first land disposal repository for radioactive waste, which was in the United States of America, dates back to the mid-1940s; land repositories followed in many other countries in the 1950s and 1960s (in the United Kingdom, India, the Russian Federation, the Czech Republic, Hungary, Poland, Bulgaria, Norway, South Africa, and others). With the exception of four relatively deep (50–100 m) mined cavity repositories in the UK and the Czech Republic, most of the repositories were constructed using at-surface designs (mounds) or near surface designs (shallow trenches). Many of these facilities were simple (without engineered barriers) or were primitively engineered, with a soil cover of typically only a few metres over the waste. The waste was often disposed of without treatment or conditioning and with very simple waste acceptance criteria (WAC) or sometimes with no criteria. Some specific facilities of this type are described in greater detail in Refs [1–4].

Some of the early established disposal facilities do not meet current safety requirements, and the disposed waste packages do not meet modern waste package quality standards. Safety assessments and environmental measurements have demonstrated that some of these repositories may represent an unacceptable risk or hazard to the environment, workers and the public, therefore requiring remediation actions.

Similarly, some old interim storage facilities contain waste and waste containers that have deteriorated, or the general storage conditions no longer meet the requirements for safety. Again, this indicates a need for remediation of the facilities. In some cases, inadequate waste storage practices continue to be applied, due to:

(a) A lack of appropriate knowledge and practical experience in radioactive waste management in general;

(b) A lack of appropriate technologies for waste processing (treatment and conditioning);
(c) A lack of well defined requirements for waste quality and acceptance criteria for long term storage or disposal;
(d) Inadequate storage or disposal conditions, and unacceptable impact of external conditions on waste and waste packages;
(e) Poor quality of waste forms, waste containers or other engineered barriers;
(f) Storage or disposal of waste in its original form and without appropriate packaging.

The concepts and requirements for safe storage and disposal have evolved over time. There is now a general international consensus that low and intermediate level waste (LILW) can and should be safely stored and disposed of in properly designed and licensed engineered facilities with site specific and package specific WAC [5, 6].

A decision to retrieve radioactive waste from some old storage or disposal facilities could be made if the present status of safety and security does not correspond to current standards or requirements, or if the existing social, political or economic situation requires such remediation actions. The cost of waste retrieval and facility or site remediation — both in terms of radiation exposure and financial expenditures resulting from the remediation — is normally justified by the improved safety and security of the facility or site after remediation, the availability of the facility or site for other purposes, etc. In all steps of waste retrieval and site remediation, safety of the staff, protection of the environment and waste security should be given the highest priorities.

Several countries have initiated or already completed the upgrading of old repositories or storage facilities for radioactive waste, or they are facing the necessity to take appropriate actions. Analysis of the existing experience in planning, implementation and management of such projects is important for improving the efficiency of relevant waste retrieval, reconditioning and site remediation in Member States. A review of the available information on this subject, along with a discussion of related problems and existing practices, would be of particular benefit to Member States facing retrieval and reconditioning projects but that are lacking corresponding experience.

The problems associated with retrieval of solid waste differ significantly from those associated with retrieval of liquid waste and disused sealed sources. In order to adequately cover all of the different aspects, the IAEA is developing separate documents for each of these waste types. This report deals specifically with the retrieval and reconditioning of solid waste. The aspects of retrieving old fluidizable or ‘wet waste’ and the retrieval and management of disused sealed radioactive sources are covered in other IAEA publications [7–10].

A common challenge for all historical waste types is the assessment of existing documentation, which is addressed in Ref. [11]. A comprehensive understanding of the retrieval and reconditioning of different types of old waste may be obtained from Refs [7–11].

1.2. OBJECTIVE

The objectives of this report are to:

(a) Discuss methodologies and technologies for retrieval and conditioning or reconditioning of historical radioactive waste;
(b) Document existing experience in the implementation of this work.

The functional objective of this report is primarily to assist managers responsible for the organization and implementation of retrieval and reconditioning projects to plan, select and use the available technologies and resources. It should also serve as an information source for waste handling technicians, characterization staff, design engineers, project planners and operators involved in solid waste retrieval and reconditioning activities from old storage and disposal facilities, as well as regulators with oversight responsibilities for such activities.

1.3. SCOPE

This report describes planning and on-site retrieval systems for solid or solidified radioactive waste emplaced in old, inadequate storage and disposal facilities. The waste to be retrieved may include waste without any kind of previous processing, waste that has undergone different stages of processing, or fully conditioned waste. The scope also includes waste retrieval as a series of integrated waste management actions, which include selection of retrieval techniques, sorting, characterization, treatment, conditioning, transport and interim storage. Disposal is addressed only in terms of WAC and general availability.

The subject of waste retrieval is complicated and diverse, such that it would be impractical to include every important aspect in the scope of a single document. To assist the reader in understanding the limitations of the scope of this report and its relationship with other existing, complimentary publications, the following considerations apply:

(a) The starting point for the scope of this report is when it is recognized that there is a storage or disposal facility from which the waste may have to be retrieved. The scope stops at the point where the waste has been properly and safely dispositioned (stored or delivered for disposal). However, additional work may be required, as discussed below.
(b) The primary motivator for a decision to pursue waste retrieval is usually the presence of unsafe or insecure conditions in the facility or of the waste that compromises the environment, worker safety or public safety. The decision making and initiating conditions that may trigger a decision to retrieve waste will vary among sites. References [7, 12] address these considerations. National legislation may also require a full or limited environmental impact assessment of the retrieval operation to be included in the background material submitted for approval of retrieval and remediation work. Such requirements are country specific.
(c) Once the waste has been retrieved and properly dispositioned, the facility and surrounding environment may require some form of cleanup in order to restore it to an environmentally safe condition. This further restoration and site remediation are described in other IAEA publications [13, 14].
(d) There are often non-radiological hazards, such as asbestos, lead and beryllium, of some waste components that need to be considered when a decision is made on waste retrieval. The relevant information can be found in other IAEA publications [15, 16].

1.4. STRUCTURE

This report is structured around the sequence of steps to be implemented in the planning for and actual retrieval of the waste and the subsequent steps specific for retrieved waste processing (see Fig. 1).

Sections 2–5 focus on activities that support the planning stage of a waste retrieval project. Section 2 provides an overview of the typical characteristics of the affected facilities and the waste subject to retrieval. Factors that may influence the development of the details in the plan for retrieval and subsequent processing of the waste are given in Section 3. Section 4 describes the initial characterization of facilities and waste to be performed before initiation of waste retrieval in order to optimize the methodology and techniques to be used in specific cases. Considerations specific to the planning

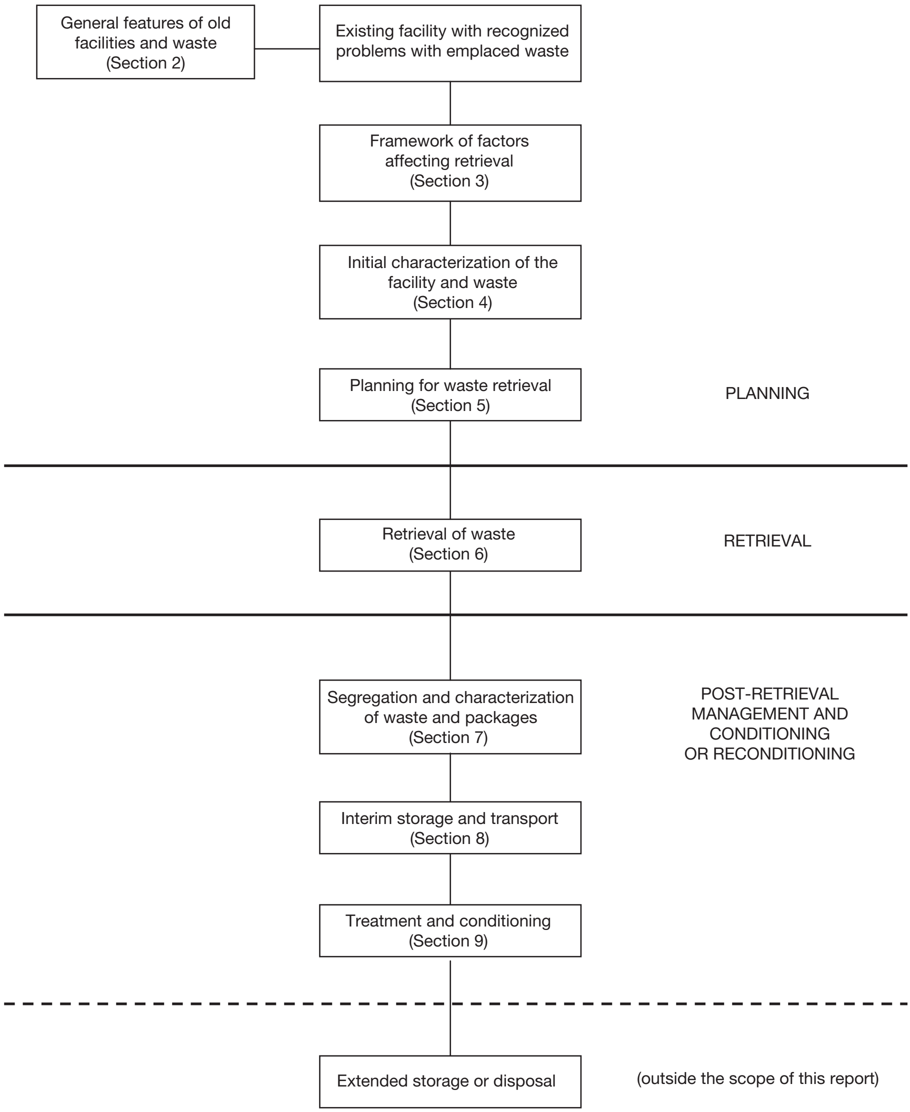

FIG. 1. Logic diagram for the retrieval and subsequent management of waste.

process for waste retrieval and subsequent processing are discussed in Section 5.

Section 6 describes the different techniques to be used for waste retrieval from different facilities.

Sections 7–9 focus on managing and reconditioning retrieved waste. Section 7 describes techniques to be used for advanced waste characterization, sorting and selection of appropriate processing options to be performed on the retrieved waste to ensure that it can be properly processed, taking into account the final waste destination. Section 8 describes interim storage and packaging, while Section 9 describes the required processing (treatment and conditioning) steps.

Concluding remarks are made in Section 10. Examples of waste retrieval projects are provided in the annexes.

2. GENERAL FEATURES OF OLD FACILITIES AND WASTE

This section discusses some general reasons for retrieval and the typical characteristics of facilities and waste that are subject to retrieval and reconditioning. The major underlying factor that triggers a retrieval operation, or at least an assessment, is a perceived need to reduce the potential hazards and risks to the environment and the public posed by the facility or waste. The hazard may come from deficiencies in both safety and security arrangements, and it may be of a radiological or non-radiological (chemical or biological) character.

As discussed in Section 1.3, the overall decision making process concerning retrieval and reconditioning is described in greater detail in other reports, such as Ref. [12]. However, every decision on whether to retrieve waste should be based in part on an assessment of the safety and security risks associated with disturbing the waste as opposed to leaving it in the present location.

2.1. REASONS FOR RETRIEVAL OF WASTE

By definition, all ‘temporary’ and ‘interim’ storage facilities will require waste to be removed at some time prior to the decommissioning of the facility (unless the facility is converted to a disposal facility in which the waste is left in situ). Retrieval of waste is often considered in the original design of the facility; if so, the task may be relatively simple. However, in some cases, retrieval may be difficult if the facility was not designed for or subsequently operated with easy retrieval in mind. Retrieval may also become unusually problematic if the waste containers or storage structures have degraded more than expected.

There are a number of reasons why waste in old storage and disposal facilities may require retrieval and reconditioning. These include:

(a) Safety reasons:
  - (i) Discovery or recognition of a real or potential problem that could lead to undesirable safety, environmental or radiological impacts (e.g. leaching of contaminants into groundwater or impending structural failure of the facility);
  - (ii) Insufficient or lack of waste inventory data, where there may be particular or potential concern justifying actions (e.g. significant uncertainty over the quantity of long lived radionuclides in a facility designed for short lived waste);
  - (iii) Degradation of waste packages or facility structures in a way that may compromise the current or future safety of the facility;
  - (iv) Waste forms not performing as predicted by previous safety analyses;
  - (v) Implementation of a conditioning programme for waste that was previously stored in an unconditioned state.

(b) Technical and financial reasons:
  - (i) A desire to reduce the volume of stored or disposed waste (e.g. to recover space to create further storage or disposal capacity and extend the life of an existing storage facility that is at or near capacity);
  - (ii) A desire to consolidate several smaller facilities into a larger one;
  - (iii) As a precursor to the decommissioning of a storage facility;
  - (iv) Retrieval of material previously considered to be waste but now considered to be useful.

(c) Legislative and public perception reasons:
  - (i) Changes in regulations (e.g. to impose additional constraints that retroactively apply to existing facilities);
  - (ii) An order from a regulatory body or other government agency (e.g. to conform to a new national standard or to meet government policy);
  - (iii) A policy decision or other requirement to extend the storage period beyond that originally considered (e.g. beyond the design life of the original facility or waste packages);
  - (iv) Lack of public acceptance of an existing facility and a subsequent administrative decision for its closure.

2.2. FACILITIES THAT MAY REQUIRE UNPLANNED OR UNEXPECTED RETRIEVAL OF WASTE

Retrieval of waste is generally performed from temporary facilities as part of the normal evolution of such facilities or from older facilities that may have been designed, licensed, constructed or operated according to regulations and requirements that are less stringent than modern standards. These facilities might include:

(a) Facilities that no longer meet current safety requirements;
(b) Facilities with a degradation of the engineered infrastructure or with degraded waste packages that could or already compromise safety;
(c) Interim storage facilities with unconditioned waste that has been stored for an extended period of time (e.g. for more than one year);
(d) Temporary storage facilities established under emergency situations (e.g. for managing waste generated during radiological accidents, as was done, for example, after the accident at Chernobyl).

There is a wide variety of waste storage and disposal facilities with different design characteristics and operating histories. Not all facilities listed above will require waste retrieval and remediation. In some cases, retrieval may not be justified after comparing the cost and radiation exposure consequences with the estimated improvement over the existing situation; for example, a low improvement estimate may not justify a high impact project. Of course, this will depend on the circumstances of the individual situation and will require careful consideration prior to undertaking the waste retrieval project.

2.3. COMMON CHARACTERISTICS OF OLD FACILITIES

Many of the facilities requiring retrieval of the waste (especially disposal facilities) share some common characteristics. These could include:

(a) Licensing, design or operation according to older, less restrictive safety regulations or WAC.
(b) Poorly documented or missing design information, as-built drawings, technical specifications, etc.
(c) Poorly documented waste inventory.
(d) Poorly documented or undocumented arrangement and location of waste packages within the storage or disposal facility.

(e) Engineered structures deteriorated to such a degree as to pose a safety hazard to workers, the environment and the public.
(f) Retrieval was not considered or was inadequately considered in the original design of the facility.
(g) Difficult access to the storage or disposal horizon (e.g. trenches covered by several metres of soil or vaults located behind thick concrete shielding walls with restricted openings).
(h) Poor design, construction or maintenance resulting in a potential for containing large volumes of contaminated water (e.g. from seepage) or sand–soil (e.g. from surrounding backfill) that must be addressed along with the original waste.
(i) Facilities in which the waste has been conditioned in situ (e.g. backfill of waste vaults with concrete or bitumen). Retrieval from such facilities becomes more difficult because of the need to break up the conditioning media.

Another inhibitor to waste retrieval from old facilities may be a lack of clear ownership of or responsibility for the waste or a lack of funding sources (e.g. due to bankruptcy of commercial operators or reorganization of government agencies or commercial companies).

2.4. COMMON CHARACTERISTICS OF OLD WASTE

Many of the types of waste requiring retrieval and reconditioning share some common characteristics, including:

(a) Poorly documented characteristics, including uncertain radionuclide concentrations, undocumented waste forms, etc.
(b) Unknown or poorly documented information on non-radiological hazards (e.g. asbestos, organic solvents, pathological agents and toxic chemicals).
(c) Deterioration of waste packages or the waste form (e.g. corrosion or putrefaction), with a potential for dispersion or leakage of radionuclides or other types of hazardous material from the original packages.
(d) Waste packages not provided with easy means of retrieval (e.g. handles or grappling hooks).
(e) Waste packages that were not originally emplaced in a uniform manner (e.g. ‘tip and roll’ emplacement) or that have subsequently collapsed over time from a uniform emplacement manner into a disorganized pile (e.g. disposal trench subsidence).

(f) Unpackaged bulk waste.

(g) A heterogeneous mixture of waste packages, waste types, waste forms or waste classes in the same facility. Waste items may also include unexpected high dose rate items, such as sealed sources, reactor core components and fuel debris.

The waste plan must recognize that the initial characteristics of the waste and packages may have changed over time due to a variety of degradation mechanisms, such as corrosion, biodegradation, chemical reactions and radioactive decay. Therefore, the original waste package documentation cannot be relied upon to describe completely the current status of the waste and waste packages.

All of the above possibilities must be considered in the waste retrieval and management plan and in the design strategy of the retrieval and handling processes. Examples of some specific remediation projects, including brief descriptions of the retrieved waste types, are provided in Section 9 and in the annexes.

3. DECISION MAKING AND PLANNING FRAMEWORK

The overall goal of any waste retrieval programme is to enhance safety and security. Before embarking on a retrieval programme, it is critical to plan the work and, in doing so, consider all the health, environmental, political, legal, social, economic and technical implications.

As shown in Fig. 2, each step in the work should result in a net reduction in the risk, although there may be a temporarily increased risk during the implementation of some specific operations, such as retrieval of hazardous objects. The importance of each step may vary from case to case, and the key to a successful rehabilitation strategy is to achieve the correct balance in considering all the issues for a particular facility. The retrieval and subsequent management of radioactive waste should be done in conformity with the national strategy for management of radioactive waste and with national legislation.

Before preparing a detailed plan, an overall strategy for the retrieval process should be contemplated in which milestones indicating decision points for the overall process are defined. In preparing a detailed plan of retrieval operation and the subsequent processing stages, it is important to know the

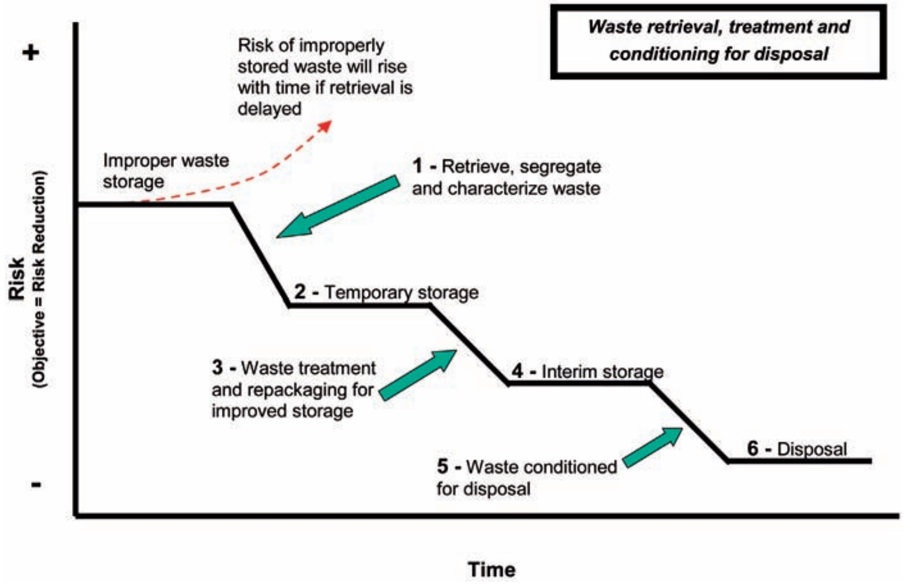

FIG. 2. Reduction of risk with time and remediation actions.

framework within which such a plan will be developed. The exact framework is related to the specific facility from which the waste is to be retrieved, the specific waste to be retrieved and the relevant national waste management infrastructure. Examples of factors affecting the operation are:

(a) International conventions and agreements;
(b) National waste management policy and legislation;
(c) Availability of WAC or requirements (generic or site specific for packaging, processing, transport, interim storage and disposal);
(d) Available national competence (technology and trained and experienced staff);
(e) Available waste management facilities (downstream processing, storage, disposal);
(f) The funding situation.

The impact of these factors on decision making and project implementation is discussed in this section.

3.1. INTERNATIONAL CONVENTIONS AND AGREEMENTS

Member States may have entered into international, bilateral or multinational agreements, signed conventions, and protocols that impose conditions and constraints on the decision making process. Some of the international conventions that could be of relevance are:

(a) The Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [17];
(b) The Convention on Environmental Impact Assessment in a Transboundary Context (the Espoo Convention) [18];
(c) The Vienna Convention on Civil Liability for Nuclear Damage [19];
(d) The Convention on Third Party Liability in the Field of Nuclear Energy (the Paris Convention) [20].

Policy making and policy enforcing bodies can include international organizations, government agencies and national and regional regulatory bodies. The IAEA, for example, has created a series of requirements and related guidance on the management of radioactive waste that has been internationally recognized as good waste management practices. Compliance with all relevant conventions and agreements is essential when developing national waste management strategies.

3.2. NATIONAL LEGISLATION AND STAKEHOLDER INVOLVEMENT

Different governmental bodies play numerous roles in nuclear energy activities and radioactive waste management. These multiple roles often lead to complex relationships among government departments or ministries. The situation can become more complicated when several government agencies have jurisdiction over different (or sometimes the same) aspects of waste management. Furthermore, different levels of government (local, regional and national) are often involved in the decision making process and regulation.

A country's governmental bodies develop principles (often codified as laws) regarding nuclear waste and related nuclear topics. These principles can describe the relevant agency's top priorities, such as public safety. The laws or regulations may contain specific requirements regarding how the identified priorities are to be met. These might include setting specific numeric limits for various technical parameters (e.g. dose rate or compressive strength for waste packages) or time limits for modifying old facilities to comply with new rules.

It must be recognized that policies may change as a country's experience grows and technologies mature; for example, the acceptability or feasibility of any given waste management option may change with time. The potential for changes in policy highlights the importance of regular communication between the responsible project manager and regulatory bodies.

In developing waste retrieval strategies, managers should also consider the opinions (as well as the reasons for the opinions) of the local government and citizen groups — known as stakeholders — that may have special interests in issues such as environmental impacts. In some countries, regulatory bodies may require stakeholder involvement in the decision making process. If not correctly handled, minor or irrelevant factors can be used by pressure groups as an excuse to delay or reject otherwise justified actions. In working with regulatory bodies and stakeholders, managers should consider the benefits of consistent and effective communication.

3.3. AVAILABILITY OF WASTE ACCEPTANCE CRITERIA

3.3.1. Need for waste acceptance criteria

In developing a successful rehabilitation plan, it is necessary to establish clarity on the final waste form and final destination of the conditioned waste. This is necessary to evaluate the full and complete scope of work. If such end points in the rehabilitation work are not defined, the entire rehabilitation activity may be ineffective or inefficient; for example, in many Member States decisions on the final waste form or disposal location have not been taken. This often delays retrieval projects, due to the potential for having to repeat all or part of the conditioning process for the same waste at a later date. To overcome this roadblock, some countries have established WAC (sometimes called conditions for acceptance (CFA)) that allow waste to be conditioned for disposal even in the absence of a disposal facility. The WAC are established based on existing laws, international agreements and international experience with waste forms and disposal practices. This allows the waste generator or processor to condition the waste into its final form and disposal packaging with a high degree of confidence that the package will be acceptable at a future disposal location. As an intermediate arrangement, the reconditioned waste is placed in interim storage pending an available disposal option.

Where specific WAC have not been provided, waste managers should at least consider how the waste can be retrieved and conditioned into a safer form without putting the waste into a form that could limit or complicate future processing or conditioning options. Such waste is still placed in interim storage in accordance with modern standards, yet it is easy to retrieve, condition and package once the disposal acceptance criteria have been established.

Therefore, it is reasonable to summarize that:

(a) The most desirable situation would be to retrieve, condition or recondition, and dispose of the waste immediately.
(b) If a permanent disposal option is not yet available but WAC exist for the disposal of specific waste forms, then the waste should be retrieved, conditioned or reconditioned in accordance with the WAC and placed in interim storage with a high certainty of acceptance at the future disposal facility.
(c) If a permanent disposal option is not yet available and WAC do not exist for the disposal of the expected waste forms, the waste should still be retrieved, conditioned for safe storage while maintaining reconditioning flexibility in accordance with future WAC, and placed in interim storage.

3.3.2. Additional considerations for waste acceptance criteria

Issues related to the segregation and processing of waste and the handling of waste packages are intended to satisfy the requirements of the WAC. Additional factors or considerations may be required depending on national policies and regulations, as discussed above.

The WAC can be specific to an individual disposal facility when a repository exists or when its location and design are agreed upon. It can also be generic for a certain group of waste if that waste is expected to be disposed of in similar but separate disposal facilities for which the site specific parameters are not available; for example, a country might choose to construct multiple, regional disposal facilities with common WAC, even though the site specific environmental or geological conditions are quite different. In those cases it is necessary to use generic — and thus more conservative — parameters when deriving the WAC so as to accommodate the most restrictive disposal considerations.

A refinement of the WAC concept can be found in Sweden, which has developed a system of predefined waste type descriptions (WTDs). According to this concept, the operator prepares a WTD for each specific category of waste to be disposed of. The WTD must then be approved by the regulatory authorities and included in the safety report of the facility before waste packages are produced. The WTD includes detailed descriptions of the waste package, how it is produced, and its characteristics and properties (which, of course, must be in accordance with the WAC). France has developed a very similar system, wherein approval of the WTD takes into consideration the acceptance criteria applicable to multiple disposal facilities.

As a final comment on WAC, it should be noted that one of the most important parameters is the radionuclide content. For near surface repositories, the IAEA provides guidance on how this parameter could be derived [21]. Examples of national WAC are also included in Refs [22, 23].

3.4. AVAILABILITY AND MATURITY OF TECHNOLOGIES

The success of a rehabilitation plan will often depend on the technologies utilized. Some relevant technologies are described in later sections of this report. The probability of success in the implementation of rehabilitation projects will also be influenced by knowledge of the waste characteristics. The more reliable and detailed the waste characterization, the greater the confidence that an appropriate technology will be selected and that the selected technology will be successful. The range of technology options available is very broad and at various stages of development, but preference should be given to currently available and proven technologies that offer flexibility in the face of uncertain or limited waste characterization.

The IAEA Contact Expert Group (CEG) supported a workshop in Petten in 2004 that addressed methods and techniques for retrieval of solid waste from old facilities. The CEG produced valuable conclusions regarding technologies to be used [24]. As a general rule, the simplest and commercially available (standard catalogue items) technologies tend to give the most reliable performance at the cheapest cost. Specially designed equipment tends to have 'first generation' unreliability problems and is typically expensive in capital cost, downtime (project delays) and repair cost. Repairs can also be expensive in terms of increased worker radiation exposures. When a technology is unproven, it should first be tested using non-radioactive simulated waste that reflects the characteristics of the real waste as closely as possible (this is sometimes referred to as a cold test).

The rehabilitation plan should allow time and funding for cold tests of unproven technologies and for training on difficult operations. Such training may include specially built mock-ups or computer simulators. This is especially important for the use of complex robotic retrieval equipment, where mechanical problems can be the limiting factor for success. Training involving practical exercises and cold tests should also be considered for the conditioning of liquid waste with a complex composition, where unwanted chemical reactions can negatively affect safety or the quality of the end product.

Assessments should also be made as to the degree of flexibility of a chosen technology, recognizing a potential for encountering unexpected waste types or waste forms. A further technology consideration relates to completion of the task, recognizing that the retrieval equipment often becomes 'secondary waste' that must also be dispositioned. The waste management planning should consider the potential for and subsequent disposition of such secondary waste, including the possibility of decontamination and further use of the equipment.

3.5. STAFF AND LABOUR COMPETENCIES

A key aspect of planning a rehabilitation programme at an old waste storage or disposal facility is to understand the competencies of both the management and the labour force available to undertake the work. While training programmes can be used to raise the skills of the labour force to handle selected technologies, it is far more difficult to upgrade the skills of managers who have little knowledge or experience in radioactive waste and retrieval management. In some cases the management may have experience in operating plants that have been in production for many years (power plants) and that have well verified flow sheets, documented instructions and work procedures to guide them. In contrast, waste retrieval may involve unpredictable situations or conditions that require the work to be proactively managed so that unexpected situations do not produce unsafe working conditions. Where possible, project planning should seek to minimize the need for upgrading the skills required. It should also rely on cold testing to familiarize the workforce with expected situations and train them to identify and respond properly when unexpected situations arise. Cold testing should be coordinated and supervised by personnel experienced in waste management, waste retrieval and the technologies selected for the project.

3.6. EXISTING WASTE MANAGEMENT FACILITIES

Once radioactive waste is retrieved and sorted into appropriate categories, it needs to be further processed, conditioned, stored and eventually disposed of. In many cases retrieved waste can be processed using the available techniques and facilities for processing waste generated by routine activities. It is advantageous if waste management and processing facilities exist at or near the place from which the waste will be retrieved. This offers the further benefit of facilitating both the planning and the downstream management of the retrieved waste.

The availability of a disposal repository is of special importance, since it offers the possibility to derive site specific WAC to be used as a basis for the categorization and further processing of the retrieved waste. In the absence of a repository, realistic or conservative assumptions should be made in order to design an optimized system for waste treatment and conditioning with the expectation of placing the packaged waste in an existing or new interim storage facility.

In most cases it is possible to use standard processing techniques and facilities for retrieved waste. However, there are situations in which retrieved waste is so unique that special processing techniques need to be developed or an existing technique needs to be adapted. A complete characterization of the waste may also suggest that the preferred option is a new processing facility or technology with specific features for handling the unique, retrieved waste.

