IAEA-TECDOC-1256

Technical considerations in the design of near surface disposal facilities for radioactive waste

INTERNATIONAL ATOMIC ENERGY AGENCY IAEA

November 2001

The originating Section of this publication in the IAEA was:

Waste Technology Section
International Atomic Energy Agency
Wagramer Strasse 5
P.O. Box 100
A-1400 Vienna, Austria

TECHNICAL CONSIDERATIONS IN THE DESIGN OF
NEAR SURFACE DISPOSAL FACILITIES
FOR RADIOACTIVE WASTE
IAEA, VIENNA, 2001
IAEA-TECDOC-1256
ISSN 1011–4289

© IAEA, 2001
Printed by the IAEA in Austria
November 2001

FOREWORD

The International Atomic Energy Agency (IAEA) has, since its inception, recognized the importance of radioactive waste management. Low and intermediate level radioactive wastes are produced in almost all countries and their safe management is of great importance. Near surface disposal of the wastes is an option being practised or planned in many countries. There is a growing need in the countries for additional information and guidance on all aspects of this disposal option. Good design plays an important role in ensuring operational as well as long term safety of near surface disposal facilities. Issues relating to the design of both small and large near surface disposal facilities were discussed at an IAEA Symposium on the Planning and Operation of Low Level Waste Disposal Facilities, Vienna, June 1996.

Since 1977, the IAEA has been pursuing an active programme on the disposal of radioactive wastes. The areas covered include generic and regulatory activities, performance and safety assessments, site selection, criteria, design, construction, operation and closure of disposal facilities. A number of valuable reports have been published through this programme. Although an earlier IAEA publication discusses briefly the design aspects of near surface disposal facilities, it was recognised that a report is needed that covers in depth the various activities involved in the design of near surface disposal facilities for low and intermediate level wastes. This publication is intended to fill the gap and reflects decades of experience in IAEA Member States in this particular area.

It is hoped that Member States, in particular the developing countries, will find the report useful for their programmes to implement near surface facilities.

The report was developed with the help of consultants and an Advisory Group (1993). K.W. Han and R. Dayal of the Division of Nuclear Fuel Cycle and Waste Technology were the responsible officers at the IAEA.

EDITORIAL NOTE

The use of particular designations of countries or territories does not imply any judgement by the publisher, the IAEA, as to the legal status of such countries or territories, of their authorities and institutions or of the delimitation of their boundaries.

The mention of names of specific companies or products (whether or not indicated as registered) does not imply any intention to infringe proprietary rights, nor should it be construed as an endorsement or recommendation on the part of the IAEA.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

The International Atomic Energy Agency (IAEA) has from the beginning made extensive efforts in assisting Member States in all aspects of safe management of radioactive wastes, in particular disposal of low and intermediate level wastes (LILW). Many IAEA documents that deal with generic and specific aspects of radioactive waste disposal have been published, covering both safety and technology issues. An earlier IAEA publication discussed briefly the design aspects of near surface disposal facilities [1].

There is no officially recognised single classification of LILW that is applied by all Member States; each country uses its own definition. IAEA's recommended waste classification is given in Ref. [2]. Broadly, low level wastes have activities in the range of 10^4 Bq/l; the intermediate level wastes 10^7 Bq/l and the high level wastes about 10^{10} Bq/l. LILW are also referred to as wastes with thermal power densities less than 2 kW/m^3 [2]. LILW is often separated into short lived (often considered to have a half life not in excess of 30 years) and long lived wastes. Those containing short lived radionuclides may be disposed in near surface disposal facilities, whilst others containing more than a specified amount of long lived alpha emitting nuclides (set by regulations/licensing) will require disposal in deep geological facilities [2].

LILW arise from all nuclear activities, ranging from users of radionuclides in medicine, industry and research, to establishments with small and large research reactors, large nuclear centres and nuclear power plants (NPPs). The global production, accumulation and disposal of LILW with varying characteristics is continuing to grow (despite the significant impact of waste minimisation programmes) and there is a growing need to ensure that adequate disposal facilities are designed and built to allow the disposal of the waste.

Various disposal options have been identified for LILW. These include disposal to: surface or near surface disposal facilities with varying levels of engineering; deeper mined or natural cavities in geological formations; injection into deep geological formations, and boreholes. Issues relating to the design of both small and large near surface disposal facilities were also discussed at an IAEA Symposium on the Planning and Operation of Low Level Waste Disposal Facilities, Vienna, 17–21 June 1996 [3]. Currently, in the IAEA Member States, there are many LILW disposal facilities of various disposal options in operation and many more in a conceptual planning stage [3, 4]; the majority being planned are for near surface disposal.

Given the importance of repository design in the overall process of developing new disposal facilities, it was recognised that a report is needed that covers in depth the various activities involved in the design of near surface disposal facilities. This publication is intended to fill the gap and reflects decades of experience in Member States in this particular area.

1.2. OBJECTIVES

Good design is an important step towards ensuring operational as well as long term safety of LILW disposal. Recognising the need of Member States to obtain specific information, the IAEA has produced this report with the objective of outlining the most important technical considerations in the design of near surface disposal facilities and to provide some examples of the design process in different countries. This guidance has been developed in light of experience gained from the design of existing near surface disposal facilities in a range of Member States. In particular, the report provides information on:

- design objectives;
- design requirements; and
- design phases.

1.3. SCOPE

The scope of the report is restricted to the design of near surface disposal facilities for LILW in support of their implementation (planning, licensing, construction, operation and closure). In particular, the report focuses on:

- near surface disposal facilities accepting solidified LILW;

- disposal facilities (with differing levels of engineering) on or just below the ground surface, where the final protective covering is of the order of a few metres thick; and

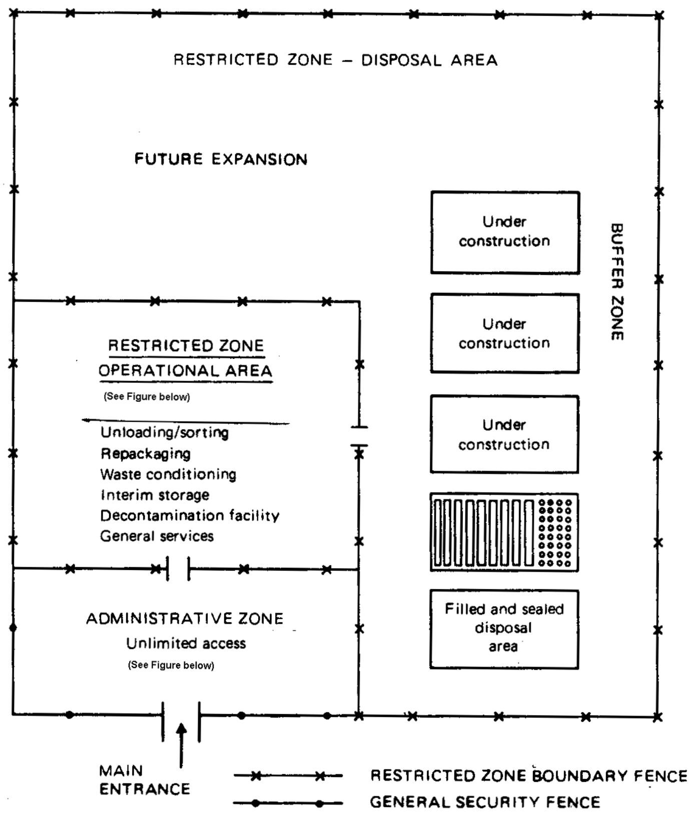
- disposal facilities several tens of metres below the ground surface (including rock cavern type facilities).

However, the same basic guidance presented in this report is relevant and can be followed in the design of any disposal facility for any type of waste (e.g. borehole disposal of sealed sources).

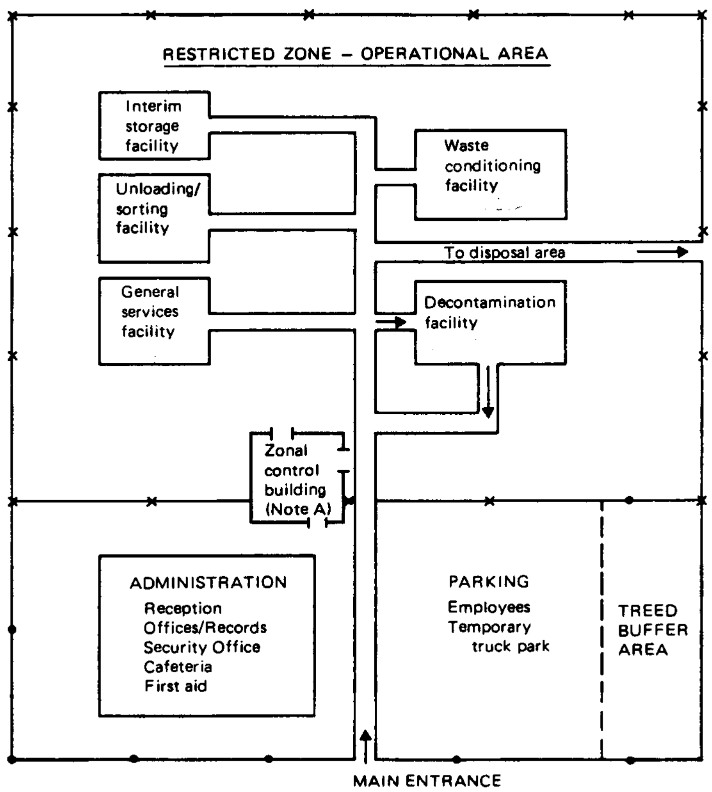
A disposal site can have many functional parts. They can include, in addition to actual waste disposal (emplacement) operations areas (for the purposes of this document, referred to as the “disposal facility”), buildings and services for administration, technical services, testing and quality control, health physics requirements, waste segregation, treatment, repackaging, etc. Based on information given in Ref. [3], general descriptions of the layout of some example near surface disposal sites are given in Appendix A. The layout of a generic near surface disposal site is given in Figure 1. The layout of a disposal site may vary (subject to certain minimum requirements for control and safety) depending on the type, characteristics, and quantities of wastes for disposal and the site characteristics. The focus of the current document is primarily on the design of the disposal facility rather than the auxiliary buildings that might be present on the disposal site.

Disposal facility design is just one factor influencing the overall safety of LILW disposal. Other factors such as waste characteristics, site characteristics, institutional control, facility construction, operation and closure are also important. Therefore, although beyond the immediate scope of the current document, their role in helping to provide the necessary degree of isolation of the waste from the accessible environment over the appropriate time frame is not to be overlooked.

In addition, waste disposal is the final stage of safe waste management, other stages are waste generation, treatment, conditioning, packaging, and transport. Even once waste arrives at a disposal site, there can be several operational steps prior to final disposal (for example see Figure 2). Again, these stages are beyond the immediate scope of this document, but it is important to ensure that their contribution to overall safety is not ignored.



Schematic layout of a near surface disposal facility



Administrative and operational area layout

FIG. 1. Layout of a generic near surface disposal facility [5].

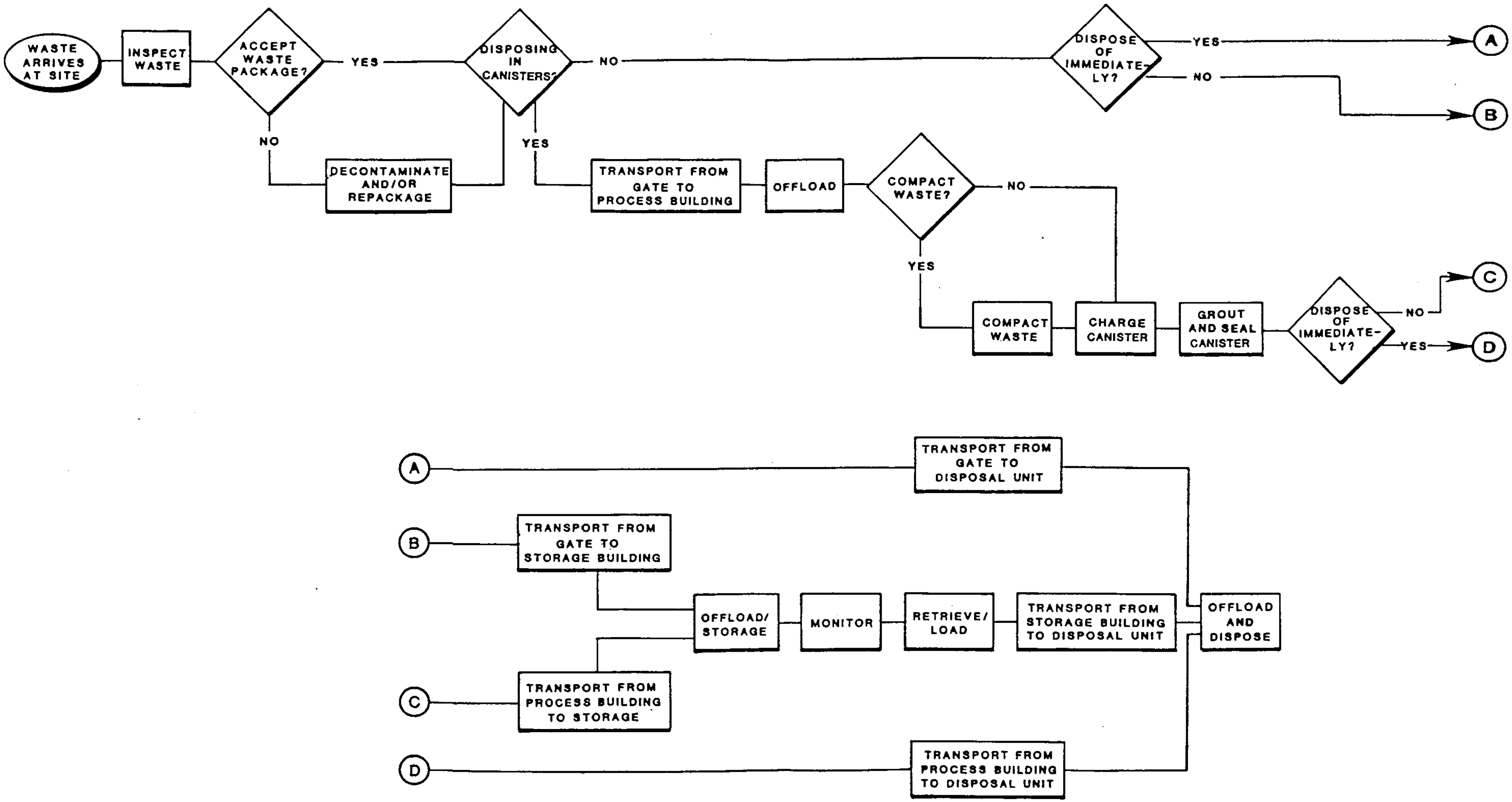


FIG. 2. Flow diagram for waste management at a near surface disposal facility [5].

1.4. STRUCTURE

Section 2 gives an overview of the fundamental design objectives for near surface disposal facilities. Section 3 discusses the design requirements relevant to waste characteristics, site characteristics, engineered barriers, operational considerations, safety assessment, and quality assurance, that are necessary to help ensure the fundamental design aims are met. The scope of each phase in the design process is then described in Section 4. Section 5 provides a summary and recommendations.

Practical examples are given in Appendices A–D to illustrate certain design issues raised in the main text. Examples of operating and closed disposal facilities are used to illustrate design issues relating to: site layout (Appendix A); facility structures (Appendix B); facility operation systems (Appendix C); and facility closure systems (Appendix D). The list of examples is not intended to be exhaustive, nor is the information provided for each facility exhaustive. It is simply provided for the purposes of illustration. More detailed and complete information is given in Ref. [3] and its associated references.

2. DESIGN OBJECTIVES

In order to place the design objectives for a LILW disposal facility in context, it is helpful to consider the fundamental principles relating to the safe management of radioactive waste and its disposal as given in [5]. A total of nine principles were promulgated in Ref. [5], five of which are particularly relevant to the design of radioactive waste disposal facilities.

- Principle 1: Protection of human health – radioactive waste shall be managed in such a way as to secure an acceptable level of protection for human health.
- Principle 2: Protection of the environment – radioactive waste shall be managed in such a way as to provide an acceptable level of protection of the environment.
- Principle 4: Protection of future generations – radioactive waste shall be managed in such a way that predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today.
- Principle 5: Burdens on future generations – radioactive waste shall be managed in such a way that will not impose undue burdens on future generations.
- Principle 9: Safety of facilities – the safety of facilities for radioactive waste management shall be appropriately assured during their lifetime.

Consistent with the above principles, the objective of the design of a disposal facility is to ensure the facility can be built and waste received, handled and disposed of without undue risk to human health and the environment, both during facility operation and after facility closure. In order to achieve this primary objective, the design aims to meet the following secondary objectives:

- isolation of the waste;
- control of the releases;
- reduction of the impacts resulting from the releases;
- avoidance/minimisation of the maintenance of the facility.