3.7. FUNDING

In the past, waste management was often given a low priority compared with operation and production activities. (This is one of the reasons that some unsuitable waste storage or disposal facilities were established.) Similarly, management of historical waste does not generate any direct financial benefit. Most of the waste to be retrieved is from past liabilities, although the funding and waste retrieval plan could be expected to minimize future costs and liabilities.

In developing a rehabilitation plan, the required funding profile must be agreed upon with the funding providers. In many cases, the ‘polluter pays’ principle is difficult to apply or cannot be applied for some historical waste, and governmental funding of the retrieval and reconditioning work may be unavoidable. In addition, such projects commonly involve government departments or agencies, which are usually subject to annual spending restrictions and changes in priorities. It is very difficult to predict government funding priorities unless multi-year funding can be secured in advance. A rehabilitation plan is most realistic when it subdivides and packages the work into clearly defined increments that can be funded and implemented in stages. This is especially true for large, long term projects, where funding packages must be annually approved or are performance based.

Once a funding profile has been agreed upon, the retrieval and reconditioning programme needs to be phased to match the profile. This is an important consideration, as new and expensive problems could emerge if funding is depleted in the middle of a critical operation.

Funding is sometimes available from international sources, although it usually includes conditions that must be satisfied as part of the work. Such conditions must be incorporated into the rehabilitation plan, together with methods for measuring success and demonstrating achievement. These conditions might include restrictions on the technology used or contractual arrangements (e.g. limited choice of suppliers from a preapproved list) or adoption and implementation of certain safety requirements (in addition to national requirements, international standards may have to be followed), or required end points may be specified (e.g. when is the job considered to be complete, which is also the point at which the international funding is usually terminated).

In conclusion, it can be said that the preparation of a retrieval and reconditioning strategy is a very difficult task that should not only define the work to be performed but should also take due consideration of the above influencing factors. Often the issues to be considered are in conflict with one another, and obtaining agreement on a retrieval work plan can take a long time, perhaps years, and involve negotiation of compromises between stakeholders with differing agendas.

4. INITIAL CHARACTERIZATION OF FACILITIES AND WASTE

4.1. OBJECTIVES AND INHERENT LIMITATIONS OF INITIAL CHARACTERIZATION

An important first step in any project to retrieve radioactive waste from an existing facility is an initial characterization of the facility and the waste. For the purposes of this report, 'initial characterization' refers to all characterization efforts that contribute to the development of the waste retrieval and reconditioning plan and that occur prior to any waste being retrieved. The initial characterization may be separately funded and required prior to obtaining full funding, thereby being used in the development of the funding profile and subsequent scheduling of project phases. Recharacterization efforts may also be required following retrieval of some or all waste and prior to downstream processing, storage or disposal. Therefore, the objectives of the initial characterization efforts may differ from later recharacterization efforts in terms of scope and application of the results. This section focuses only on initial characterization efforts.

The objective of the initial characterization is to gather enough information about the facility and the waste to perform detailed planning and optimization of a system to retrieve the waste and to identify all necessary subsequent processing steps appropriate to the recovered waste. A detailed characterization is needed in order to minimize the safety, technical and financial risks associated with retrieval and further management of the waste. Characterization includes documenting the physical and chemical characteristics, radiation dose rates, activity concentrations, waste and package dimensions, weight and condition of packages, safety hazards, etc. The primary purpose — and the inherent limitation — of the initial characterization is to collect and analyse the data needed to:

(a) Establish a reasonable picture of the present status of the facility and the waste;
(b) Define potential hazards (radiological, chemical, physical);
(c) Identify the needs for and the extent of radiation protection;
(d) Identify other needed safety measures;
(e) Identify the potential techniques, technologies and instrumentation needed for the retrieval work and associated activities (storage, transport, characterization, treatment, conditioning, etc.).

The level of detail required for the initial waste and facility characterization must be balanced against the degree of potential hazard and the cost to obtain the required information. A review of existing files and staff interviews are examples of initial actions that are always justified. More complicated actions for old waste characterization may require significant handling of the waste, which may be both risky and costly. Different facilities may also require different initial characterization; for example, a facility with a well documented history or that is known to contain only low hazards may not require as much of an initial characterization effort as a facility with poor waste history data [25].

This also implies that sophisticated equipment and techniques for initial waste characterization are not required in all cases. A review of existing documentation and a few simple measurements may be sufficient. Therefore, the complexity of the initial characterization depends on the case by case situation and a preliminary review of the previous, documented characterization efforts. It needs to be reasonable and balanced against the specific circumstances of the facility, the future management of the waste and the available resources.

As a minimum, the initial characterization of waste should always identify which classes and types of waste are to be retrieved (e.g. low level unstable or bulk waste, intermediate level filter cartridge waste, large equipment and other major end items). It should also identify the radiological hazards due to the potential presence of highly irradiating material (e.g. spent sealed sources, activated material and nuclear fuel fragments), as well as other potentially hazardous material (e.g. dangerous chemicals and toxic material).

4.2. CHARACTERIZATION IMPACT ON STARTING RETRIEVAL ACTIVITIES

Practical retrieval of waste should be started only after the required sequence of steps is known and the required technologies are identified. Selection of these steps and technologies depends on the characteristics of the facility, the characteristics of the waste and the established requirements for final waste form criteria. Initiating a waste retrieval project without an adequate initial characterization is much like walking into an unfamiliar dark cellar without a torch; it presents an unnecessary and unacceptable risk. Characterization serves as the lamp that is essential to light the safe path forward.

It should be noted that in some old facilities it may not be possible to obtain all the required information during the initial characterization stage without actually retrieving the waste, thereby expediting the start of the retrieval effort. More detailed characterization of the waste can be performed in parallel with project startup, such as obtaining and analysing samples of unusual or unexpected waste. Essentially, this approach is a combination of the initial characterization effort and subsequent recharacterization, recognizing that the resulting characterization data and analyses assist both the forward motion of the retrieval project and the downstream processing and dispositioning options.

4.3. LIMITING THE SCOPE OF INITIAL CHARACTERIZATION

The initial (pre-startup) characterization of the facility and waste is vitally important to identify the aggregate set of actions and activities associated with the waste retrieval and rehabilitation. No retrieval work should ever begin prior to completing at least the minimum characterization identified in Section 4.1.

Inadequate initial characterization can lead to inadequate or incorrect choices of equipment or facilities or to an underdesigned or overdesigned system. In general, overdesigning is basically a monetary issue, while underdesigning can also be a safety issue.

Recognizing that waste may exist in places that are not easily accessible, and that the radiation hazard could be higher than anticipated, it is a delicate task to decide when enough information has been gathered to envelope the initial characteristics. Often it may be enough to determine the limiting characterization (most restrictive characteristics) of the waste classes, waste types and potential radiological and other hazards. However, every retrieval case is unique and has to be evaluated on its individual merits.

4.4. COLLECTION AND PROCESSING OF EXISTING DOCUMENTATION

The initial characterization of waste is generally conducted in two phases:

(a) Collecting and processing of existing documentation (addressed in the following paragraphs);
(b) Conducting complementary direct investigations and measurements (addressed in Section 4.5).

The existing documentation for any storage or disposal facility is likely to contain a record of how the facility was designed, licensed, constructed and operated. The initial step in facility characterization is typically comprised of a ‘paper study’, which is a review of all existing facility documentation. For old facilities, the documentation of the design and the included waste may be of poor quality, but it will still contribute to the characterization effort.

For initial evaluation of the facility, three types of documentation are of interest:

(i) Documents related to the facility and buildings;
(ii) Documents related to the waste received, its characteristics, the work activity or project from which it was generated, and any waste processing (treatment and conditioning) applied before storage and disposal;
(iii) Documents related to the operating history of the facility.

4.4.1. Documentation for facilities and buildings

Characterization of the facility and related buildings begins by obtaining and analysing the following documentation, as available:

(a) Facility layout and design documentation, including piping and instrument drawings of affected buildings (especially if there are any potential discharge pathways);
(b) Documentation on the construction of the facility or building, including as-built drawings and information on modifications;
(c) Safety analysis report and licence documentation;

(d) Documentation on important technical characteristics of the facility, such as technical specifications and documentation on the practical capacity, drainage and sumps, ventilation systems, repository liners and backfill;
(e) Other relevant information that may assist in planning waste retrieval and reconditioning activities.

4.4.2. Documentation for the waste to be retrieved

Characterization of the waste emplaced in the facility begins by obtaining and analysing the following documentation, as available:

(a) Records of received waste and all of its physical and chemical characteristics (e.g. in the former USSR this information is referred to as the waste 'passport');
(b) Records of on-site measurements and verification of received waste;
(c) Waste shipment records at the facilities where the waste was originally generated (these may have more or different details than the 'waste receipt' records at the storage or disposal facility);
(d) Documents related to the facilities and processes that generated the waste;
(e) Information on waste processing (treatment and conditioning) methods applied, if any;
(f) Documentation on the placement arrangements of waste of different types, categories and classifications;
(g) Other relevant documents.

It would also be useful to analyse the information on the facilities where the waste was generated. Even when the waste documentation at the storage or disposal facility seems to be complete, it is necessary to compare this with that of the facilities where it was generated. Records and information on waste generation activities could provide additional insights on the possible composition and characteristics of the waste.

The radiological characteristics of waste are of particular importance, since these define the level of radiation protection measures required, the selection of waste retrieval and handling techniques, and the potential final waste form and destination. Therefore the quality and interpretation of the existing relevant documentation is of great importance. This special subject is discussed in detail in IAEA reports [4, 11, 12]. If the initial characterization information is not sufficient, additional investigation by waste sampling and analysis is required, which may be expensive and could involve additional radiation exposure of the staff.

4.4.3. Documentation for operating history

Characterization also requires a review of the operating history, which begins by obtaining and analysing the following documentation, as available:

(a) Logbooks and other recorded data from the operation of the facility;
(b) Records from monitoring and inspections of the facility and the adjacent environment;
(c) Documentation of incidents (e.g. spills and leaks), accidents and other unplanned events;
(d) Interviews with current and former managers and staff of the facility — including retired workers — and follow-up of anecdotal information;
(e) Other relevant information.

The item on anecdotal information is often overlooked as an important source of clues regarding the actual conditions of the facility. The workers who constructed and operated the facility generally have significant knowledge about details that may not be included in the formal operating records — such as unusual operating events — and which are important to consider during waste retrieval operations.

4.5. SUPPLEMENTAL INVESTIGATIONS AND MEASUREMENTS

When all the existing information is collected, it may provide a solid basis for establishing a retrieval and conditioning or reconditioning programme. However, experience shows that this information is often neither complete nor fully reliable, especially for old facilities and for waste emplaced decades ago. In addition, the completeness and value of the information may be affected by the legibility of paper and microfilmed copies, as well as the accessibility of stored computer files (e.g. the original technology used to store the records may be obsolete or not compatible with modern hardware and software). Imaging and computerization of old and non-electronic records should be considered. (However, care must be taken to avoid the electronic obsolescence described above.)

In general, the older the facility, the less likely the information is to be complete, reliable, readable and accessible. Therefore, it is often necessary to supplement the paper study with site investigations and measurements.

4.5.1. Supplemental investigations related to facilities and buildings

Typical supplemental investigations related to facilities and buildings may include:

(a) Measurements of external radiation and contamination levels.
(b) Sampling and analysis of surrounding soils, vegetation and surface and groundwater.
(c) Engineering review of civil constructions, especially evaluating infrastructure degradation and structural stability; this may also include sampling of structural material for evaluation.
(d) Physical surveys, including detailed mapping and ground scanning (e.g. use of ground penetrating radar or sonar, sensitive metal detectors, radiological survey equipment, etc.).

4.5.2. Supplemental investigations related to waste

Typical supplemental investigations related to waste may include:

(a) Visual inspection of accessible waste packages or storage structures. In the case of high dose rates, remotely operated cameras or robotics could be used.
(b) In situ measurements of the activity and radionuclide composition of the waste and of surface contamination of waste items (dose rate, gamma spectrometry, neutron counting with proportional counter).
(c) Retrieval and analysis of selected waste packages or waste samples in accordance with a carefully prepared plan.
(d) Using adequate sampling methods (which may include drilling of bore holes or digging test pits) to collect representative samples for analysis.

These analyses would not only concern the radioactive composition of the waste but also its physical and chemical characteristics. This may also include analysis of waste package contents, such as the presence of:

(i) Free standing liquids;
(ii) Toxic elements, reactive material or chemically aggressive material;
(iii) Flammables and explosives.

To some extent, the scope and approach of supplemental investigations and measurements is linked to the selected waste retrieval processes (remotely controlled or hands-on access to waste) and subsequent processing (treatment and conditioning) steps. Such supplemental investigations apply primarily to additional characterization methods and techniques applied after waste retrieval is made (discussed in Section 7).

5. PLANNING ASPECTS OF WASTE RETRIEVAL

Development of a detailed waste retrieval plan and selection of the technical solutions for the retrieval and subsequent processing of waste from an old storage or disposal facility has to be carried out within the constraints of the framework discussed in Section 3 and with inputs from the initial characterization of the facility and waste, as discussed in Section 4. Further, it needs consideration of all the different steps in the chain of actions eventually leading to the final destination of the conditioned or reconditioned waste (e.g. to develop or use a complete integrated system for the retrieval, sorting, processing and disposal of waste, including a complete site remediation if required). The system should be adequate to meet the actual needs (e.g. correspond to the potential waste hazard, complexity of the facility or safety requirements). On the other hand, the system should have a reasonable degree of flexibility, because in some cases only limited information is available on old facilities and waste. In this situation, the system may need to be modified during the course of the retrieval work if unexpected waste is discovered or an unpredictable situation occurs. The different components and steps required for a normal feasibility study and development of a detailed work plan are discussed below.

5.1. SAFETY AND ENVIRONMENTAL PROTECTION CONSIDERATIONS

One of the primary reasons for retrieving and conditioning or reconditioning old waste is a real or perceived adverse impact on human safety, security of waste or protection of the environment. This implies that proper implementation of a retrieval and conditioning or reconditioning plan will result in improved safety and a reduction in environmental risks; also, it must not create any additional adverse effects in its own right. The safety and environmental protection factors to be considered in a remediation plan should include:

(a) A risk assessment of the dispersal of radioactive material during remediation operations;
(b) A risk assessment of occupational exposure to ionizing radiation;
(c) A risk assessment of occupational exposure to potential chemical and biological hazards and to hazardous material (e.g. asbestos and sharps) when retrieving or handling the waste;
(d) Utilization of adequate and acceptable practical means and available technology to minimize the impact on the environment and protect workers and the general public;
(e) Utilization of the as low as reasonably achievable (ALARA) concept;
(f) Minimization of disruption of adjacent areas, including waste storage or disposal areas not subject to the remediation (e.g. the effects of inadvertent removal of shielding from adjacent areas).

These factors are important for the safe execution of a rehabilitation project and may lead to decisions regarding the selection of remotely operated technologies versus hands-on practices. There are many structured systems for evaluation of safety issues, such as hazards and operability (HAZOP) analyses, that can be used to identify and quantify the risks associated with various alternatives.

5.2. TECHNOLOGICAL ASPECTS OF RETRIEVAL

The method of waste retrieval is often dictated by a few key parameters, including:

(a) The type of waste being retrieved (e.g. raw waste versus conditioned waste, homogeneous packages versus heterogeneous discrete items, large heavy objects versus small light ones).
(b) The condition of the waste packages (e.g. are they intact and structurally sound to be lifted? Do they have integrated lifting features?).
(c) The potential presence of free liquids with the solid waste.
(d) The physical condition of the storage or disposal facility, access to the waste and availability of handling equipment.
(e) The status of the radiological hazard (e.g. dose rate and risk of loose contamination).
(f) The requirements for and interfaces with downstream processes (e.g. sorting, characterization, treatment and conditioning).
(g) Access to supporting waste management facilities and infrastructure (e.g. existing and available on the site or not).

These parameters will influence the complexity of operation, the degree of automation required, the mechanics of retrieval, etc. An economic trade-off is often required between increased automation, occupational exposure, ease of operation and other practicalities. The degree of automation required may also be influenced by national policies and regulations, which may differ from country to country.

5.3. TECHNOLOGICAL ASPECTS OF CHARACTERIZATION AND SORTING

Once the waste has been retrieved, it is typically sorted and characterized prior to further processing and/or packaging. Usually, initial sorting is carried out before a comprehensive characterization process, but in some cases characterization could be performed on waste before sorting. The requirements for the selected processing and packaging technologies, as well as the further storage or disposal options, will dictate the requirements for characterization and sorting. These requirements can be accomplished on the basis of physical, chemical and radiological properties, or some combination thereof, depending on waste acceptance for particular processing methods or a particular disposal option. Conversely, the degree to which it is possible to characterize or sort the waste may dictate the selection of further processing and packaging technologies. If two types of waste are intimately mixed such that it is not possible to separate them, and if one of them might interfere with a processing option, then a process that can tolerate both types of material should be selected. For example, aluminium and Magnox waste has been stored together in some UK facilities. Magnox waste can be conditioned in cement, whereas aluminium reacts with the high pH of cement to create hydrogen. Therefore a costly separation step must be included or another conditioning media should be selected that is chemically compatible with all waste stream components.

Sorting might not be justified for the retrieval and overpacking of some old conditioned waste packages (e.g. 200 L drums with cemented waste). However, some consideration should be given to grouping similar waste packages by some logical characteristic (e.g. original type or origin of the waste, dose rate or package size).

5.4. TECHNOLOGICAL ASPECTS OF PROCESSING

The technical selection of an appropriate processing method is very much governed by its two defining end points: the type and condition of the waste to be processed and the desired end product or waste form (normally as specified by the WAC for the receiving facility). Two approaches can be taken with respect to the incoming waste: design the system to accept what will be retrieved without further action (use of a robust process) or impose restrictions on what can be fed into the system in order to optimize the processing technique (use of a number of special processes for different waste streams).

With waste retrieved from old repositories, this latter approach can carry significant risk, since the exact characteristics of the waste are often not well defined or are uncertain. It may also lead to the need for several different processes to handle the waste. In these cases a more versatile, robust, single process that produces an acceptable (but not necessarily the best) product could be considered over a series of individual processes, each optimized to produce the best product quality for a single waste stream.

When working with a wide range of potential waste streams, selection of versatile, robust processes generally reduces both capital and operating costs and may also reduce the need for sorting and characterization of the retrieved waste.

5.5. WASTE ACCEPTANCE CRITERIA

The WAC define the end point of the retrieval and conditioning or reconditioning process. For Member States or facilities that have clearly defined WAC, the task of designing a waste treatment and conditioning plan to meet these criteria becomes deterministic. Where WAC do not already exist, they should be developed. These can be based on generic principles (see Section 3) and conservative assumptions, taking into consideration international experience [5, 21, 26–28].

5.6. WASTE RETRIEVAL PLAN

The waste retrieval plan (sometimes called a project execution plan) is the technical and managerial approach for remediation of a specific site or waste facility. It typically identifies:

(a) The overall plan for waste retrieval and management of a waste facility;
(b) The waste data and characterization required to select and/or support retrieval processes;
(c) Where retrieval and processing actions fit into the overall remediation sequence;

(d) The further waste characterization required to define potential downstream processes;
(e) The defined or potential downstream processes and disposal conditions for the waste;
(f) The final waste product to be produced for interim storage and/or disposal;
(g) The operators and managers responsible for each set of actions;
(h) The interfaces with other functional activities;
(i) The project schedule and budget;
(j) Cooperation and interface with the regulatory authority;
(k) The change control process for incorporating and approving changes in the plan that may occur over the project life.

There are many considerations involved in the formulation of a successful waste remediation plan. These considerations include cost, time scales, risk reduction, hazard identification and mitigation, the complexity of the old waste, the extent of inventory knowledge, the scale of the task (single or multiple waste streams to treat large or small volumes), the waste types, the required treatment and conditioning, and identification of the point of final waste disposition. As the plan develops, changes may occur because of policy shifts, emerging situations, change of process data, etc. Some changes impact upon only a few elements, while other changes may have effects throughout the entire plan. With these larger changes, waste facility managers must assess the impact on the current retrieval system and the processing plant design and operations. This is normally addressed in a formal change control process incorporated into the planning process. While the plan is being developed, and often throughout the entire remediation effort, waste managers must also communicate with policy makers, regulators and stakeholders to ensure that the retrieval process remains acceptable.

One common approach to developing a waste retrieval plan is to produce a diagram or route map for waste streams. This map covers the entire waste management process, identifying process stages leading to a defined final waste state or end state. With the top level strategy defined in the route map, it is necessary to underwrite the plan with a technical basis of design. Not every piece of information can be fully underwritten; sometimes the inability to underwrite later stages may not necessarily prevent the implementation of the early stages. However, in line with the development of an integrated system, efforts should always be made to capture as much detail as possible on downstream processes before the work is commenced.

Typical activities in a waste retrieval plan are shown in Fig. 3. The figure shows that there can be complex interactions between planning and

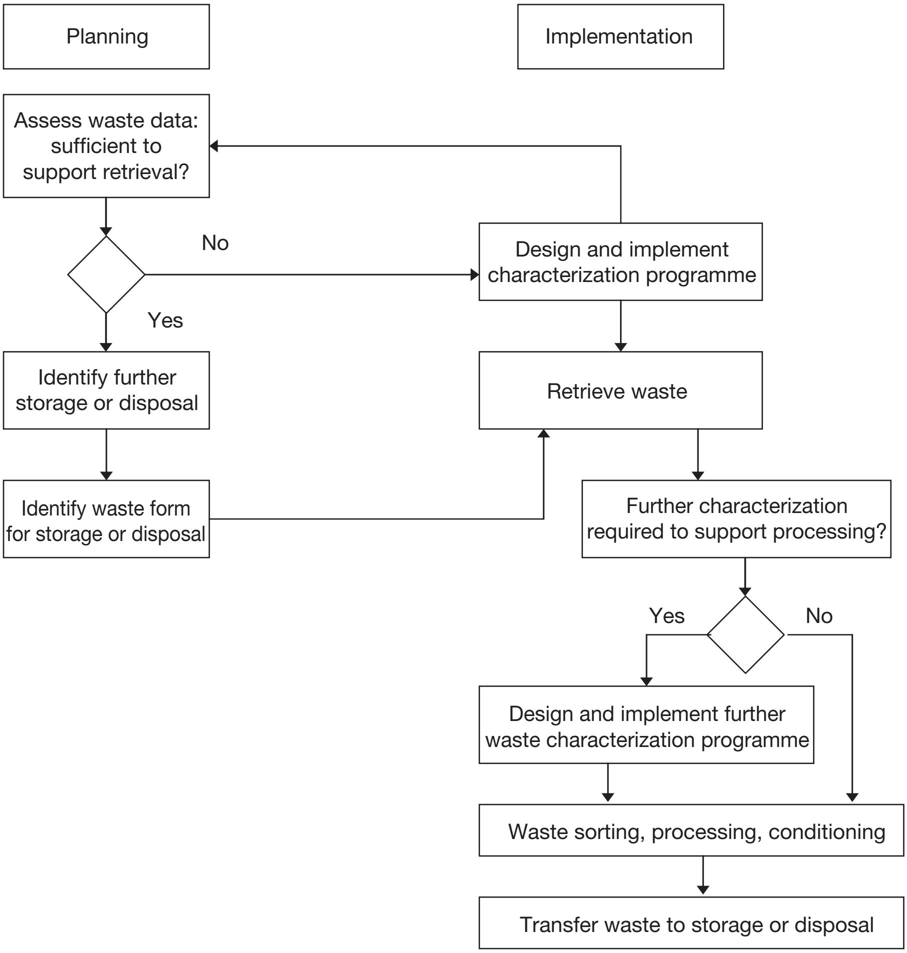

FIG. 3. Typical activities in a waste retrieval plan.

implementation. There are often hold points or decision points or milestones where implementation cannot proceed until the results of previous steps are known and further planning has been done.

The waste manager and other involved parties must have reviewed the strategy and be confident that the overall strategy is robust. Ongoing or phased development work and testing can progressively increase confidence in the plan. A flexible plan supported by the waste manager, policy makers and stakeholders facilitates the retrieval operation and ensures that the objective is met.

If the parties involved can gain consensus and are confident in their plan, the acceptability of the retrieval plan will be strengthened.

There are a number of factors to be considered in the decision making and planning for waste remediation and reconditioning activities [29]. As described in the following sections, these factors include both technical and non-technical issues. These factors should be considered in the context of the specific circumstances of the facility and are normally evaluated within a structured process such as a multicriteria analysis. This is especially useful for large, complex projects. In other cases, the choices may be fewer and may also be clearer such that the decisions are easier to make.

It should be recognized that, in some situations, important decisions may be made primarily based on non-technical factors, such as social or economic factors [30, 31].

6. WASTE RETRIEVAL TECHNIQUES

The retrieval of waste from inadequate repositories or old storage facilities is normally a technically difficult operation that requires detailed planning and preparation. For old facilities and waste, the information that should be available is normally not available; therefore, there is a need for significant flexibility in the detailed planning of the work, as discussed in Section 5, and in the equipment and techniques used.

Given the broad differences among the various types of waste and retrieval facilities, the techniques and equipment to be used must be adapted to the site specific situation. This includes consideration of radiation fields, contamination levels, waste forms and other site specific and environmental variables. Some sites may contain a variety of waste with a wide range of radiological and physical properties. Therefore, more than one retrieval technique may be required at a given site.

Various technologies and methods that could be employed in retrieval projects are described below. Examples of various retrieval and waste handling schemes that have actually been used in different projects are provided in Section 9 and in the annexes.

6.1. PLANNING THE RETRIEVAL

The waste retrieval operation is often the most difficult step in the remediation of an old waste facility, especially if the waste was not properly treated or conditioned. The process and equipment must be flexible enough to respond to a wide range of conditions. The typical steps in an old waste retrieval process are shown in Fig. 4.

The retrieval plan should be adjusted to the retrieval goals, and the techniques and technologies should be selected based on these goals. An important input to the planning process is the information from the initial characterization on dose rates and contamination levels necessary to ensure that the work can be accomplished without undue exposure of the staff and spread of contamination to the environment. It must further be recognized that both the radiation and contamination levels will change during the retrieval process, making it necessary to have continuous radiation and contamination control during the whole operation. This may also impact upon the work plan, again highlighting the need for a flexible plan.

The overall plan needs to consider the worker training requirements. It may include the construction of mock-ups for testing equipment and for training the staff. This allows workers to practice complex tasks in a safe environment.

To a practical extent, the overall retrieval plan should consider and cover the separation process for non-radioactive and radioactive waste during the retrieval process. It should also consider emergency and abnormal situations that could occur throughout the retrieval process.

The remainder of this section focuses on the technological aspects of the waste retrieval operation.

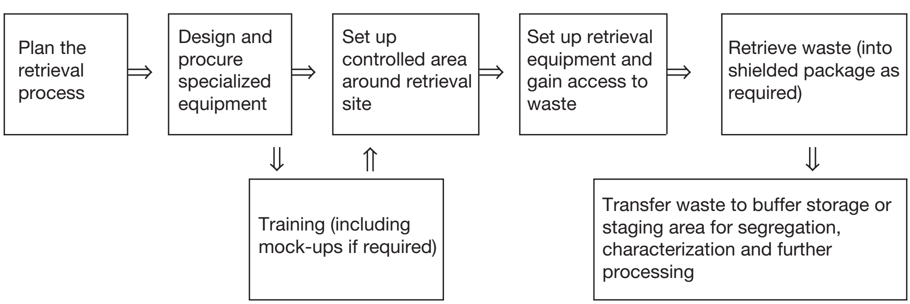

FIG. 4. Typical steps of a waste retrieval process.

6.2. DOSE RATE CONTROL

In areas where the dose rate may vary during the process of retrieval, continuous monitoring of the dose rates is necessary. This may be accomplished in different ways:

(a) Fixed monitors placed at strategic positions with readout units in staffed control rooms; they should be equipped with an alarm that sounds at a preset level. This may be effective, but it is generally not considered adequate if it is the only method applied.
(b) Another method is that a radiation safety technician performs regular surveys. This has the disadvantage that changes are not noted until the survey is made (no real time survey) and that the survey itself results in exposure of the health physicist.
(c) All persons working in such environments should carry electronic dosimeters that alarm at preset levels. This method provides an immediate warning to the individual if he or she enters a high dose rate area or if the work activity results in a sudden increase in the dose rate.

6.3. CONTAMINATION CONTROL

The first step for implementing the retrieval process is usually to set up a controlled area around the retrieval site. This can be a temporary structure, such as a tent, or a more permanent facility, such as a building. The purpose of this structure is to limit access to the area during operation and to control the potential spread of contamination that may be created by disturbing the waste. If the work is to be performed outdoors, the structure will also protect the site and workers from sun, rain and wind. Some typical enclosures are shown in Fig. 5.

Where there is a potential for loose or airborne contamination, the enclosure should be fitted with a ventilation system that includes a coarse pre-filter (also called a roughing filter) and a high efficiency particulate air (HEPA) filter. If there is a potential for fire or sparks, one or more spark arrestors should be included in the ventilation system. If high humidity or moisture is anticipated, a moisture separator may also be needed upstream of the roughing filter but downstream of the spark arrestor. Depending on the contaminants being filtered, the ventilation system may be either a once-through system or a recirculating system. To further reduce the risk of spread of contamination, a slightly lower pressure area can be established close to the waste, as illustrated in Fig. 5, where the trench is kept under low pressure by means of a tarpaulin.

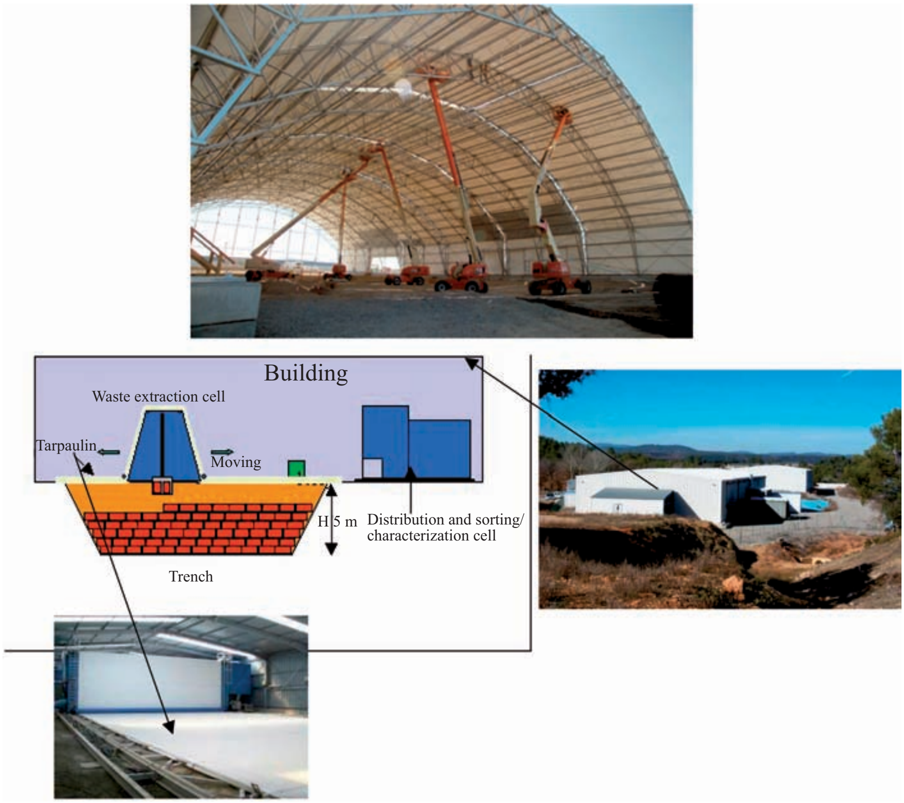

FIG. 5. Examples of temporary containment areas around LLW retrieval sites.

Radiation protection controls at and adjacent to the retrieval area should include personnel contamination monitors, portable radiation instruments and personal dosimetry and appropriate personnel protective gear. If there is a potential for internal contamination, whole body counting or bioassay may be appropriate.

Any equipment or waste package should be removed from the control area only after checking the surface for loose radioactive contamination by swipe tests. Therefore, a lock system and administrative procedures should be established to ensure positive control over material and equipment movement. In higher dose rate situations, such as with intermediate level waste (ILW), the use of supplemental portable shielding and remote handling techniques is often required; worker scheduling and rotation may also be considered. Further guidance on contamination control and radiation protection in waste retrieval can be found in Refs [5, 32].

6.4. ACCESS TO THE WASTE

The second step in implementing the retrieval process is gaining access to the waste. This may involve the use of conventional excavation equipment such as shovels, pickaxes, bulldozers or backhoes to remove topsoil and sand cover. It may also require the use of cranes to remove concrete or other shielding covers or intruder barriers over the waste. In the case of retrieval from vaults, access may also involve cutting a suitable opening in the roof or wall of the vault to allow for entry of equipment.

Note that all closed vaults and most open vaults represent a confined space that may be a toxic or oxygen deficient environment. Personnel should never access any confined space until it has been monitored for toxic gases or vapours and also monitored to ensure that there is a sufficient oxygen content. It is not unusual to require a 24 h or longer forced air ventilation period prior to accessing a vault that has just been opened.

At the beginning of access, the available layout plans and logs of waste emplacement (if these are available) should be studied in order to minimize the possibility of operational errors or unplanned direct contact with the waste and to minimize the probability of industrial accidents. See Ref. [7] for further details on this topic.

Typical methods for access to waste under various circumstances are summarized in Table 1.

The degree of technological sophistication required for accessing old waste will depend upon the circumstances of the situation, including the nature of the waste, the topography of the area, the network of the existing infrastructure for personnel, material and equipment movement and the favourability of the working conditions (e.g. ambient temperatures). Examples of some such types of equipment that have been typically used in radioactive environments are given in Refs [33–35].

Access to waste to be retrieved from most storage facilities is relatively easy, since they are generally designed with access and retrieval in mind (e.g. the presence of doors or large removable covers). In situations in which access is restricted or inadequate, access to the waste in the storage facility can be achieved using an approach similar to the above situations for disposal facilities.

6.5. WASTE RETRIEVAL

The specific design of the retrieval equipment is often unique to an individual situation and will be influenced by a number of factors, including the

TABLE 1. TYPICAL METHODS FOR GAINING ACCESS TO WASTE

Activity	Typical methods employed	Comments
Removal of soil cover	Conventional digging equipment such as a backhoe or bulldozer Dump truck or other large vehicle for moving excavated material For small volumes, a manual shovel or vacuum device can be used	Removed soil material is checked for contamination Removed material can be saved for future use as backfill when restoring the site, if contamination levels are very low (i.e. exempt levels)
Entry to trench or vault with removable shielding cover	Conventional lifting equipment such as mobile cranes, grapplers, lifting scissors	Dose rates will determine if direct access can be allowed after removal of shielding
Entry to sealed trench or vault	Cutting equipment such as jackhammers or diamond saws Lifting equipment such as mobile cranes to remove cut pieces	Control of dust during cutting operation may be required; this may be done by a local filtered exhaust system or by use of a wet operation Efforts must be made to avoid damaging waste located behind the wall and/or roof Cutting equipment may require water or other liquid as a cooling or lubrication medium; this liquid may become contaminated by contact with the waste

volume of the waste, radiological and other hazards, the size and weight of individual waste components and the condition of the waste packages. There are often regulatory or other restrictions (e.g. trade union contracts) on the maximum weight a person can lift without mechanical assistance (typically 15–20 kg) and on the maximum length of time a person is allowed to work in certain environments (e.g. to avoid heat stress), and radiation dose limitations and problems with the availability of a skilled/semi-skilled workforce, etc. All of these need to be considered in the design and operation of the retrieval system.

FIG. 6. Remote controlled digger.

For retrieval of unconditioned LLW, simple industrial equipment may be used, such as backhoes, remotely controlled clamshell diggers (see Fig. 6), forklift trucks, small mobile cranes and similar equipment. For retrieval of ILW, more sophisticated, remotely operated or shielded equipment may be required (Fig. 7). This may include robotic arms, shielded transfer casks, long reach cranes, remote grappling devices and similar equipment.

Standard industrial equipment often can be used, but sometimes custom designed devices are needed for a specific job; for example, large volumes of soil, sand and gravel that are sometimes used for backfill of waste repositories can be removed using conventional digging equipment, or if it is loosely packed it can be removed with vacuum equipment. It must be remembered, however, that all removed soil, sand and gravel may be contaminated and needs to be monitored. In situations in which it can be shown to be only very slightly contaminated, much of this material may be cleared for conditional or free release, depending on the national regulations. Guidance on the application of clearance principles can be found in IAEA publications such as Ref. [36]. Alternatively, the material could be reused for backfill or in the construction of other waste disposal facilities.

Typical methods for retrieving various types of waste are summarized in Table 2.

Much of the equipment mentioned in the preceding discussion and in Table 2 is available from standard industrial sources or can be easily adapted

FIG. 7. Removal of waste from a vault with a custom designed manipulator.

TABLE 2. TYPICAL METHODS FOR RETRIEVING WASTE

Waste category	Typical equipment employed	Comments
Loose LLW, low dose rate	Manual removal, clamshell bucket, small crane	Some initial characterization and segregation may occur at the retrieval site (e.g. have several receiving containers, properly identified by colour coding or numbering, available to sort the waste at source); waste is typically placed in a container suitable for transfer to a buffer storage or staging area for further segregation, characterization, treatment, etc.
Waste in intact containers	Crane, forklift truck	Depending on the condition of the original container, it may be placed into a secondary container or overpack for transfer to a buffer storage or staging area

TABLE 2. TYPICAL METHODS FOR RETRIEVING WASTE (cont.)

Waste category	Typical equipment employed	Comments
Higher dose rate waste	Remotely operated crane (required capacity depends on the size and weight of the shielded package), custom designed robotics, remote grapple, shielded casks	Waste is usually retrieved remotely and placed immediately into a shielded container or cask for transfer to a buffer storage or staging area; retrieval of higher dose rate waste typically requires a high degree of planning in order to avoid radiation exposure of the workers
Waste that was previously subject to in situ conditioning	Cutting equipment such as diamond saws or jackhammers to remove the waste from the conditioning matrix or to cut the monolith into pieces that can be handled, crane	Great care must be taken to minimize the risk of cutting through waste objects such as spent sealed sources or through containers of unconditioned, mobile waste such as ion exchange resins and sludge; depending on the dose rate, remote operated equipment may be required; if concrete was used as the conditioning matrix, the dose rate may rapidly increase as the concrete (shielding) is removed; a high level of loose or airborne contamination may result from breaking up the matrix or by cutting through a discrete waste item during matrix cutting and removal
Sand, soil and gravel backfill	Small diggers or shovels, vacuum equipment	Removed soil material is usually checked for average or bulk contamination (hot spots may be removed and managed separately); radiation level may be increased during the removal; removed material can be saved for future use as backfill when restoring the site
Liquids	Pump into portable tank, proper selection of pump is important depending on the liquid being pumped and where it is being removed from (e.g. suspended solids, low available suction)	Water may be collected in the storage or disposal cell; this water will more than likely be contaminated and will require transfer to a liquid radioactive waste treatment facility; may be a multiphase mixture of aqueous and organic liquids, suspended solids and sludges

FIG. 8. Lifting a 25 t encapsulated ILW container with a conventional crane and forklift truck.

for waste retrieval (Fig. 8). As such it can normally be procured without much difficulty and at modest cost. In contrast, custom designed robotics may require months or more to design, build and test. Such equipment is generally much more expensive than conventional off the shelf equipment. In addition, the use of good, serviceable, second hand equipment could be considered where new equipment is costly and there is a high risk of contaminating the equipment.

At the end of the retrieval programme, any equipment that was used may require decontamination before it can be removed from the work area. Taking precautions during retrieval operations to prevent contamination of the equipment can minimize the required decontamination effort; for example, where loose contamination is expected, this might include wrapping hydraulic cylinders in plastic sheeting or locating as much equipment as possible outside the containment area.

6.6. RETRIEVAL OF IN SITU CONDITIONED WASTE

For waste that has been conditioned in situ — such as by pouring cemented or bituminized waste directly into a storage cell without any other container, or by backfilling a storage cell with a concrete cap [37] — special equipment may be required to break up and remove the resulting monolith. Examples include the use of diamond wire saws or jackhammers. This type of equipment is typically associated with the decommissioning of nuclear facilities (e.g. removal of nuclear power plant containment structures) or the demolition of civil structures.

Great care must be taken to control any dust and/or loose particulates that may be generated during such processes, since this material could be radioactive and spread contamination. The collection and packaging of the resulting rubble may also add to the complexity of the overall task. Cutting through waste items embedded in the matrix should be avoided. However, the possibility of accidentally cutting through or exposing mobile waste (such as sealed sources, ion exchange resins, sludge or filters) needs to be carefully considered in the planning. Remote handling of the rubble may also be considered, especially where ILW or highly dispersible waste (e.g. powder, dried sludge or ash) may be present in the waste matrix.

The breakup of the matrix or storage structures also may result in very low level waste (VLLW) or may even leave some level of residual contamination in situ. Management of these situations is described in Section 6.9.

6.7. TEMPORARY STORAGE

Once retrieved, the waste is generally placed into rigid, standard containers (Fig. 9), then moved and stacked in a temporary (buffer) storage or staging area to await further characterization, segregation, processing, etc. The use of temporary storage allows waste to be further segregated and characterized in order to optimize further treatment, overpacking or conditioning. It also disconnects the retrieval from the treatment, allowing the two operations to be managed as independent operations.

For higher dose rate waste, some form of shielding is usually required. This can either be integral to the waste package (e.g. use of a concrete or thick walled lead or steel waste container) or external shielding, such as a shielding wall or a shielded overpack. With large volumes of waste, use of a shielding wall or a reusable shielded overpack is often more cost effective than providing integral shielding on each waste package. For smaller total volumes of waste, individually shielded packages are generally more cost effective. Individually shielded packages also simplify any future inspection or handling of the package by allowing the packages and/or the storage area to be approached directly. The requirements of downstream storage and/or processing may place further restrictions on package dimensions, weights, configurations, etc.

Depending on the circumstances, the staging area or buffer store may be integral to the temporary containment structure, may be a separate purpose built facility, may be part of an existing storage facility or may even be unused sections of the facility being remediated. In general, it has to be suitable for the type and characteristics of the waste and packages being stored as well as for the anticipated duration of the storage. Storage facility design and operation is described in other IAEA publications [38–41].

6.8. WORKER RADIATION EXPOSURE (ALARA) CONSIDERATIONS

Determining whether any given waste retrieval task should be performed hands-on or remotely, and determining which tools to use, are important parts of an ALARA study. A main objective of an ALARA study is to reduce the occupational dose to the workers to a level as low as reasonably achievable. The key factors for assessing worker dose are:

(a) The radiation dose rate of the waste;
(b) The type and level of contaminants (i.e. the potential hazard from inhalation or ingestion);
(c) Time (how long will the worker be exposed to the dose);
(d) Distance (how far away is the worker from the radiation field);
(e) Shielding (what shielding is in place to protect the worker).

The relative impact of these considerations is influenced by the design and operation of the retrieval equipment. The worker external dose is the

FIG. 9. Example of retrieved LLW in a transfer/storage container.

product of the dose rate at the worker's location times the length of the exposure time. The external dose rate at the worker's location is inversely proportional to the distance from the source (by as much as the inverse square of the distance, depending on the relative dimensions of the source and its geometry) — the further from the source, the lower the dose rate. The external dose rate is also reduced by placing shielding between the worker and the source. This shielding could be around the source (e.g. a shielded waste package) or around the worker (e.g. a shielded control room).

Internal dose is calculated in a similar manner where ingestion or inhalation conditions exist, with the committed dose being tempered by the sophistication of the protective equipment (e.g. protective clothing or respirator type). The time of external and internal exposure is related to the nature and complexity of the task and how often the worker repeats it. It should be noted that complex retrieval technologies, which may require a longer time to operate, might result in a higher worker dose than simple techniques, which are often much faster.

In addition to the characteristics of the waste (mainly the radiation dose rate), designing for ALARA depends on many criteria, such as legislation, cost, occupational dose targets and the state of the art of technology. The influence of different factors on the decision making process is very important, because some of these factors and criteria may be conflicting; hence the final decision depends on the weights given by the decision maker to each of these criteria.

6.8.1. Assessment of the radiation and contamination hazards

An essential aspect of an ALARA study is a thorough measurement and assessment of the radiation and contamination levels of the installation. Various types of radiological hazard need to be considered in the assessment: direct alpha, beta and gamma radiation, airborne volatiles (e.g. tritium, iodine, noble gases) and particulates (e.g. loose contamination, dust). When compared with radiation exposure regulations and standards, the results of these analyses determine whether tasks can be carried out hands-on or should be performed remotely.

To this end, it is essential first to make an inventory of the radiological hazards and the risk of contamination during each phase of retrieval and for each expected waste type. Unfortunately, the very making of this inventory itself brings about a risk of radiation exposure and contamination to those performing the surveys. To some extent, this investment in terms of money and occupational dose will be offset by lower exposures during the actual retrieval process, but the issue needs careful consideration to find the balance point.

Several tools exist that may help to reduce exposures to radiological and other hazards while performing the survey. The decision to use any of these tools necessarily depends on local people knowing the history of the installation and thus having a fairly good idea of what hazards to expect.

Remotely controlled automatic or semiautomatic radiation scanners are available from many radiation instrument suppliers. These scanners have a number of actuated computer controlled degrees of freedom (typically pan and tilt). As accurate measurements require some time, a complete scan over the full range of the actuators typically may take a number of hours, depending on the complexity of the area being scanned, the type of equipment used and the strength of the radiation fields. Generally, lower fields require longer count times to achieve reasonable spectrum resolution. Even taking into account the time required for installing the system, this reduces significantly the exposure of people compared with a completely manual, hands-on survey. Gamma imaging devices may be very helpful in identifying hot spots and locating areas with elevated radiation levels. An example of a gamma image is shown in Fig. 10.

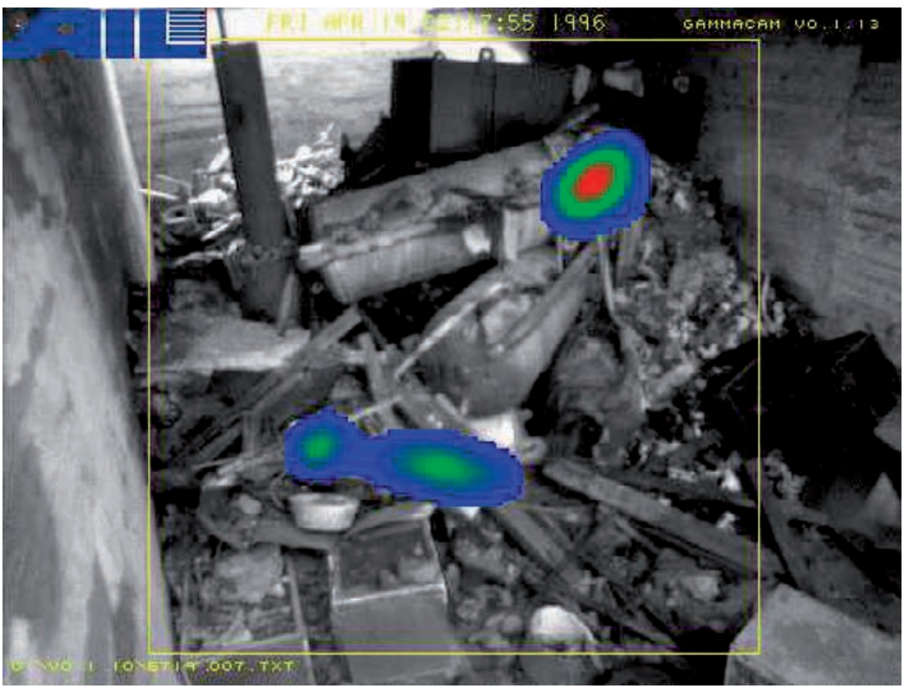

FIG. 10. Gamma image of an old waste storage cell identifying hot spots.

If even this limited exposure is undesirable, one could think of first performing a completely remote coarse survey using commercially available devices built for this purpose. The choice among these depends heavily on the terrain and the expected obstacles. However, as discussed in the next section, the overall reliability of such systems during task execution should be carefully studied.

Software exists that helps make the best use of the acquired data, such as plotting inventory data on a three dimensional (3-D) model. The inventory of radiation and contamination hazards can be used to plan mock-ups, sequence operations, control worker movements and optimize interventions. This software allows for calculating the dose received by workers during a certain task. Simulations with this software reveal the effect of placing additional shielding, of removing contamination, of alternative paths, etc. The experience of the workers will contribute to a realistic estimate of the time needed to carry out typical jobs. An example of a 3-D model of an old waste facility, showing the locations of different waste items, is given in Fig. 11.

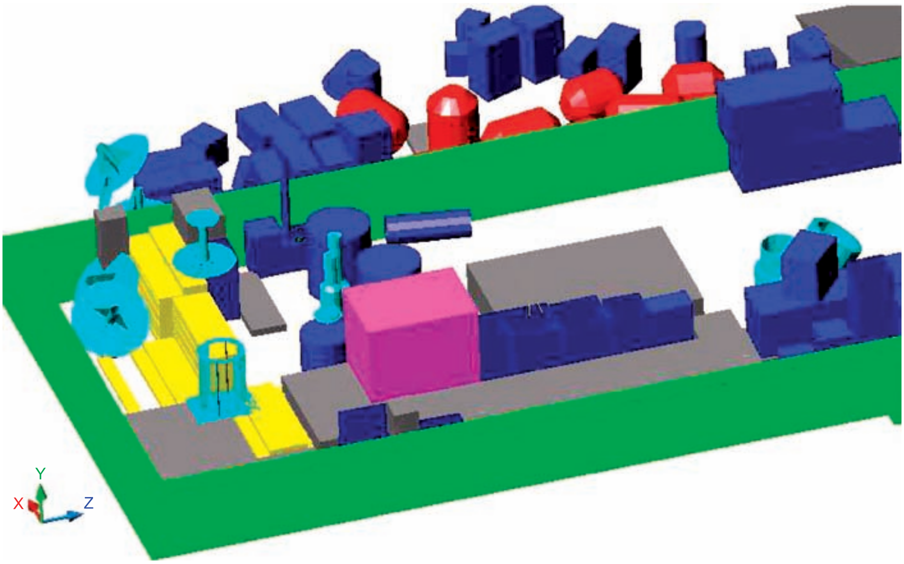

FIG. 11. Three dimensional model of an old waste storage facility.

6.8.2. Non-radiological hazards

In addition to the radiological hazards, old waste may present hazards such as chemical toxicity due to the presence of certain types of material or chemicals (e.g. heavy metals, organic chemicals). This is especially true for waste that was originally stored without complete characterization and segregation. Retrieval practices, equipment and procedures may need to take into account potentially unknown hazards. Further guidance on dealing with chemical hazards can be found in other publications [15].

6.8.3. Selecting the right tools for the job

Various tools are used to reduce the hazard to personnel and to reduce labour requirements for complex or repetitive tasks (and therefore reduce the overall cost of executing the project). Such tools generally serve to minimize the level of hands-on work. The following considerations suggest reasonable alternatives to hands-on work. All these considerations are, of course, closely related.

6.8.3.1. Reduction of exposure

Reducing the radiation exposure of workers is perhaps the most important incentive for performing tasks remotely, especially when dealing with ILW. This is an aspect that may seem obvious. However, not all remote handling tools produce the expected exposure reduction. This may be due to difficult installation procedures that take a long time in a radiation field, difficult repairs in the event of failure, difficult decontamination afterwards, etc.

6.8.3.2. Cost

An important factor that determines the choice of equipment is cost. In addition to the direct costs of purchase, maintenance costs and many indirect costs or benefits must be considered, including:

(a) Increase of the waste volume. If a machine cannot be decontaminated, the machine itself becomes expensive waste.
(b) Increase of exposure of operators. The use of tools might lead to increased exposure of workers if installation takes a long time, if operators are not working reliably or if they are the wrong tools for the job.

(c) Cost of breakdown maintenance and equipment repair, including the effects of ease of access and the nature of the work environment (e.g. proximity to radiation fields).
(d) Delays in the project. Every tool may fail. Theses failures might delay the project.
(e) Reduction of unproductive time. Working hands-on often requires people to put on protective clothing such as pressurized suits and masks. Wearing these items is often uncomfortable, slows down the work and requires additional workers to ensure safety. The time needed to put on or take off this protective clothing is often non-negligible, and more frequent work breaks may be required, especially in hot environments.
(f) Reduction of time needed for task execution by automating repetitive tasks.
(g) Improvement of operator efficiency by giving workers tools to do the job faster (without necessarily removing workers from the hazard).

6.8.3.3. Operator working comfort

This is an important issue that is often overlooked. It is important to note that, through improving the working comfort and efficiency of the operator, the job is done faster and therefore exposure to hazards is reduced. Comfort and efficiency may require ergonomic assessment of the work tasks and provision of mitigating measures, such as cooling suits, lifting aids and rest periods. A comfortable worker is also more likely to be alert to hazards, thus improving the margin of safety.

6.8.3.4. Reliability of the task execution

An important concern with the use of remote handling tools is reliability. Here, reliability refers to the overall reliability of task execution, and not only to the reliability of the hardware. Many failures of remote handling systems are due to incorrect use or inappropriate application of the technology to a particular job, even though the equipment may be functioning according to its design specifications. Since retrieval is a very unusual task, incorrect use of equipment is a common, although undesirable, reality.

As noted above, remote handling is often employed to reduce the radiation exposure of the retrieval workers when dealing with large quantities of waste. However, the use of remote handling equipment can sometimes increase the collective exposure of workers compared with hands-on work; this is unusually due to the interventions that are needed to repair the equipment. This is especially true where maintenance must take place in a high radiation field. Therefore, remote handling equipment should be mechanically as simple as possible. If the task requires mechanically more complex devices, then the operator should be assisted by a computer controlled system that monitors and controls the equipment to ensure the operating parameters are within safe limits.

6.8.3.5. Equipment availability

The first choice of remote handling tools should be those tools that are already available on the site. These tools are normally already adapted to the geometry of a specific installation. In addition, they may already be installed, and hence do not bring about additional waste compared with new equipment. Equally important, if one chooses an immediate retrieval strategy, trained staff experienced with and qualified to use these tools may still be available. These staff know the operating limits and techniques that may take newly trained operators years to learn. These tools are often mechanically very simple and reliable, and include bridge cranes and long reach tools used for fuel handling.

6.9. MANAGEMENT OF RESIDUAL CONTAMINATION

Once the primary waste has been retrieved, there may be some residual radioactive contamination left behind that needs to be properly managed. This can consist of slightly contaminated storage structures, rubble, other debris or slightly contaminated soil, other backfill and surrounding material. The residual contamination is generally caused by leakage and leaching from the original waste and subsequent migration into the surrounding areas. (Detection of such escape of radioactivity is often one of the factors that lead to the original decision to retrieve the waste.)

Such material may be large in volume and mass and may have a very disperse radioactivity content. Some of this material may be contaminated to the point where it must be handled as radioactive waste; other material may be so slightly contaminated that it may be a candidate for clearance and free release, depending on the nature of the contaminants, the type of material and the applicable national laws. The technical methods for management of this material may include:

(a) Leaving the material in situ with some form of barrier to prevent further escape into the environment, as appropriate for the situation;
(b) If sufficiently low in activity, it may be possible to convert and requalify the repository for disposal of exempt waste or VLLW;

(c) Moving all residual material to a different storage location or repository suitable for the material, such as a separate repository for exempt waste or VLLW;
(d) Monitoring and clearance as per the applicable regulations.

The decision on which method to adopt generally requires a safety assessment of the hazards, risks and consequences, and the location conditions and potential future use of the area (e.g. is it a remote, uninhabited area, is it located in the middle of a heavily populated or agricultural area or is it near a body of potable water used for domestic or agricultural consumption) must be taken into account.

Further guidance on planning and implementing a programme for managing residual contamination can be found in other publications, such as Refs [14, 24, 37, 42–45]. Further guidance on clearance and free release can be found in Ref. [36].

7. TECHNIQUES FOR WASTE SEGREGATION AND CHARACTERIZATION

The retrieved waste requires segregation and characterization to ensure that the subsequent processing steps can be carried out in a safe and optimized way, including transport, conditioning or reconditioning, interim storage and disposal. Ideally, all waste should be characterized immediately upon retrieval to permit suitable segregation at the retrieval point. However, in many cases retrieved waste is moved to a specially designed sorting and/or characterization facility for segregation of each individual waste stream in accordance with the accepted waste processing system (e.g. LLW, ILW, waste for compaction, waste for incineration or waste for direct immobilization). It should be noted again that, due to insufficient pre-retrieval information, there may be surprises during waste retrieval that justify temporarily halting the campaign while reconsidering parts of the work plan.

Characterization and segregation are very closely linked, and there may be a sequence of steps — with or without temporary storage of the waste between the steps — that must be performed before the final characterization and segregation is achieved. The techniques to be used during these steps are discussed in this section.

7.1. WASTE SEGREGATION

7.1.1. Establishing criteria for waste segregation

Segregation is the separation of waste into categories for subsequent steps in the waste management process by grouping them according to specific characteristics. The first consideration in designing the segregation system is to establish the criteria for segregation. These criteria are influenced by national policies and regulations, the available processing routes, the facility operating procedure or practices and the final storage and disposal options.

There are two main families of technical criteria that are often used as the basis for segregation:

(a) Radiological based segregation (e.g. low or medium level waste, alpha or non-alpha bearing waste, high or low dose rate). The waste categories may be based on dose rate measurements or total gamma activity (e.g. analysed using scintillation counters), or they may be based on measurement of key nuclides by gamma spectrometry. These measurements could be supported by calculations for the evaluation of radionuclide inventories. Segregation by dose rate segregation is most often used for operational reasons (e.g. worker safety, speed and the need for remote handling). Segregation on the basis of radionuclide inventory may be used for storage or disposal purposes, particularly for segregation of individual items (e.g. based on the specific activity and half-life of the radionuclides).

(b) Physicochemical based segregation (e.g. solids versus free liquids, combustible versus non-combustible, intact packages versus rubble). The waste categories are based on some observable or measurable physical or chemical property important to the downstream processing or to storage or disposal; for example:
   (i) Combustible material can be incinerated or pyrolysed [46];
   (ii) Compactable material can be compacted or supercompacted [46];
   (iii) Non-compactable material can be supercompacted or directly conditioned in cement [46];
   (iv) Liquids are collected and can undergo various processes, depending on the nature of the liquid [47].

The combination of the radiological and physicochemical criteria can produce a number of segregation categories. In general, the number of categories used should be minimized and they should be clearly distinguishable (i.e. field operators should be able to easily, quickly, consistently and clearly determine the appropriate category).

7.1.2. Initial segregation during waste retrieval

Waste in old repositories can be in many different forms, ranging from raw waste without any confinement to intact individual packages (e.g. 200 L drums and plastic bags). It may also include incidental liquids from infiltration or it may include contaminated soils and other loose material from backfill. All these types of material have to be segregated after retrieval to meet the acceptance criteria for the further treatment, conditioning or reconditioning, and storage or disposal.

The initial segregation is generally carried out by the field workers conducting the retrieval. The segregation needs to be performed on the basis of an easily recognizable visual characteristic (e.g. package type or material type) or dose rate measurement compared with a standard (e.g. dose rate less than x is category 1 and greater than x is category 2).

For practical purposes, the initial segregation is usually a relatively simple one. It is typically accomplished by placing the retrieved waste into dedicated transfer containers, drums, bins, locations, etc. (one dedicated to each different segregation category) or by applying identifying marks to the retrieved containers. The method employed needs to consider the physical characteristics of the waste as well as the radiological and conventional (e.g. mechanical, chemical) hazards associated with the waste. The waste packages are then directed to the appropriate further treatment, storage or disposal steps. During this initial segregation, the waste or waste containers should be appropriately labelled with any of the particular characteristics that may influence further treatment to be applied (e.g. combustible waste, putrefying waste, waste with biological hazard, wood or steel).