The design of a facility aims to provide adequate isolation of the disposed waste for an appropriate period of time, taking account of the waste and site characteristics and the appropriate safety requirements [6]. It is recognised that, especially in the long-term, there might be certain processes and events that might result in the release of radionuclides from the disposal facility. However, the design, as well as other aspects of the disposal system (e.g. the geosphere characteristics), aim to ensure that such releases do not exceed applicable regulatory limits during either the operational or post-closure phases and are as low as reasonably achievable (ALARA) taking into account relevant economic and social factors. During operation and closure of a facility, as well as subsequent to its closure, some maintenance might be required to ensure that the objectives of isolating the waste/controlling the releases, and minimising the impacts, are met. However, the objective during all three stages is to achieve the necessary degree of safety through the use of passive rather than active control systems.

In addition to the above three objectives, the importance of gaining public confidence is increasingly being recognised in all aspects of radioactive waste management, including the design of disposal facilities [7]. Achieving isolation of waste/control of releases, reduction of impacts, and avoidance/minimisation of maintenance, will undoubtedly help in the process of building public confidence. However, additional reassurance can be gained through the adoption of designs that: allow the monitoring of the facility's performance; allow corrective action to be taken should monitoring indicate unacceptable performance; and provide the ability to retrieve the waste once it has been placed in the facility. Public involvement in the early phases of the design and site selection process is necessary when attempting to gain an insight into public interest, concerns, reservations and confidence. The nature and extent of the public role may vary from country to country; but public confidence is important for successful implementation of any disposal facility programme. This can therefore be of key importance in disposal facility siting and design.

3. DESIGN REQUIREMENTS

A range of requirements is to be taken into account to help achieve the design objectives discussed in Section 2. These requirements are discussed in the following sub-sections.

3.1. WASTE CHARACTERISTICS

The diverse sources of LILW means that its characteristics can vary considerably. It can contain individual radionuclides with different half-lives and toxicity, non-radioactive components with degradable or non-degradable properties and can vary in physical and chemical form. Wastes favoured for near surface disposal are solid/solidified wastes with low leaching rate of radionuclides and a small, non-degradable toxic chemical content. Those wastes not conforming to these requirements may be made acceptable by waste treatment, conditioning, volume reduction, appropriate packaging and provision of barriers. Good engineering practices based on appropriate designs can further complement these to improve containment of wastes with difficult characteristics.

It is important for waste producers to liase with the disposal facility operator and provide the designer with basic data on the following interrelated aspects of the waste.

- **Radionuclides in the waste** – the type of radionuclides and their associated activity levels determines the length of time for which the waste remains a hazard. This in turn influences the nature and longevity of the design features required to limit the release of radionuclides. The activity levels in the waste also influence the dose rate to the workers and so impact on the operational aspects of the design.

- **Waste origin and nature** – waste from different sources (e.g. nuclear power plant operation, reactor decommissioning, hospitals) have different characteristics and consideration needs to be given to the characteristics to ensure that appropriate design features are incorporated into the disposal facility.

- **Waste quantities** – need to be considered both in terms of the total quantity (mass and volume) to be disposed and in terms of the waste received for disposal at the facility as a function of time. It is important for the design to be capable of accommodating the current and anticipated waste on a reasonable time scale, taking into consideration the potential total capacity of the disposal facility,. Phasing of disposal is necessary from operational considerations, and continues until the capacity of the disposal facility is used up. Phasing of construction may also be advisable and necessary from financial and technical and safety reasons. In addition, provision may be made in the design for possible future expansion of the disposal facility if it becomes necessary.

- **Physical dimensions and weight** - influences the choice of handling systems as well as the facility design. Considerations include whether the waste is compactable or non-compactable, and how it is encapsulated.

- **Contents and properties of the waste packages** – in terms of major radionuclides and other important contaminants, as well as the physical, chemical, mechanical and radiological properties. The size and weight of individual waste packages are additional input data requirements for design. Disposal specific waste acceptance criteria (WAC) can be developed that specify information concerning the content and properties of waste packages [6]. Such WAC may: set limits on the radioactivity in individual packages or consignments and the total inventory of radioactivity in the wastes disposed in the entire facility [8]; specify the physical, chemical and biological properties of the waste (e.g. only solid/solidified wastes not containing flammable, pyrophoric, organic and liquid and sludge wastes); and specify procedures for the configuration and identification of waste packages.

Although there are no international standards governing waste packages, it can be useful for the design to classify waste packages on the basis of the following characteristics:

- total and/preferably (if possible) radionuclide specific activity, which could have consequences for selection of the design elements (e.g. in some countries, as in the USA, very low radioactivity wastes may be disposed without previous stabilisation), or the placement of waste packages (e.g. in Spain it is an operational requirement that the top layer of waste packages should be of lower radioactivity);

- radiation dose rate, physical dimensions or weight which could impose different handling systems;

- additional conditioning or treatment requirements at disposal site to facilitate, if necessary, incorporating the waste into an acceptable waste form; and

- type of container (depends on site requirements, e.g. in France different types of backfilling, buffer, and barrier materials are used depending on the durability of the waste package containers to compensate any deficiencies in them meeting safety requirements).

3.2. SITE CHARACTERISTICS

Site characteristics (both physical and chemical) are evaluated as part of the design process to ensure that the disposal system design is compatible with the site characteristics, and that the construction, operation and closure of the disposal facility can be accomplished in a safe manner. During site selection, a number of factors such as logistics (for example, proximity to the waste source, transportation links, and/or an existing disposal facility) need to be taken into account, as well as its isolation characteristics. The role of the designer is, following the multi-barrier principle, to balance any specific site characteristics by appropriate technical solutions based on an understanding of the effects of relevant physical and chemical parameters within the disposal system. The objective is to compensate any limitations of the site with improved performance of the other parts of the system (e.g. waste packages, barrier materials, integrity of disposal structure, etc.) to ensure overall safety.

The detailed design is fully site specific and consequently site characteristics significantly influence the design and need to be taken into account [6]. Important site characteristics to consider are listed below:

- existing infrastructure and services;
- space availability;
- proximity to waste arisings;
- topography;
- climatology and hydrology;
- geological structure and its properties (geomechanics, geomorphology, fissures, faults, seismicity, etc.);
- hydrogeological and geochemical features (permeability, groundwater flow pattern, water chemistry, retardation processes, etc.); and
- geomorphological processes.

The design can take into account, using safety assessment as a tool, the various events and processes (some normal, some abnormal and some accidental) that can significantly influence the safety of the disposal facility during the regulatory period of concern. The design aims to minimise the impact of such events and processes be they during the operational phase or the post-closure phase.

3.3. ENGINEERED BARRIERS

When disposal facilities for LILW were initially developed 40 to 50 years ago, they were designed with limited engineered features, at least by present day standards. To achieve the design aims, emphasis was often placed on the use of natural barriers (such as a low permeability geosphere) rather than engineered barriers. However, since then, it has become recognised that in many cases there is a need to use engineered barriers to augment natural barriers in helping to ensure that the increasingly stringent design aims are satisfied to an appropriate level. In addition, the benefits of introducing some degree of redundancy into the system are now recognised. Such an approach helps avoid over-reliance on one component of the disposal system, such as the geosphere, to provide the necessary safety and allows for certain components to fail without compromising the overall safety of the system.

Various engineered disposal facilities have been developed for LILW, each with their own specific engineering features depending upon factors such as site and waste characteristics, national radioactive waste management strategies and regulatory approaches, and social and economic factors (see for example Refs [1, 9, 10]). Most LILW disposal facilities have been built on the surface or within 10 m of the surface. However, some such as the Swedish Final Repository (SFR) have been built at depths of up to 100 m.

For low level wastes containing short lived radionuclides, disposal in trenches with simple engineered barrier materials might be appropriate, provided that the migration of radionuclides is at an acceptable rate as determined by evaluation of the engineering used. Such might be the case in an area where wastes may be exposed to very little water due to low precipitation rates and/or in an area where the geological conditions retard radionuclide migration. It is important for appropriate drainage to be provided to ensure water does not accumulate in the trench resulting in subsequent release of radionuclides through bathtubbing. For disposal of LILW with higher levels of radioactivity and/or long lived radionuclides more heavily engineered disposal facilities might be required.

Despite such differences in design, it is possible to identify the following engineered barriers:

- the waste package comprising the waste matrix (cement, bitumen, polymers, glass and ceramics), package, overpackage and coatings (thin wall carbon steel, concrete, stainless steel);

- the disposal unit comprising the engineered structures/isolation layers (concrete, porous medium for drainage, bitumen, polymers, clay), and lining and backfilling materials (concrete, fly ash, clay mixtures); and

- the man-made cover (not required for cavern disposal facilities) comprising a series of alternate low and high permeability layers.

Important features to be considered in selection of barrier structures and materials is their long-term durability, their compatibility with site characteristics, associated media and other materials, and their availability. Long term (300-500 years) can be interpreted as the time period of regulatory concern during which the barrier serves to improve the disposal facility safety function. During the selection phase of the barrier materials and their use in the design, the designer therefore evaluates their potential for long term integrity. This evaluation can address processes relevant to the specific site environment, in particular:

- resistance to chemical attack (e.g. for concrete, corrosion of reinforcement bars by chlorides and carbonates, or degradation of concrete by the action of sulphates or other agents in groundwater or wastes, or alkali aggregate reactions),

- leaching effects,
- microbial degradation,
- corrosion and erosion stabilities,

– radiation and thermal effects, if any, on some materials (this may be non-existent or negligible in the case of LILW),
  - mechanical strains,
  - freeze and thaw effects

The engineered barriers can be designed to:

– minimise the release of radionuclides from the waste packages or from the engineered barrier itself;
– restrict infiltration of precipitation water or groundwater;
– control infiltrating groundwater to provide beneficial aqueous conditions;
– minimise the probability of potential human intrusion;
– provide a mechanism for the restriction and dispersal of gases, if any, generated within the facility, in particular the waste package;
– provide long term structural stability;
– protect waste package integrity from degradation through ingress of degrading materials;
– assist in the monitoring designs to collect and direct infiltrating water for monitoring and/or conditioning;
– control erosion of the disposal facility top surface/soil); and
– provide physical and chemical conditions in the near field to minimise radionuclide release rates.

The detailed design of the engineered barriers is very important to the overall design of the disposal facility. Therefore, the expected properties and functional efficiencies of these barriers are often defined within the context of general requirements so that some quantitative guidance can be given to the safety assessment at an early stage. Feedback from safety assessment is important in defining areas where improved performance is required. Alternatively, it is possible that the engineered barriers may have been over specified and the specifications can be revised.

In either case, some reference standards can be specified to aid design. For example, the containers do not degrade during interim storage or before they are backfilled, and the gas venting system and intrusion resistant structures perform adequately on the timescale during which the release of gases or the consequences of intrusion are significant. Likewise, if a backfill is chosen to provide a beneficial aqueous chemical environment it has adequate capacity to achieve those conditions for the required period. Similarly the overall structure of the disposal system (trench, vault etc.) is not subject to physical degradation leading to significant structural deformation or collapse in the period considered in the safety assessment.

3.4. OPERATIONAL CONSIDERATIONS

An important design goal is to ensure that the safety and operational requirements are met during construction, operation and closure phases of the facility. These three phases can overlap if the disposal facility is built and operated in a modular manner. However, for the purposes of clarity, each of these phases is discussed separately below. Due to the scope of this report, emphasis is placed on radiological safety aspects. Nevertheless, when designing a disposal facility, consideration is also given to conventional (non-radiological) operational health and safety issues.

3.4.1. Construction phase

The construction phase is the period during which all construction work is undertaken including site preparation, and construction of operational and administrative buildings, storage facilities, and the disposal facility itself. For technical and financial reasons, it is often advisable to use a phased approach for the construction of the disposal facility. This allows disposal cells to be constructed as and when they are required depending on the throughput of waste.

For the construction phase, the disposal facility designer takes into account information related to:

- construction integrity over the long term;
- construction procedures (e.g. grout or other backfilling material preparation, placement of concrete, curing, etc.);
- selection of construction materials and components (e.g. cement type, reinforcement materials, aggregate) from the viewpoint of durability, construction compatibility and safety (shielding);
- availability of materials;
- possible requirement for temporary drains for any precipitation and/or infiltrating groundwater that might need subsequent collection, monitoring, treatment and discharge;
- the volume and nature of waste to be disposed;
- the projected temporal history of waste arisings; and
- service requirements during construction (power, communication, access routes, etc.).

Judicious choice and use of materials enables improved construction techniques and integrity over the long term to enhance safety and reduce costs.

This may be apparent for example, from the many components of a concrete vault (used commonly for disposal of wastes packaged in drums mixed with mortar or concrete) consisting of:

- compacted and uncompacted backfill inside and outside of the vaults,
- a compacted cap which may consist of many layers, such as final top soil, clay earth, asphalt/concrete mixture, concrete, plastic foil, or even grout,
- drainage collection directly or through a concrete basin,
- bottom of vaults filled with undisturbed sand compacted mixed sand/clay,
- vaults divided into multiple cells.

In some cases fully-grouted product containers with grout infill and capping grout within the lid may be used.

Details of the disposal structures (trenches, vaults, silos, etc.) used in some example near surface facilities are presented in Appendix B, based on information presented in Ref. [3].

3.4.2. Operation phase

The operation phase is the period during which waste is received at the disposal site and emplaced in the disposal facility.

During this phase there is adequate provision for health physics operations such as protection of the work force, and the monitoring and clean up of possible external contamination of the packages. Specifications related to worker protection, monitoring and decontamination are required in the design process.

All wastes received are checked to see if they meet the waste acceptance and disposal criteria. On arrival at the disposal facility, wastes could be stored for an interim storage period, which if properly programmed, could be short. This would allow time for verification checks and, if required, allow a delay in handling for operational reasons and flexibility. In either case it would be necessary to provide adequate handling, shielding and buffer storage capacity to deal with both the normal rate of waste delivery, unexpected peaks in waste delivery and potential delays in disposal operations.

In particular, factors to consider in the design relative to the operational period during which waste packages are placed in the disposal facility include:

Transportation

- transportation of waste packages around the site;
- transportation of workers and equipment around the site; and
- transportation of construction, backfilling or other materials around the site.

Waste processing and management (could be done at the disposal facility, at the waste source or in other parts in the overall waste management system)

- waste treatment facilities, including segregation, packaging, super compaction and incineration;
- interim waste storage requirements for an operational buffer and/or decay;
- waste conditioning facilities;
- inspection, verification, and certification of waste packages;
- capability for radiochemical analysis of waste packages;
- decontamination provisions for waste packages;
- identification and tracking of waste packages and inventory of disposed activity;
- optimisation of the placement of waste packages (by their type, dose rate, durability, size, etc) in order to minimise disposal volume used, operation time, and radiation impact;
- protection of waste packages from precipitation during operation;
- requirements for drains during the operational phase and their control;
- provision, if required, for expansion of disposal facilities;

- compatibility of operation with construction activities, if additional disposal structures are built in the same area; and
- compatibility with backfilling or covering processes if these are to be done during operations.

Administration, health and safety

- radiological protection and monitoring of workers;
- radiological protection of the potentially affected public and monitoring of releases;
- non-radiological occupational safety and health, for example consideration of non-radiological hazards (flammability, explosiveness; chemotoxicity);
- environmental monitoring (e.g. monitoring of liquid or gaseous effluent releases);
- fire protection (depending on materials present in the waste form, backfilling, etc.);
- physical protection (usually simple fences are sufficient);
- decontamination provisions for personnel; and
- facility for documentation and filing requirements for long term record keeping.

Maintenance and auxiliary services

- support systems (water, power, sewage, heating, ventilation, communication);
- decontamination provisions for equipment (e.g. vehicles);
- definition of the number of operating (preventive and corrective maintenance and protection) staff at an early phase, to permit provision of adequate design of ancillary facilities such as offices, change rooms, etc.; and
- preventive and corrective maintenance.

Examples of operation systems for disposal facilities are presented in Appendix C, based on information provided in Ref. [3].

3.4.3. Closure phase

The closure phase is the period between the emplacement of the last waste package and the start of the post-closure phase. Ancillary facilities (such as administrative buildings and waste stores) are decommissioned and the site is prepared for the start of post-closure institutional control period.

As distinct from closure of individual disposal units, in many cases, the detailed design of the final covers for the entire facility only occurs near the end of the operational period, which may be several decades after the pre-operational design depending on the disposal policies and modes adopted. Nevertheless, the feasibility of closure is considered during the detailed design phase.

The main items to be considered in the design for closure are:

- stability over the time period of regulatory concern;
- resistance to erosion (may be achieved in surface disposal designs by vegetation, crushed rocks, and adequate slopes);
- minimisation of water infiltration or flow through the disposal units;
- diversion of water to drain system (surface options) and control of this water;

- compatibility of materials used in closure with the intended durability of other engineered barriers;
- operational and final documentation and records, especially of the inventory and distribution of radioactivity, and toxic non-radioactive materials in the waste (documentation and record keeping start with the initial phases and continue until closure and afterwards during the site monitoring phases);
- intrusion barriers;
- warning signs;
- decommissioning of auxiliary facilities;
- need for a buffer zone if required;
- resistance against freeze-thaw and/or wet-dry cycles; and
- need for gas venting.

Although retrieval of wastes is not the intention in disposal, provision may be made if national policies so require, for retrieval options for a stipulated period to safeguard against unforeseen incidents, accidents or due to public concerns. In such cases, the need for retrievability can be taken into consideration in the design, for example through the use of waste packages and backfill material that allow the waste to be retrieved without excessive radiation exposure of workers or the public.

Examples of closure systems are given in Appendix D, based on information provided in Ref. [3].

3.5. LICENSING AND SAFETY ASSESSMENT

The licensing procedures, standards and requirements and the relative roles of the proponent of the disposal facility, and the regulatory bodies, differ from country to country and is outside the scope of this report. However, general guidance on safety principles and technical criteria and license application reviews are given in [6]. It is essential, however, that early contact with the licensing authorities be made to establish their requirements. The licensing process is very likely to involve several stages, with conditions or restrictions applied at each step.

The performance of facility designs can be evaluated through the application of a safety assessment methodology. The assessment allows the impact of the various designs to be evaluated and compared against appropriate regulatory standards or criteria, be they radiological or non-radiological. Safety assessment needs to be applied on a regular basis to aid in developing the design because it is not always possible to determine by intuition the effects of design changes on the performance of the facility. The detailed design also needs to be subjected to safety assessment, as part of the assessment and licensing procedure for the disposal facility. The undertaking of these assessments is an iterative process occurring throughout all the development stages of a disposal facility. Early assessments conducted during the conceptual design phases can be based on generic information or limited site-specific information available at that time. Results from these assessments are useful for making decisions and can, if appropriately used, also be used to help promote public involvement and help gain acceptance of the concept. As additional information becomes available (for example site-specific radionuclide inventories, packaging data, barrier concept and materials), more detailed site-specific assessments can be completed supported by information from the site characterisation programme. These assessments can be used for a variety of purposes, for example to apply for, defend and obtain the licensing of the disposal facility. In the context of the development of a design, safety assessment can be used to:

- assist in making decisions between various designs options;
- determine the effect of proposed modifications to specific designs; and
- demonstrate adequate safety of the facility for use in documentation to support an application for licensing the construction of the disposal facility.

References [11, 12] provide information relevant to safety assessment requirements for near surface disposal facilities. The safety assessment process as described in [12] is shown in Figure 3.

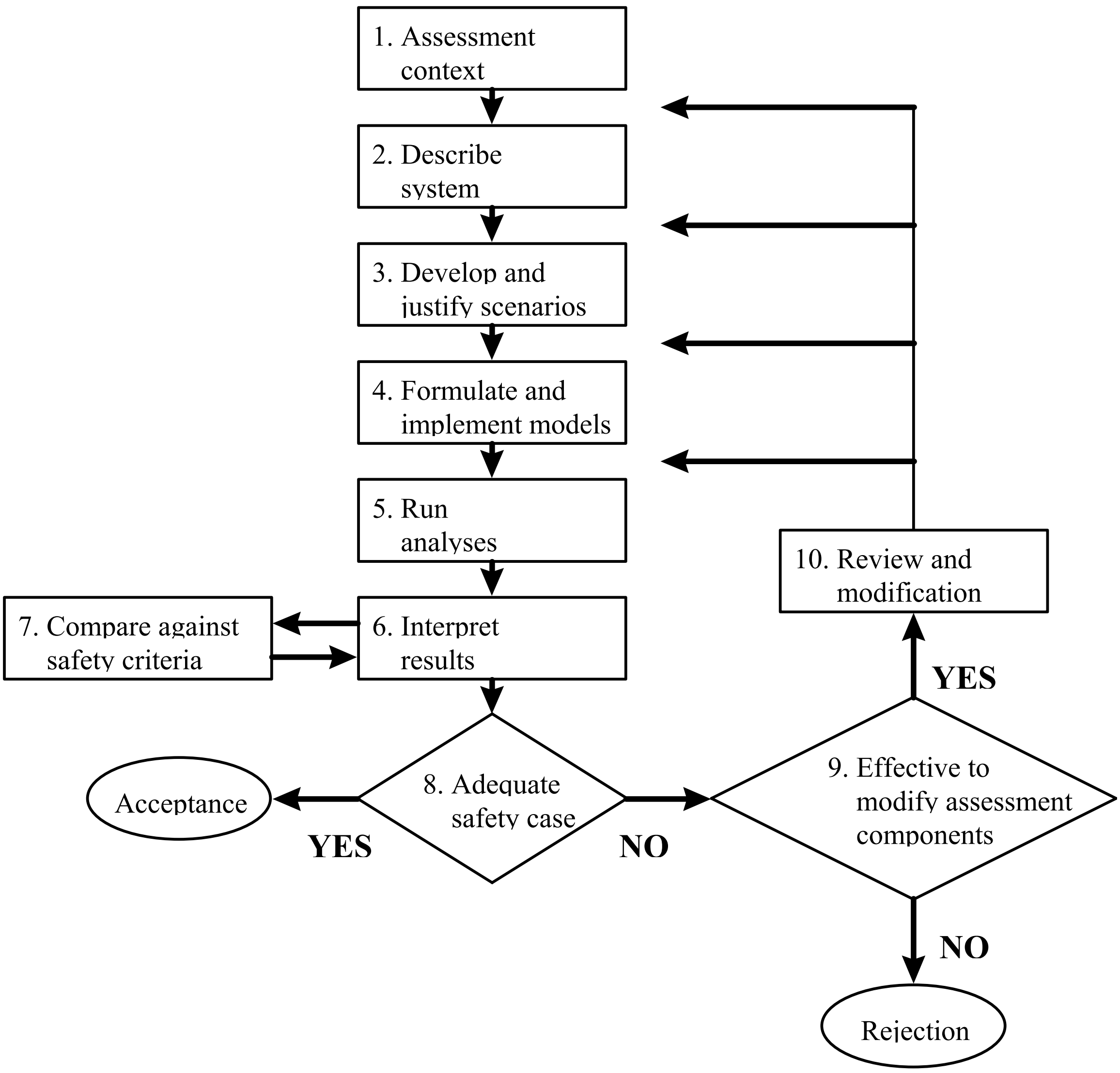


FIG. 3. The safety assessment process as described in Ref. [12].

3.5.1. Radionuclide exposure scenarios and pathways

The safety assessment process allows the identification of scenarios and associated pathways for the exposure of humans to disposed radionuclides during the operational, closure and post-closure phases of the facility.

During the operational and closure phases, exposure of both workers and public needs to be considered — they can be divided into routine and non-routine exposures. Routine exposures result from the normal operation of the facility and can be divided into direct exposure to the waste/waste packages and exposure to controlled solid, liquid and gaseous emissions from the waste. Such exposures can be controlled using standard radiation protection measures incorporating duration of exposure, distance to the source and shielding of the source. The disposal facility can be designed to provide adequate shielding of workers from the waste. Non-routine exposures result from abnormal operation of the facility (i.e. unplanned incidents such as equipment failure, operating error, and events and processes generated outside the facility) and can include physical damage to waste packages, leakage, fire and explosions. They may result in the unplanned dispersal of radionuclides from the waste package into the surrounding environment. Their impacts can be limited by controlling the form and contents of the waste package, designing appropriate engineered barriers, and establishing suitable facility operating procedures. Requirements for safety in the operational period are set out in the IAEA's Safety Requirements for the Near Surface Disposal of Radioactive Waste [6]. They are expressed in terms of radiation dose constraints for workers and members of the public and are intended to be applicable to the assessment of releases from both routine and non-routine exposures.

Reference [13] considers a range of operational exposure scenarios for near surface disposal facilities. Two example disposal facilities are considered, a minimally engineered trench and a more heavily engineered vault. The following routine exposure scenarios are identified: gas release for conditioned wastes in a vault and unconditioned wastes in a trench; direct irradiation for unconditioned waste in a trench; liquid release from unconditioned waste in a trench; and solid release from unconditioned waste in a trench before the covering of the waste. The non-routine scenarios are: dropping and crushing of a waste package to be disposed into a vault during unloading; a fire in the unconditioned waste tipped into a trench before covering; the accidental spreading of waste in a trench; and the overflow of leachate from a trench due to the rate of infiltration of precipitation being higher than the rate of exfiltration through the base (bathtubbing).

Potential radiological impacts following closure of the disposal facility may arise via a number of pathways. Requirements for safety in the post-closure period are set out in the IAEA's Safety Requirements for the Near Surface Disposal of Radioactive Waste [6]. They are expressed in terms of radiation dose or risk constraints to members of the public and are intended to be applicable to the assessment of releases from both gradual processes and disruptive events. Typically consideration is given to the migration of radionuclides from the disposal facility to the surface environment and the subsequent exposure of humans. The following four pathways and associated scenarios, taken separately or in combination (via a process of scenario identification) are often considered in post-closure safety assessments of near surface disposal facilities (see for example Ref. [8]):

- transport, dissolved or in suspension, by water;
- transport as a gas;

– direct transfer as a result of human intrusion;
– releases as a result of natural disruptive events.

The analysis of each of these pathways and associated scenarios requires a significant amount of data, many of which are determined by the design of the disposal facility.

(a) Groundwater

A full analysis of the infiltration/groundwater pathway begins with an analysis of the groundwater flow regime, resulting in an understanding of the flow velocity and the area(s) of discharge of water that passes through the disposal facility site. The input data for these analyses are largely derived from the site characterisation programme. However, design features also need to be taken into account for example: the dimensions and position of the disposal system; the radionuclide inventory of the wastes; the characteristics of waste forms and packaging; the chemical and physical characteristics of the disposal system barriers; their impact upon the hydrogeological and hydrogeochemical properties of the surrounding geosphere and groundwater.

Usually regulatory requirements or performance objectives are based on an analysis that extends to the calculation of potential doses in the biosphere to exposed individuals or groups. In such a case it is necessary to calculate the transfer of radionuclides through the geosphere and into the biosphere. In the biosphere both concentration and dilution mechanisms operate, and radionuclides can be taken up into the food chain or onto surface sediments. The calculation of doses to humans can then be compared with regulatory requirements or performance objectives. The information required to undertake this part of the calculations is also provided from the site characterisation programme. The disposal facility can potentially be designed to take advantage of particular geological strata that are highly sorbing or to discharge only into biosphere environments that result in low exposures (e.g. due to dilution and dispersion).

(b) Gas

Gases can be generated within the disposal facility as a result of anaerobic corrosion of metals (principally iron in steels), microbial activity, radioactive decay and radiolysis. In the case of the disposal of LLW, radiolysis will probably not be important. If oxygenated water can percolate into the disposal facility (due to the near surface location of the disposal facility) at a rate equal to or greater than the rate at which it is consumed by the corrosion process, then anaerobic corrosion may not be significant either. However, this can vary from case to case, being determined by the depth of the disposal facility, the design of the cover material and of the gas vent arrangement (if fitted). Transport of radionuclides in the gas phase can only occur if radionuclides (such as H-3 or C-14) are present in a volatile form.

(c) Human intrusion

Human intrusion into a disposal facility, resulting in the inadvertent extraction of waste materials containing radionuclides, is a mechanism whereby the natural and engineered barriers can be by-passed. It is usually assumed that intrusion can only occur after the period of (active and passive) institutional control. Through the careful design of barriers and markers, both physically at the site and in public records, the probability of inadvertent intrusion may be reduced. Nevertheless, consideration still needs to be given to intrusion into a near surface disposal facility because many initiating events (leading to exposure scenarios) can be defined and long term effectiveness of such barriers and markers cannot be guaranteed. Usually, scenarios of residence and construction activities are considered (for example, excavation for foundations of major roads, large buildings, etc. [8]).

The performance assessment requires data on the physical dimensions of the disposal facility, the radionuclide inventory and its distribution within the disposal facility, the nature of intrusions (usually based on recent historical frequency to reflect human behaviour with similar technological abilities as today) and, for some exposure scenarios, an assessment of the behaviour of the radionuclides in the biosphere.

(d) Natural disruptive events

A near surface disposal facility is more vulnerable to natural disruptive events than one sited at depth. Performance assessments normally address natural disruptive events either as a mechanism for the direct transfer of waste materials and radionuclides from the disposal facility to the biosphere, thus by-passing the engineered and natural barriers altogether, or as a mechanism that allows one or more barriers to be breached, allowing more rapid, but not direct, transfer of radionuclides to the human environment.

Consideration is often given to controlling erosion to acceptable levels for the time period of concern. Erosion can occur gradually or rapidly due to wind, water, ice or landslide (which is usually prompted by wind or water erosion). Geological events, such as seismicity, vulcanism, etc. can also play a role, and if relevant are taken into account in the siting design and safety assessment processes. Analysis of erosive processes requires data to describe their rate and magnitude, both the slow (wind and ice) and the potentially rapid (river floods and landslides) and their frequency. Other disruptive events may also have to be considered such as explosions, projectiles and dam failures.

3.5.2. Feedback to disposal facility design

Safety assessments, undertaken on a regular and iterative basis at various key stages of the design process (see Section 4), can provide valuable inputs to the design of the disposal facility.

The impact of many of the operational and closure exposure scenarios can be eliminated or reduced by modifying the facility design, for example by adopting a more heavily engineered vault design. Several scenarios (such as bathtubbing, fire, and liquid release scenarios) can be engineered away, for example the conditioning of the wastes and the operation of the vault can be used to prevent liquid and solid releases under normal conditions.

In terms of designing the facility to reduce impacts in the post-closure phase, the analysis of the groundwater pathway can provide input to the choice of disposal system (use of vault, backfilling buffers, capping, etc.) and its subsequent design (materials, size, aspect ratio, orientation and precise location within the chosen site area). The analysis of the gas pathway may similarly provide input to the design of the disposal facility with respect to its depth, the type and thickness of cover material and the design of a gas vent system. Safety assessment aimed at the intrusion pathway may suggest a requirement for activity limits, better institutional records, special intrusion barriers, preferred siting within the selected site area. Finally, if the possibility of deleterious effects from natural disruptive events is likely, then the dose impacts can be mitigated through the use of improved designs, such as thicker and more heavily engineered covers.

Ultimately the assessment process drives the design towards a solution that optimises the design objectives given in Section 2.

3.6. QUALITY ASSURANCE

The intent of a quality assurance (QA) programme is to ensure conformance to the pre-established technical requirements. Therefore, requirements can be established for such activities as data collection, design including safety assessment, construction, commissioning, operation and closure. The establishment of quality assurance programmes can also contribute to the gaining public acceptance for proposed disposal facilities. The IAEA provides additional information for establishing quality assurance programmes [14, 15], which is summarised below.

A design control programme is often documented and established before design work starts. Measures can be taken to assure that relevant regulatory requirements are taken into account appropriately in the design documents. These measures can include provisions to ensure that appropriate technical, operational and quality standards are specified and included in the design documents, and that any deviations from such standards are controlled. Measures can also be established for selection, and for review for suitability of application, of materials, parts, equipment and processes that are essential to the functions of the structures, systems and components.

In particular, the quality assurance programme describes and identifies the following:

- The measures used to assure verification or checking of design adequacy, such as design review, use of alternative calculational methods, or performance of a qualification testing programme under the most adverse design assumptions.
- The positions or organisations responsible for design verification or checking. Verification and checking can be done by individuals or groups processing an appropriate level of skill who are independent of those responsible for the original design.
- The measures taken to assure that the verification or checking process is performed; and
- The measures for validation of the design, i.e. the item or service conforms to defined user needs and/or requirements. Any deficiency in the design that could adversely affect the performance of any item covered by the quality assurance programme are identified, documented and corrective action taken.
- The measures of identifying and controlling design interrelationships, both internal and external, and for providing co-ordination between participating design organisations. It is helpful for the control of information between these interfaces to be formalised.

Information collected outside the quality assurance programme (termed “existing data”) may be used to support the design process. An example of such existing data is published research results on radionuclide sorption properties on various disposal facility materials and rock types. Such data can be reviewed and evaluated before use.