Techniques such as gamma imaging (using gamma cameras) could allow detection of hot spots in piles or trenches of unpacked waste. They may also identify some particularly high activity packages commingled among other packages.

When segregating waste coming from hospital or research establishments, special attention should be given to the risks related to sharps (e.g. needles or broken glass) and to the associated potential biological and chemical hazards.

7.1.3. Segregation techniques and facilities

If segregation cannot be carried out at the retrieval site, or if further segregation is required for processing purposes, a dedicated or purpose built segregation facility is often used. This can range from a simple area with proper ventilation and containment (Fig. 12) to a dedicated facility with enclosed gloveboxes, remote handling equipment, master–slave manipulators, etc. (Figs 13 and 14).

For LLW with relatively low dose rates, manual sorting could be carried out by field workers, if an ALARA study supports the practice. Nevertheless, if the level of radiation hazard is high (e.g. due to the dose rate or presence of loose contamination (especially alpha contamination) or tritium), manual sorting should be performed in dedicated gloveboxes or sorting boxes equipped with adequate ventilation and containment. In all cases, workers should wear adequate protective equipment. In many cases, cut and puncture resistant gloves are particularly recommended [48].

When dose rates are not acceptable for workers, or when the risk of contamination is high (e.g. alpha bearing waste), remote handling equipment should be used, possibly including master–slave manipulators in shielded gloveboxes.

FIG. 12. Example of a very simple waste segregation area.

FIG. 13. Examples of waste segregation gloveboxes.

7.2. WASTE CHARACTERIZATION

7.2.1. Waste characterization techniques after segregation

An important step after segregation and before treating or conditioning or reconditioning is characterization of the waste to the extent required by national regulations and by the subsequent steps of the waste management process (e.g. packaging, storage or disposal). Characterization consists of the determination of the essential radiological and chemical properties.

This characterization information is needed in part to:

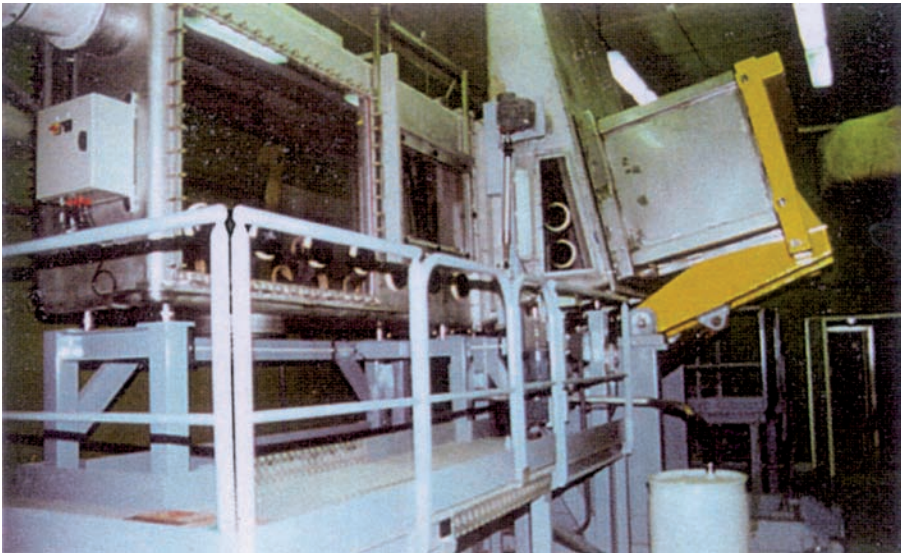

FIG. 14. Example of a segregation unit for alpha bearing waste.

(a) Confirm that the waste is in compliance with the operating licence of treatment and conditioning facilities;
(b) Confirm that the selected treatment and conditioning approaches are appropriate for the retrieved and segregated waste;
(c) Facilitate the routing of the waste to the appropriate treatment or conditioning process;
(d) Gather the necessary information that ensures that the final waste package (after treatment and conditioning) will meet the WAC for storage or disposal.

The characterization effort considers the following aspects:

(i) Legal: requirements of the national authorities (e.g. requirements or acceptance criteria can range from simple measurements to full characterization of each waste package).
(ii) Safety:
- Establishing the suitability of waste for further handling, processing, storage, transport and disposal;
- Compliance monitoring to ensure that the conditions of the operating licence for the processing, storage and disposal installations are met;

- Confirming the assumptions made about the waste prior to retrieval and segregation.

(iii) Economy: waste streams for subsequent treatment, conditioning, storage, transport and disposal should be optimized.

(iv) Quality control: the accuracy of historical and new data should be verified.

(v) Social: information for future generations (e.g. input to a waste tracking system) should be provided.

7.2.2. Radiological characterization

The parameters that need to be considered for radiological characterization include:

(a) The type of emitted radiation (alpha, beta, gamma and/or neutron);
(b) The total activity and specific activity of the different radionuclides;
(c) The form of radioactivity (e.g. induced activity in a matrix, fixed or loose surface contamination, dissolved or particulate in liquids, or airborne).

These will influence the types of measurement required, as well as the selection of analytical equipment and analysis protocols. Further, the radiological characterization may be made for different reasons, such as:

(a) Worker occupational safety;
(b) Environmental protection;
(c) Long term safety of the waste.

For occupational safety, the external dose rates and contamination levels are the primary concern when dealing only with radioactive waste. For environmental protection and long term safety, the inventory of radionuclides is the primary concern (especially the longer lived radionuclides). If a biological or chemical hazard is present, additional occupational safety and environmental protection measures will apply.

Non-destructive assay techniques allow measurements to be taken from outside of the package and without disturbing the contents. Such techniques are typically used for assessing certain radiological characteristics, such as identification of gamma emitting radionuclides and neutron emissions. Non-destructive assay techniques can also include computational methods such as scaling factors, which calculate or infer the value of a characteristic from some other easily measured parameter. These methods are usually performed on waste packages or objects of defined geometry, using the geometry for the calculation of the counting efficiency and for scaling total activity.

Intrusive (invasive) measurements and characterization (also referred to as destructive assay) provide access to parameters not accessible by non-destructive means. Such techniques include sampling and subsequent direct measurement of low energy beta emitters and chemical compositions.

The final selection of radiological characterization techniques depends mainly on:

(a) The waste type:
   (i) Gamma, beta and alpha activity;
   (ii) Presence of fissile and fertile isotopes;
   (iii) Isotopic composition (or lack of knowledge about it);
   (iv) Matrix composition (e.g. shielding effect);
   (v) Package size and geometry.
(b) The required output:
   (i) Mass or activity data, isotopic specific or not;
   (ii) Detection limits;
   (iii) Accuracy and uncertainties attached to the measurement methods.
(c) The cost of measurement:
   (i) Number of packages to be assayed;
   (ii) Investment, operational and maintenance costs.

Gamma radioactivity is typically the easiest to measure in waste. Key radionuclides, such as ^{60}Co and ^{137}Cs, can be measured non-destructively using relatively simple equipment such as portable gamma spectrometers. More sophisticated but readily available equipment such as segmented gamma scanners can also be used. Either method can usually provide fast, detailed results of the gamma activity of a waste package with measurement times of the order of a few minutes and without having to remove the waste from the package.

Direct measurement of pure beta emitters, such as tritium, ^{14}C, ^{90}Sr and ^{63}Ni, generally requires destructive sampling of the waste followed by sophisticated radiochemical analysis techniques. This may require considerable time (and cost) per sample in a specialized laboratory.

Measurement of alpha emitters can be accomplished either by radiochemical analysis of samples or by the use of neutron passive counting or neutron interrogation techniques performed on conditioned samples or waste packages.

Difficult to measure (DTM) radionuclides (such as beta and alpha emitters) are often calculated from the easier to measure gamma activities (key nuclides) using scaling factors or from radiological fingerprints. For these techniques, a few representative samples of the waste are subjected to comprehensive radiochemical analysis for the radionuclides of interest. For the scaling factor method, ratios are then calculated for the DTM radionuclides relative to an easy to measure radionuclide, such as ^{60}Co or ^{137}Cs. In subsequent samples, only the easy to measure nuclide is measured, and the DTM nuclide values are calculated from the DTM value using the previously determined scaling factor ratios. Of course, this only applies to samples from the same waste, and it should not be assumed that any two types of waste will have the same scaling factors.

A typical application of the fingerprint method is when the radiochemical spectrum is related to an easy to measure property, such as the package gamma dose rate. Future packages are then measured for the dose rate, and all radionuclide inventories are calculated from the standard fingerprint using the ratio of the dose rates and the waste geometries.

Both scaling factor and fingerprint methods work best only with well defined waste streams of consistent characteristics. The calculated ratios may vary significantly among waste streams and among different facilities. Scaling factors are more challenging and expensive to analyse, but they typically produce more accurate results. However, the fingerprint method may rely on old nuclide ratios; for example, the ^{60}Co:^{14}C ratio may be several years old or may be derived from a standardized fission yield table that is no longer applicable to the decayed waste. Thus the ratios used with the fingerprint method may have to be corrected based on factors such as the age of the waste (e.g. to take into account the different rates of radioactive decay among the constituent radionuclides). In cases where the origin or age of the retrieved waste is uncertain or the characteristics vary widely, the fingerprint method becomes unreliable, and the only alternative is sampling and laboratory analysis for the purpose of developing new scaling factors or gamma correlation ratios. However, even dated fingerprint estimates might still be useful for determining the bounding characteristics of a waste stream, and may be sufficient to avoid costly sampling and analysis.

Several techniques are available for radiological characterization. These are described in greater detail in Refs [49, 50].

Spectrometric measurements are routinely used to determine radionuclide composition. Small portable instruments may be used in the field for gamma measurements of waste or waste packages. The total gamma activity can often be estimated from the dose rate using a dose to activity conversion factor that has been developed for that particular type of waste or package. (Generally, alpha spectrometric and alpha or beta global measurements require more sophisticated equipment and are confined to the laboratory.)

With these measurements it is possible to determine quantitatively the gamma isotopes present. Often the gamma spectrum is also used to calculate the presence of DTM nuclides by applying scaling factors or fingerprints. Gamma emitting nuclides are by far the easiest to detect using standard equipment such as:

(a) Sodium iodide detectors (NaI)) for applications for which low resolution gamma spectrum information is sufficient (good efficiency, poor resolution);
(b) High purity germanium (Ge(Li)) or intrinsic silicon detectors when high resolution spectrometry is required (poor efficiency, good resolution).

An example of non-destructive measurements by gamma spectrometry is the ALCESTE system in Cadarache, France, shown in Fig. 15. Figure 15(a) demonstrates that this is a hot cell arrangement; Fig. 15(b) shows the sample analysis equipment. This gamma spectrometry measurement system is used to obtain the distribution of gamma activity in the sample under study, thereby defining the radioactive homogeneity of the package (the uniformity of the distribution of nuclides and activity within the sample). It can perform dry sampling of cores (mortar, concrete, polymers and metals, special sampler for bitumen) for characterization tests on samples representative of the package. The operation is performed remotely, and it allows the exploration and reconstitution of previously sealed packages.

(a) *(b)*

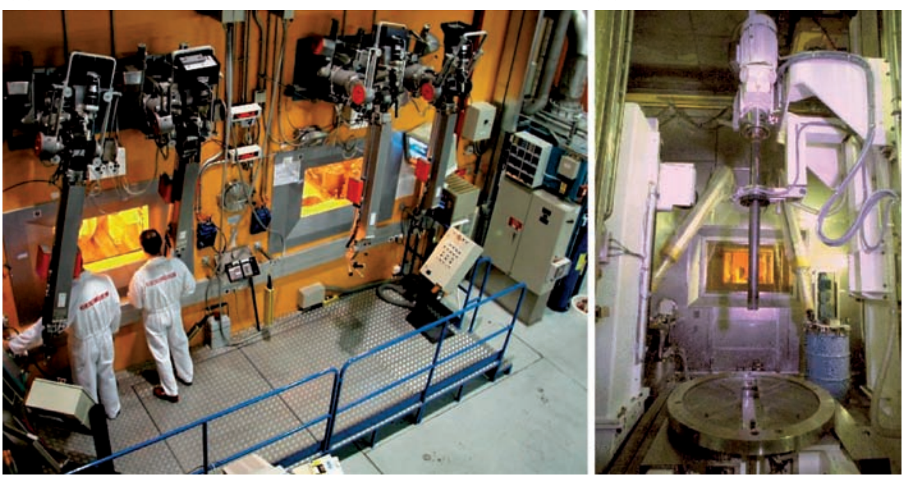

FIG. 15. ALCESTE cell at Cadarache.

This shielded cell allows sampling and inventorying to be made for LILW packages for surface disposal, or for waste packages with high level waste (HLW) and waste with long lived alpha, beta and gamma radionuclides. The cell is designed to handle packages of up to 2 m^3, weighing up to 10 t and with an activity not greater than 7.4 TBq. It is fitted out with sampling means and a gamma spectrometry measurement bench.

The different samples taken from the cores are submitted to several tests and measurements:

(a) Chemical and radiochemical characteristics: chemical composition of the waste, long lived alpha, beta and gamma radioelement activity, actinide isotopes content, water content, etc.
(b) Physical characteristics: resistance to compression, traction or flexion, behaviour under loads, density, diffusion coefficients, leaching rate, permeability, porosity, etc.

Neutron measurements (e.g. passive global neutron counting, passive coincidence neutron counting and active neutron counting) are used specifically to account for actinides and fissile material. Neutron methods are significantly affected by waste characteristics and usually involve relatively high uncertainties. Like spectrometric measurements, neutron methods often require a knowledgeable physicist to manage the measurement campaign to ensure accurate interpretation of the results.

Most mainstream methods rely on tritium proportional detector tubes. Spectroscopic methods are not in wide use; nor would they typically be reliable for identifying specific radionuclides, as neutrons are not emitted at fixed energies. Additionally, most waste types possess a degree of moderating properties, so all but the smallest of packages of virtually neutron transparent material corrupt the neutron energies well before the neutrons are captured for analysis. Thus by virtue of how neutrons are detected, they cannot be conclusively identified as to what source they came from.

For accurate characterization using neutron measurement, some minimum amount of knowledge of the waste stream characteristics is required. Neutron methods involve a combination of measurement processes and matrix correction techniques. Any combination is possible. Unlike gamma measurement processes, all matrix correction techniques are inherently complex, and the technique chosen needs to be closely matched to the waste stream.

An example of a neutron measurement system is the COQUINA (shown in Fig. 16), which is used in Cadarache, France. It is applied for on-site characterization of fissile material (^{235}U + ^{239}Pu + ^{241}Pu) and of neutron emitting

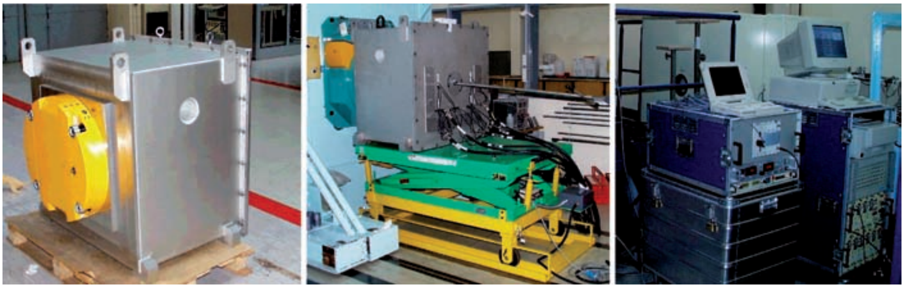

FIG. 16. COQUINA equipment at Cadarache.

isotopes (^{242}Cm + ^{244}Cm + ^{240}Pu) in waste prior to conditioning. These are mobile systems that can be fitted and adapted to allow the measurement configuration to be changed (active or passive). Neutron generators equip the system. A typical configuration for measurement of fuel hulls in a 1 L flacon by active neutron interrogation consists of 24 tritium counters, each 45 cm in length, with a detection efficiency of 4–6%. The mass detection limit for a measurement of 15 min with this equipment:

(a) In active measurement is 1.07 mg of ^{239}Pu;
(b) In passive measurement is 10.00 mg of equivalent ^{240}Pu.

Tomography techniques: tomography gives a 3-D representation of a waste package. Two types of tomography can be used:

(a) Transmission tomography for the control of waste packages (Fig. 17). This device enables the non-destructive evaluation of the inner physical structures of different types of waste. Image reconstruction, processing and analysis (e.g. threshold, contrast or filtering) allow and improve the identification and dimensioning of voids, cracks and inclusions, and permit the determination of their density. The method uses the ratio between the initial intensity emitted by an external irradiation source and the outgoing flux transmitted through the object. According to the Beer–Lambert principle, this datum is equivalent to the linear attenuation along the measuring line. The measurement is repeated under varying spatial positions around the object.
To carry out the image reconstruction, the collected data are treated by a filtered backprojection algorithm. The whole device also enables digital radiography, especially for identifying and localizing any region of interest before a detailed tomographic inspection. Transmission

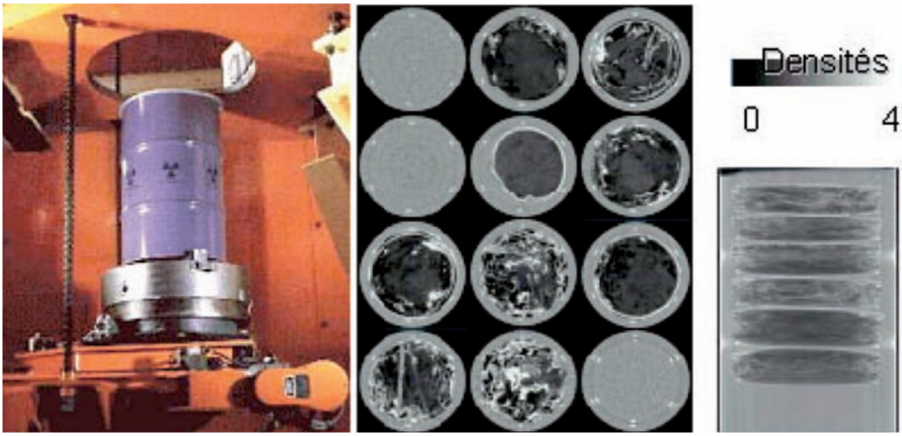

FIG. 17. Example of a transmission tomograph system (Transec).

tomography is applicable to all waste types that respect dimensioning constraints inherent to the cell.

However, transmission tomography is limited to a matrix attenuation range of about three decades. The reconstructed image has a geometrical resolution of about 2 mm. Contrast between two types of material must be at least 10% to enable their identification. This type of equipment is also used for the measurement of the matrix density, which may affect other non-destructive methods (e.g. emission tomography, gamma spectrometry and neutron measurement).

(b) Emission tomography is used for the non-destructive control of non-homogeneous radioactive waste packages (whether in terms of density or activity partitioning (Fig. 18)). The quantification is achieved via correction of the attenuation term, which is obtained by a prior knowledge of the matrix composition, or more precisely with numerical coupling of the images furnished by transmission tomograph. Generally speaking, the radionuclides that are selected have an energy peak ranging from 100 keV to more than 2 MeV, and the operator chooses those that have a major contribution to the total number of counts in the spectrum. From different points of measurement located in a transaxial segment of a drum, the activity distribution is computed by a reconstruction algorithm. An algebraic modelling of the physical process corrects the different degrading phenomenon, in particular the attenuation and the detector geometric response.

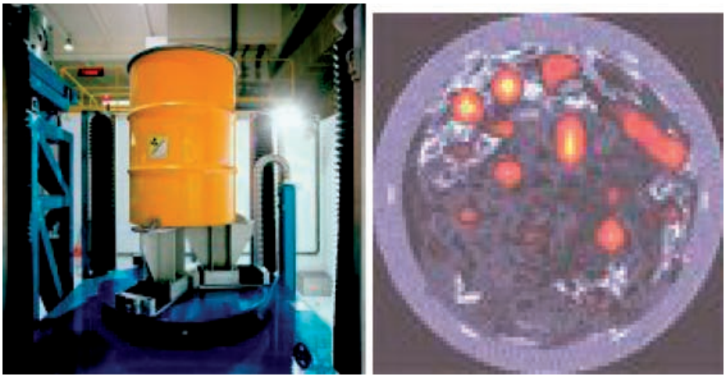

FIG. 18. Example of an emission tomography system (Temisec).

Gamma imaging provides a visual representation of a radiation field by overlaying a visual camera image with a survey of dose rate. Some systems incorporate spectroscopy, so overlays are nuclide specific. Gamma imaging is a very powerful survey tool that helps to identify hot spots and/or areas where more focused surveys should be made. As such, it can save planning time and reduce surveyor total dose. It is not normally used as a final quantitative survey, as uncertainties can be large when surveying a large area at a significant distance.

As shown in Fig. 19, gamma photons are collected on a scintillator plate through a double cone pinhole collimator, in accordance with the principle of a black chamber. Their interactions in the scintillator generate visible photons. The bright signal is amplified with an intensifier tube, then transmitted to a detector (a charge coupled device (CCD) matrix, similar to a digital camera) via an optic fibre network. The CCD converts this image into an electronic signal readable by a computer. When associated with a gamma spectrometry measuring system, it allows an in situ radiological characterization of irradiating waste.

In the case of inconsistent source emitters, the quantification step cannot be performed in real time. It then requires a spectrum interpretation, followed by a calculation modelization.

A number of other characterization techniques can also be used, including:

(a) Destructive analysis of samples (beta, alpha, gamma) taken during the sorting process;

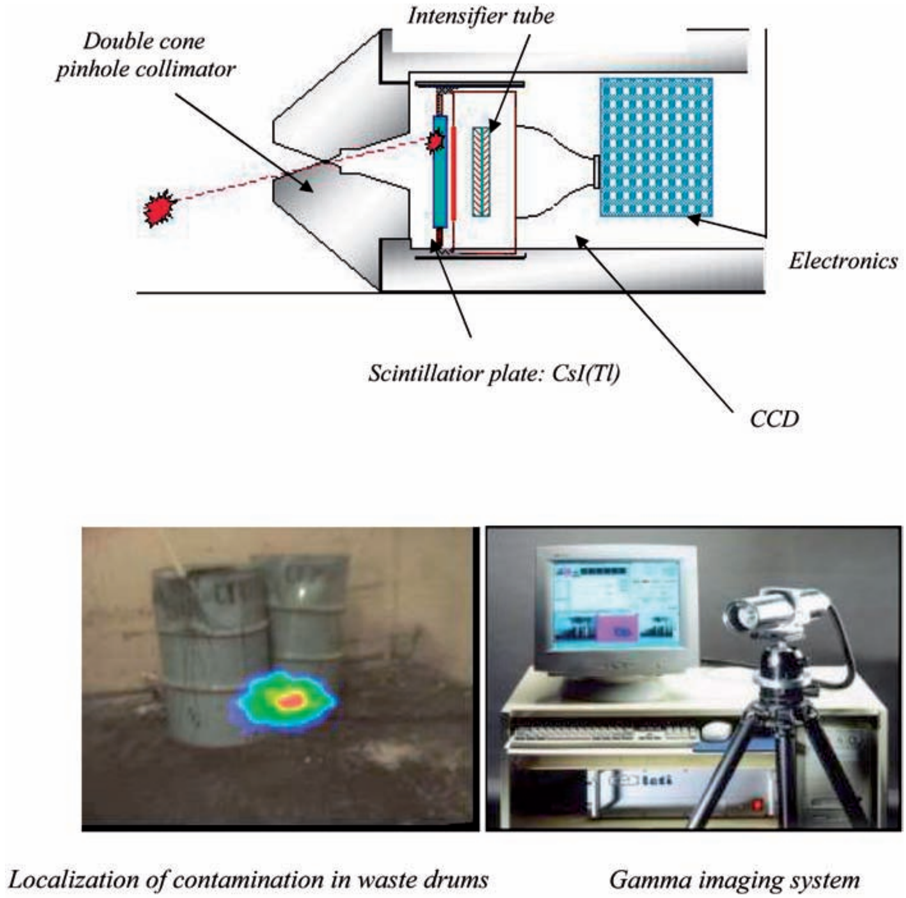

FIG. 19. Example of a gamma imaging system.

(b) X radiography techniques, commonly used to verify light density matrices (in order to detect heavy material in light weight drums);
(c) A combination of these techniques.

For each method one has to evaluate all of the advantages, limitations and disadvantages [49, 50]. Table 3 provides a summary of typical characterization methods that could be applied to retrieved waste, raw waste, waste packages or waste samples.

Some specific examples of characterization methods used during waste retrieval projects are given below:

TABLE 3. TYPICAL CHARACTERIZATION METHODS FOR RETRIEVED WASTE

Characteristic	Reason for measurement	Typical techniques
Radiological property		
Alpha nuclide content	Radionuclide inventory declaration Assessment of fissile content Radiation protection	Alpha spectroscopy (S) Passive neutron counting (S, P) Neutron interrogation (S, P) Process knowledge and calculation (W) Radiochemical analysis (S)
Beta nuclide content	Radionuclide inventory declaration	Direct beta measurement (S) Process knowledge and calculation (P, W) Radiochemical analysis (S) Liquid scintillation counting (S)
Tritium content	Radionuclide inventory declaration Radiation protection (e.g. internal dose uptake)	Liquid or air sampling, followed by liquid scintillation counting (S) Direct tritium measurement (S)
Gamma nuclide content	Radionuclide inventory declaration Radiation protection (e.g. shielding requirements)	Direct gamma dose rate measurement (P) Gamma spectroscopy (S, P) Segmented gamma scanning (P)
Surface contamination	Radiation protection (e.g. contamination control)	Swipe test, followed by counting (P)
Physical property		
Dimensional characteristics and distribution	Selection of waste handling methods Selection of appropriate packaging Optimization of subsequent storage	Visual observation (W, P) Simple measurements (depends on dose rate) (P)

TABLE 3. TYPICAL CHARACTERIZATION METHODS FOR RETRIEVED WASTE (cont.)

Characteristic	Reason for measurement	Typical techniques
Mass	Selection of waste handling methods Selection of appropriate packaging Optimization of subsequent storage	Weighing (W, P)
Density	Process selection and optimization	Calculation
Chemical property		
Chemical content	Selection, control and optimization of waste processing and conditioning	Visual observation (W, P) Chemical analysis (S) Process knowledge (W)
Combustibility	Selection, control and optimization of waste processing and conditioning Industrial safety hazard assessment	Visual observation (W) Flammability test (S)

Applicability of method: S: on sample; P: on package; W: on waste pile or raw waste.

(a) Dose rate measurement and mapping of radiation fluxes of historical waste stored at the Gremikha site, Russian Federation, were successfully performed using comprehensive non-destructive radiation survey equipment [51];
(b) Dose rate measurement and the fingerprint method were successfully used on waste conditioned in 120 L drums, before compaction, during the retrieval of solid waste from the La Hague north-west pits, France [52];
(c) Gamma spectrometry of 200 L drums and the fingerprint method were used at the Commissariat à l'énergie atomique (CEA) centre at Fontenay-aux-Roses, France, for the retrieval of historical waste from the west moats [53] (Fig. 20);
(d) Gamma spectrometry, neutron passive counting and the neutron interrogation technique are planned to be applied for the retrieval of thousands

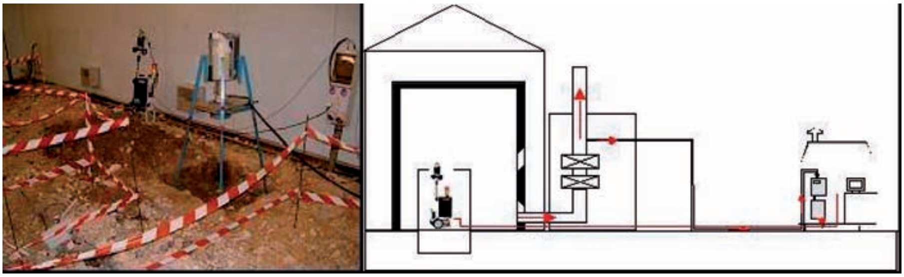

FIG. 20. Gamma spectroscopy system used at Fontenay-aux-Roses.

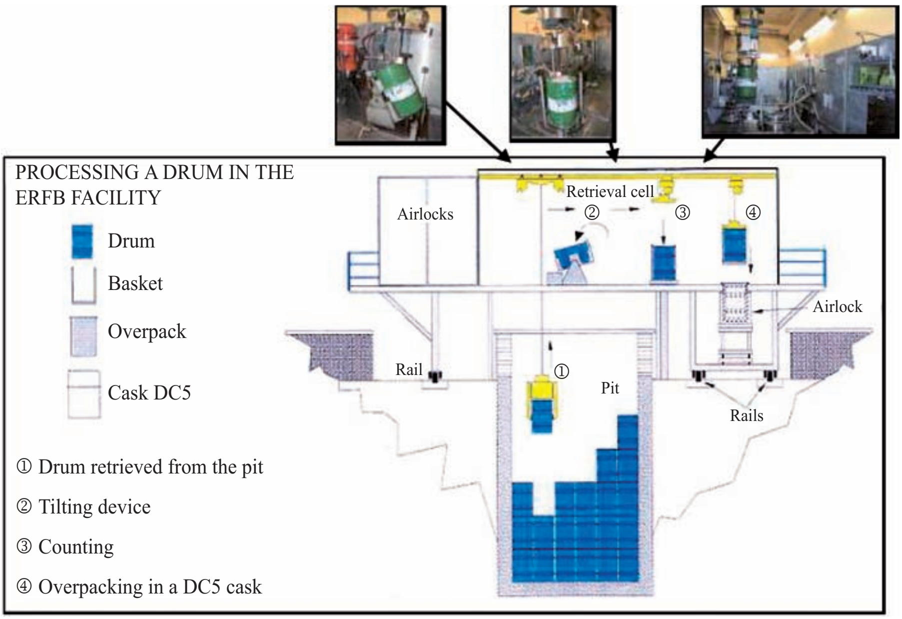

FIG. 21. Gamma spectroscopy system used for bitumen drum removal at Marcoule.

of drums containing bituminized waste at the Marcoule centre, France [53] (Fig. 21);

(e) Characterization of waste retrieved from five trenches at the CEA Cadarache centre, France, containing 3000 m^3 of LILW, is being carried out using two gamma spectrometry units. Plastic scintillation counters make it possible to segregate very low level and low level contaminated soil [54] (Fig. 22);

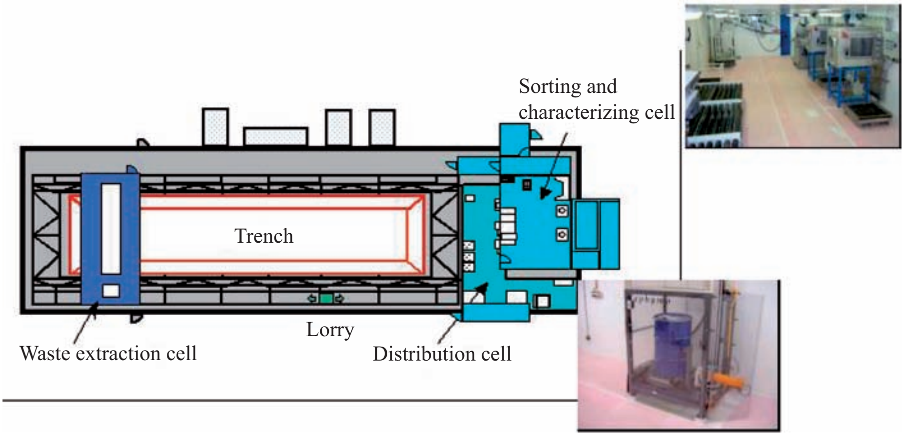

FIG. 22. Gamma spectroscopy system used for trench waste removal at Cadarache.

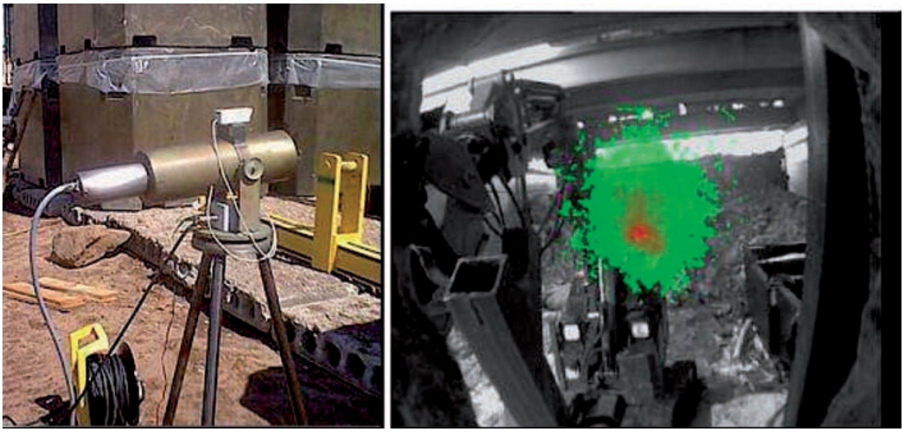

FIG. 23. Gamma imaging system used at the Kurchatov Institute, Russian Federation.

(f) Gamma spectrometry performed on waste packages, using collimated detectors, and a gamma locator automated computer based system were used to characterize key nuclides and to measure the dose rate distribution in the waste retrieved from the Kurchatov Institute Nuclear Research Centre, Russian Federation [55] (Fig. 23).

Examples of visual inspections of waste in pits and vaults are shown in Fig. 24.

FIG. 24. Examples of visual inspections of waste.

7.2.3. Chemical characterization

In many cases, the chemical characteristics of waste should also be determined, since this is important for:

(a) Validation of the appropriate treatment methods;
(b) The risks posed to human health and the environment;
(c) The safety precautions necessary for subsequent process steps;
(d) Determination of the appropriate class of dangerous waste for transport and disposal purposes.

The chemical properties that are essential for predicting the long term waste behaviour in the repository environment should also be investigated where feasible. The following chemical properties could be of interest: chemical stability, pyrophoricity, ignitability, reactivity, corrosivity, explosivity, chemical compatibility, gas generation, toxicity, decomposition rate of organic waste, etc. Several methods are available for chemical characterization:

(i) Analysis of data available in the record system;
(ii) Calculations based on known characteristics or measured values;
(iii) Special chemical analysis techniques;
(iv) A combination of several techniques.

Note that reliance on copies of old documentation may not be adequate, since physical and chemical changes may have occurred in the time between waste emplacement and retrieval. However, the original documentation can provide important clues as to the physical and chemical nature of the original waste and to what parameters should be measured. Comprehensive chemical characterization generally involves chemical analysis of samples in a specialized laboratory that can handle radioactive material.

8. PACKAGING, STORAGE AND TRANSPORT OF WASTE AFTER RETRIEVAL

8.1. PACKAGING

Proper packaging of radioactive waste greatly simplifies subsequent waste handling, buffer storage and transport. Proper packaging also contributes to the safe storage and transport of unprocessed, containerized waste, which is important due to the increased potential for radionuclide mobility and the spread of contamination. Use of reusable containers for the transport and buffer storage of retrieved waste before sorting, characterization and processing could be an attractive option, depending on the site specific or project specific situation and on local arrangements and requirements.

The purpose of the packaging is to:

(a) Contain the retrieved and/or segregated waste;
(b) Associate waste characterization data with discrete waste packages;
(c) Facilitate waste handling and transfer to waste processing;
(d) Allow the waste to be easily monitored while in storage;
(e) Allow the waste to be easily retrieved from the buffer storage for future activities in the waste management process.

The design of containers can contribute to increased safety and a reduction in the environmental impact of waste by:

(a) Withstanding foreseeable events, such as corrosion effects and impact from dropping;
(b) Containing any incidental liquid that may be associated with otherwise solid waste;
(c) The external shape being in a form such so as to allow safe stacking, easy decontamination, etc.

There could be more than one type of container involved in retrieved waste handling; for example:

(a) Reusable containers for the transport of unprocessed, retrieved waste to the sorting and characterization facility or location;
(b) Reusable or non-reusable containers for sorted and segregated waste for transport or transfer to the treatment and conditioning facility;
(c) Non-reusable containers for storage or disposal of conditioned waste.

Requirements for containers and packaging for the storage of conditioned waste are well documented in IAEA publications [38, 49, 56–60]. Details of currently available waste package designs used in Member States are also widely available.

The way a package is used can affect the design and operation of the auxiliary equipment; for example, an overpack may only require that the old package be placed inside of it. This usually involves relatively simple handling equipment. On the other hand, repackaging generally requires that waste be removed from the old package (or interim transport container) and placed into the new one (after segregation and characterization). This often requires more sophisticated handling facilities; it also requires a method to disposition the old packages, which would become a separate waste.

8.2. STORAGE

Storage of radioactive material is a frequently occurring stage in the management of most radioactive waste. Specifically, retrieved waste can be stored in the following forms:

(a) In the original form as it has been retrieved, without additional processing but placed in new appropriate containers;
(b) In conditioned packages in accordance with the WAC for further storage or disposal;
(c) In a properly processed form and in approved containers for extended storage awaiting further conditioning or reconditioning (e.g. for acceptance in a deep geological repository).

When storage is used for the purpose of accumulating enough material to undertake the next step in the process, it is generally called temporary or buffer storage. Often no processing step is taken before buffer storage except placing the waste in suitable containers that can easily be handled and that ensure that the radioactive material does not pose any unacceptable risk to the staff. This storage period should be short, typically not exceeding a few months. In some cases it may be advisable to take pretreatment actions, such as size reduction of large items, to enable the use of standard containers for efficient utilization of storage capacity, container stacking or easy handling. The design of the buffer storage facility should also be able to accommodate unexpected items of retrieved waste.

Waste that is properly conditioned may be placed in interim storage (storage for a much longer time) awaiting its eventual disposal. Proper conditioning implies that the waste will meet the requirements for the intended storage time, which could conceivably be many decades. WAC for storage facilities should be compatible with the WAC for a specific repository. If there is no repository available in which the waste can be disposed of, it may be difficult to define the WAC to ensure that the conditioned waste can be disposed of without reprocessing when the repository is made available. However, for low and intermediate level short lived radioactive waste there is enough international experience to feel confident with using generic WAC for near surface repositories. For waste that requires deep geological repositories, there is very little such experience to refer to. Such waste might need to be stored in a way that both facilitates conditioning or reconditioning at a later stage and ensures the safety of the stored waste package until WAC for deep geological repositories are derived. Again, this storage period may last for many decades.

Storage for a period of many years is normally in dedicated buildings or sections of buildings designed or refurbished to fit the requirements for the extended period of storage. The design of the storage facility for conditioned waste should correspond to the characteristics of the waste to be stored and the estimated period of storage. Depending on the local situation, either an existing storage facility or a new storage facility can be used. However, if an existing storage facility is used, actions must be taken to ensure that it meets today's requirements for storage of radioactive waste.

The new store should house the waste (conditioned or unconditioned) in a retrievable and safer form than the previous facility. This may be achieved by:

(i) Designing and constructing the storage facility to modern structural standards, including for foreseen extreme events (e.g. seismic events, external impact and climatic events);
(ii) Incorporating all required environmental protection measures;
(iii) Providing an engineered waste removal route for easy retrievability of waste from storage;
(iv) Designing and manufacturing the packages to appropriate standards;
(v) Providing in situ package inspection arrangements;
(vi) Providing suitable equipment maintenance facilities (e.g. to ensure reduced dose uptake to operators and application of ALARA principles);
(vii) Minimizing the need for active safety systems, maintenance and monitoring;
(viii) Using remote handling equipment for manipulation;
(ix) Maintaining the desired waste characteristics after the proposed storage period;

(x) Considering the non-radioactive dangerous characteristics of the waste (e.g. gas production, flammability and chemical toxicity);
(xi) Establishing a waste record keeping system to preserve and transfer information on the stored waste packages.

8.3. TRANSPORT

The requirements for the transport of waste packages are well documented in IAEA publications [61–63]. These regulations deal with the transport of material over public roads and railways (e.g. from one site to another). Many countries have less stringent requirements for transport within a licensed nuclear facility, which is commonly referred to as on-site transfer. However, the safety intent of the above regulations must still be considered for on-site transfer casks (e.g. shielding and containment functions), especially if they are moved outside the confines of a building. Some countries adopt a philosophy of equivalent safety; for example, in special or emergency cases, the transport package may not have a formal licence, but must meet the safety intent of the IAEA requirements and be approved by the regulatory authority.

Details of currently available transport package designs used in Member States are widely available (see, for example, the IAEA Directory of Package Certificates in the latest update of Ref. [63]).

9. RETRIEVED WASTE TREATMENT AND CONDITIONING

The proper segregation and characterization of the retrieved waste will result in a set of identified waste streams with characteristics suitable for further processing to obtain waste packages that eventually can be disposed of in licensed repositories. This further processing can normally be carried out with standard techniques and the equipment normally used for treatment and conditioning of radioactive waste. Many of these technologies are described in a number of IAEA publications [46, 64–75].

The goal of waste treatment and conditioning is to convert waste from its initial form into a product that meets the WAC for the receiving facility. Commonly employed processes comprise volume reduction and immobilization techniques, such as:

(a) Compaction and supercompaction, for compactable waste;
(b) Incineration with a well engineered off-gas cleaning system, for combustible waste;
(c) Pyrolysis, for solid organic radioactive waste;
(d) Melting, for metallic waste (to obtain maximum volume reduction, but also to facilitate accurate activity determination);
(e) Decontamination and segmentation, for bulk waste and large items;
(f) Direct immobilization, for some miscellaneous types of solid waste (e.g. in cement, bitumen or polymer matrices);
(g) Vitrification, for some wet intermediate level radioactive waste (although also used for solid LLW);
(h) Plasma arc processing, for dry solid waste, wet solid waste, liquids, etc.

The resulting secondary waste should be immobilized in a suitable and appropriate matrix. Secondary waste might include the ash from incineration or the radioactive residue from pyrolysis. Intermediate waste products, such as the compressed drums from supercompaction, as well as waste not amenable to any treatment processes, should also be immobilized in a suitable matrix. Such a matrix might consist of cement, bitumen or polymer, depending upon the physical and chemical properties of the waste and the qualification requirements for the conditioned matrix.

Some treatment processes, such as incineration and metal melting, result in a high volume reduction ratio. Others, such as direct cementation of wet waste, increase the volume. Many mature technologies are available for the treatment and conditioning of most waste streams. For retrieval and reconditioning activities, the most logical and appropriate approach would be to use technologies already available on the site or in the country. However, if a needed technology is not available, consideration should be given to buying or developing a specific technology to solve the problem of treating the retrieved waste in the most efficient way.

The nature of the treatment and conditioning process may dictate the boundaries of any detailed segregation and characterization scheme, including repackaging scheme; for example:

(a) Unconditioned waste could be segregated into streams appropriate for treatment and volume reduction, depending on their as-retrieved condition and applicability to the available technologies.
(b) Easily identifiable solid waste could be segregated in accordance with their acceptance for particular treatment processes and their radiological characteristics.

(c) Decomposed waste and wet solids are more difficult to segregate and prepare for treatment. Such waste may sometimes be immobilized directly in cement without detailed segregation. However, radiological characterization of such waste is essential.
(d) Damaged containers with conditioned waste, such as damaged drums with cemented or bituminized waste, could be repacked into larger containers and subsequently immobilized by filling the void space with a suitable matrix. Of course, prior characterization is required.
(e) Recovered drums may be placed inside a reinforced concrete canister. After cementation of the void space between the drums and the concrete canister, the canister is sealed with a reinforced concrete cover. This is similar to the concept illustrated in Fig. 25, which shows recovered drums placed in concrete canisters (cubes) in preparation for backfilling with cement. This technique is especially beneficial when the integrity of the original container is in question, although it does result in a net increase in the stored and disposed waste volume. Again, prior characterization is required.
(f) Reinforced concrete canisters could also be used for some non-compactable and non-combustible solid waste, such as metallic components of equipment, pipes and other non-processible waste. After radiological characterization, such waste is conditioned inside the container by cementation.

FIG. 25. Example of a concrete overcontainer for a drum.

The treatment and conditioning of retrieved waste will normally be governed by the following factors:

(a) The quantity of retrieved waste to be handled.
(b) The physical, chemical and radiological waste characteristics, including loose contamination.
(c) The possibility of segregation of retrieved waste into acceptable categories, such as: combustible and non-combustible, compactible and non-compactible, and metallic and non-metallic.
(d) The condition of the retrieved waste packages, such as stability and reliability for further handling without spilling the waste.
(e) The availability of particular waste treatment and conditioning technologies.
(f) The cost of treatment and conditioning.
(g) The availability of experienced, trained and skilled staff who can be assisted by less experienced (semi-skilled) staff to carry out treatment safely and economically.
(h) The necessity of expensive technologies for waste treatment, such as gloveboxes, manipulators and robots.
(i) The availability of a final destination for the waste and of corresponding WAC.

As indicated above, some processes may already exist in Member States with integrated waste management systems. In such cases, the suitability of the existing processes for treating the recovered waste should be evaluated. Some processes in a waste treatment facility may not need to be operated continuously. The suitability of an existing process includes technical parameters, in addition to safety and cost aspects. If no suitable process already exists, a new process should be chosen that provides the most versatile and cost effective waste processing solution. The new process should be integrated as much as possible with existing processes and the whole waste management scheme.

Table 4 summarizes a range of treatment and conditioning processes and shows their application to various waste streams. Examples of various waste retrieval, reprocessing and reconditioning projects are presented in Table 5. It is not intended that this be an exhaustive list, rather it represents a range of experiences in a number of countries with various types of waste. Short descriptions of some selected waste retrieval and site remediation projects are provided in the annexes. Further details on the projects can be found in the references.

TABLE 4. SUMMARY OF COMMON WASTE TREATMENT AND CONDITIONING PROCESSES

	Melting	Incineration	Pyrolysis	Compaction or super-compaction	Cementation	Bitumini-zation	Polymeri-zation	Over-packing	Decontami-nation or segmentation	Vitrification	Plasma arc processing
Waste stream											
Unconditioned organic solids		Yes	Yes	Yes	Yes		Yes	Yes		Yes	Yes
Unconditioned inorganics				Yes	Yes			Yes	Yes		Yes
High dose rate solids					Yes			Yes			
Sand, soil and gravel				Yes	Yes			Yes			Yes
Cemented solids								Yes			Yes
Bituminized solids		Yes						Yes			Yes
Metals	Yes				Yes			Yes	Yes		Yes
Unconditioned wet solids		Yes	Yes		Yes	Yes		Yes (after drying)		Yes	Yes
HEPA filters				Yes							
Ion exchange resins					Yes		Yes			Yes	Yes

TABLE 4. SUMMARY OF COMMON WASTE TREATMENT AND CONDITIONING PROCESSES (cont.)

	Melting	Incineration	Pyrolysis	Compaction or super-compaction	Cementation	Bitumini-zation	Polymeri-zation	Over-packing	Decontami-nation or segmentation	Vitrification	Plasma arc processing
Technology summary											
Final product	Metal ingot	Ash in container	Ash or residue in container	Compacted waste in container	Cemented waste in container	Bitumen waste in container	Polymer block in container	Waste in container	Waste in container	Glass-like slag in container	Slag in container
Technology sophistication	Low to high	Medium to high	Medium to high	Low to medium	Low to medium	Medium to high	Medium	Low to medium	Low to medium	High	High
Versatility	Metals	Good	Good	Solids only	Good	Liquids and wet solids	Organics only	Good	Metals and inorganics only	Good	Very good
Cost	Medium to high	Medium to high	Medium to high	Low to high	Low to high	Medium to high	Medium	Low	Low to medium	Very high	Very high
Notes	(5)	(1), (5)	(1), (5)	(2)	(3)	(3)		(4)	(1)	(5)	(5)

Notes:

(1): Secondary waste products may require further conditioning or packaging to be suitable for long term storage or disposal.

(2): Low force compaction can generally be used only for low density material (e.g. plastic and thin metals), while high force compaction can also be used for heavier material.

(3): Cement and bitumen solidification can be sensitive to trace amounts of certain chemicals in the waste. Neither is effective for containment of aqueous tritium.

(4): Costs of overpacking will increase if special containers or remote handling equipment is required.

(5): Thermal processes may result in the release of volatile radionuclides (such as tritium, iodines, ^{14}C). The higher the operating temperature, the more radionuclides will become volatile.

TABLE 5. SUMMARY OF SELECTED LOW AND INTERMEDIATE LEVEL WASTE RETRIEVAL AND REMEDIATION PROJECTS

Country	Site	Date	Waste	Reason	Description	Ref.
Belgium	HRA/ Solarium	2003–2010	Remote handled ILW and HLW from research activities	Modernization of facility	Retrieval of 2600 m^3 of waste in 4800 packages; characterization, segregation, processing, repackaging and storage of waste Lower activity waste to be supercompacted at the CILVA facility Higher activity and transuranic bearing waste to be overpacked, grouted and packaged in standard 400 L drums for long term storage	[76]
Canada	Bruce radioactive waste operations site 1, Ontario	2001–2002	ILW from nuclear power plant operation	Modernization of facility	Retrieval of waste in 23 in-ground concrete tile holes (approximately 0.7 m outside diameter (OD) $\times$ 3.6 m deep); tile holes contain ILW from nuclear power plant operation, including ion exchange resins, filters and irradiated hardware, grouted in place The entire pit is encapsulated in a steel sleeve with the annular space filled with concrete then removed from the ground and transported to an above ground engineered storage facility The final package is 1.5 m OD $\times$ 4.3 m long, with a mass of approximately 25 t	[77]

TABLE 5. SUMMARY OF SELECTED LOW AND INTERMEDIATE LEVEL WASTE RETRIEVAL AND REMEDIATION PROJECTS (cont.)

Country	Site	Date	Waste	Reason	Description	Ref.
	Bruce radioactive waste operations site 1, Ontario	1992–1998	LLW from nuclear power plant operation	Modernization of facility	Retrieval of LLW from engineered concrete storage trenches A total of 835 m^3 was removed in two campaigns The waste was sorted, processed by incineration or compaction and stored in above ground storage buildings at a new storage facility A total of 160 drums of sand and loose material were vacuumed from trenches Conventional hazards encountered included asbestos, unknown chemical waste and sharps (e.g. syringes)	[78]
	Point Lepreau nuclear power plant, New Brunswick	2004–	LLW from nuclear power plant operation	Recovery of storage space	Ongoing programme to retrieve, sort, compact and free release approximately 75 m^3 of LLW per year Waste was stored in compressed bales stacked in concrete bunkers Bales were retrieved and moved to a sorting area, where they were cut open and sorted Clean material was segregated and monitored for free release (<1000 Bq/kg gross beta–gamma, 10 Sv/h tritium) In the pilot test, only 157 kg of the original 2125 kg was retained as radioactive	[48]

TABLE 5. SUMMARY OF SELECTED LOW AND INTERMEDIATE LEVEL WASTE RETRIEVAL AND REMEDIATION PROJECTS (cont.)

Country	Site	Date	Waste	Reason	Description	Ref.
Czech Republic	Nuclear Research Institute, Rez	2003–2010	LLW from research activities	Cleanup and decommissioning of old facility	Approximately 600 m^3 of waste was stored in eight concrete cells The detailed inventory was not known (only general descriptions) Waste to be retrieved, processed by cutting, packaging and conditioning for storage in a new facility Approximately 90 t of large items (decommissioned research reactor components, old waste processing equipment, etc.) stored outdoors Waste to be segmented, decontaminated and free released or packaged for disposal	[79]
Estonia	Paldiski	1996–2000	LILW from naval reactors	Cleanup and decommissioning of old facility	Retrieval of waste from LILW storage vaults, including soft waste, steam generators, control rods and water Custom designed remote crane used to remove most waste Repackaged into 200 L drums, 1 m^3 concrete containers and custom shielded containers for control rods Waste now stored in a modern interim storage facility	[80]

TABLE 5. SUMMARY OF SELECTED LOW AND INTERMEDIATE LEVEL WASTE RETRIEVAL AND REMEDIATION PROJECTS (cont.)

Country	Site	Date	Waste	Reason	Description	Ref.
France	Cadarache	1992–2010	LLW from research activities	Cleanup and decommissioning of old facility	A total of approximately 3000 m^3 of waste from five shallow land burial trenches, consisting of 100 L and 200 L drums, 1.2 m^3 concrete containers and other miscellaneous containers and bags Waste extracted from the trench, sorted per nature and type of contamination, radiologically characterized, repackaged and removed to a modern storage or disposal facility Approximately 2100 m^3 of VLLW, 1200 m^3 of category A waste and 200 m^3 of category B waste expected to be produced	[55, 81]
	Fontenay-aux-Roses	2000–2002	Drums and LLW solids	Cleanup of soil	Located soil anomalies by means of a geo-radar system Most of the recovered material was very low activity	[53]

TABLE 5. SUMMARY OF SELECTED LOW AND INTERMEDIATE LEVEL WASTE RETRIEVAL AND REMEDIATION PROJECTS (cont.)

Country	Site	Date	Waste	Reason	Description	Ref.
	La Hague	1990–1998	Short lived LILW from reprocessing activities	Retrieval and preparation of old waste for disposal	A total of 11 000 m^3 of humid solid waste was retrieved from 23 pits Compressible waste was compacted, dried in a centrifuge and placed in a 3.1 m^3 CBFK (cubic fibre) concrete container for disposal Non-compressible waste (mainly metal parts) was sheared, then grouted into CBFK containers Liquids extracted from the waste were treated in the on-site liquid treatment system	[82]
	Marcoule	2000–2006	Bitumen drums	Cleanup and decommissioning of old facility	A total of 6000 drums (200 L) is stored in 35 half buried pits Drums stacked in rows Concrete cover blocks were not watertight Drums are being reconditioned for disposal	[54]

TABLE 5. SUMMARY OF SELECTED LOW AND INTERMEDIATE LEVEL WASTE RETRIEVAL AND REMEDIATION PROJECTS (cont.)

Country	Site	Date	Waste	Reason	Description	Ref.
Germany	Verein für Kernverfahrens-technik und Analytik, Rossendorf	1998–2000	Remote handled ILW from research activities	Modernization of facility	Retrieval of approximately 4 m^3 of ILW from three concrete pits Total activity approximately 66 TBq (in 1995), consisting mostly of ^{60}Co, ^{137}Cs, ^{154}Eu and ^{90}Sr The waste included metal parts, sealed sources, ion exchange resins and concrete Waste was retrieved using remote manipulators, sorted, characterized and packaged in 200 L drums A total of 72 drums were filled	[83]
Hungary	Solymár repository	1976–1980	LLW from institutional and research activities	Cleanup and decommissioning of old facility	A total of 900 m^3 of LLW and 3000 disused sealed sources were retrieved from the old repository, repackaged and transferred to the newer repository	[84]
	Püspökszilágy repository		LLW from institutional and research activities	Modernization of facility		[85]

TABLE 5. SUMMARY OF SELECTED LOW AND INTERMEDIATE LEVEL WASTE RETRIEVAL AND REMEDIATION PROJECTS (cont.)

Country	Site	Date	Waste	Reason	Description	Ref.
Italy	Joint Research Centre Ispra	2000–	ILW from a research reactor	Cleanup and decommissioning of old facility	Retrieval of waste in 15 in-ground ‘Roman pits’ (1.35 m diameter concrete ring sections stacked to 7 m depth below the ground) The entire pit is encapsulated in a steel sleeve with the annular space filled with concrete, removed from the ground and transported to an interim storage facility	[86]
	Impianto Trattamento Elementi Combustibile, Trisaia, Rotondella	1989–1991	LLW from fuel reprocessing research	Cleanup and decommissioning of old facility	A total of 3000 drums of LLW and 6000 drums of contaminated soil were removed LLW drums were processed by supercompaction and placed in 400 L overpacks (average of six pellets per overpack) and encapsulated with cement The resulting waste was stored in an above ground building The emptied trench was refurbished to bury lightly contaminated soil (less than 50 Bq/g)	[87]
Slovenia	Zavratec	1996–1999	Institutional LLW	Cleanup and decommissioning of old facility	Retrieval and repackaging of approximately 30 m^3 of historical LLW stored in an old military barracks	[88]

TABLE 5. SUMMARY OF SELECTED LOW AND INTERMEDIATE LEVEL WASTE RETRIEVAL AND REMEDIATION PROJECTS (cont.)

Country	Site	Date	Waste	Reason	Description	Ref.
UK	Harwell	2002–	Remote handled ILW	Modernization of facility	Retrieval of remote handled ILW from the B462.2 and B462.9 storage facilities, characterization, sorting, repackaging into standard Nirex 500 L drums and storage in a modern vault store The waste is originally stored in small volume cans of various designs (mostly painted mild steel), stacked in tube stores of approximately 200–400 mm diameter and 2.4–4.5 m deep; a total of about 1300 tubes A special retrieval machine remotely extracts each can (or individual waste items if the can has deteriorated) into a shielded transfer cask A hot cell with remote manipulators is used to sort, characterize and repackage the retrieved waste	[89]
	Sellafield		Magnox swarf	Cleanup and decommissioning of old facility		[90]

TABLE 5. SUMMARY OF SELECTED LOW AND INTERMEDIATE LEVEL WASTE RETRIEVAL AND REMEDIATION PROJECTS (cont.)

Country	Site	Date	Waste	Reason	Description	Ref.
	Trawsfynydd nuclear power plant	2001–2005	Remote handled ILW	Cleanup and decommissioning of old facility	Miscellaneous activated components are stored in two vaults and fuel element debris is stored in two vaults Remote retrieval of waste, packaging, immobilization into Nirex 3 m^3 stainless steel boxes and storage in concrete overpacks A total of approximately 150 waste packages to be produced	[91]
Ukraine	Chernobyl nuclear power plant	2004–	LILW from nuclear power plant operation	Modernization of facility	Retrieval of waste from the existing storage facility, characterization, sorting, processing by incineration and compaction, grouting, disposal in a modern near surface engineered facility The processing facility is capable of handling 3500 m^3 per year Funded by the European Union Tacis Programme	[92]
USA	East Tennessee Technology Park G pit, Oak Ridge, Tennessee	1999–	Solvents, crushed drums and classified mixed waste from military production	Cleanup and decommissioning of old facility	Approximately 200 m^3 of waste and contaminated soil to be removed from the pit, segregated, characterized and packaged for on-site interim storage Waste is classified as mixed radiological–chemical hazard waste	

TABLE 5. SUMMARY OF SELECTED LOW AND INTERMEDIATE LEVEL WASTE RETRIEVAL AND REMEDIATION PROJECTS (cont.)

Country	Site	Date	Waste	Reason	Description	Ref.
	East Tennessee Technology Park K-1070-A burial ground, Oak Ridge, Tennessee	2002–	Uranium and mixed waste from military production	Cleanup and decommissioning of old facility	Approximately 15 000 m^3 of waste and contaminated soil to be removed from the pit, segregated, characterized and packaged for on-site interim storage Waste is classified as mixed radiological–chemical hazard waste	
	Fernald OU-1, Ohio	1999–2005	Thorium, uranium and radium, and mixed LLW from military production	Cleanup and decommissioning of old facility	Approximately 600 000 m^3 of shallow land buried waste plus 75 000 m^3 of contaminated subsoils to be retrieved from eight pits, then sorted, crushed and shredded, and repackaged for off-site disposal; some low activity soils may be disposed of on the site	
	Hanford 618-4 burial ground, Hanford, Washington	2000–	Transuranic contaminated waste from military production and research activities	Cleanup and decommissioning of old facility	Ongoing programme to retrieve from shallow land burial, sort, repackage and dispose of approximately 75 000 200-L drums Waste to be disposed of at other facilities on the Hanford site or at the Waste Isolation Pilot Plant (WIPP), depending on the content	[93]

TABLE 5. SUMMARY OF SELECTED LOW AND INTERMEDIATE LEVEL WASTE RETRIEVAL AND REMEDIATION PROJECTS (cont.)