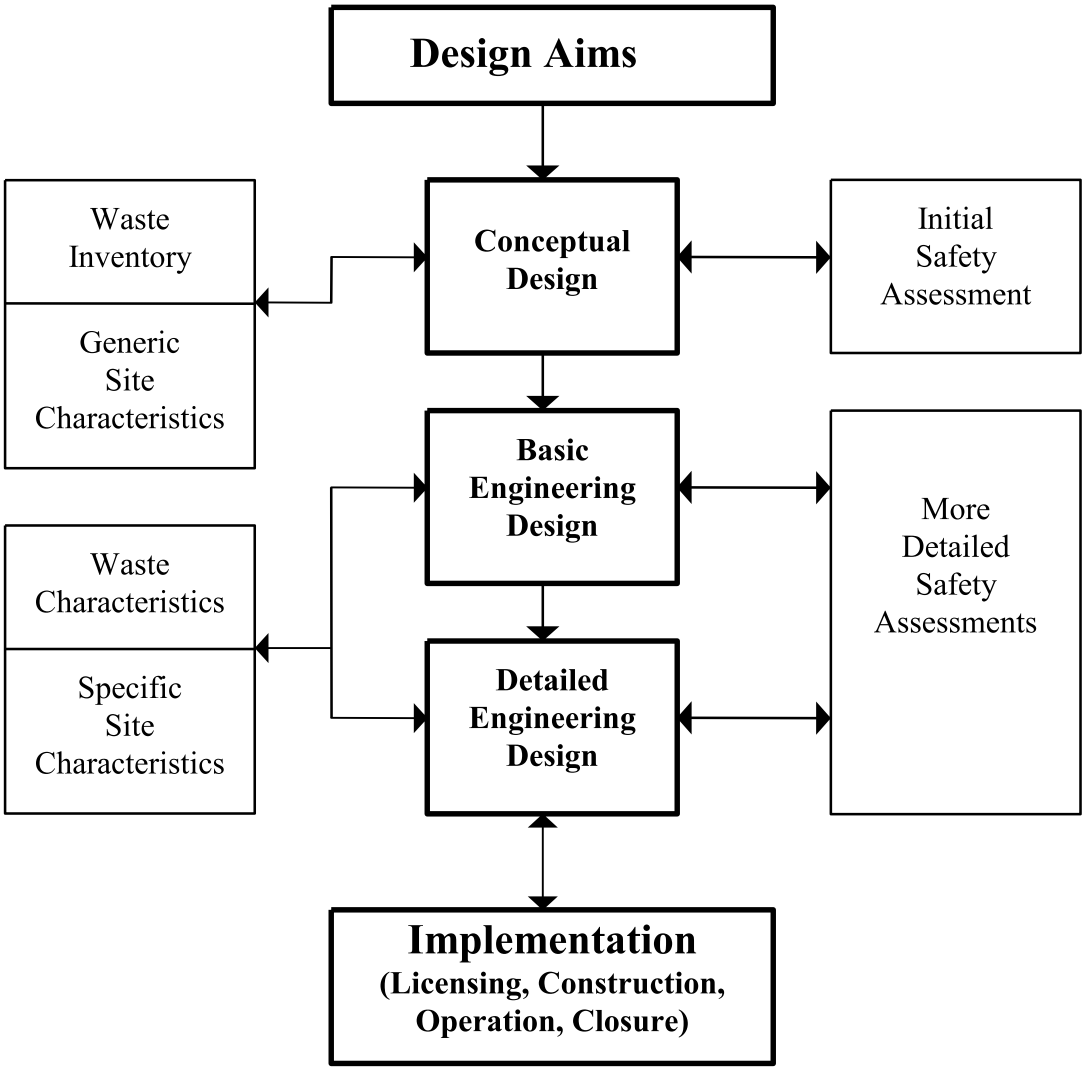


FIG. 4. The design process showing the relationship between the design phases and the design aims, assessment, information input and implementation.

Any design changes are usually subject to design control measures commensurate with those applied to the original design and are reviewed and approved by the organisation that performed the original design, or by another qualified organisation that has access to the original design information.

4. DESIGN PHASES AND CONTENTS

The design process for a near surface disposal facility is multi-staged and iterative, involving safety assessment and information on packaging, engineered barrier materials, site characteristics, etc. This process allows designers to modify the disposal facility design to achieve the desired safety requirements consistent with good engineering practices, operational needs, and cost constraints. It is important to recognise the iterative nature of developing and optimising a disposal facility design. The design process is often developed in conjunction with site characterisation, waste characterisation, treatment, and packaging, and safety assessment activities and not in isolation. The design process showing the interrelationship of the various components in implementing a near surface disposal facility is shown in Figure 4. An example of the application of the design process to an above water table near surface disposal facility is given in Figure 5.

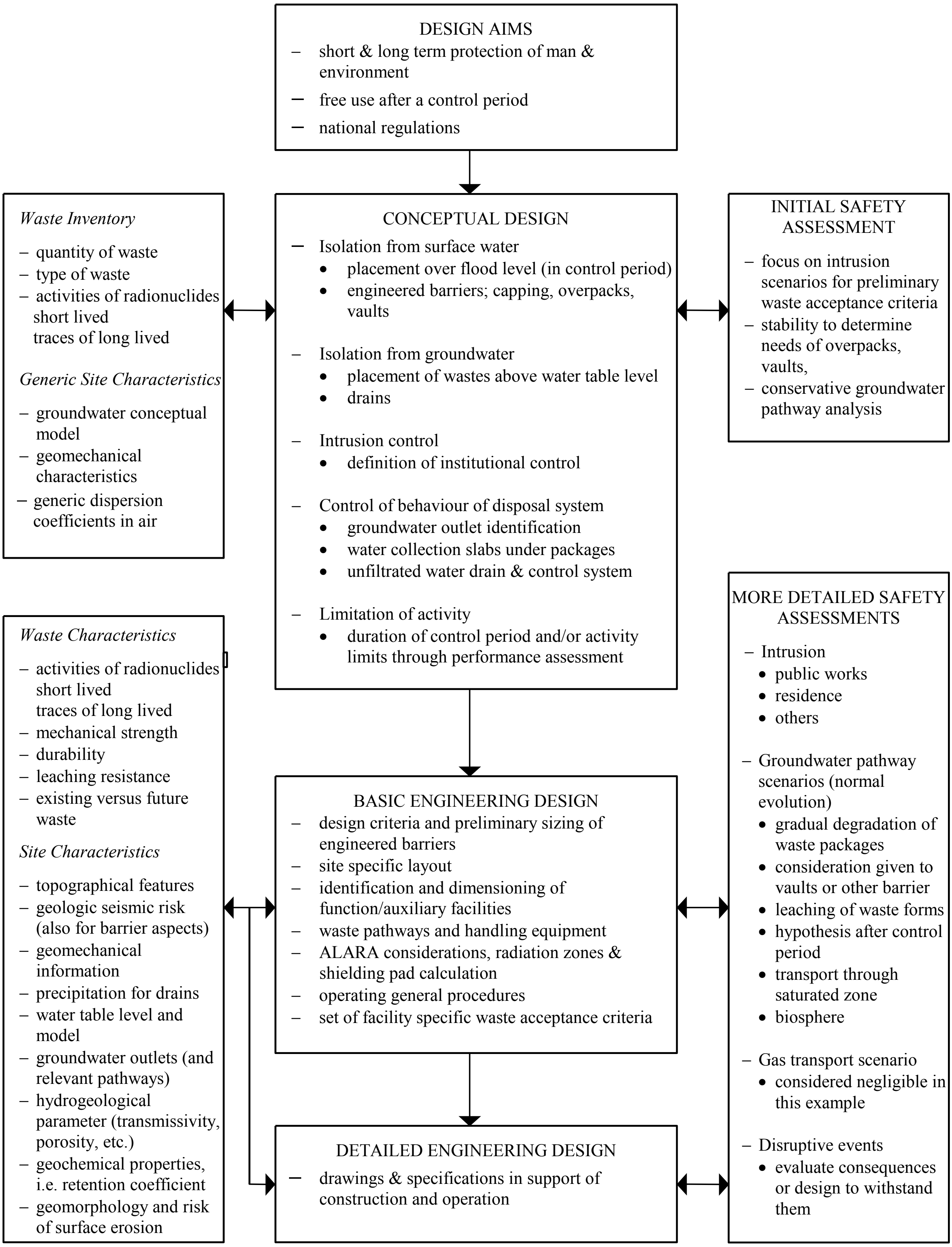


FIG. 5. Example of the design process applied to an above water table near surface disposal facility.

The three major steps generally followed in the design process are:

- first, the generic conceptual design phase at a very early stage of the disposal project;
- then, the basic engineering design phase, once a confirmed site has been selected and the site and its environment, waste characteristics and inventory are better defined; and
- finally, the detailed engineering design phase when all input data (site, waste, environment, etc.) have been fixed.

Each of these phases is discussed below.

4.1. CONCEPTUAL DESIGN PHASE

4.1.1. Objectives

The main objective of the conceptual design phase is to select the waste disposal option to be used. This, in turn, improves the co-ordination of the different groups or organisations involved in the management of the waste. In particular, it allows the establishment of general acceptance criteria for the waste packages, and provide guidance on further information requirements relating to site, waste, and design characterisation.

4.1.2. Scope of conceptual design

The conceptual design phase of a near surface disposal project consists of a technical, economic and safety evaluation of various disposal options. At this stage, a disposal site may or may not have been selected. It is expected that the evaluation should show near surface disposal is the most viable option, taking account of factors such as: safety (e.g. compliance with the established safety principles and licensing requirements); environmental impact (e.g. compatibility with the characteristics of available sites or of generic sites); technical issues (e.g. ability to handle the amount and general characteristics of wastes that will be produced); social and economic factors; and cost. The evaluation describes the intended disposal technical options including the descriptions and functions of the waste package, buffer and barrier materials proposed to be used, and the intended performance and safety functions assigned to each of the components that comprise the multi-barrier system.

To carry out the conceptual design work, the following data are required:

- estimated waste inventory, general characteristics, and their places of origin;
- site characteristics (generic or specific), and data (geology, hydrology, hydrogeology, geochemistry, climate, soil condition, etc.); and
- safety and regulatory criteria (operational and long term).

At this stage in the design process, there is generally a lack of specific information regarding the site and/or the waste characteristics. At the conceptual phase of design, the safety assessment often therefore has to use estimated waste inventory and characteristics, and generic site characteristics. Sensitivity studies from the conceptual performance assessment can be helpful in identifying information needed from site characterisation and from research programmes on waste characteristics and engineered barriers.

The conceptual design can be based on the available disposal options, and their feasibility and safety performance evaluated versus the desired design aims given in Section 2. Disposal system structures can be in trenches, pits or engineered structures and can be either above or below the ground and above or below the water table. Likewise, wastes can be in different packages with practically no conditioning (other than the drums that contain them) to highly stable solid media after extensive treatment.

4.2. BASIC ENGINEERING DESIGN PHASE

4.2.1. Objectives

The main objective of the basic engineering design phase is to confirm that the disposal option selected from the conceptual design phase could become a licensable, operational option. This is done by demonstrating that the disposal system meets all safety and design criteria and that it can be constructed and operated in a safe and cost efficient manner. The results of the basic engineering design phase are used in the safety assessment that, in many cases, is used, in this phase, in the licensing process.

Additional objectives are:

- to ensure that the design is consistent with the specifics of the:
  - site and environment; and
  - waste volumes, quantities, characteristics; waste forms and packages;
- to better define the overall disposal facility for final design;
- to better evaluate and complete:
  - the project feasibility;
  - the operational and long term safety performance assessment; and
  - the operational feasibility and flexibility and determine whether the facility can be successfully operated and closed;
- to evaluate the costs and the schedules;
- to define further requirements for:
  - site data;
  - waste packaging specifications;
  - barrier materials (specifications, testing, etc.); and
  - additional R&D studies or other required work;
- to define needs for additional infrastructure in the site region (transportation, communication, power, etc.);
- to provide information to support the performance assessment and final safety assessment of the facility;
- to make provisions to provide information for:
  - governmental authorities;
  - the public;
  - industry; and
  - waste producers, etc.;
- to define the requirements and specifications for waste handling and to investigate the availability of equipment;
- to define the QA programme for detailed design, construction, commissioning and closure;
- to provide information to support impact evaluation studies:

  - environmental; and
  - socio-economic;
- to help demonstrate that the design can meet the requirements for regulations and licensing relating to planning, construction, operation and closure.

4.2.2. Scope of basic engineering design

The basic design expands on the conceptual design and incorporates any additional site-specific information obtained during the site selection and characterisation activities. It covers the following:

- the description of the overall disposal system and individual units within the system including ancillary facilities and services;
- the description of disposal activities from reception of waste packages to final placement in disposal structures;
- the description of the operational and long term safety requirements to ensure the safety of workers and any potentially exposed surrounding populations and the environment;
- the design requirements for closure;
- the data to be provided for safety assessments and the documents to be provided to the regulatory authority(ies); and
- the description of active and passive institutional control requirements and provisions in the design as necessary.

All descriptions are supported by technical documents such as reports, notes, calculation sheets, drawings, figures, flowsheets, diagrams, etc. They are accompanied by design and construction schedules, operational diagrams and cost estimates. Records required for long term keeping are identified and filed appropriately.

The overall disposal system design normally includes basic design details for the following:

- location of the disposal site;
- facility layout;
- site preparation (excavation, drainage, earthwork, roads, etc.);
- access and service roads, parking areas, fences;
- run-off and disposal system drainage, collection point design and treatment of collected liquids if warranted;
- disposal system (engineered structures, pits, etc.);
- definition of backfilling and capping systems (materials and description of emplacement techniques);
- radiation protection and monitoring systems;
- power, heating, ventilation, communication and other support systems; and
- fire protection and security system.

In addition to the disposal system, auxiliary buildings and services need to be considered for reception of waste, interim storage, conditioning or repackaging of waste, and preparation and storage of buffer, barrier, and construction materials. Additional buildings and services that may be required and need consideration in the design include those with radioactive zone restrictions (such as chemical and radiochemical laboratories, control room, liquid effluent treatment facility, and decontamination facility) and without such restrictions (such as personnel rooms (shower, toilets, etc.), administration buildings, visitors' centre, truck, railway or boat terminal, shops, stores, and garages).

Preliminary operational procedures are drafted at this stage of the project to help assess whether the disposal facility can be operated in a safe and efficient manner. These procedures, supported by flowsheets and diagrams, are used to confirm that the waste package quantities delivered to the disposal facility can be handled according to the design and safety criteria given for the future site operation. The site plan indicates the various control zones, where applicable, and access conditions to each zone. Operational safety criteria serve to determine radiation protection and facility shielding requirements.

If considered necessary, provision can be made in the design for future extension of the site and to accommodate construction of new disposal structures along with current disposal activities. Also, provision can be made to deal with the possibility of incidents and accidents requiring potential relocation of already disposed or stored wastes in the operational phase and the initial part of the post closure phase.

Cost estimates can be provided regarding the construction and operational activities. The uncertainty of the estimated cost is a function of the level of precision in the input data and design work.

4.3. DETAILED ENGINEERING DESIGN PHASE

4.3.1. Objectives

The main object of the detailed engineering design phase is to prepare for the construction phase and the operational and closure phases. These phases confirm that the disposal facility can be operated and closed safely and efficiently. Detailed design is completed to the satisfaction of the relevant regulatory/licensing authorities.

Additional objectives are:

- to include any additional requirements from regulatory authorities introduced following their review of and comments on the basic design;
- to further develop the basic design taking into account more detailed information on:
  - site and environment; and
  - waste packages;
- to finalise details of the design for the overall disposal system and ancillary and auxiliary facilities and produce associated drawings and other design documents;
- to finalise specifications for construction, equipment procurement and commissioning of the facility;
- to finalise cost estimates for facility construction, operation and closure;
- to complete the development of facility specific waste acceptance criteria;
- to provide information to support the safety assessment undertaken for licencing purposes;
- to define environmental surveillance and radiological monitoring programmes to be conducted during operations and after closure of the disposal facility;
- to define operations personnel and staff training and support requirements;

- to provide to all concerned parties with the information requirements for final closure of the facility;
- to finalise QA programmes for construction, operation, commissioning, and closure; and
- to prepare operational procedures, specifications and manuals.

4.3.2. Scope of detailed engineering design

The detailed design further expands on the basic design by providing more detailed descriptions of the design and safety features, construction, operational and closure requirements. The associated work programme usually covers most of the same items (facilities, buildings, systems, etc.) as in the basic design phase. However, the description of the disposal facility and its subsystems and their components (units, structure etc.) facility are more detailed. Each component of the disposal system is described and sized through engineering specifications and drawings in sufficient detail for construction, inspection, and operation.

Detailed technical analyses and cost projections are finalised during this design phase and detailed cost projections are prepared. Specifications for construction and equipment procurement are finalised at this stage. Feedback from equipment manufacturers and/or suppliers are also incorporated in the design work. Construction details and schedules are finalised to facilitate, if appropriate, the tender for award of work contracts.

In some cases, the detailed engineering design of the facility for construction or operation may not include the detailed design of the final capping system. However, the technical details and implications of closure, using existing technologies, are usually taken into account in the design of the other parts of the system.

As required, additional information and supporting documents are provided to the regulatory authorities for evaluation of safety of the facility during construction, operation, closure and post-closure phases.

The final end result of the entire effort is:

- to complete the detailed design of all technical and engineering parts of the overall disposal system;
- to complete the safety assessments; and
- to complete all design work for meeting the regulatory/licensing requirements and to enable construction of the facility.

5. SUMMARY AND RECOMMENDATIONS

Good design is an important step towards ensuring operational as well as long term safety of LILW disposal. Recognising the need of Member States to obtain specific information, the IAEA has produced this report with the objective of providing guidance focused on the design of near surface disposal facilities. This guidance has been developed in light of experience gained from the design of existing near surface disposal facilities in a range of Member States. In particular, the report provides information on:

- the design objectives, i.e. isolation of waste/control of releases, reduction of impacts, avoidance/minimisation of maintenance, and attainment of public acceptance;

- the design requirements relevant to waste characteristics, site characteristics, engineered barriers, operational considerations, safety assessment, and quality assurance, that are necessary to help ensure the fundamental design aims are met ; and

- the design phases, i.e. the conceptual design phase, the basic engineering design phase, and the detailed engineering design phase.

In light of the discussion in this report, the following recommendations are made:

- The overall waste management system (treatment, conditioning, storage, transportation, siting, construction, handling, operation and closure) is considered in its entirety to ensure the safety of the disposal system. Disposal design is an important aspect of the overall waste management system.

- Although the various steps described in this report are not necessarily to be followed universally, the concepts given in Figure 4, if followed, are expected to contribute to a safe design.

- It is important to recognise that the design process is iterative and requires input information from site and waste characterisation programmes and safety assessments.

- The designer ensures that, from the outset of the design process, there is a clear understanding of the regulatory requirements of the facility life cycle.

- The designer identifies and takes into account, as soon as practical, all of the data/parameters required to achieve the final design in a timely manner.

- The designer takes into consideration the cost implications of the facility from conception to closure and the cost implications of institutional control after closure.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Design, Construction, Operation, Shutdown and Surveillance of Repositories for Solid Radioactive Wastes in Shallow Ground, Safety Series No. 63, IAEA, Vienna (1984).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Classification of Radioactive Waste: A Safety Guide, Safety Series No. 111-G-1.1, IAEA, Vienna (1994).

[3] Planning and Operation of Low Level Waste Disposal Facilities (Proc. Symp. Vienna, 1996), IAEA, Vienna (1997).

[4] HAN, K.W., HEINONEN, J., BONNE, A., Radioactive Waste Disposal: Global Experience and Challenges, IAEA Bulletin **39** 1 (1997) 33–41.

[5] UNITED STATES DEPARTMENT OF ENERGY, Conceptual Design Report: Alternative Concepts for Low Level Radioactive Waste Disposal, DOE/LLW-60T (1987).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, The Principles of Radioactive Waste Management: A Safety Fundamental, Safety Series No. 111-F, IAEA, Vienna (1995).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Near Surface Disposal of Radioactive Waste: Safety Requirements, Safety Standard Series No. WS-R-1, IAEA, Vienna (1999).

[8] HOOFT, E., Working with local partners: ONDRAF/NIRAS's approach to the disposal of short-lived low-level radioactive waste", Proc. of TOPSEAL'99, Antwerp 1999, ENS (1999).

[9] TORRES-VIDAL, C., LITTLE, R., SANTUCCI, P., "Derivation of quantitative acceptance criteria for disposal of radioactive waste to near surface facilities: Development and implementation of an approach for the post-closure phase", Safety of Radioactive Waste Management (CD-ROM in Proc. Conf. Cordoba, Spain, 2000), IAEA, Vienna (2000).

[10] INTERNATIONAL ATOMIC ENERGY AGENCY, Review of Available Options for Low Level Radioactive Waste Disposal, IAEA-TECDOC-661 (1992).

[11] INTERNATIONAL ATOMIC ENERGY AGENCY, Report on Radioactive Waste Disposal, Technical Reports Series No. 349, IAEA, Vienna (1993).

[12] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Assessment for Near Surface Disposal of Radioactive Waste: Safety Guide, Safety Standard Series No. WS-G-1.1, IAEA, Vienna (1999).

[13] KOZAK, M.W., TORRES, C., "The International Atomic Energy Agency programme to improve safety assessment methodologies for near surface radioactive waste disposal facilities (ISAM)", Proc. of the United States Department of Energy Low-level Waste Conference, Salt Lake City, 1998.

[14] TORRES-VIDAL, C., GAGNER, L., LITTLE, R., "Derivation of quantitative acceptance criteria for disposal of radioactive waste to near surface facilities: Review and implementation of an approach for the operational phase", Safety of Radioactive Waste Management (CD-ROM in Proc. Conf. Cordoba, Spain, 2000), IAEA, Vienna (2000).

[15] INTERNATIONAL ATOMIC ENERGY AGENCY, Application of Quality Assurance to Radioactive Waste Disposal Facilities, IAEA-TECDOC-895, IAEA, Vienna (1996).

[16] INTERNATIONAL ATOMIC ENERGY AGENCY, Quality Assurance for Safety in Nuclear Power Plants and other Nuclear Installations, Code and Safety Guides Q1–Q14, Safety Series No. 50-C/SG-Q, IAEA, Vienna (1996).

APPENDIX A
NEAR SURFACE DISPOSAL SITE LAYOUTS

A disposal site can have many functional parts. They can include, in addition to the waste disposal operations areas, buildings and services for administration, technical services, testing and quality control, health physics requirements, waste segregation, treatment, repackaging, etc. The precise nature and function of these additional buildings varies from site to site. Two illustrative examples are provided below.

A.1. CENTRE DE L'AUBE, FRANCE

The following description of the site is based on information given in Refs [A-1, A-2].

The Centre de l'Aube disposal site is located in north-eastern France and started operations in January 1992. The site occupies 60 ha, 30 ha of which is used for disposals. It has a capacity of 10^6 m^3 that is expected to last until around 2040. The site contains facilities for waste disposal and waste conditioning, as well as other buildings (Figure A.1).

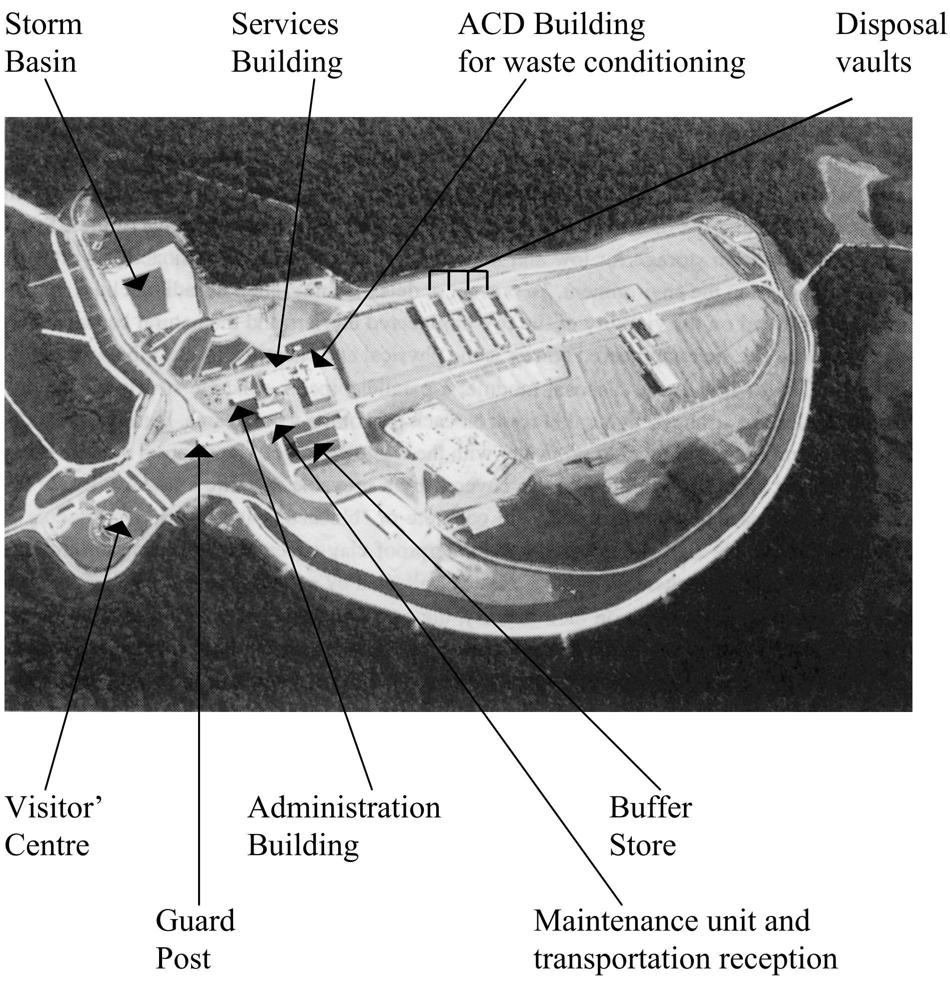


FIG. A.1. Aerial view of the Centre de l'Aube disposal site.

The disposal facilities are a series of disposal vaults arranged in parallel rows over the disposal area (details of the design of these vaults, their operation and closure are provided in Appendices B, C and D, respectively).

The waste conditioning facilities are housed in the ACD (Atelier de conditionnement des déchets) building. They consist of: a compacting unit for 200 l metallic drums; a grouting unit for 400 l metallic drums and a metallic container embedding unit for 5 and 10 m^3 containers.

Other buildings include:

- an administration building equipped with a computer system which allow real time tracking of each waste package;
- a services building including changing rooms, a laboratory for environmental monitoring, health physics services, laundry services and medical services;
- a buffer store for the storage of waste packages prior to disposal;
- a maintenance unit and transporation reception office providing controlled access for vehicles to the disposal area, and facilities for general maintenance and decontamination of vehicles;
- a storm basin with capacity to collect runoff water and control its discharge to the local river;
- a visitors' centre; and
- a guard post to control access to the site.

A.2. EL CABRIL, SPAIN

The following information is taken from Ref. [A-3].

The El Cabril disposal site is located in southern Spain and was commissioned in October 1992. The site (Figure A.2) occupies 20 ha and is divided into two zones, i.e. the disposal zone, and the conditioning and auxiliary buildings zone. It receives all L/ILW produced in Spain and has a capacity that is expected to last until 2015.

A.2.1. Disposal zone

Twenty-eight vaults have been built in the disposal zone, grouped in two areas or platforms; the north platform, with 16 structures, and the south platform, with 12. The platforms are horizontal surfaces some 90 metres wide, excavated in trenches in the hillside, and side banks have been left on which to rest the final covering. In each of these areas, the vaults are half-buried with regard to the operating level and are laid out in two rows.

This zone also contains the control tank of the seepage control network, the rainwater collection pool, and the concrete preparation and storage container manufacturing plants.

A.2.2. Conditioning and auxiliary buildings zone

The conditioning and auxiliary buildings zone contains buildings for waste treatment and conditioning and their control, as well as the auxiliary services needed for the operation and maintenance of El Cabril. The Spanish radioactive waste agency, ENRESA, chose to construct and operate the container production plant at El Cabril, primarily so that it could control the quality of the concrete components, a fundamental element of barrier durability, as well as the manufacturing process itself.

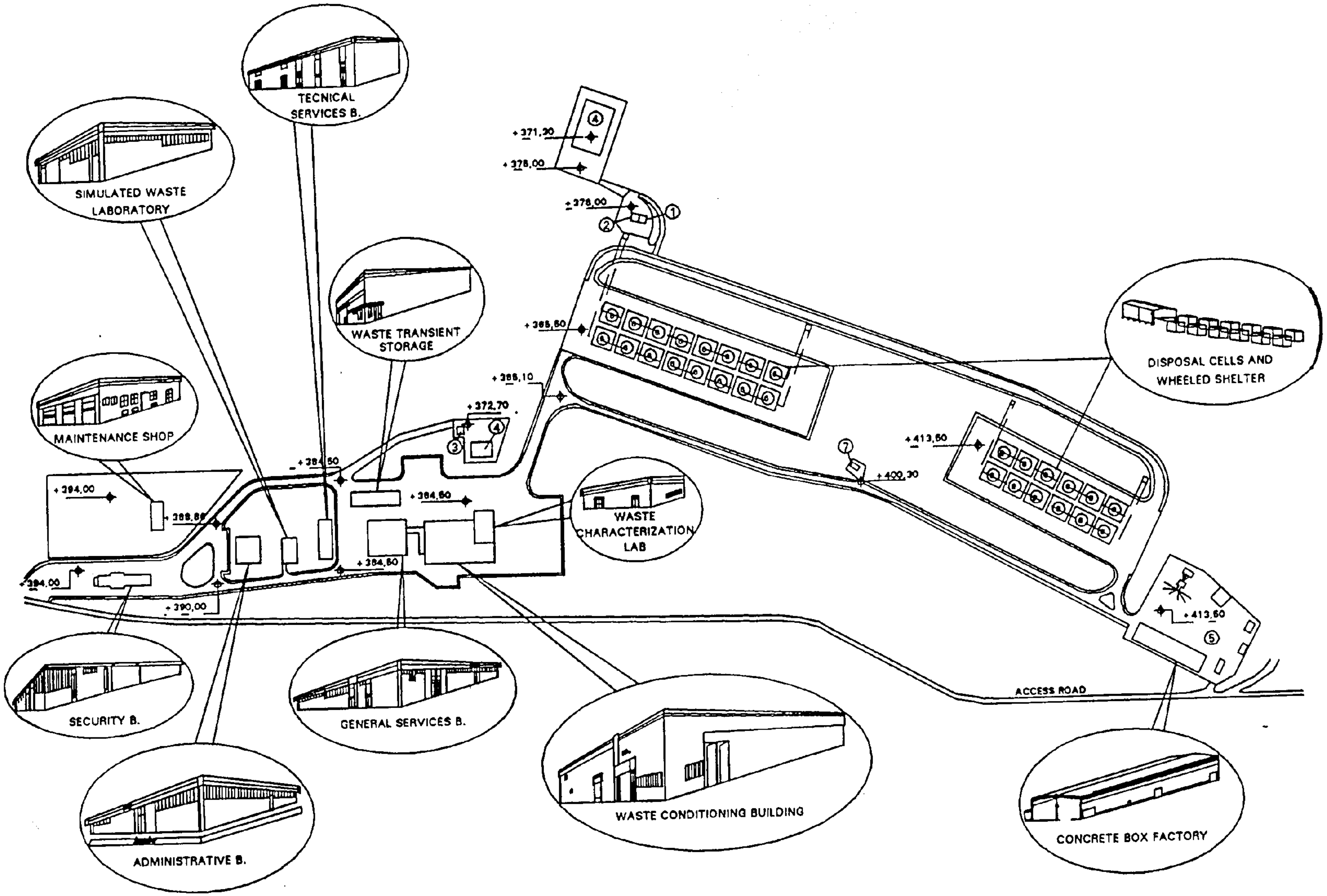


FIG. A.2. General layout of the El Cabril disposal site.

The functions of the principal buildings are as follows:

(a) *Industrial safety building:* This building houses the access control station, the central monitoring post and fire-fighting equipment.

(b) *Maintenance workshop:* Includes vehicle, electrical and mechanical workshops.

(c) *Administration building:* This building houses the offices of the site manager, the different departments and the administrative services.

(d) *Inactive waste quality verification laboratory:* This building is used for testing and checking non-active samples having characteristics similar to those of the different types of package to be disposed of. It basically consists of a concrete and mortar laboratory, with a climatic chamber, tri-axial cell, presses, chemical laboratory, etc. It likewise houses the offices of the characterisation laboratory operating personnel.

(e) *Technical services building:* This building houses the main equipment of the different auxiliary services systems: transformer centre, electrical distribution, stand-by diesel generator, cold and heat producing plants, and water treatment plant. It also houses the auxiliary services control panel.

(f) *General services building:* Houses the radiological protection services, medical service, dressing rooms. laundry, environmental monitoring laboratory, calibration equipment, chemical laboratory, counting equipment, and personnel access radiological control station. All personnel, except for vehicle drivers, access the monitored zone through this building.

(g) *Transitory reception building:* This building contains the vehicle radiological control post and the vehicle decontamination post, as well as a transitory drum storage area for 4.000 drums. From the radiological protection viewpoint, and together with the General Services Building, it separates the non-regulated zone from the monitored zone.

(h) *Conditioning building:* All the treatment and conditioning operations described in the following section are performed in this building. Almost all wastes pass through it. It also houses the Control Room, from which most of this building's systems, as well as the storage zone waste handling equipment are operated. Centralised in this buildings is all information on the operation of the whole facility, the electrical distribution of this building and the adjoining Characterisation building, the uninterrupted power supply, controlled ventilation and radiation monitoring systems.

(i) *Active waste quality verification laboratory:* This building is used for performing tests to determine the characteristics of the different types of packages, on active test pieces and actual packages, and for the technical verification of some of the packages reaching the centre.

Research and development work on the optimisation of the waste solidification process is also foreseen here. The laboratory is arranged around a handling cell made of concrete with a stainless steel inner lining, and controlled ventilation. This cell is equipped with lead glass, two remote-controlled manipulators, a travelling crane with heavyweight remote-controlled manipulator, equipment for cutting and removing the metal casing of the drums, drum-drilling and dry sample extraction equipment and mechanical test equipment.

Lastly, the laboratory has a package radiological characterisation system (non-destructive), a spraying and lixiviation system for test pieces and (unskinned waste packages), testing equipment for transport regulations tests (compression, drop test), sample preparation cell, chemical laboratory and counting laboratory.

(j) *Waste water plant*. The waste water treatment plant, used for conventional treatment, is located next to the covered rainfall collection pool of the buildings zone.