Country	Site	Date	Waste	Reason	Description	Ref.
	Pit 9, Idaho National Engineering and Environmental Laboratory, Idaho	2003–	Plutonium contaminated LLW from military production	Cleanup and decommissioning of old facility	Test programme to retrieve from shallow land burial, characterize, sort, repackage and dispose of approximately 100 m^3 of waste and soil Waste to be disposed of at the WIPP May lead to a much larger full scale project in the future	
	Rocky Flats Trench 1, Colorado	1998–	Uranium contaminated LLW from military production	Cleanup and decommissioning of old facility	Work consists of excavation of trench material, segregation of material, stabilization of uranium metals, packaging and off-site disposal	

10. CONCLUDING REMARKS

There is a consensus that modern waste disposal facilities for LILW are meeting the internationally accepted requirements for long term safety, while the realization of deep geological repositories for HLW is still under investigation and discussion. However, there are a number of old waste storage and disposal facilities from which waste needs to be recovered for relocation to other facilities, with or without additional conditioning or reconditioning.

This is often the result of the unexpected degradation of some old storage and disposal facilities and waste packages that were produced many years ago and that do not correspond to the current, more stringent safety requirements. It may also be the result of changes in the existing social, political and economic situation. In either case, old waste from such facilities will need to be retrieved for conditioning or reconditioning in accordance with modern safety requirements before being disposed of in new, properly designed and licensed repositories.

The present status, characteristics and quality of waste at these old facilities vary significantly, as do the reasons and urgency for waste retrieval. Retrieval and conditioning or reconditioning of radioactive waste from old storage facilities or repositories is a complex and complicated task. It requires extensive planning and preparation, selection of an appropriate strategy for work implementation, and selection of corresponding technologies for waste retrieval, segregation, characterization, transport, treatment and conditioning. All this must be accomplished in accordance with up to date, accepted and approved options for the subsequent storage or disposal.

A wide range of technical and non-technical factors must be considered when planning the retrieval of old waste. Each waste retrieval project is different, and in general such tasks are much more complicated than the management of initial waste from well defined sources and with well defined characteristics. Management of retrieval and conditioning or reconditioning of some historical radioactive waste requires special attention, specific preparation and appropriate implementation. Initiation of retrieval activities introduces many challenges associated with the selection of appropriate techniques, instrumentation, protective equipment and well defined WAC. All activities in connection with the retrieval of old waste need to be carried out in full conformity with radiation protection quality and safety requirements as defined by national legislation.

The important points relevant to old waste retrieval and conditioning or reconditioning could be summarized as follows:

(a) The deteriorated conditions of waste, packages and facility structures should all be considered in the planning and execution of any waste retrieval operation. The planning should also anticipate surprises such as the potential for the presence of unexpected radiological and conventional safety hazards during retrieval and subsequent waste handling. Accordingly, planning should remain flexible and should provide contingencies for managing such situations.
(b) The initial analysis and characterization of the facility and waste is critical to planning the waste retrieval project and to the selection of treatment and conditioning processes for the recovered waste. The scope of the characterization needs to include all anticipated hazards (radioactive and otherwise) and provide for at least some level of screening of other, unexpected hazards.
(c) Once the waste has been retrieved, much of it can be treated using conventional radioactive waste treatment techniques. However, lack of detailed information about the waste will often complicate the selection of an appropriate treatment process, and may favour processes that are less sensitive to variation in the waste being treated. The wide range of the types of waste that may be retrieved may necessitate the selection of multiple treatment processes or a single, versatile process that can cope with the broad range of waste characteristics.
(d) The existence of a final waste destination and corresponding WAC is critical to the planning and implementation of the entire waste retrieval project. In the absence of WAC for a known repository, generic internationally accepted criteria should be applied as the minimum criteria for treatment, conditioning, packaging and storage.

Extensive experience is available in several countries on the retrieval of old radioactive waste from storage and disposal facilities. This experience clearly shows that old waste retrieval projects, even under difficult situations, can be successfully implemented.

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Annex I

CANADA

I–1. RWOS 1 TILE HOLE REMOVAL (BRUCE NUCLEAR SITE, ONTARIO)

I–1.1. Introduction

Ontario Power Generation owns 20 CANDU nuclear units, ranging in size from 500 MW(e) to 900 MW(e). Operational intermediate level waste (ILW) from these reactors is stored at a centralized waste management facility located on the Bruce reactor site. Two waste storage facilities are located on the site: RWOS 1 (Radioactive Waste Operations Site No. 1), which operated from the mid-1960s to the mid-1970s and consists of a series of in-ground engineered concrete storage structures such as trenches with a total capacity of approximately 1000 m^3, and the WWMF (Western Waste Management Facility), which has operated since the mid-1970s and consists of a waste treatment building with an incinerator and a medium force compactor for low level waste (LLW) and a series of in-ground and above ground engineered storage structures. The WWMF currently stores approximately 60 000 m^3 of waste.

The current technology of choice for storage of ILW at the WWMF is in in-ground, steel lined storage structures called IC-18s (in-ground container, 18 m^3) or in above ground engineered concrete warehouse type buildings known as low level storage buildings, with each building storing approximately 8000 m^3 of packaged LLW.

I–1.2. The problem

The old in-ground storage structures were not designed to current standards. An operational decision was made to consolidate the waste from the older facility (RWOS 1) into the newer one (WWMF) and to improve the packaging for the ILW.

I–1.3. Waste type

ILW stored at RWOS 1 consists of spent ion exchange resins and filters from reactor systems as well as miscellaneous high dose rate irradiated core components.

I–1.4. Storage arrangements

ILW was stored in 23 tile hole structures at RWOS 1. A tile hole is an in-ground storage structure consisting of a length of concrete pipe (approximately 0.75 m outside diameter (OD) and 3.6 m long) set on a concrete base. After placement of waste inside the tile hole, the structure was backfilled with cement grout to form a monolith.

I–1.5. Objectives of retrieval

For operational reasons, a decision was made to remove much of the waste from the RWOS 1 site and consolidate it in the modern storage structures of the WWMF.

I–1.6. Retrieval strategy

The tile holes were removed by sinking a 1.5 m diameter steel sleeve around the outside, removing the sand and gravel from the annular space between the outside of the tile hole and the inside of the sleeve (using a vacuum system) and backfilling the annular space with concrete (Fig. I–1). Once the concrete had set, the entire monolith was lifted out by crane (Fig. I–2), grouted into a base plate and transported to the WMWF (approximately 1 km away) by a heavy forklift truck for above ground storage. The final encapsulated package is 1.5 m OD × 4.3 m long with a mass of approximately 25 t.

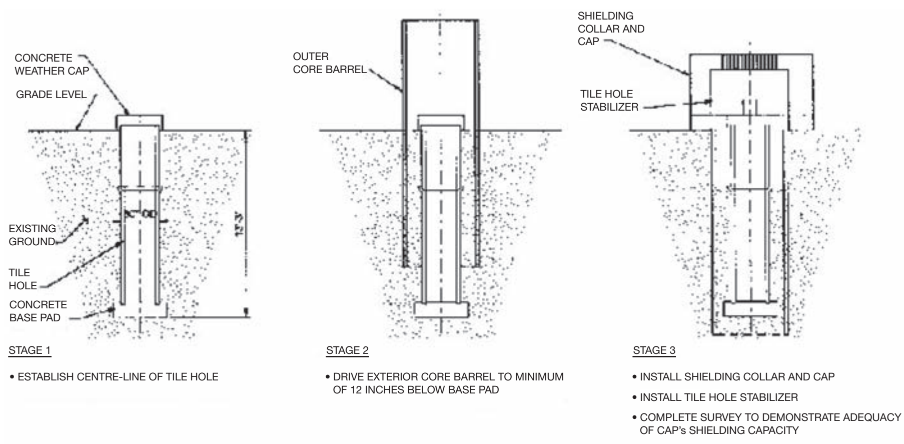

FIG. I–1. System for tile hole removal.

FIG. I–2. Lifting of an encapsulated tile hole.

I–1.7. Results achieved

All 23 tile holes from RWOS 1 were removed in 2001 and 2002, and are now stored in a low level storage building at the WWMF (Fig. I–3).

The only serious problem encountered during the removal operation was the separation of a base while the tile hole monolith was being lifted out. This was caused by poor grouting of the original waste in the original tile hole and left some of the original waste exposed on the tile hole foundation. The base section was subsequently regrouted into the encapsulated tile hole monolith and removed [I–1].

I–2. RWOS 1 TRENCH WASTE REMOVAL (BRUCE NUCLEAR SITE, ONTARIO)

I–2.1. The problem

As mentioned above, the old in-ground RWOS 1 storage structures were not designed to current standards. Much of the waste was placed into the older storage facility without processing or discrete packaging (e.g. bags of waste were placed without additional packaging). An operational decision was made to retrieve and consolidate the waste from the older facility into the newer one. Retrieval of the waste also allowed the opportunity to reduce the volume of the waste by modern techniques (incineration and compaction) and package it in durable metal containers.

FIG. I–3. Storage of encapsulated tile holes in a low level storage building.

I–2.2. Waste type

RWOS 1 consists of two in-ground engineered concrete trenches for LLW (each divided into three sections) and one trench monolith for ILW (divided into 13 sections). The typical composition of routine dry active waste (DAW) from nuclear power plants includes drums, bags and boxes of LLW. Some of the trenches were backfilled with sand or other granular material. It should be noted that DAW from CANDU heavy water reactors typically has higher levels of tritium than similar waste from light water reactors (boiling water reactors (BWRs) and pressurized water reactors (PWRs)).

I–2.3. Objectives of retrieval

For operational reasons, a decision was made to remove much of the waste from the RWOS 1 site and consolidate it in the modern storage structures of the WWMF. As part of the retrieval process, waste was sorted, the volume reduced by compaction or incineration and the waste was packaged for storage at the WWMF.

I–2.4. Retrieval strategy

As shown in Fig. I–4, a temporary enclosure was erected around the trenches, consisting of a large fabric tent equipped with large end doors for equipment movement and a HEPA filtered air circulation system. Loose backfill material was moved into drums by a vacuum system. The waste was removed by a clamshell digger and placed in an approximately 3 m^3 steel box container for transfer to the WWMF, where it underwent further processing by compaction or incineration prior to further storage.

After contamination checks, the waste boxes were moved by truck to the WWMF. The transfer was over on-site roads only, with no transport on public roads.

Lack of data about the stored waste dictated a ‘slow and cautious’ approach, with frequent contamination and radiation level checks. (Occasionally, a high dose rate object was found mixed in with lower dose rate waste). Other hazardous types of material identified included some chemical waste, asbestos and hidden sharps.

I–2.5. Progress and experience to date

Two campaigns were conducted in the 1990s to retrieve waste from trenches in RWOS 1, which operated from the mid-1960s to the mid-1970s. The waste mostly originated from Douglas Point nuclear power plant (an early prototype reactor, now shut down), with some coming from the early operation of the Pickering A nuclear power plant. Most of the waste was placed directly in the trenches without prior processing. Typical containers used were plastic

FIG. I–4. Trench waste retrieval operations at RWOS 1.

bags, drums, boxes, pails and other simple containers. In 1992 and 1993 approximately 205 m^3 of old waste was removed from one trench section. In 1997 and 1998 a further 630 m^3 was removed from three additional trench sections, including approximately 160 drums of sand and other loose material that was vacuumed from the trench sections. The original intent was to free release the sand. However, subsequent measurements showed that it was above the free release limits. The waste was removed to the WWMF, with some being compacted or incinerated before further storage [I–2].

In addition to the radiological and conventional hazard concerns about dealing with poorly characterized waste in the older trenches, one of the main worker health and safety issues addressed heat exhaustion, since the retrieval campaigns were conducted in the summer. Workers wearing respirators and protective coveralls needed to take frequent breaks, wear cooling vests and drink plenty of liquids to ensure that they remained hydrated.

I–3. POINT LEPREAU WASTE RETRIEVAL PROJECT (POINT LEPREAU NUCLEAR POWER PLANT, NEW BRUNSWICK)

I–3.1. Introduction

Point Lepreau is a single unit CANDU heavy water power reactor rated at 600 MW(e). It has an on-site LILW storage site consisting of five above grade engineered concrete bunkers. The total waste storage capacity is approximately 1500 m^3. The waste production rate at the nuclear power plant is currently 60–100 m^3 per year.

I–3.2. The problem

The existing storage facilities were approaching full capacity. In order to delay the construction of additional storage facilities, it was decided to recover space in the existing facilities through a campaign of sorting, reprocessing and free release.

I–3.3. Waste type

LLW from the Point Lepreau nuclear power plant is routine DAW and consists of cardboard boxes of waste, some compressed, some not, approximately 0.5 m^3 per box, wrapped in plastic (Fig. I–5). Typically, DAW from

FIG. I–5. Typical box of retrieved waste prior to sorting.

CANDU heavy water reactors has higher levels of tritium contamination than similar waste from light water reactors (BWRs and PWRs).

I–3.4. Storage arrangements

Waste boxes are stacked in above grade concrete bunkers (Fig. I–6). Each bunker is divided into four sections with a capacity of approximately 130 m^3 each. The sections are approximately 3 m wide × 3 m deep × 14.5 m long. Waste boxes are stacked five boxes across and five high. The sections are monitored for ingress of water and a subfloor drainage system collects any water that may have seeped through the floor.

I–3.5. Objectives of retrieval

The storage bunkers were reaching their capacity and a decision was made to extend the life of the existing facility by retrieving, sorting, reprocessing and free releasing some of the older waste stored to recover some storage capacity. The retrieval was strictly for space recovery; there were no concerns about the integrity of the storage structures.

FIG. I–6. LLW storage bunker.

I–3.6. Retrieval strategy

The waste was manually retrieved from the storage bunkers, using small capacity lifting equipment where appropriate, and transferred to an interim storage area. Boxes of waste were moved to a designated sorting area, where they were cut open and the contents manually sorted, measured for radiation levels and dispositioned as radioactive waste or for free release. The waste found to be radioactive was repackaged and restored in the storage bunkers. The sorting was performed as part of a campaign to sort similar new waste types generated during a station maintenance outage.

I–3.7. Progress and experience to date

In early 2004 a pilot study was conducted at Point Lepreau nuclear power plant in New Brunswick to retrieve waste from an old storage bunker and sort it with the objective of recovering storage space. A total of 44 cardboard boxes of waste, with a weight of 2125 kg, mostly dating from 1983, was retrieved. The boxes were emptied on to sorting tables and manually sorted (Fig. I–7). This was done in conjunction with a larger project to sort waste from an outage. The measurement set points were 10 μSv/h for tritium (on an Overhoff tritium meter) and <1000 Bq/kg gross beta–gamma using a waste bag monitor. These free release criteria were approved by the regulator (the Canadian Nuclear Safety Commission) for release to a local off-site conventional waste landfill. Of the original waste, only 157 kg was measured as active, the rest (92%) was

FIG. I–7. Sorting area for retrieved LLW.

diverted to the off-site landfill (about 1500 bags). As a prerequisite for off-site disposal, all activity trefoils and radioactive labels were cut out of the plastic bags and wrappers, resulting in a total of 15 kg of such labels (this is included in the 157 kg quoted above). The labour effort was estimated to be approximately one person day to sort two boxes. Typical hazards encountered were broken glass and syringes in the older waste. In order to protect the workers from these sharps, commercially available puncture resistant protective gloves were used. Some mould and dust was also encountered. Workers were protected by the ventilation over the sorting tables and by using standard particulate breathing masks. About 100 waste boxes were retrieved for sorting between late 2004 and early 2005 [I–3].

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Annex II

ESTONIA

II–1. RETRIEVAL OF SOLID WASTE AT THE FORMER PALDISKI TRAINING CENTRE

II–1.1. Introduction

In the 1960s the Soviet Union established a training centre for the safe operation of reactor systems for nuclear submarine crews at Paldiski, which is 45 km west of Tallinn in Estonia. Two full size nuclear reactors were built in two full scale submarine reactor compartments; the first went critical in 1968 and the second in 1983. Both reactors were of the PWR type with a thermal power of 70 and 90 MW, respectively. At the time of last criticality in 1989 the first reactor had been operated for about 21 000 h and the second for about 5000 h.

At the site were auxiliary systems including a processing facility for liquid waste and special buildings where solid waste and liquid waste concentrates was emplaced. When Estonia proclaimed its independence in 1991, it inherited the facility and the responsibility for its decommissioning. In September 1995, when the Russian Navy had transported the spent nuclear fuel to Mayak, the Estonian authorities took full control of the site.

II–1.2. The problem

In order to decommission the site, retrieval and processing of the liquid and solid radioactive waste was required. The conditions of the waste were not acceptable for long term storage, and the documentation concerning the waste was not satisfactory. There was thus a need to retrieve, characterize and condition the waste in such a way that it could be safely stored and eventually disposed of.

II–1.3. Storage arrangements

The solid waste storage (SWS) was an on the ground concrete construction (with dimensions of 28 m × 12 m × 4 m) divided into ten compartments into which the waste had been dumped without conditioning or packaging. No proper inventory of the waste was kept. During the characterization of the dumped waste, all types of solid waste were discovered (e.g. control rods, steam generators, sealed sources, scrap, plastic and rags). Waste had been dumped in three compartments; the rest were empty.

II–1.4. Retrieval strategy

II–1.4.1. Sampling and waste characterization

Initial characterization was made by visual inspection (a television camera was frequently used, due to the high radiation level), dose rate measurements, in situ gamma spectroscopy and a gamma imaging camera (Fig. II–1). The initial characterization revealed that in addition to the expected unsorted waste from the operation and maintenance of the reactors, there were also 20 control rods in one of the compartments.

II–1.4.2. Infrastructure upgrade

As a preparation for waste retrieval and conditioning, local manufacturing of waste containers was initiated. To facilitate the work and to reduce the risk of spreading contamination, a lightweight building was established on top of the SWS (Fig. II–2). An interim store for the retrieved and conditioned waste was prepared in the old main reactor building.

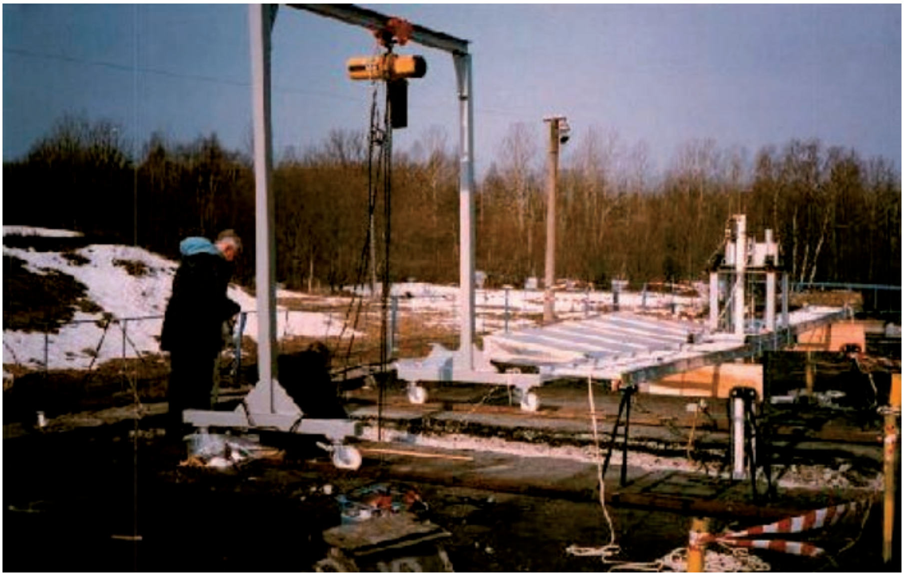

FIG. II–1. Initial investigations of the SWS at Paldiski.

FIG. II–2. Lightweight building erected on top of the SWS to facilitate retrieval of the waste.

II–1.4.3. Retrieval process

The retrieval was planned and initiated based on very limited information about the waste to be retrieved. Therefore flexible techniques were used and a tight follow-up of the situation was carried out. The waste in one of the cells could be retrieved manually; it consisted mainly of low level soft waste. This cell was decontaminated and used as an airlock to sluice material in and out of the facility.

Most of the waste had to be retrieved using remote handling techniques with the help of two standard cranes, one small crane inside the cell and one larger crane on top (the small crane is shown in Fig. II–3). A control room was established in one of the unused cells (Fig. II–4).

A number of unexpected difficulties and surprises were experienced during the work; for example, the control rods needed to be cut, but the information on where the absorbing material was located was not available. This was overcome by liaison with Russian experts and engineering estimates. Due to the high activity of the control rods, a special control rod container had to be developed for the retrieval of the rods, their transport to the on-site interim store and their storage (Fig. II–5).

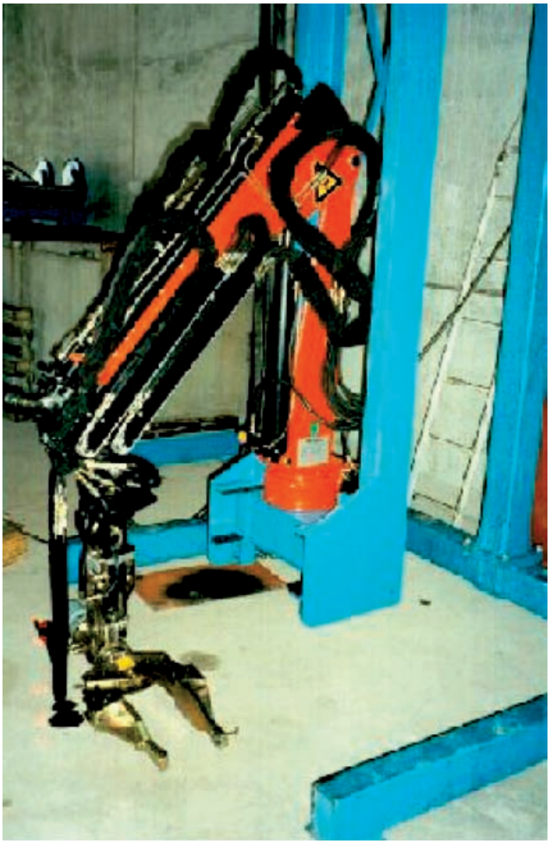

FIG. II–3. Small crane inside a cell.

Another surprise was that the eight steam generators all contained about 500 L of water when they were taken up from the compartment. This water, which was slightly contaminated, was removed and used for making active grout for encapsulation of waste in the standard concrete waste packages used for certain types of waste.

All the waste retrieved was transferred to a newly established interim storage facility on the site (Fig. II–6).

II–1.5. Progress and experience to date

The whole retrieval operation was carried out in less than one year by the local organization AS ALARA, whose staff had been trained in Sweden. It resulted in 76 1-m^3 concrete containers, three control rod containers, eight

FIG. II–4. Control room for remotely controlled cranes.

FIG. II–5. Control rod container on top of the SWR ready for transport to the interim store.

steam generators and 67 200-L drums of compacted solid waste. There was no significant incident and no accident during the work. The total dose received during the recovery operation was 14 mSv. The constructive cooperation with

FIG. II–6. Interim store for conditioned solid waste at Paldiski.

the national regulatory authority was of great importance for the successful implementation of the project in a very short time and at a reasonable cost.

Further details on the Paldiski project can be found in Ref. [II–1].

REFERENCE TO ANNEX II

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Annex III

FRANCE

III–1. SOLID RADIOACTIVE WASTE RETRIEVAL FROM THE LA HAGUE NORTH-WEST PITS

III–1.1. Introduction

At the La Hague reprocessing plant in France, short lived low and medium level waste called technological waste was stored from 1969 in concrete pits called the north-west pits. In 1989, COGEMA decided to retrieve and condition this waste to send it to an existing surface disposal site.

III–1.2. The problem

The waste stored in the north-west pits was generated during the first years of operation of the La Hague plant (a time when land disposal was not available and specifications for the acceptable form were not available). As a consequence, the technological waste was stored without conditioning. In addition, as the pits aged, the possibility of water leaking to the surrounding soil and groundwater increased.

III–1.3. Waste type

The technological waste was the waste produced by maintenance of the La Hague reprocessing facilities. The waste was composed of the following:

(a) Waste bags, representing 80% of the total volume, containing gloves, cleaning clothes, wet smears, PVC protective suits and cotton wool soaked with chemical decontamination reagents, etc.
(b) Bulk waste, representing 14% of the total volume, generated by equipment replacement and/or dismantling operations. There is a large range of sizes and types of material, such as wood, plastics and steel.
(c) Steel containers, 1 m^3 each, representing 6% of the total volume and containing incinerable clothing.

Some of the waste was wet and all of it was considered to be short lived low and medium level waste (i.e. lower than 3700 Bq alpha per gram and lower than 370 000 Bq beta–gamma per gram).

The total volume of waste initially stored in the pits was 11 000 m^3.

III–1.4. Storage arrangements

There are 23 concrete pits with volumes varying between 100 and 1000 m^3.

(a) Pits 1–17 have different storage volumes (from 100 to 350 m^3) and are made of rough concrete and are not leaktight. Their contents represent around 30% of the total waste volume to be treated.
(b) Pits 18–23, each with a 1000 m^3 capacity, are made of concrete reinforced with a carbon steel liner embedded in concrete and have an adequate leaktightness.

Steel slabs cover all of the pits, which prevent intrusion and provide waterproofing against rainwater. The pits are laid out in three lines.

III–1.5. Objectives of retrieval

France has now developed waste specifications for low and medium level waste disposal, and disposal facilities are available. Thus it became possible to retrieve old untreated waste for processing and conditioning into a form acceptable for final disposal, in order to remove the hazards associated with these storage pits. Additional objectives were to minimize the waste volume and to limit as much as possible the production of secondary waste.

III–1.6. Retrieval strategy

III–1.6.1. Sampling and characterization

No specific sampling operations were performed before the start of operations. Nevertheless, because conditioning treatments were selected according to the nature of the waste, each waste subject to retrieval was inspected before being transferred for treatment. In addition, representative samples were taken during retrieval operations to characterize the waste package to be produced and sent for disposal. Due to the variety of waste types, it was not possible to perform their complete characterization. Nevertheless, because they are of the same nature as those still generated by the plant operation, COGEMA could rely on lessons learned and have a good idea of what could be found in the waste.

III–1.6.2. Infrastructure upgrade

The pits themselves were not modified, but a mobile intervention facility (total weight about 100 t) was built to be installed above a pit (see Fig. III–1). Two rails installed on each side of the pits allow movement of the intervention facility from one pit to another on the same line. A mobile crane (1100 t) was used to move the mobile facility from one line to another. The mobile intervention facility was provided with the equipment necessary for opening the pit slab, retrieving the waste, sorting it and placing it in a drum. Additional fixed facilities were built for waste treatment.

III–1.6.3. Downstream process

The waste was first sorted and then treated according to its nature:

(a) Waste suitable for crushing (plastic, small metallic parts, etc.) was crushed then sent to a centrifuge to remove any liquid initially contained in the solid waste. The crushed and liquid free waste was then put in metallic drums for compaction. The compacted product was then placed in a CBFK (cubic fibre concrete container of 3.1 m^3, qualified for a final repository).

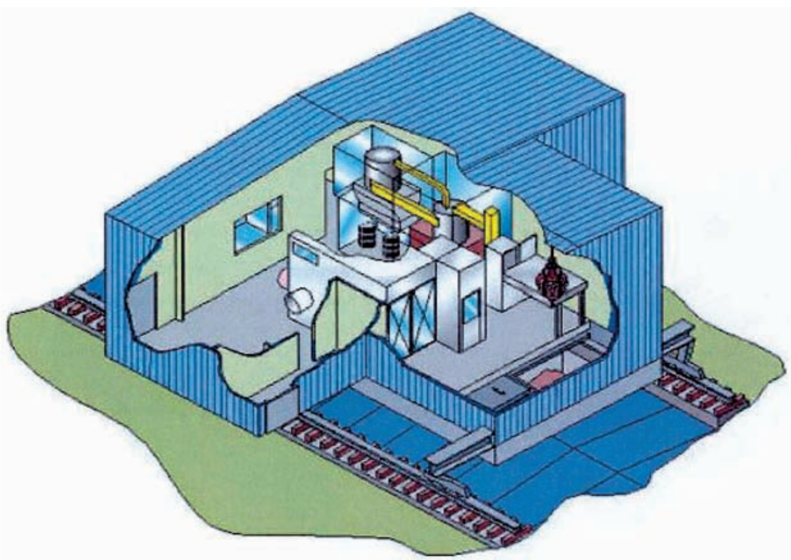

FIG. III–1. Diagram of the La Hague north-west pits waste retrieval.

(b) Waste not suitable for crushing (mainly metallic parts of significant size) was sheared then placed and grouted in a CBFK.
(c) The liquid waste recovered from waste draining was pumped and transferred to a pretreatment unit that had been included in the project. The waste was treated by precipitation of hydroxides then sent to the existing La Hague liquid waste treatment facility.

III–1.6.4. Retrieval process

The solid waste was retrieved from the pit using a gripper handled by a crane (Fig. III–1). This crane was located in the mobile intervention facility. The gripper was lowered inside the pit through a sliding trap located between the open slab of the pit and the mobile intervention facility. This approach allowed the gripper to catch the bulk waste (or the waste bag), extract it from the pit, and then lower it on to the sorting table for downstream treatment.

III–1.6.5. Implementation

The precautions to be taken for such waste are not because of irradiation but because of contamination. The retrieval operations were performed in the mobile intervention facility in ventilated containment airlocks, in order to prevent any spread of radioactive particles into the environment. As much as possible, the operation was performed remotely. Some manual operations, such as waste handling, were performed with a protective suit and restricted as much as possible.

III–1.7. Results achieved

The retrieval operation was performed in two phases: one between 1990 and 1992 and the second (after transfer of the mobile intervention facility to the second series of pits) between 1992 and 1998. All the retrieved waste has been conditioned according to the applicable specifications and is now disposed of at the final repository [III–1].

The second phase benefited from the lessons learned from the first phase, especially the recommendations on maintenance work and optimization of equipment subject to rapid wearing.