REFERENCES TO APPENDIX A

[A-1] ANDRE, T., "Experience of an engineering company in shallow land disposal of L/ILW, planning and operation of low level waste disposal facilities", Planning and Operation of Low Level Waste Disposal Facilities (Proc. Symp. Vienna, 1996), IAEA, Vienna (1997) 313–328.

[A-2] DUTZER, M. AND NICOLAS, M., "Operating the Centre de l'Aube", Planning and Operation of Low Level Waste Disposal Facilities (Proc. Symp. Vienna, 1996), IAEA, Vienna (1997) 243–247.

[A-3] ZULOAGA, A., GUERRA-LIBRERO, A., MORALES, A., "L/ILW disposal experience in Spain after the startup of El Cabril disposal facility", Planning and Operation of Low Level Waste Disposal Facilities (Proc. Symp. Vienna, 1996), IAEA, Vienna (1997) 261–274.

APPENDIX B
DISPOSAL STRUCTURES USED IN NEAR SURFACE FACILITIES

A range of disposal structures is used and has been used for the disposal of L/ILW in near surface disposal facilities (see for example the various papers given in Ref. [B-1]). They include: trenches; vaults; tile holes; rock caverns; and silos. A description of some examples from various countries is given below.

B.1. CENTRE DE L'AUBE, FRANCE

The following description of the disposal structures is based on information given in Refs [B-2, B-3].

At Centre de l'Aube, concrete vaults are used for the disposal of waste (Figure B.1). They are designed to isolate the waste from groundwater and to have mechanical integrity for 300 years. The watertight base of each vault is built above the groundwater table and four external concrete walls are sunk into the base. Each vault is divided by internal concrete walls into a series of four or five cells. One of the external walls has an opening in it to allow the vehicles used for transporting the waste to gain access to the vault. The opening is closed once the vault have been filled.

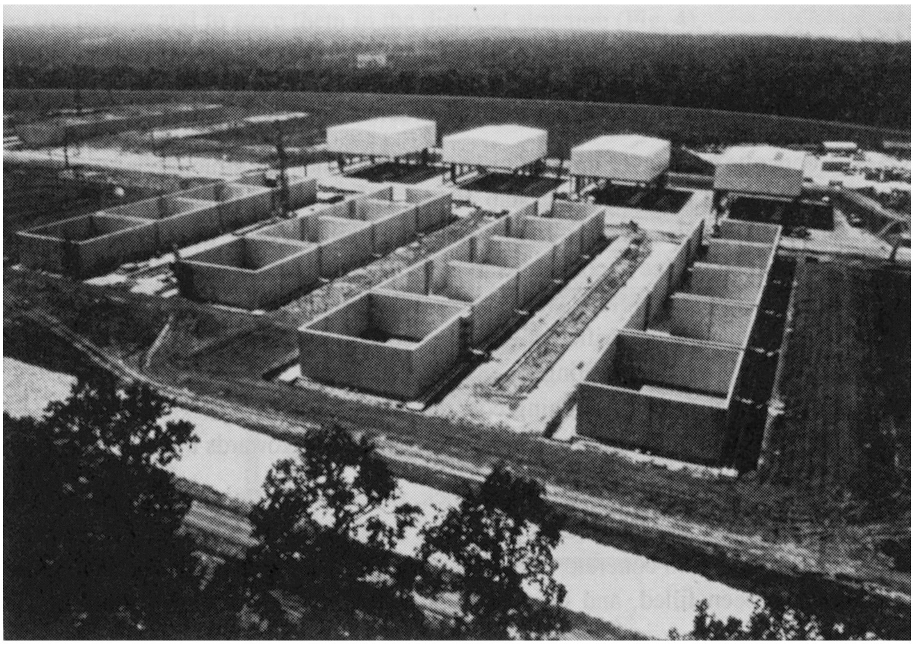


FIG. B.1. View of the disposal area at Centre de l'Aube.

The general architecture of a disposal structure consists of (from bottom to top):

- a concrete base layer grouted on sand, upon which the structure is built;
- a reinforced concrete floor slab 40 cm thick, covering an area of 21.5 m × 21.5 m; this concrete has good waterproofing properties. In the middle of the structure an orifice is connected to the water collection system;
- a sloping concrete floor (slope about 1%) located on the slab, the slope converging towards the orifice of the water collection system. The floor is covered with a polyurethane coating;
- a horizontal layer of draining concrete upon which the packages are stacked and from which the infiltration water is drained off towards the collector.

Reinforced concrete walls, 40 cm thick, rise from the floor of the structure. At the top of the walls, the reinforcing iron mesh is left in position, folded and encapsulated in concrete. This concrete is broken away and the mesh is unfolded when the structure has been filled, and the mesh connected to the reinforcing mesh of the cover slab.

B.2. TROMBAY, INDIA

The following description of the disposal structures is based on information given in reference [B-4].

The Trombay site has been operational since the 1960s. It accepts L/ILW produced by the adjacent Bhabha Atomic Research Centre. The facilities available at the Trombay site are:

- earth trenches — unlined excavations in soil, 1 to 4 m deep with backfill of vermiculite and bentonite to improve the retention of activity (Figure B.2). They are used for low activity wastes with a surface dose rate of less than 2 mGy h^{-1};
- reinforced concrete trenches – typically 2 to 4 m deep, 2 m wide and 15 m long. Outer containment is a 300 mm thick reinforced concrete wall (Figure B.3). All outermost surfaces are given waterproofing treatment. The civil engineering design takes into account the uplift pressure due to the water table, loading due to the disposal of the waste, and shielding;
- tile holes – designed and constructed for disposal of waste having activity higher than permissible for reinforced concrete trenches (>500 mGy h^{-1}). They are also used for storage or disposal of a contaminated waste. These are cylinders of 700 mm inside diameter and 4 m depth (Figure B.4). Each tile hole has a carbon steel shell, 6 mm thick, with one end closed. The plate material and welder are qualified as per Indian Standards or the ASME Code. All longitudinal and circumferential weld joints are inspected under a quality assurance programme. The inside and outside of the shell are covered with 25 mm thick cement mortar applied by spinning and gunniting over reinforcing mesh. Hydrotesting up to 90 Pa is done to ascertain the integrity of the shell and the weld joints. Additional protection with waterproofing tiles is done on the outer surface.

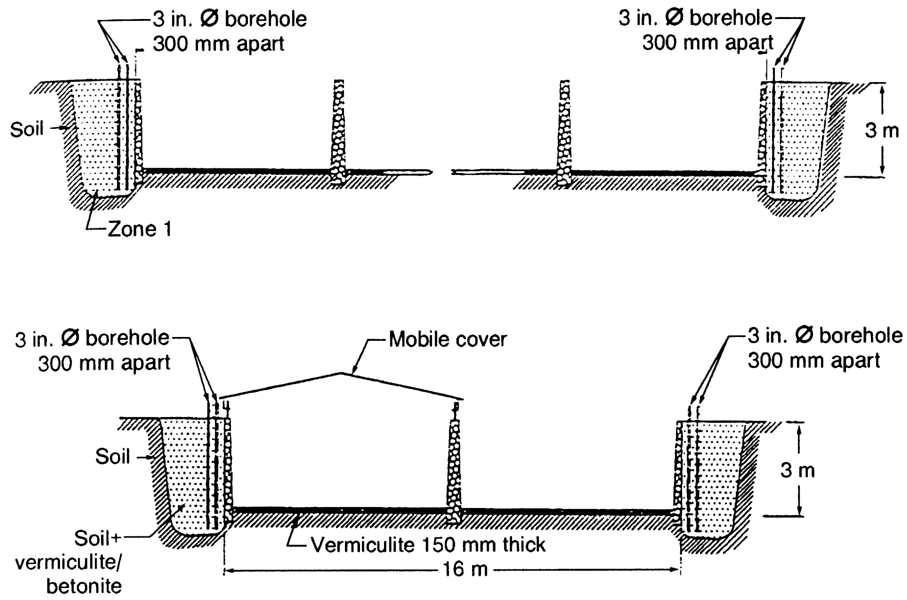


FIG. B.2. Typical earth trench at Trombay.

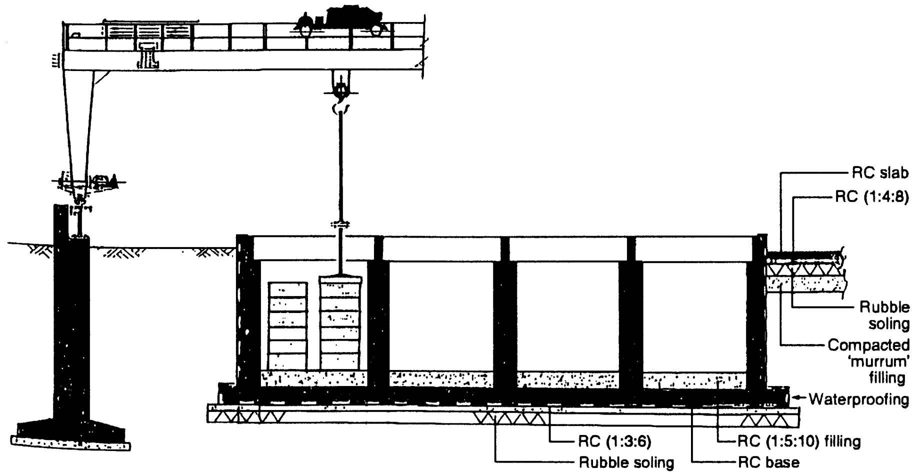


FIG. B.3. Typical reinforced concrete trench at Trombay.

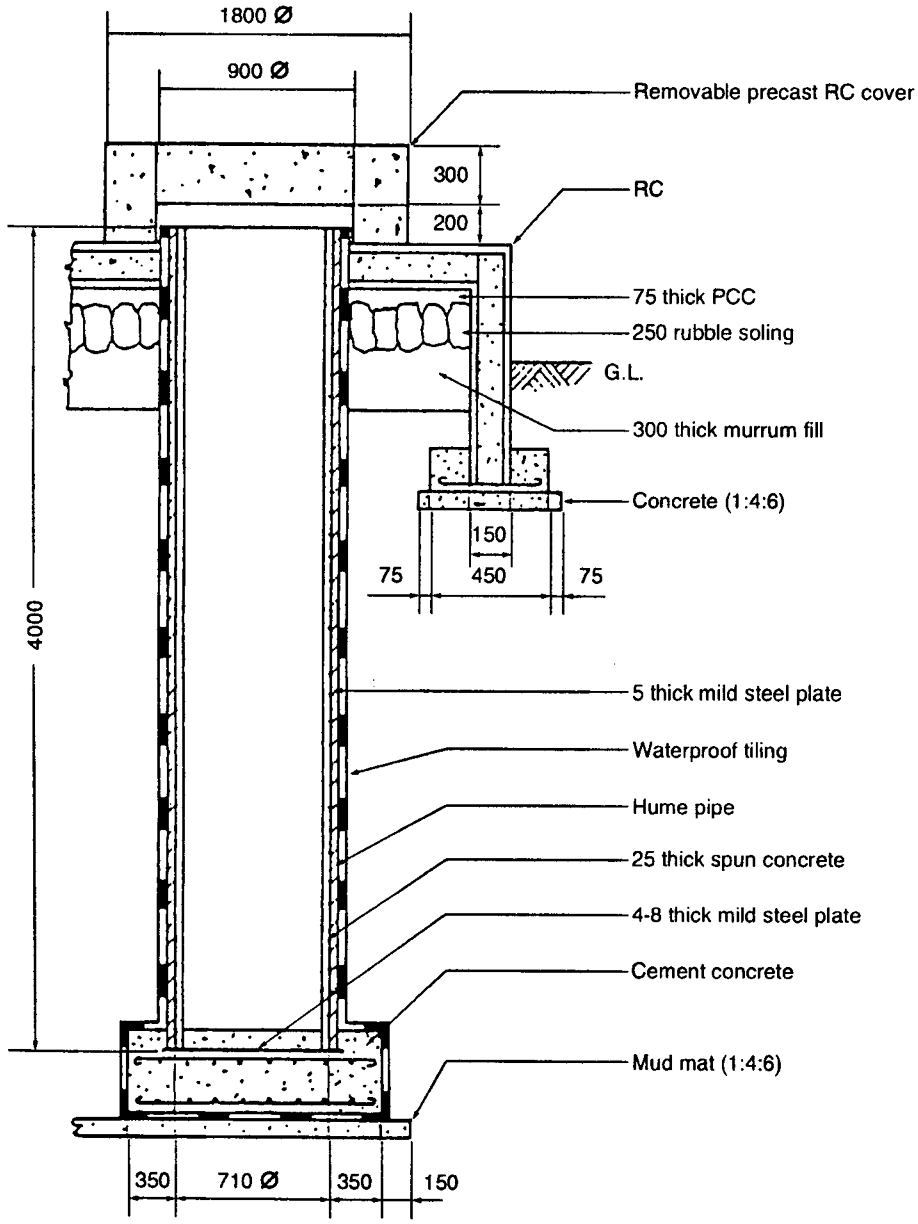


FIG. B.4. Typical tile hole at Trombay (dimensions in mm) [B-4].

B.3. VAALPUTS, SOUTH AFRICA

The following description of the disposal structures is based on information given in Ref. [B-5].

The Vaalputs site is located in the Northern Cape Province and has been operational since 1986. It receives L/ILW primarily generated by the Koeberg nuclear power station. Vaalputs is situated in an arid area and met the site selection criteria eminently satisfactorily. Initial modelling showed that groundwater contamination by radionuclide migration was unlikely to be a problem. It was therefore decided that near surface disposal in the overlying clay would be appropriate. On the basis of waste generation forecasts two trenches, 100 m long by 20 m wide by 7.5 m deep (Figure B.5) were constructed. In one trench are concrete containers in which ILW is immobilized. The other trench contains other waste, mainly in metal drums. The clay layer is very stable, and the walls of the trenches were constructed at an angle of 10° to the vertical. Modelling has shown that the configuration of concrete containers shown in Figure B.5 gives a reduced probability of cracking in the proposed trench cap if subsidence occurred at the sides of the trench.

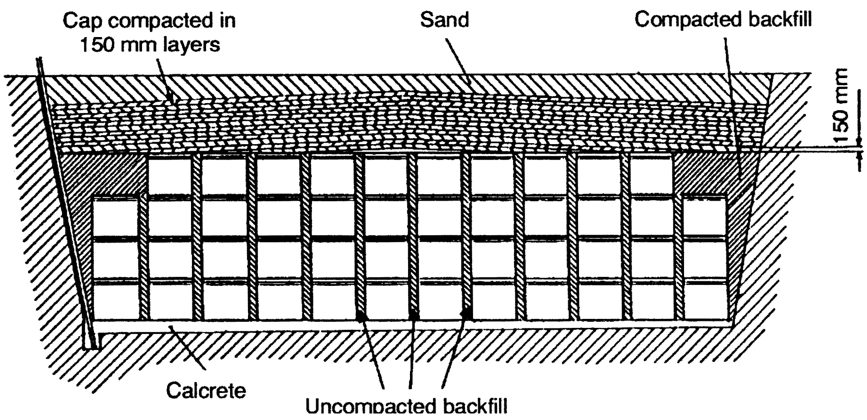


FIG. B.5. Cross-section of a Vaalputs Trench.

B.4. EL CABRIL, SPAIN

The following description of the disposal structures is based on information given in Ref. [B-6].

At El Cabril, concrete vaults are used for the disposal of waste. Waste containers are placed in the vaults, each of which has a capacity for 320 containers and approximate external dimensions of 24 m by 19 m by 10 m. The bottom plate is the main element of the vault. It is 0.6 m thick at the edges and 0.5 m thick in the centre, and is covered with a waterproof layer of polyurethane and a 10-20 cm layer of porous concrete. This forms a horizontal surface on which the containers are placed.

Both the containers and the storage vaults are designed to withstand extreme loads, including a ground accelerating seismic event of 0.24 g. The concrete used in the vaults and containers was defined by a research programme conducted by the Instituto Eduardo Torroja of the Consejo Superior de Investigación Científica (CSIC – Scientific Research Council), the objective of which was to optimise the durability of the concrete barriers. The concrete used is of high characteristic resistance (350 kg cm^{-2}) and compactness, and sulphate resistant (despite the low concentrations of sulphates and chlorides in the site water).

B.5. SFR, SWEDEN

The following description of the disposal structures is based on information given in references [B-7, B-8].

The Swedish final repository (SFR) for L/ILW started operation in 1988, and has a capacity of 60 000 m^3 of waste (enough for all reactor waste from the 12 nuclear power plants now in operation in Sweden until around 2030). The total underground volume of the disposal facility is about 430 000 m^3. The facility can be expanded to accommodate another 100 000 m^3 of waste arising from the eventual decommissioning of the nuclear power plants. It is located 150 km north of Stockholm at the Forsmark Nuclear Power Plant.

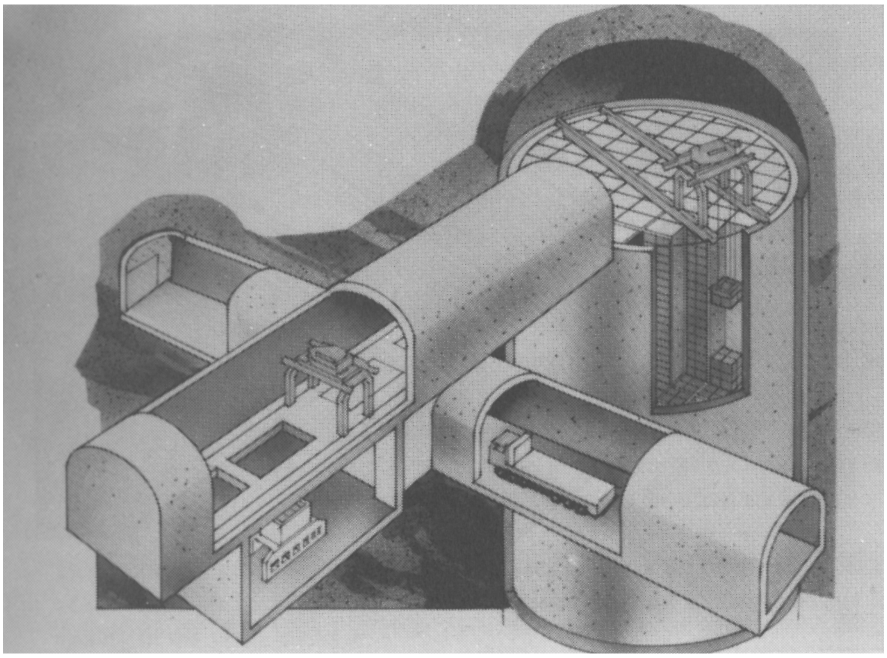


FIG. B.6. Silo for disposal of ILW at SFR.

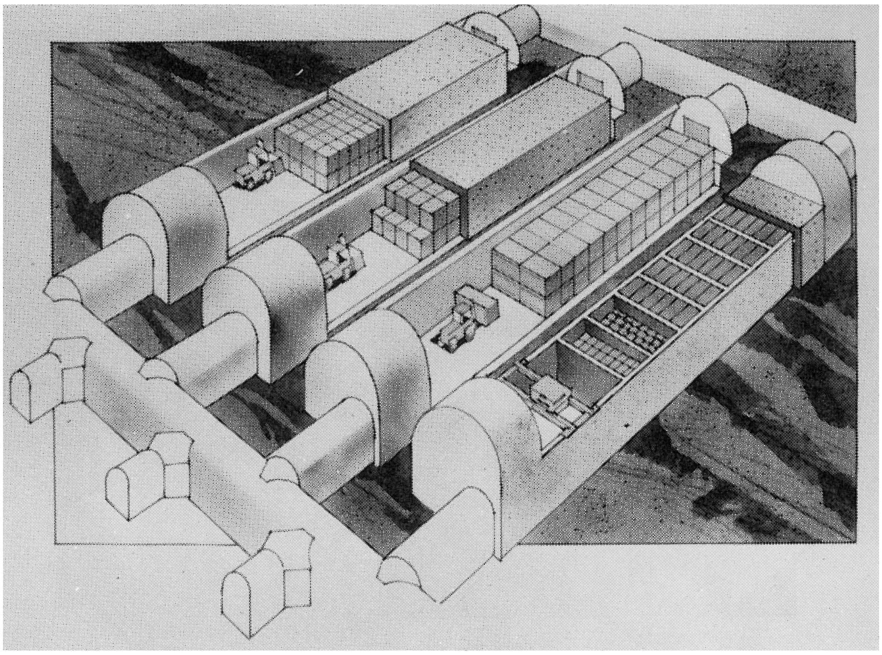


FIG. B.7. Rock caverns for disposal of L/ILW at SFR.

Waste is disposed in bedrock 50 m under the seabed, about 1 km out in the Baltic Sea. The SFR consists of a silo (Figure B.6) and four rock caverns (each 160 m long, with widths varying from 15 to 20 m and heights varying from 10 to 17 m) (Figure B.7), especially designed for the different types of waste packages:

– Silo: contains ILW, mainly ion exchange resins solidified in cement or bitumen. The waste packages are concrete or steel cubes (1.2 m by 1.2 m by 1.2 m). Ordinary 200 l steel drums are also used. Up to 90% of the total activity in SFR, will be placed in the silo, where the highest acceptable surface dose rate on the packages is 500 mSv h^{-1}. The concrete silo is 50 m high and 25 m in diameter and is surrounded by a bentonite clay barrier.

– BMA (rock cavern for intermediate level waste): contains ILW, mainly ion exchange resins from condensate cleaning systems solidified in cement or bitumen. The waste packages are of the same type as those stored in the silo. About 7% of the total activity in SFR will be placed in this vault, where the highest accepted surface dose rate on the packages is 100 mSv h^{-1}. BMA is divided into pits.

– 1 BTF (rock cavern for concrete tanks and large components) – contains L/ILW, mainly ash from incineration activities but also large components such as reactor vessel lids. The ILW originates from the condensate cleaning systems and consists of dewatered powder resins in concrete tanks. The volume of the waste package emplaced is 10 m^3 (3.3 m by 1.3 m by 2.3 m). About 1.4% of the total activity in SFR will be placed in this vault, where the highest accepted surface dose rate on the packages is 10 mSv h^{-1}.

– 2 BTF (rock cavern for concrete tanks) – contains ILW, mainly dewatered powder resins from the condensate cleaning systems. The volume of the package is 10 m^3 (3.3 m by 1.3 m by 2.3 m). About 1.4% of the total activity in SFR will be placed in this vault, where the highest accepted surface dose rate on the packages is 10 mSv h^{-1}.

– BLA (rock cavern for low level waste in containers) – contains LLW (i.e. all kinds of trash, sweepings, scrap and used components) in ordinary 20 ft ISO containers (1 ft = 0.3048 m). About 0.2% of the total activity in SFR will be placed in this vault, where the highest accepted surface dose rate on the packages is 2 mSv h^{-1}.

REFERENCES TO APPENDIX B

[B-1] Planning and Operation of Low Level Waste Disposal Facilities (Proc. Symp. Vienna, 1996), IAEA, Vienna (1997).

[B-2] ANDRE, T., “Experience of an engineering company in shallow land disposal of L/ILW, planning and operation of low level waste disposal facilities”, Planning and Operation of Low Level Waste Disposal Facilities (Proc. Symp. Vienna, 1996), IAEA, Vienna (1997) 313–328.

[B-3] DUTZER, M., NICOLAS, M., “Operating the Centre de l’Aube”, Planning and Operation of Low Level Waste Disposal Facilities (Proc. Symp. Vienna, 1996), IAEA, Vienna (1997) 243–247.

[B-4] GUPTA, M.P., MONDAL, N.K., BODKE, S.B., BANSAL, N.K., “Indian experience in near surface disposal of low level radioactive solid wastes”, Planning and Operation of Low Level Waste Disposal Facilities (Proc. Symp. Vienna, 1996), IAEA, Vienna (1997) 275–284.

[B-5] MOORE, P.E., HAMBLETON-JONES, B.B., “Planning and operation of Vaalputs, the South African National Radioactive Waste Management Facility”, Planning and Operation of Low Level Waste Disposal Facilities (Proc. Symp. Vienna, 1996), IAEA, Vienna (1997) 67–77.

[B-6] ZULOAGA, A., GUERRA-LIBRERO, A., MORALES, A., “L/ILW disposal experience in Spain after the startup of El Cabril disposal facility”, Planning and Operation of Low Level Waste Disposal Facilities (Proc. Symp. Vienna, 1996), IAEA, Vienna (1997) 261–274.

[B-7] DYBECK, P., KAWEMARK, B., "Experience from eight years of operation of SFR, the final repository for LLW in Sweden", Planning and Operation of Low Level Waste Disposal Facilities (Proc. Symp. Vienna, 1996), IAEA, Vienna (1997) 305–311.

[B-8] CARLSSON, J.S., KARLSSON, F., RIGGARE, P., "Assessment of the long term performance of the Swedish final repository fro radioactive waste, SFR", Planning and Operation of Low Level Waste Disposal Facilities (Proc. Symp. Vienna, 1996), IAEA, Vienna (1997) 353–368.

APPENDIX C
NEAR SURFACE DISPOSAL FACILITY OPERATION SYSTEMS

A variety of operating systems can be used for the disposal of waste (see for example the various papers given in [C-1]). This appendix describes the operation of each of the example disposal facilities described in Appendix B.

C.1. CENTRE DE L'AUBE, FRANCE

The following description of the operation is based on information given in Refs [C-2, C-3].

C.1.1. Disposal cell and mobile framework

During operation, in order to prevent any contact between rainwater and the waste packages, the cell that being filled is covered by a roofed metallic framework. This framework covers the cell being filled and part of the preceding cell in the same vault; it is therefore used as an unloading station for trailers. The framework supports the travelling crane, which places the packages in the cell. It can cover all the structures successively, by moving along a row or from one row to another; metallic rails on concrete beams are provided for this purpose.

The overall dimensions of the mobile framework are length 40 m, width 26 m and height 18.5 m. It weighs about 200 t. In order to assure the accurate positioning of waste packages during operation, wind induced structural deformation must be limited. Disposal operations cease when the wind speed exceeds 90 km h^{-1}. The mobile frameworks are supported by four supports situated at the bottom of the main portal frames. Each support is equipped with a bogie. In the filling configuration of a disposal structure, the frame is supported by studs mounted inside the bogie's frame, fixing it over the rails on its four supports. The framework is supported by four bogies during transit. These bogies can be lined up longitudinally to enable the frame to move along the structures on the rolling longitudinal rails or perpendicularly for transit along the central road in order to allow the mobile framework to change rows. Each bogie consists of two rolling elements, one of which is motorised by a detachable electric motor/reduction set and transmission chain.

C.1.2. Waste package handling system

The waste package handling system consists of an overhead travelling crane, a drivers cab and a container grasping device. Its purpose is to unload incoming containers brought in by the trailers and to store them in the disposal structure (Figure C.1).

The travelling crane can reach the entire useful disposal area of the structure in operation and part of the preceding area, enabling containers to be unloaded from transport vehicles and stored at any point in the structure. The crane must present each package in front of the bar code identification device connected to the tracking system before disposal.

To reduce the radiation dose to operators, the travelling crane is remotely controlled from a local shielded cab. The cab, located inside the metallic framework, is equipped with lead glass windows allowing direct visual control of unloading operations. The operator can also use video cameras to control package handling operations in the disposal structure.

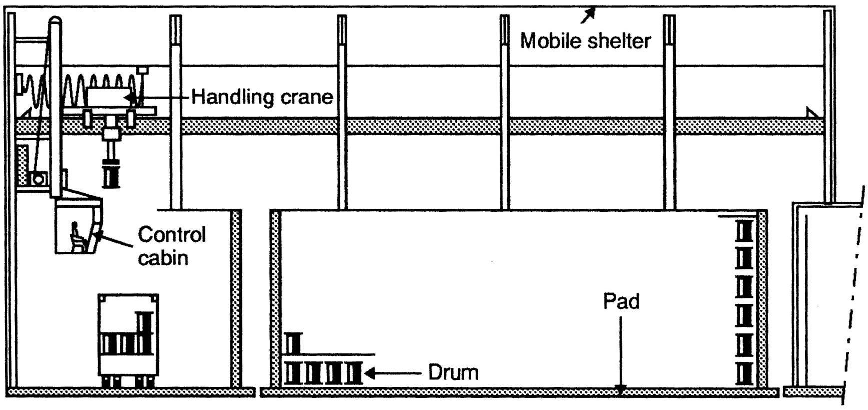


FIG. C.1. The handling system at Centre de l'Aube.

The packages can be grasped by different devices, depending on their geometry, dimensions and weight. Cranes of 3, 10 or 30 ton capacity are available.

The automation of the travelling crane is designed for package cartography management inside the disposal structure, and particularly to delimit the motion of packages of different types.

C.1.3. Runoff collection system

A gravity based water collection system is operated to collect any water that may seep into the cells during operating. The water is routed to basins where it can be sampled and analysed for activity. The collection system starts at the base of each vault, runs through underground drains, and discharges into two 250 m^3 basins.

C.1.4. Closure of disposal cells

There are two types of disposal cells.

- Those designed to receive packages with durable walls (e.g. concrete boxes). In these cells closure operations begin when the cell has been filled with waste packages. Gravel is transferred on a conveyor belt onto the waste packages and is spread out with a bucket suspended from a crane.
- Those designed to receive packages which do not have durable walls (e.g. metallic drums). In these cells, successive layers of waste packages are backfilled with concrete before the following layers are put into place. All pouring operations are performed with a system using a concrete pump and a long-reach articulated arm mounted on a truck.

When a cell has been backfilled, it is closed with a concrete slab consisting of biological concrete shielding covered with a reinforced concrete layer. To protect the close cell whilst the remaining cells are filled, a provisional polyurethane layer is placed over it. The final cover is a waterproof protection consisting of several layers of drainage material and clay with a top surface vegetation cover. The cover is sloped to prevent stagnant water from collecting. It is envisaged that the cover will be maintained during the 300 year institutional control period.

An illustrative cross-section through the closed disposal facility is given in Figure C.2.

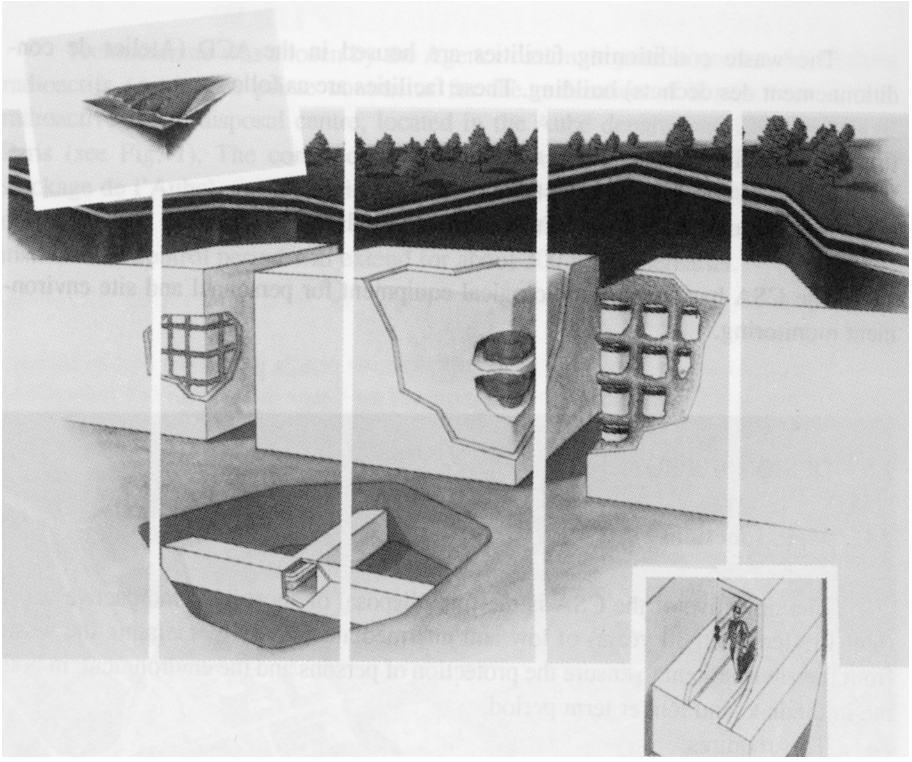


FIG. C.2. Illustrative cross-section through the closed disposal facility at Centre de l'Aube.

C.2. TROMBAY, INDIA

The following description of the operation is based on information given in Ref. [C-4].

All active operations are carried out using mechanical devices such as forklift trucks, mobile cranes or gantry cranes. The reinforced concrete trenches are serviced by gantry crane or mobile crane. Each trench can receive waste packed in drums, cartons or polythene bags, depending upon the origin and nature of the waste. Drums are stacked in two to four tiers, with the higher activity drums in the bottom layer. The entire battery of tile holes is serviced by a gantry crane or a mobile crane for handling shielded containers and waste packages.

The earth trenches are closed by adding about 1 m of soil cover. Each tile hole is provided with a concrete plug on top for shielding during operation and for permanent sealing. A special closure procedure, updated with experience, has been adopted to prevent ingress of rainwater into the reinforced concrete trenches. Pre-cast concrete slabs are placed on top after the trenches are filled to give necessary shielding. Over the slabs, a reinforced concrete cover is provided with properly spaced construction joints. The upper cover is given a suitable slope to facilitate quick self-drainage. To prevent ingress of monsoon water, the reinforced concrete cover is then covered with a polythene sheet, rich cement mortar and rubble consisting of broken brick ('brick bat coba'), and is finally plastered with water repellent cement.

C.3. VAALPUTS, SOUTH AFRICA

The following description of the operation is based on information given in Ref. [C-5].