The work was performed not only in compliance with the applicable exposure regulations but also according to the ALARA goals on the La Hague site (10 mSv per worker over a 12 month period). The improvement in the procedures on this project is demonstrated by the overall figures for phases 1 and 2:

(a) Phase 1. Actual total integrated doses: 441 man mSv for 470 GBq retrieved and conditioned.
(b) Phase 2. Actual total integrated doses: 581 man mSv for 1935 GBq retrieved and conditioned.

III–2. RETRIEVAL OF OLD RADIOACTIVE WASTE IN TRENCHES AT CEA CADARACHE

III–2.1. Introduction

Since its creation in 1945, the CEA has built and operated facilities of various types for its research programmes, mainly experimental reactors, process study facilities and research laboratories.

III–2.2. The problem

Radioactive waste produced during these activities was stored using the available techniques of the time (prior to 1975); however, these techniques no longer meet the current protection criteria. All this waste must be retrieved and, as required, sorted, processed, packaged for disposal or, failing that, stored under safe conditions that meet the current criteria pending final disposal.

III–2.3. Waste type

The waste mainly comes from the CEA Cadarache facilities and other centres of the CEA and occasionally from small producers (universities). The different types of waste vary in nature: sludge, either wrapped or unwrapped, metallic waste, technological waste, gravel, soil, resins, ashes, glass, pipes, ventilation ducts, etc. This waste may be classified in the following categories:

(a) Traditional technological waste. This type of waste can be broken down into two categories: waste that can be incinerated and waste that can be compacted.
(b) Process or specific waste. This waste mainly consists of sludge (that for the most part comes from the Cadarache effluent treatment facility), ashes, resin, fluorine and metallic chips.

The following waste packages were used:

(i) Metallic 100 and 200 L drums;
(ii) Concrete shells of 1.2 and 1.8 m^3;
(iii) Metallic settling pots;
(iv) Vinyl bags for small bulk waste;
(v) Vinyl wrapping for large bulk waste.

The volume of the waste to be recovered from the trenches at CEA Cadarache is shown in Table III–1.

III–2.4. Storage arrangements

The storage area is made up of five trenches numbered from T1 to T5 in the chronological order of their filling. Each trench is different, particularly

TABLE III–1. VOLUMES OF WASTE PER TRENCH

Packaging	Contaminant	Trench 1 (m^3)	Trench 2 (m^3)	Trench 3 (m^3)	Trench 4 (m^3)	Trench 5 (m^3)
100 L drums	Beta–gamma (solid)	0	20	5	25	45
	Pu (solid)	0	5	20	1	0
	U (solid)	0	5	1	1	5
	Sludge	20	1	10	1	0
200 L drums	Beta–gamma (solid)	20	100	80	150	65
	Pu (solid)	0	40	20	2	0
	U (solid)	0	0	5	0	5
	Sludge	270	15	120	90	0
1.2 m^3 concrete shells	Sludge	0	25	60	0	0
Miscellaneous (exclusive of sludges)	Beta–gamma (solid)	60	250	170	350	550
	Pu (solid)	0	10	210	80	0
	U (solid)	0	40	5	22	50
	Total	370	511	706	722	720

Note: Sludge constitutes a specific category of solid waste, packaged in drums, essentially contaminated by beta–gamma emitters with the possible presence of alpha emitters (mainly uranium) in low concentration.

with regard to the nature of the land at the selected location and the available space.

Table III–2 shows the size of each trench, based on a geophysical prospecting performed in 1998 that made it possible to detail the outline of the trenches.

It should be noted that:

(a) The bottom or 'floor' of the trenches is covered with a 10 cm layer of gravel for rainwater drainage purposes;
(b) The buried waste is covered with 1 m of compacted soil and a dirt dome measuring 1–1.5 m thick.

III–2.5. Objectives of retrieval

These actions are being carried out within the framework of the CEA cleaning and environmental restoration programme, which has been ongoing since 1992. The objective is to retrieve the waste, sort it and process it according to its radiological and physical characteristics, in order to make packages acceptable for final disposal.

III–2.6. Retrieval strategy

III–2.6.1. Pilot worksite

Considering the size of the operation, it seemed necessary to study its feasibility with a pilot worksite (Fig. III–2) prior to the start of work in order to validate the retrieval procedures. The first retrieval and activity measurement was carried out between July and September 1995.

TABLE III–2. TRENCH SIZES

Dimensions (m)	Trench 1	Trench 2	Trench 3	Trench 4	Trench 5
Length at opening	26	25	39	32	34
Length at trench bottom	21	19	35	27	29
Width at opening	10	10	10.4	10	10
Width at trench bottom	4	4	6.4	5.5	4
Depth	5	5	3.5	4.5	5

FIG. III–2. Pilot worksite.

The validation concerned the retrieval of 15 m^3 of waste from the T2 trench, which was deemed representative in terms of the different varieties of waste involved. An assembled shed was built above the retrieval operations zone with both static confinement (the vinyl tent) and dynamic confinement (ventilation), as well as radiological surveillance.

Feedback from this worksite produced the following conclusions:

(a) The presence of water due to infiltration of rainwater was limited by the waterproof tarpaulin on each of the trenches and the drains connected to a sampling tub.
(b) The concrete and plastic material exhibited good resistance, but carbon steel casings had deteriorated.
(c) The alpha activity of the buried waste was higher than expected.
(d) A few drums with significant masses of plutonium (a few grams) were present.
(e) The total dose cost was 0.2 mSv for the retrieval operations (eight people for three months) and 0.34 mSv for the sorting operations (seven people for 1.5 months).
(f) The waste from the validation worksite included three specific types: extracted waste (15 m^3), waste resulting from the storage of this waste (25 m^3 of soil and 31 m^3 of water) and technological waste from the retrieval worksite (1.6 m^3).
(g) The distribution of the waste extracted according to its activity was the following: 75% category A (LLW) and 25% category B (LLW or ILW with alpha emitters).
(h) There was low contamination of the land surrounding the waste that can be classified as very low level waste (VLLW; contamination of the order

of 1–10 Bq/g of beta–gamma emitters and of the order of 0.1–1.0 Bq/g of alpha emitters).

The pilot worksite revealed nothing likely to question the feasibility of the entire retrieval of all the buried waste. Feedback on this experiment was taken into account in the design of the full scale retrieval worksite.

III–2.6.2. The operations

The waste has been extracted successfully from five trenches, sorted by nature and type of contamination, radiologically characterized and transferred to the treatment facility.

Setting up this worksite included the following:

(a) Setting up an operations building (shed) that can be both assembled and disassembled, covering the trench in operation. This building includes cells and equipment that are either mobile or that can be taken down and reassembled.
(b) An empty shed for eventual use as the new operations building on the next trench.
(c) A logistics building equipped with locker rooms, offices and technical areas.
(d) An empty field or a spreading area and a buffer zone for the storage of the waste packages before they were processed.

III–2.7. Work plan

The operations building is a metal shed standing on longitudinal concrete beams. The whole assembly is modular and can be disassembled and hence moved from one trench to another and its dimensions adapted to those of the next trench.

The operational units based in this building are:

(a) A waste extraction cell, made up of a mobile metallic structure on two rails, equipped with:
    (i) Manual, hydraulic and pneumatic tools used in the extraction of soil and waste: chiselling and chipping tools, twist drills, clamshell buckets, shovels and pickaxes.
    (ii) Specific tools designed for the cold cutting of large waste: nibbling machines and shears.
    (iii) A transport bin for four 220 L drums.

(iv) A specially designed barrel for transporting soil.
(v) A pulley with a series of tackles (lifting beam, nets and slings).
(vi) A water recovery pump and a vacuum pump for dust.

(b) A confinement tarpaulin (a fabric coated with a protective layer of fireproofed heavy duty plastic). This 'blanket' covers the entire trench and the extraction cell. Depressurization in the extraction cell ensures the watertightness of the tarpaulin on the chassis. The cell's moorings by means of straps and rollers allow it to slide under the protective covering of the tarpaulin when it needs to be moved.

(c) A remote controlled transfer lorry equipped with video camera assistance, containing a shuttle container moving along the rolling tracks, which are located along the edge of the trench inside the operations building.

(d) A distribution cell made up of a stationary metallic structure, equipped with:
(i) A distribution and control station (radiological and visual) and a measurement system.
(ii) A sorting system allowing characterization.
(iii) Several transfer stations for the waste, the soil and the original emptied drums. From these points waste can be sent either to the sorting cell or to the final destination.

(e) A sorting–characterization cell that is a stationary metallic structure. It is equipped with:
(i) Sorting gloveboxes for the waste packages;
(ii) Gamma spectrometry chains for characterization of the drums;
(iii) A control room with video surveillance.

(f) Technical buildings (ventilation blocks, entrance hatch, hot laboratory, locker rooms, etc.).

Upon completion of the retrieval of the waste in each of the five trenches, the method for final cleaning was as follows:

— Drilling for core samples at the bottom of the trench (around 1 m deep core samples) and gamma spectrometry activity measurements of the core samples;
— From the obtained results, calculation of the soil depth to be removed in order to remove all the contaminated soil;
— After removal of this soil and if no more activity is measurable at the bottom of the trench (alpha and beta–gamma portable probe), the trench was filled with clean soil and with the previously removed soil dome;

— If activity was still measurable, another layer of soil was removed following new core sample drilling and calculations;
— If activity was still measurable but not far from the probe detection limits, an impact study on the environment was carried out.

The aim was to remove all activity within the trenches that exceeds the VLLW reference points: soil activity at the bottom of the trenches less than 10 Bq/g (alpha emitters) and 100 Bq/g (beta–gamma emitters).

Finally, the empty trenches were filled with soil, in the form of 50 cm layers of compacted backfilling, up to the level of the natural land. Upon completion of all the operations, the trenches were covered with a layer of topsoil 10–20 cm thick [III–2].

III–2.8. Progress and experience to date

Setting up a worksite necessitates the following operations:

(a) Earthwork operations: digging up and disengagement of the edges of the earth dome, banking and compaction, construction of the concrete foundations for the metallic chassis that serve as a support for the pathways and installation of the longitudinal beams in the operations building (shed).
(b) Assembling the shed at its designated location: the building is partially assembled above the trench and anchored on the concrete beams. The metallic chassis, serving as a support for the pathways, is installed.
(c) Removal of the soil dome: a layer of 0.20 m up to a maximum of 0.80 m under the level of the earth, removed with the aid of a power shovel. A radiological control is included. The soil is stored on the spreading area pending further use.
(d) Equipment set-up: assembly of the extraction cell, the tarpaulin (protective covering) and the different sorting cell modules and their equipment, then final closure of the shed.

III–2.8.1. Extraction cell

The waste in the trenches is extracted manually by means of specially designed tools. A foolproof plutonium detection system keyed to 5 g of plutonium is used for each object at the time of the extraction in order to detect any loaded drum and to manage it as an individual waste unit. The standard waste packages (drums and integrated bags) are placed in the transfer bin manually or by means of a pulley and net. Deteriorated and unconditioned waste is first placed in either one or several vinyl envelopes. Specific waste (large, voluminous waste, concrete hulls and so on) is processed individually after cutting operations, if necessary. The soil surrounding the waste is removed using manual tools and placed directly in transport tanks. Operators carrying out these operations wear protective suits (Fig. III–3).

The transfer bin (the transport barrel for the tanks or large volume packages) is subsequently transferred by means of a pulley to the inside of the shuttle container located in the lorry.

FIG. III–3. Operator in an air supplied protective suit.

III–2.8.2. Distribution cell

After the arrival of the shuttle container, the transfer bin containing the waste is lowered to the floor of the cell.

(a) The tanks of soil are transferred to the soil distribution and conditioning system and measured. The different types of soil are transferred to 223 L drums (LLW) or to large bags (VLLW).
(b) Very large volume packages (concrete hulls) are directly removed and the waste in bulk is placed in 870 L containers and removed after contamination checks have been performed through hatches (airlock zones).
(c) Standard packages (drums and non-voluminous bags) are taken and placed in leak tanks. These packages are opened, checked (alpha detection) and then transferred into the sorting enclosures or reconditioned in hatches.

III–2.8.3. Sorting cell

The waste is sorted inside gloveboxes, repackaged in the form of 20 L packages, then measured (alpha and beta–gamma counting). These packages are placed in drums of 100 L (compactable), 118 L or 223 L (for incineration), which are subsequently measured (gamma spectrometry), then removed and dispatched to their final destination.

III–2.9. History and provisional schedule

— 1969–1974: The area of the trenches received low activity waste.
— 1974–1995: No further movement of waste to or from the site; monitoring continued.
— 1992: Preliminary retrieval study.
— 1995–1996: Operation of the pilot worksite (first retrieval, activity measurement, sorting, radiological characterization and packaging operation).
— Late 1996: Processes are validated and safety options established based on feedback from the worksite.
— 1997–2000: Design studies, preliminary safety analysis, construction of buildings and equipment.
— 2001: Completion of the building and equipment, performance of tests in inactive conditions.
— 2001: Transmission of the safety report and general operating rules to the French nuclear authority.

— 2003: Authorization issued for the operation of retrieval and sorting facilities.
— 2004: Retrieval startup (trench T2).
— 2009: Completion of waste retrieval,
— 2010: Dismantling and cleaning of the area.

REFERENCES TO ANNEX III

[III–1] BODIN, F., ALEXANDRE, D., FOURNIER, P., "COGEMA experience on retrieving and conditioning solid radwaste previously stored in pits: The La Hague northwest pit case", paper presented at Waste Management 2000, Tucson, AZ, http://www.wmsym.org/wm2000/pdf/03/3-2.pdf

[III–2] GRON, G., SIMONETTI, J.C., MUNOZ, C., "CEA Cadarache: Retrieval of old radioactive waste in trenches", paper presented at ICEM'05, Glasgow, 2005.

Annex IV

HUNGARY

IV–1. RETRIEVAL AND REMEDIATION OF THE SOLYMÁR REPOSITORY

IV–1.1. Introduction

The Solymár repository was opened in 1959. The disposal units were constructed with prefabricated concrete rings with a diameter of 0.8–1 m (Fig. IV–1); the wells varied in depth from 3 to 5.5 m and had a concrete floor. To prevent the penetration of rainwater, bitumen was spread on the external, and partly on the internal, surfaces of the wells. Until 1976, 900 m^3 of radioactive waste with an estimated activity of 400 TBq and some 3000 disused sealed sources were emplaced at the facility. Solid waste was packed in polyethylene bags or metal drums.

IV–1.2. Reasons for retrieval

In 1976 the available capacity was substantially depleted. Extension was not possible, mostly due to limited funding and poor site characteristics (permeable properties of the soil). A decision was made to establish a new repository at Püspökszilágy and to proceed with retrieval of the waste and remediation of the Solymár site.

IV–1.3. Retrieval strategy

Before planning the recovery operation, some disposal wells were opened in order to examine the condition of the packages and to decide how the waste should be removed. It was evident that the packages, which had been stored for almost 20 years, were seriously damaged, and many had become externally contaminated. The primary objectives of the design were therefore to ensure the required radiological protection of the personnel who would do the work and to prevent any large scale contamination of the environment.

Practical waste removal caused some problems. In many cases the steel drums were corroded to such a degree that while hoisting them by crane the drums split, thereby discharging the waste back into the well or contaminating the surrounding area. The open waste packages and discharged waste were repacked in new drums or polyethylene bags by personnel wearing gas

FIG. IV–1. Remediation of the Solymár repository.

protective clothing with supplied air equipment. A special waste carrier vehicle transported damaged drums. The dose rate measured on the surface of the drums varied between 0.1 and 5 mGy/h.

Owing to the potential risk of environmental contamination during removal and repacking of the waste, a protective tent was erected. The floor of the tent could be decontaminated easily and was securely joined to the open storage well. Three persons wearing supplied air protective clothing worked inside the tent. One person in the well passed out the radioactive waste packages, while the other two repacked the removed waste to prevent secondary contamination.

In many cases there was a large quantity of water in the bags, sometimes as much as 1–2 L. These bags and those that were badly damaged were packed into drums for lifting out of the well.

The surface contamination of the wells in small areas was removed by using manual abrasion or by polishing the surface. The bottom of the wells had to be cut up by pneumatic hammer. During the decontamination of the well cylinders the larger surface contaminated areas were gouged out. In the cases of more extensive contamination the whole well cylinder was removed. This was achieved by using pneumatic stretching equipment to loosen its retention in the ground. If the whole well was contaminated, it was removed in one piece by crane, after removal of the surrounding soil.

It was found from measurements and calculations that the radioactive contamination remaining in the area was less than one tenth of the authorized value. In the area of the Solymár disposal site, the radioactive contamination was eliminated by the removal of a 5–10 cm layer of topsoil. Finally, the upper part of the well cylinders was removed and filled and covered with a 50 cm soil layer. The area was then covered with a humus soil to enable vegetation growth.

IV–1.4. Results achieved

All the radioactive waste was recovered and disposed of at the Püspökszilágy repository.

IV–2. PREPARATION FOR PARTIAL WASTE RETRIEVAL FROM THE PÜSPÖKSZILÁGY REPOSITORY

IV–2.1. Introduction

Institutional radioactive waste generated in Hungary is currently disposed of at the Püspökszilágy repository, which is a typical near surface engineered facility consisting of concrete vaults and steel lined wells for the disposal of spent sources. The vaults and wells are located above the water table in the unsaturated zone within a series of heterogeneous Quaternary rocks. Some waste in the vaults has been backfilled with cementitious material; other waste is not yet backfilled.

The Püspökszilágy disposal facility was designed to accept institutional radioactive waste after appropriate treatment and conditioning. However, no WAC were put in place. At the request of producers, spent sealed sources were also accepted for disposal, as well as some ^{238}Pu and ^{239}Pu sources.

IV–2.2. The problem

During the 1990s several safety assessments of the facility were undertaken. Based on these safety assessments it was concluded that continuation of the existing operation and environmental safety programmes until the end of the passive institutional control period was acceptable. The facility as a whole is suitable for the safe disposal of LILW short lived waste. Beyond the passive institutional control period, mostly because of the significant quantity of long lived components disposed of (^{14}C, ^{226}Ra, ^{232}Th, ^{234,235,238}U, ^{239}Pu and ^{241}Am), inadvertent human intrusion (or any other scenario resulting in exposure to waste after deterioration of the concrete barriers) could exceed both the dose constraint and the dose limit. Consequently, the Püspökszilágy repository is considered to be unsuitable for some of the long lived waste formerly emplaced in the facility.

IV–2.3. Facility arrangements

The repository is a shallow land disposal type consisting of four concrete trenches with engineered barriers. In addition, there are several other storage facilities and disposal wells on the site:

(a) An SWS facility (type A);
(b) A liquid waste storage facility (type C);
(c) Thirty-two wells for small radioactive sources (type D);
(d) Four wells for large radioactive sources (type B).

IV–2.4. Objectives of retrieval

The key recommendations relating to the future management of the site were as follows:

(a) Certain types of long lived waste and high activity spent sources should be removed from the existing repository.
(b) The repository closure cap should be redesigned.
(c) Long term settlement within the vaults should be minimized. At an appropriate time, the vaults should be completely backfilled.
(d) Steps should be taken to minimize the chances of future human intrusion by recording information about the facility and by providing an extensive period of administrative control following the repository's closure.

IV–2.4.1. Identification of the corrective action options

Further work was planned to resolve these issues with the objective of providing full assurance of post-closure safety. Due to the large number of parameters involved, an optimized intervention programme was established on the basis of a feasibility study. As the implementation will be expensive, it is important that the decision be well developed. The intervention programme was enhanced by the application of a formal multiattribute analysis approach.

When considering the potential waste recovery alternatives, several options were evaluated:

(a) Removal of the readily identifiable sources from the easily accessible vaults;
(b) Removal of the readily identifiable sources from all vaults;
(c) Removal of all the sources from the easily accessible vaults;
(d) Removal of all the sources from all the vaults.

Other recommended options were:

(i) Removal of the waste from the vaults containing less than 10 m^3 of concrete backfill.
(ii) Removal of the material of safety significance and storage on the site pending disposal elsewhere.
(iii) Conditioning of other types of material as necessary, including the application of low force compaction where appropriate, and return to the vaults.
(iv) Buffer storage of institutional waste appropriate for disposal in a near surface facility on the Püspökszilágy site pending appropriate conditioning and disposal using the space created by conditioning the recovered waste.
(v) Backfilling of the vaults with concrete when full, ensuring that all space between and above the waste packages is filled. The vaults that are already backfilled would be subject to any remedial action needed to ensure that the backfilling for these vaults meets the same standard as the newly backfilled vaults.
(vi) Construction of an engineered clay cap above the vaults when the facility is closed. Active institutional control of the facility would be maintained for 150 years after closure. The construction details and inventory of the facility would be lodged in local and national archives.
(vii) Erection of a permanent site marker.

It is proposed to undertake a demonstration project in which four vaults are opened and their contents treated. Such an arrangement ensures that the details of the approach are properly tested before committing to a full restoration programme.

IV–2.5. Retrieval and remediation plan

Once a preferred strategic option has been selected, a waste processing flow diagram can be developed. This diagram shows how waste will be managed from retrieval, through all appropriate processing steps, to long term storage or redisposal. The pre-existing and planned facilities at Püspökszilágy are taken into account in developing the process diagram.

Each of the steps identified in the process flow diagram should be analysed to identify the equipment and instrumentation associated with the step. The identified equipment and instrumentation should then be collated to allow the production of a schematic design for the plant showing an indicative layout of the equipment and instrumentation and a timetable for the implementation of the preferred strategy.

The retrieval activities will be carried out in two places: in and around the existing vaults and in what is subsequently referred to as the processing facility. The latter is a semi-permanent controlled area within the new Püspökszilágy storage building set up solely for handling vault waste.

The main stages of waste retrieval are as follows:

(a) Task 1 takes place in and around the vaults and results in material being removed and sent either to the processing facility or for free release. This task poses the greatest challenge in terms of operator safety and project risk.
(b) Task 2 is essentially transport operations.
(c) Task 3 is the operation inside the processing facility and determines the subsequent route that the waste will take (radioactive sources will be disposed of in long term surface storage, while the remaining material will be treated and conditioned).
(d) In task 4 the reconditioned waste is returned to the vaults.

IV–2.5.1. Plant and equipment needed to retrieve the waste

The waste was originally loaded directly into the vaults by operators, and it is a reasonable assumption that it can be removed in the same way, without the need for special remote handling equipment. (This of course assumes that the sources have not been exposed, either as a consequence of degradation of the shielding during storage in the vault or by the retrieval process itself.) Hence the equipment required can be comprised largely of conventional industrial plant, and the retrieval process is concerned mainly with contamination control.

IV–2.5.2. Containment around the vaults

It is currently assumed that the containment will cover an area somewhat larger than that of the two vault pairs (Fig. IV–2). This is to allow the initial retrieval demonstration to address one vault pair with loose waste (i.e. not backfilled with concrete) and one vault pair in which the waste has been immobilized. Subsequently, depending on experience and long term programme needs, the decision may be made to cover more or fewer vaults. The additional space around the vaults beyond the minimum requirement is to allow the deployment of plant and equipment around the vault edge.

The outer tent is a commercially available system based on an aluminium section frame covered with robust sheeting firmly laced to it. One of the attractions of this is that the arrangement may have to be varied during the operations to accommodate, for example, more space for a large item of equipment. The section frame allows this to be done quickly and easily, without the need for special plant other than a scissor lift or a similar access platform. The function of the outer tent is to protect the inner tent from the weather, in particular wind, since experience has shown that a satisfactory negative pressure cannot be maintained inside a single skin tent. The inner tent is constructed from plastic sheet over a suitable scaffold frame, similar to that used inside conventional nuclear facilities.

The tents will need to be provided with a suitably sized airlock to allow personnel and plant to enter and leave, together with a change and shower facility. There will also need to be a means for safely getting radioactive material in and out.

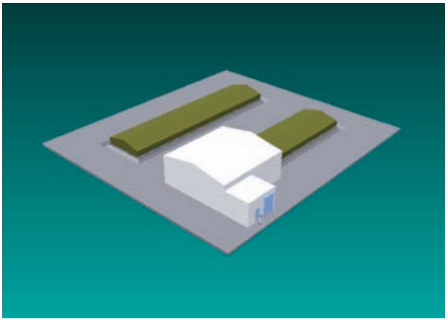

FIG. IV–2. Aerial view of the tent covering two vaults.

IV–2.5.3. Main plant items inside the tent

The two key activities that will be necessary are removal of the slabs covering the vault and removal of the waste. The slabs are each approximately 3 m × 0.65 m × 0.15 m, and weigh around 650 kg. It is proposed that these be lifted and moved using a simple A-frame with a hand operated chain hoist (Fig. IV–3). The slabs will be removed and stacked three high on the adjacent vault roof. It is possible that the undersides of these slabs may be contaminated to some degree, so it is important that plastic sheeting be used to prevent possible spread of contamination to the clean slabs covering the next vault.

It is important that operators do not enter the vaults themselves to recover waste. It is proposed that the waste be removed using a commercial quality hydraulic arm. This can be operated from a joystick control unit carried by the operator, with the advantage that he or she can move around for a better view and, if required, use closed circuit television (CCTV) and stand some distance from the vault. The hydraulic arm deploys a simple grab, usually pneumatically actuated, to pick up the waste (Figs IV–4–IV–6). In fact, it is likely that three different grabs will be required to pick up bagged material and small dense items such as shielded sources, debris from failed drums, etc.

The hydraulic arm will need to be mounted on a steel frame with a counterbalance weight to ensure that it operates from a firm base. For ease of maintenance, the power pack should be positioned outside the tent and the hoses run in through a sealed penetration.

In addition, if the vault has been backfilled with concrete, some means will need to be found to deploy a pneumatic or electric breaker (Figs IV–7 and IV–8). It may be possible that the design of the hydraulic arm would allow

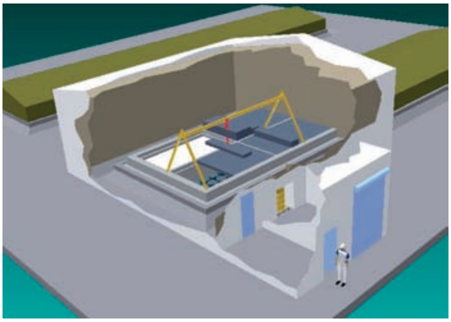

FIG. IV–3. View of the vault slabs being removed.

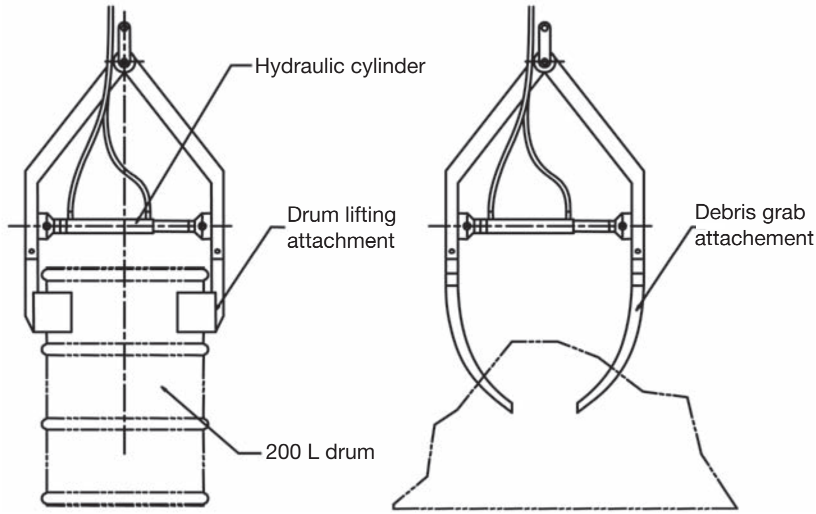

FIG. IV–4. Conceptual designs of drum and debris grabs.

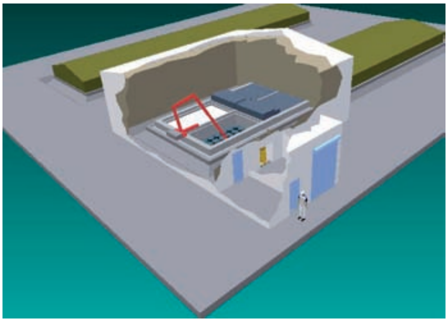

FIG. IV–5. Aerial view of the hydraulic arm working on a vault.

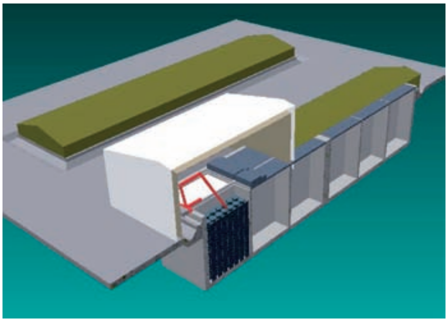

FIG. IV–6. Section through a vault.

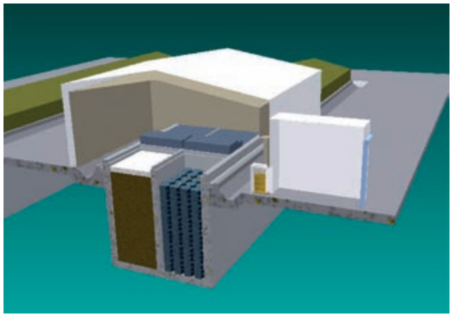

FIG. IV–7. Section through a vault showing the proposed waste posting route.

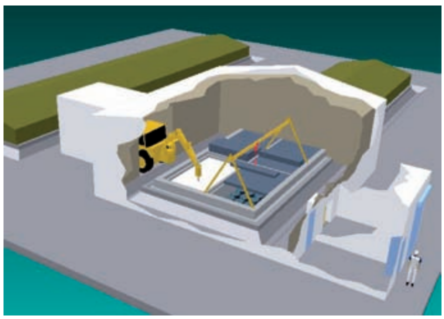

FIG. IV–8. View of the concrete backfill being broken up.

it to deploy the breaker as well as the grabs, and it is likely that the tent will have to be extended to accommodate it. Considerable care will need to be taken when breaking up the concrete backfill — there is clearly a danger of breaking open a shielded container and exposing the source, or of damaging a bag or drum and spreading loose contamination. The operators will need an emergency plan for dealing with such situations.

IV–2.5.4. Handling the waste

Some of the waste will be in bags that may have split, either in storage or during retrieval. Other waste will be in steel drums. The latter may be retrieved intact, although after an extended period in the vault it is quite possible that the drums will disintegrate when picked up. In either case, to control the spread of contamination the material will need to be placed in another container before being transported across the site to the processing facility. The simplest container is an open head drum of sufficient size to accommodate an intact drum retrieved from the vaults. A shielded overpack may also be required. Since, as was noted above, it is likely that many of the waste drums will be corroded, it would be prudent to have tools for size reducing unsound drums (and indeed other material) in the vault tents, for example a nibbler and a reciprocating saw.

To minimize the spread of contamination, waste will need to be removed from the tents in a controlled fashion. The precise method will need to be determined later, and will depend on the results of an assessment of the likely quantities of loose activity. The method of transferring drums will depend on the hazard presented by each vault, and therefore could be expected to vary from vault to vault. At one extreme, drums could be introduced into the vault tent and filled directly, before being given a wipe down and a check before being dispatched to the processing facility. At the other extreme, if high levels of contamination and/or alpha emitters are anticipated, a fully engineered double lidded containment system may be required.

In the case of a backfilled vault it is expected that the loose rubble produced by the breaker will be lightly contaminated and will need to be sealed in a drum similarly to the other waste. However, since there will be no further treatment required it can be stored adjacent to the vault and returned as soon as convenient.

IV–2.5.5. Equipment required around the vaults

The following is a list of the infrastructure, equipment and types of material that will be needed to recover the waste from the vaults.

(a) An outer tent.
(b) An inner tent.
(c) A-frames and an associated chain winch and lifting gear for removing the vault covers.
(d) A hydraulic arm, mounted on a steel base frame, counterbalanced, with a separate power pack and hoses.
(e) Three grabs.
(f) A ventilation plant rated at 0.75 m^3/s, fitted with two stage HEPA filtration.
(g) A small hoist with a 250 kg safe working load.
(h) General lifting equipment.
(i) Air hoods and other personal protective equipment.
(j) A change barrier with a monitor and washing facilities.
(k) Monitors: alpha in air, beta–gamma, hand/body.
(l) A temporary power supply.

(m) Security fencing.
(n) A shielded overpack.
(o) Plant hire: a small crane, a personnel lift (scissor or cherry picker), a forklift truck, an excavator (probably with a separate hydraulic power pack), a dumper truck, floodlighting, fire-fighting equipment and a concrete breaker.
(p) Consumables: overpack open head drums, fabric bags for lifting waste out of the drums, plastic sheeting, overalls, overshoes, gloves and tarpaulins.

IV–2.5.6. The processing facility

The processing facility will be set up inside the new waste store. It could be a simple plastic sheet tent, although it might be prudent to use a more robust structure. An example of the latter is Moducon, a semipermanent containment cell that is assembled from standard moulded sections of glass reinforced plastic that simply bolt together. Since the processing facility will be considerably smaller than the vault tent (e.g. 5 m × 4 m × 3 m) and Moducon is an engineered construction, the air in-leakage will be far less and the ventilation will probably be able to be taken from the building installed system rather than from a separate unit. Moducon can also be obtained with a prefabricated personnel entry.

There will essentially be three waste streams leaving the processing facility:

(a) Drummed waste that is returned to the vaults for disposal.
(b) Sources that are to be placed in long term storage in the new Püspökszilágy waste store. These will first be sent to the shielded cell for assaying and possibly repacking.
(c) Waste requiring additional treatment. There is likely to be only a small quantity of this material, and the decision on how to deal with it will be made on a case by case basis.

The following is a list of the plant, equipment and types of material that will be needed to process and repack the waste.

(i) A semipermanent containment system.
(ii) A small hoist and associated lifting equipment.
(iii) A waste compactor.
(iv) Air hoods and other personal protective equipment.
(v) A change barrier with a monitor and washing facilities.
(vi) Monitors: alpha in air, beta–gamma, hand/body.

(vii) Process monitors and instrumentation: a drum gamma scanner and a portable neutron counter.
(viii) Consumables: 200 L drums, plastic sheeting, overalls, overshoes and gloves.

IV–2.6. Characterization techniques and equipment

The types of technologies and methodologies that can be used to characterize the waste are discussed below.

IV–2.6.1. Visual inspections

It may be possible visually to inspect loose or packaged waste and determine the waste type. Local experience may help to determine the contents of drums of different colours, shapes and sizes. CCTV could be used and video recordings made.

IV–2.6.2. Dosimeter and contamination monitor

Dosimeters will be required for measurement of doses at almost every stage in the process. Contamination monitors will also be required at almost every stage in the process.

IV–2.6.3. Portable gamma detector

A portable gamma spectrometer will be useful for measurements where the geometry is variable and accuracy is not a major requirement. Examples are inspection of retrieved waste to determine the predominant gamma emitters.

IV–2.6.4. Drum gamma scanner

A drum gamma scanner can be used for assay of drums containing waste that has been sorted and segregated and is ready for return to the vaults. Examples are segmented gamma scanners, which allow movements of the drum relative to the scanner in a vertical direction.

IV–2.6.5. Portable neutron counter

A small portable neutron counter could be used to determine the presence of neutron sources. Small electro-cooled portable systems are available with interchangeable gamma and neutron detectors.

IV–2.6.6. Intrusive sampling and analysis

When the retrieved waste is inside the processing building, it may be necessary to take samples, for example to confirm the presence of isotopes, such as tritium, that are not easily detected using handheld instrumentation. However, this is a lengthy and costly process and should be avoided.

IV–2.7. Future programme

Having established a preferred strategy and a concept plant design for carrying it out, it is useful to outline the main activities required to allow the project to move to the implementation phase. These can be conveniently grouped under five headings.

It will be important to the success of the project to ensure effective interactions with the regulatory authority. These interactions will be of crucial importance throughout both the planning and implementation phases, and it is important to ensure that systems to allow these interactions are working effectively at the very start of the project.

The infrastructure and management systems for the project will cover areas such as:

(a) Project management;
(b) Works supervision;
(c) The management of safety;
(d) Quality assurance arrangements.

The outline plans must be developed in considerably more detail to allow implementation planning and to act as an adequate basis for monitoring project progress. These planning activities should include:

(a) Production of a phased budget for the work based on the cost and funding approval.
(b) Production of a detailed timeline for the work and identification of the critical path. This plan must include adequate time for the preparation and approval of the suite of documents.

(c) Identification of the resource requirements and mobilization of the relevant personnel.
(d) Identification of which work will be subcontracted out, preparation of specifications for the work, undertaking a tender exercise, evaluation of the tenders received and appointment of contractors.

The project requires the preparation of a significant suite of documentation and its approval by the appropriate authorities. This documentation should cover the following issues:

(a) The remediation methodology;
(b) A post-closure safety case;
(c) An operational safety case;
(d) Method statements;
(e) WAC;
(f) A health and safety plan;
(g) A secondary waste handling programme;
(h) A public relations plan;
(i) An emergency response plan;
(j) A training programme;
(k) A quality programme;
(l) An environmental impact assessment.

On-site preparations for waste retrieval include:

(a) Setting up facilities and equipment on the site (e.g. vault containment, waste processing, source manipulation and storage, waste storage and fire protection) in preparation for the remediation work;
(b) Commissioning the facilities and equipment;
(c) Setting up systems to ensure that during all operations the ambient dose rates are recorded and events are recorded by video.

Additional information on these projects can be found in Refs [IV–1–IV–6].

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Annex V

INDIA

V–1. RETRIEVAL AND TREATMENT OF SPENT HIGH EFFICIENCY PARTICULATE AIR FILTERS

V–1.1. Introduction

The use of ventilation systems in a nuclear facility results in active HEPA filters and pre-filters as radioactive solid waste. This waste is categorized as category I (<2 mGy/h). In the past, in the absence of volume reduction and disposal treatment processes for such waste, it was stored in engineered trenches with the intention of its retrieval and treatment at a later date (Fig. V–1).

V–1.2. Current storage arrangement and waste type

Each spent HEPA filter, with standard dimensions of 610 mm × 610 mm × 290 mm, was packed in a double layer of polythene film bags at the source of waste generation, monitored for external surface dose levels and tagged. The

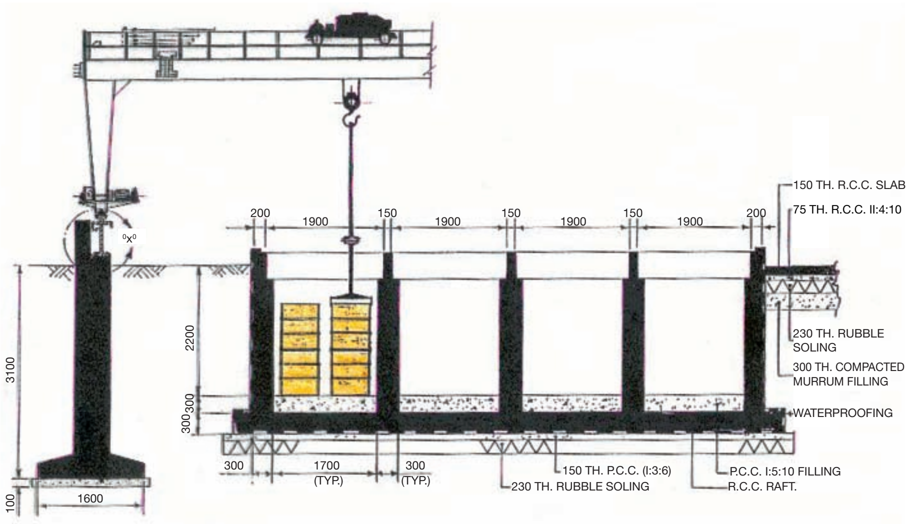

FIG. V–1. Interim storage of waste in engineered trenches.

surface dose on the spent HEPA filters as measured was very low. The consignment as received at the waste storage site was stored in trenches, with well logged data on the waste and its location.

V–1.3. Objectives of retrieval

Retrieval of the stored HEPA filters was required for volume reduction, packaging and disposal in order to conserve storage space.

V–1.4. Retrieval strategy

The spent HEPA filter waste interim stored in engineered storage trenches was retrieved by trained workers wearing protective clothing and mask respirators. The waste was handled by mobile cranes and dedicated gantry cranes over the engineered storage trenches using suitable grapplers and material movement devices such as forklift trucks and mobile trailers.

V–1.5. Waste processing

After a detailed consideration of the technical requirements of volume reduction of active HEPA filters, a hydraulically operated vertical ram compactor with additional transverse hydraulic rams for initiating horizontal prepinching on the HEPA filters from two sides was installed at the site. After initial inactive operations for ensuring compliance with the regulatory requirements and radiation protection, the compactor unit was commissioned for radioactive operations.

The spent HEPA filters are lined up on the conveyor platform. The conveyor platform has provision for indexing and feeding the filters in sequence up to the hydraulic ram bed (Fig. V–2).

Figures V–3–V–5 depict the various steps and stages of the compaction of HEPA filters.

V–1.6. Progress and experience to date

A volume reduction of five has uniformly been obtained after compaction of HEPA filters. The surface dose on compacted filters was observed to be very low. The spread of contamination was fully controlled and exposure was minimal. The compacted filters are placed in a secondary steel container and disposed of in trenches.

FIG. V–2. HEPA filters lined up on the compactor platform.

FIG. V–3. HEPA filter prepinched.

FIG. V–4. HEPA filter compaction stage.

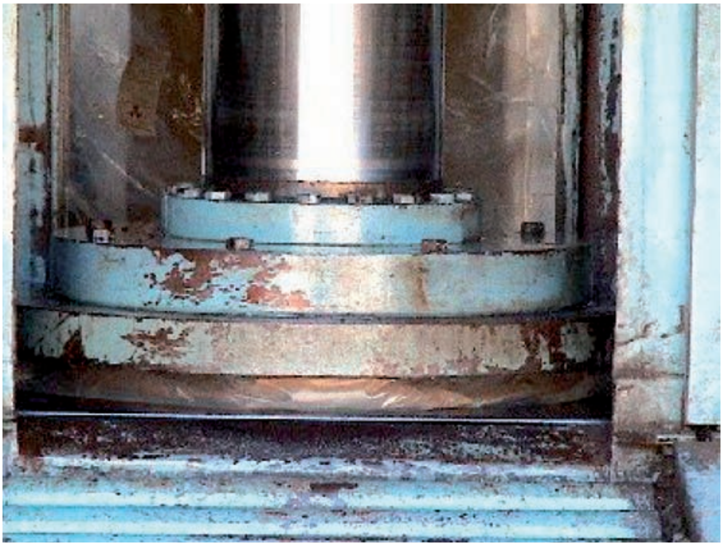

FIG. V–5. Fully compacted HEPA filter.

Annex VI

RUSSIAN FEDERATION

VI–1. RETRIEVAL OF HISTORICAL RADIOACTIVE WASTE AT THE KURCHATOV INSTITUTE RUSSIAN RESEARCH CENTRE

VI–1.1. Introduction

The Kurchatov Institute Russian Research Centre was established in 1943 for research and development work on nuclear technologies for military and civil applications. During the years of its operation, the Kurchatov Institute accumulated large amounts of solid radioactive waste and spent nuclear fuel at its site [VI–1].

VI–1.2. The problem

Up until the mid-1960s, solid radioactive waste, including high level radioactive waste, was put in temporary storage at the Kurchatov Institute site. In 1974 these storage facilities were closed, and since then the waste has been moved to MosSIA Radonin in Moscow for treatment, conditioning and storage.

VI–1.3. Current storage arrangement and waste type

The old waste repositories are located in the north-western part of the site and occupy an area of about two hectares (Figs VI–1 and VI–2) [VI–2]. Temporary repositories were assigned identification numbers from 1 to 10. Only one of these repositories (repository No. 7) is still in operation. The design features of these repositories and the types of waste are summarized in Table VI–1 [VI–3].

VI–1.4. Reasons for retrieval

The Kurchatov Institute site is now surrounded by a densely populated urban district, and in 1998 the government issued a decree on speeding up the removal of hazardous facilities, initially all old radioactive waste repositories,

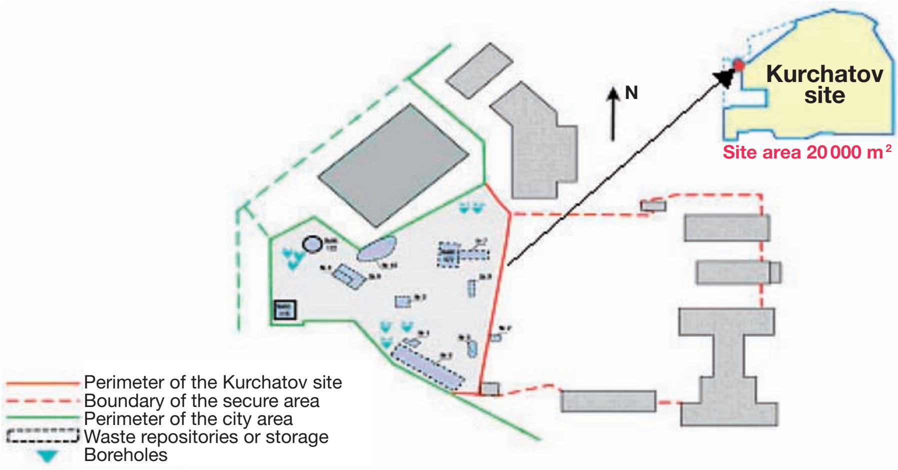

FIG. VI–1. The Kurchatov Institute temporary radioactive waste repository site.

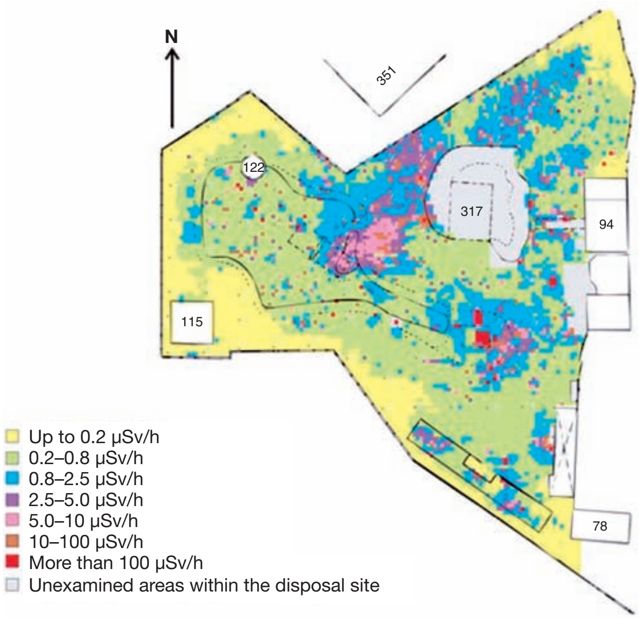

FIG. VI–2. Map of the gamma dose rate within 0.05 m from the soil surface at the radioactive waste storage site.

TABLE VI–1. SUMMARY OF REPOSITORIES AT THE KURCHATOV INSTITUTE

Repository	Description	Capacity/waste volume (m^3)	Types of waste
No. 1	Two rows of 30 reinforced concrete wells, each 1.5 m in diameter and 1.2 m deep	160/30	LLW
No. 2	A steel tank 1.5 m in diameter and 4.0 m deep and three reinforced concrete wells, each 1.1 m in diameter and 5.5 m deep	7.1/6.2 (tanks); 10.5/7.0 (wells)	LLW, ILW
No. 3	A buried reinforced concrete repository (6 m × 6 m × 3 m) and a reinforced concrete roof with five metal hatches	110/80	LLW, ILW
No. 4	An underground reinforced concrete repository (18 m × 7 m × 4.5 m) divided into three compartments having a common monolithic concrete roof with three hatches	650/625	ILW, HLW
No. 5	Six underground reinforced concrete wells in a concrete mass, each 1.5 m in diameter and 4.0 m deep	60/50	LLW, ILW
No. 6	A trench type repository of trapezoidal section (the upper base is 18 m, the lower base is 7 m and the depth is 4 m); the walls are reinforced concrete and bricks	900/600	ILW, HLW
No. 8	A trench type concrete repository (60 m × 10 m × 1.8 m), with a roof of reinforced concrete plates	1100/300	LLW
No. 9	A repository constructed from foundation blocks	24/0.5	LLW
No. 10	A trench type repository using a natural ravine as a trench (depth 5–6 m)	2500/300 (waste); 2000 (soil)	LLW

from the site. At present, all rehabilitation activities at the Kurchatov Institute are conducted under a single rehabilitation project in which other Russian institutes and organizations are involved [VI–4]. The objective of the rehabilitation project is to remove all historical radioactive waste from the existing storage facilities and to clean and rehabilitate the whole site [VI–5].

VI–1.5. Retrieval strategy

Very few historical records on the design features of the old repositories and the radioactive waste characteristics are available. The work on the radioactive waste removal and site rehabilitation was performed in the following order [VI–6, VI–7]:

(a) Exploratory drilling and examination of the waste conditions in the repositories (Fig. VI–3);
(b) A radiation survey of the repositories;
(c) Removal of filled soil from the repository roofs;
(d) Opening, demolition and removal of the repository roofs (Fig. VI–4);
(e) Extraction of radioactive waste from the repositories, waste sorting and placement into containers (Figs VI–5 and VI–6);
(f) Examination and demolition of the repository structures;
(g) Sorting and removal of contaminated soil from the repository pits;
(h) Final radiation survey of the repository pits and their refilling with clean soil.

The technologies for radioactive waste removal and demolition of the old repositories were selected based on the peculiarities of the repository structures, as well as on the condition, composition and activity of the waste contained in the repositories. All operations were accompanied by continuous

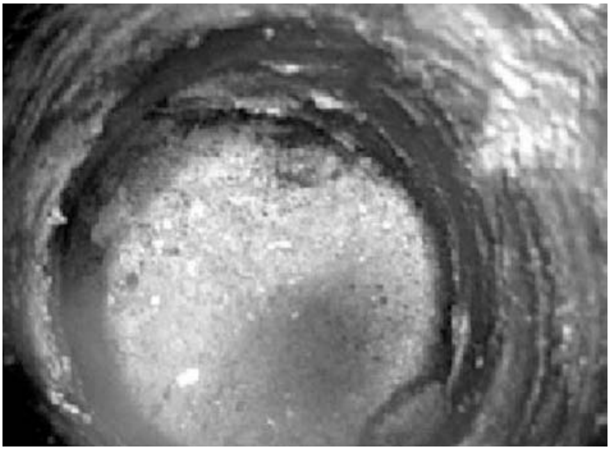

FIG. VI–3. Video image of the cavity opened at a depth of 1.2 m when drilling and examining repository No. 6.

FIG. VI–4. Breaking of the mass concrete roof of repository No. 2 with an electric discharge unit.

FIG. VI–5. Waste extraction with an excavator clamshell bucket.

radiation monitoring of the work areas and control of the radiation situation on the site as a whole. Air pollution in the work areas was also monitored during these activities, and dust suppression technologies were used. Special equipment and vehicles used in the work were subject to decontamination.

FIG. VI–6. Radioactive waste extraction with robotics equipment.

VI–1.6. Results achieved

From late 2002 until mid-2004, seven old repositories out of the ten were emptied and demolished. These activities resulted in the removal of more than 600 m^3 of waste with a total activity of over 3.8×10^{12} Bq. The radiation doses to personnel did not exceed the prescribed levels in the course of these activities. Remediation of the remaining repositories in which waste is immobilized in situ requires additional equipment and new technology development for fragmentation, radiation monitoring and handling of waste with relatively high levels of activity.

Such technologies when developed could be used also in the decommissioning of the research reactors at the Kurchatov Institute and for the retrieval of other radioactive legacy waste, for example at submarine fleet bases and other sites that were involved in the development of nuclear technologies for civil and military applications.

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Annex VII

UNITED KINGDOM

VII–1. SWARF RETRIEVAL FACILITY AND SILO EMPTYING PLANT MACHINES

VII–1.1. Introduction

First generation nuclear power plants in the UK used fuel clad in a magnesium alloy known as Magnox. Irradiated Magnox fuel elements were stored under water in a pond to allow cooling and decay of short lived radionuclides. Immediately before reprocessing, the cladding was removed in a process called decanning. Reprocessing operations on the Sellafield site in the UK include the decanning of irradiated Magnox fuel elements, resulting in the production of ILW in the form of swarf (Magnox cans) and other solid material [VII–1]. Much of this waste is currently stored in either dry or wet (water filled) silos.

VII–1.2. The problem

Decommissioning activities required removal of the waste from the silos, conditioning and packaging for long term storage.

VII–1.3. Waste type

The majority of the waste in the wet silos is partially corroded Magnox swarf (magnesium metal, magnesium hydroxide, uranium, uranium dioxide) with physical properties that vary enormously, ranging from thin wet sludge to caked or toothpaste-like masses. In the newer parts of the wet silo building, mainly uncorroded swarf exists. Mixed in with the swarf and sludge is a certain amount of miscellaneous beta–gamma waste, including charge tubes, swarf bins, scaffold tubes, wire ropes, hoses, PVC and cans [VII–2].

VII–1.4. Storage arrangements

The wet silo is comprised of 22 compartments in four blocks. Each compartment is approximately 6 m^2 and 18 m deep. The first six compartments became operational in 1964; the most recent in 1983. Swarf from the site's old decanning plant is stored in the early compartments, while Magnox swarf from the modern Fuel Handling Plant is stored in the final four compartments [VII–1]. The compartments are arranged in two rows, with each compartment having a single centrally located filling hole (measuring about 1.5 m × 2 m) in the roof. The original silos consisted of compartments 1–6, which were extended by adding a further six compartments (7–12) separated from the original by a void approximately 3 m wide. The second extension consists of two concrete compartments (13 and 14), which are separated from the first extension by a service annex. The third extension is comprised of eight concrete compartments (15–22) and is structurally separate from the second extension, although they share various services. The operating floor of the building forms the roof of the compartments and spans all four parts of the building [VII–3].

VII–1.5. Reasons for retrieval

The current conditions and arrangements are not suitable for long term storage, and the need exists to retrieve and immobilize the waste so that it can be safely stored pending the availability of a final disposal route. BNFL engineers carried out a thorough inventory of the waste and problem areas on the Sellafield site and developed techniques, processes and routes to decontaminate and decommission these various facilities [VII–4]. The silo compartments require emptying prior to eventual decommissioning of the B38 plant. To complete the emptying process, approximately 11 000 m^3 of waste needs to be retrieved [VII–3].

VII–1.6. Retrieval strategy

VII–1.6.1. Sampling

Table VII–1 shows the range of percentage by weight of uncorroded metal swarf in the compartments (established by sampling and analysis).

TABLE VII–1. WET SILO CONTENTS [VII–2]

Wet silo compartments	Uncorroded metal swarf (wt%)
1–6	0–5
7–12 (excluding 11)	30–40
13–18	70–80
19–22	Mainly uncorroded

VII–1.6.2. Waste characterization

Retrieving the contents of compartments 1–12 is a challenging task. Over the years, most of the Magnox swarf has corroded into a clay-like substance consisting of magnesium hydroxide sludge. There are an estimated 60 000 items of miscellaneous beta–gamma waste in compartments 1–12 [VII–3]. Compartment 11 contains wet zirconium and stainless steel hulls [VII–2]. Compartments 13–18 contain partially corroded swarf, and compartments 19–22 contain mainly uncorroded material [VII–2].

VII–1.6.3. Infrastructure upgrade

A substantial amount of modification work is currently being carried out to prepare the building to accommodate the Silo Emptying Plant. The main items are as follows:

(a) Structural improvements and removal of radiation sources. This includes the removal of high radiation sources, installation of the mobile cave support structure and upgrading of the steelwork for additional loads and seismic loading.
(b) Rail installation. No fewer than 32 rail sections and 60 seismic brackets, weighing a total of 500 t, will be needed to support the Silo Emptying Plant machines.
(c) Crane replacement. The existing overhead crane is unreliable and obsolete. A special 55 t replacement unit will be installed to service the emptying machines throughout their operational life, and the existing crane structure will be upgraded to support it [VII–3].

VII–1.6.4. Downstream process

Recovery of material commenced in 1993 using the Swarf Retrieval Facility [VII–1] situated on compartments 19–22. The swarf was transferred to the Magnox Encapsulation Plant for encapsulation. However, this route is possible for only a small proportion of the inventory because of the corrosion of the longer stored material.

Current proposals are to recover the bulk of the material from the silos by the Silo Emptying Plant machines and route the material to the Sellafield Drypac Plant [VII–5]. It will then be encapsulated in the Waste Encapsulation Plant [VII–6].

VII–1.7. Description of the retrieval process

Waste in compartments 19–22, which contain largely uncorroded Magnox swarf, is being recovered by the Swarf Retrieval Facility [VII–2], which is a sealed and shielded modular structure with a gamma gate on top for transferring loaded swarf bins to transit flasks. Inside the cubicle, the stainless steel equipment is comprised of a grab, a swarf bin trolley, lighting, simple manipulators, rinsing–washing nozzles and a grab deflector arm [VII–7]. This machine uses a rope deployed grab that deposits the swarf in a skip, which is then transported in a flask to the Magnox Encapsulation Plant [VII–2].

Waste in the other compartments will be retrieved by the Silo Emptying Plant machines (SEPs); these will move on rails between one compartment and another to retrieve sludges and miscellaneous items. The compartments are configured in two rows, with the building layout dictating that the machines SEP 1 and SEP 2 will be mirror images of each other. Each machine or cave (i.e. a machine within a mobile enclosure) will consist of a retrieval module, a skip transfer system, a winch and hose reel module, a gamma gate, an operator bulge and a dedicated performance level category based control system. Powerful, hydraulically operated petal grabs with a 120 L capacity will work below the water level [VII–3]. Where possible, grab operations will be guided using sonar to ensure efficient operations [VII–2]. The process will be assisted by size reduction, where necessary, and by the use of manipulators to load problematic waste into the export skip.

In the middle sections of the wet silo building, specific compartments, 13–18, were used for Magnox swarf, except for compartment 15, which was reserved for beta–gamma waste. Another mobile cave, SEP 3, has been developed to retrieve items from this area for treatment in the Sellafield Drypac Plant. This will run on rails and will use a turnaround system to move from one row of compartments to the other [VII–3].

VII–1.7.1. Implementation

The choice of different systems for the oldest compartments and the middle compartments was made on the basis of extensive operational research studies, which examined the cost and timescale implications of different configurations of equipment and operational sequences for waste removal.

Throughout each stage of the design process and project, there have been a number of important safety issues, including the control of hydrogen, effluents, dose uptake and building structural integrity. Every safety issue has been given the utmost priority when deciding upon the way in which the project proceeds [VII–4].

VII–1.8. Results achieved

The Swarf Retrieval Facility machine has been operating for more than six years. Approximately 1100 m^3 of ILW has now been retrieved and encapsulated using this facility. The Swarf Retrieval Facility served a dual purpose by providing the necessary experience for designing the more complex Silo Emptying Plant machines and also by retrieving the mainly uncorroded swarf in the youngest compartments before it degraded further. Valuable hydrogen monitoring data have been collected during the retrieval operation.

It has been identified that emptying the compartments will place different hydrostatic loads on the dividing walls. To keep the deflection of these walls within acceptable levels, staged emptying of all the remaining compartments may be implemented. Four of the 22 compartments have been emptied to date.

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This report provides information and discussion on planning, methodologies and technologies for retrieval and reconditioning of radioactive waste recovered from old, inadequate disposal or storage facilities. The objective of such projects is to improve waste safety and security in accordance with modern requirements. Selected international experiences in waste retrieval and recovery projects are included. This report serves as a guide for storage and disposal facility personnel responsible for the organization and implementation of waste retrieval and reconditioning projects to optimize planning, selection and use of available and applicable technologies and resources.

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