Although Vaalputs is a national repository, the client is almost exclusively Koeberg nuclear power station. LLW from Koeberg is packed in metal drums, and ILW is immobilized in concrete containers of varying wall thickness to accommodate wastes of different activities. The dose rate on the outside of each package must not exceed 2 mSv h^{-1}. Blanket approval was obtained from the Council for Nuclear Safety (CNS) to transport 'standard' loads of waste packages from Koeberg to Vaalputs by road. A standard load consists of four concrete containers and up to 16 metal drums, all of which must meet Vaalputs' waste acceptance criteria. Permission to transport other loads must be obtained from the CNS. Only limited waste treatment is carried out at Vaalputs, e.g. treating damaged backages, immobilising any radioactive effluent produced at Vaalputs and immobilising cobalt sources in concrete containers. No radioactive liquid effluent has been produced at Vaalputs.

A 50 t mobile crane is used to unload waste consignments at Vaalputs using suitable handling equipment. The waste packages are placed in an orderly manner in the trenches, and details of the packages and their positions in the trenches are recorded in a database.

The intention is to construct clay caps on the trenches, consisting of a number of layers 150 mm thick and compacted at an optimum moisture content of approximately 13%. The caps will be approximately 2 m thick at the centre and 1.5 m thick at the side of the trench.

C.4. EL CABRIL, SPAIN

The following description of the operation is based on information given in reference [C-6]. Key elements of the disposal system are shown in Figure C.3.

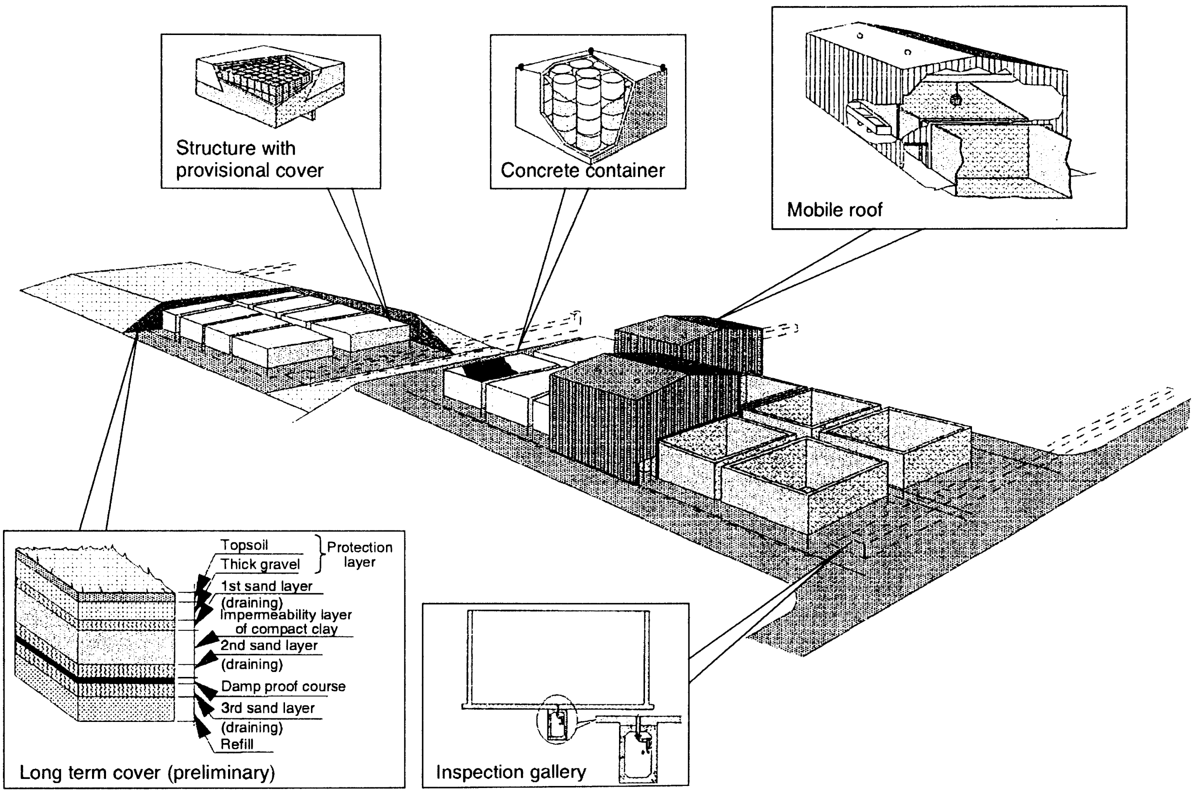


FIG. C.3. Key elements of El Cabril disposal system.

During the operational phase, each row of disposal vaults is served by a rail mounted roof shelter, which is placed above the disposal vault currently in operation. After the vault has been waterproofed, the shelter is moved to the adjoining vault. The shelter carries a 32 tons travelling crane for handling the waste containers. The travelling cranes are operated by remote control from the Control Room, located in the Conditioning Building, thus minimising doses in operation.

The waste container transport lorries are placed in a side corridor located between the disposal vaults and the roof wall. Outside this is an additional corridor. The width of this corridor may seem excessive at first sight, but it is needed to allow the storage facility to be covered with the waterproof covering, with adequately sloping banks.

The waste packages, most of which are 0,22 m^3 steel drums, are stored inside concrete storage containers. The drums are immobilized inside the container, forming a concrete block weighing some 24 tonnes and with external dimensions of 2.25 × 2.25 × 2.20 metres. These containers are placed in piles in vaults. The containers are placed in contact with each other, a central cross or strip being left to allow for container manufacturing or positioning tolerances. Once each disposal vault has been fully loaded, the central strip is filled with gravel to stiffen the assembly and fill in gaps, and an upper closing slab is built. The structure is then waterproofed with a synthetic covering.

Any seepage water is collected at the base of each vault and is channelled to a network of pipes installed in inspection drifts located below the disposal vaults. Each vault is linked to this network, called the infiltration control network, via a holding tank, so that if water is collected in the control network, it is possible to know which vault it has come from in order to repair the protective covering, and to take samples of the water collected. This passively operating network of pipes discharges into a final control tank, with a year's collection capacity, taking into account both the rated seepage and infiltration resulting from possible covering subsidence. This makes it possible to monitor the working of the disposal system, detecting and determining the origin of abnormal amounts of seepage water, as well as its possible contamination.

When El Cabril is closed, the disposal facility will be covered with a low permeability cap formed by alternating layers of waterproofing and drainage material.

C.5. SFR, SWEDEN

The following description of the operation is based on information given in Refs [C-7, C-8].

Transport of waste packages to SFR is mainly by sea. About 100 large steel containers are received and unloaded in SFR every year by a transport vehicle, which is also use to transport the waste down into the facility. The handling operations for ILW are remote controlled from an underground control centre using an overhead crane installed in the silo or cavern. LLW packages are handled by a shielded forklift truck. After each third layer of waste packages is emplaced in the silo, the waste is sealed in the shafts using a special type of concrete. The concrete mixing station is placed in a rock cavern close to the silo, which allows direct lifting and pouring of the concrete into the silo shafts. Sealing is done in campaigns during the year. Sealing is also performed in the BMA. After the pits have been filled with waste, concrete ‘roof’ elements are placed over each pit.

A computerised management system is in operation, consisting of a waste database connected to all Swedish nuclear power plants. It allows the Swedish Nuclear Fuel and Waste Management Company (SKB) to check all waste packages before they are sent to SFR. The database is connected to remotely controlled operation systems in SFR.

During summer, outside temperatures can be much higher than the temperature in the caverns and the atmospheric humidity is very high. This can sometimes cause fog to appear in the caverns. The high humidity can also cause corrosion damage to the installed equipment. To solve this problem a heat pump has been installed. The pump heats the air in the caverns in the winter and cools it during the summer.

REFERENCES TO APPENDIX C

[C-1] Planning and Operation of Low Level Waste Disposal Facilities (Proc. Symp. Vienna, 1996), IAEA, Vienna (1997).

[C-2] ANDRE, T., "Experience of an engineering company in shallow land disposal of L/ILW, planning and operation of low level waste disposal facilities", Planning and Operation of Low Level Waste Disposal Facilities (Proc. Symp. Vienna, 1996), IAEA, Vienna (1997) 313–328.

[C-3] DUTZER, M., NICOLAS, M., "Operating the Centre de l'Aube", Planning and Operation of Low Level Waste Disposal Facilities (Proc. Symp. Vienna, 1996), IAEA, Vienna (1997) 243–247.

[C-4] GUPTA, M.P., MONDAL, N.K., BODKE, S.B., BANSAL, N.K., "Indian Experience in near surface disposal of low level radioactive solid wastes", Planning and Operation of Low Level Waste Disposal Facilities (Proc. Symp. Vienna, 1996), IAEA, Vienna (1997) 275–284.

[C-5] MOORE, P.E., HAMBLETON-JONES, B.B., "Planning and operation of Vaalputs, the South African National Radioactive Waste Management Facility", Planning and Operation of Low Level Waste Disposal Facilities (Proc. Symp. Vienna, 1996), IAEA, Vienna (1997) 67–77.

[C-6] ZULOAGA, A., GUERRA-LIBRERO, A., MORALES, A., "L/ILW disposal experience in Spain after the startup of El Cabril disposal facility", Planning and Operation of Low Level Waste Disposal Facilities (Proc. Symp. Vienna, 1996), IAEA, Vienna (1997) 261–274.

[C-7] DYBECK, P. AND KAWEMARK, B., "Experience from eight years of operation of SFR, the final repository for LLW in Sweden", Planning and Operation of Low Level Waste Disposal Facilities (Proc. Symp. Vienna, 1996), IAEA, Vienna (1997) 305–311.

[C-8] CARLSSON, J.S., KARLSSON, F., RIGGARE, P., "Assessment of the long term performance of the Swedish final repository for radioactive waste, SFR", Planning and Operation of Low Level Waste Disposal Facilities (Proc. Symp. Vienna, 1996), IAEA, Vienna (1997) 353–368.

APPENDIX D
NEAR SURFACE DISPOSAL FACILITY CLOSURE SYSTEMS

There are four types of barrier concepts that may be used singly or in combination to help isolate the waste once a disposal facility is finally closed. These are resistive barrier, conductive barrier, infiltration control, and vegetated soil cover. This appendix provides two examples of multi-barrier concepts of the closure system, i.e. one for a disposal facility that is yet to be closed (IRUS, Canada), and the other one for closed disposal facility (Centre de la Manche, France). Some other examples are briefly mentioned in Appendix C.

D.1. IRUS, CANADA

The following description is based on information given in Refs [D-1, D-2].

The IRUS (Intrusion Resistant Underground Structure) is situated at the Chalk River Laboratories of the Atomic Energy of Canada Limited (AECL). It is designed to accommodate Canada's LLW derived from nuclear applications.

IRUS (Figure D.1) will be a below ground vault, 31.6 m long, 21.6 m wide, by 8.6 m high, measured from the bottom of the foundation to the underside of the roof, and will be constructed entirely of reinforced concrete, with the walls and roof 0.61 m and 1.0 m thick respectively. The outer walls will be arched in the plane view so that when the cells are empty, the external soil pressure creates compressive stresses within the wall reducing the reinforcing bar requirements and decreasing the costs. Internal walls separate the unit into six cells, with a combined internal volume of 3,800 m^3 available for the waste packages and backfill.

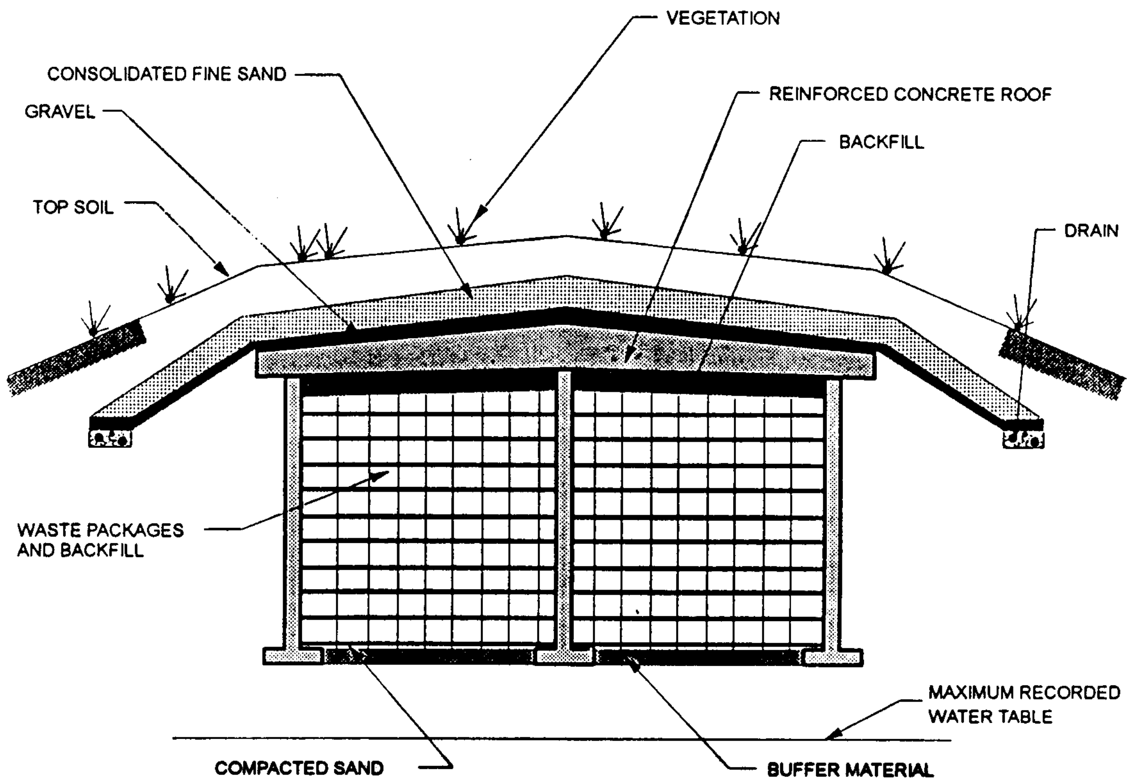


FIG. D.1. Transverse section through IRUS after closure.

The foundation of the unit will be located on well compacted ground at least one metre above the maximum recorded water table. To avoid the possibility of the vault becoming filled with water for a prolonged period of time due to eventual leakage, the floor of the vault is permeable. The floor will consist of two buffer layers, the first composed of a mixture of sand and clinoptilolite, and the second a mixture of sand and Dochart clay. The clinoptilolite and Dochart clay have the ability to absorb many critical radionuclides, and can thus reduce radionuclide escape from the vault.

After the unit is filled with waste and backfill (sand and clinoptilolite), the one metre thick, reinforced-concrete roof slab will be poured in place and will be given a waterproof coating. The whole unit will then be buried beneath an earthen cover of at least 2 m thickness (Figure D.1) to place the concrete roof well below the expected frost penetration and so prevent any damage resulting from freeze-thaw cycles. The earthen cover will incorporate various layers to divert infiltrating rainwater and snowmelt away from the vault. It will also be contoured to facilitate runoff and will be protected from erosion by gentle slopes and hardy vegetation.

D.2. CENTRE DE LA MANCE, FRANCE

The following description is based on information given in reference [D-3].

Centre de la Manche was opened in 1969 for the disposal of LLW. From then until 1994, 525,000 m^3 of waste were disposed over an area of 14 ha. Site preparation and cap emplacement were conducted over the period from 1990 to 1996. As part of the French Nuclear Safety Rules (NSRs) governing the surface disposal of short lived radioactive wastes, a cap has to be built to cover the disposal facility. The cap should be design to be part of the engineered barrier to provide long-term protection for the disposed waste against water and biological intrusion.

D.2.1. Design criteria of the cap

The cap is designed to restrict the flow of water into the disposal structures to no more than a few litres per square metre per year. Therefore, the final cap must meet five criteria, as discussed below.

Impermeability: The amount of rainwater penetrating the cap and coming into contact with the waste must be extremely low to prevent radionuclide leaching and subsequent migration.

Integrity: The cap must retain the required impermeability under all environmental conditions, including oxidation, exposure to mineral salts and the presence of organic acids in infiltration water, micro-organic attack and mechanical load.

Elasticity: The cap must remain impermeable under topographical changes that may occur as a result of subsidence of the engineered disposal modules and settling of waste packages.

Protection: The cap must resist external forces such as erosion, freeze-thaw cycles and biological intrusion. The disposal cap must be sufficiently thick and made of appropriate materials to protect the disposal units from such external forces.

Repairability: The impermeability performance of the disposal cap cannot be guaranteed over a period of several hundred years without maintenance or repairs. Even if the construction materials are selected for their reliability over the long term, the cap must be designed to minimise maintenance and facilitate repairs.

D.2.2. Design of the cap

The final cap at the Centre de la Manche looks like a roof made of sloped panels. Each panel is 25 m wide and the largest panel measures 140 m × 25 m. The panels on the outer edge of the disposal zone are approximately at the same elevation as the top of the disposal modules. The total thickness of the final cap varies from 4 to 10.5 m. From the disposal zone to the side boundaries, the cap slopes at a 2.3:1 incline until it reaches the perimeter road.

D.2.2.1. Multiple layer cap

The final disposal cap consists of a multiple layer complex, as shown in Figure D.2. Starting from the base of the cap, it comprises:

- A bottom layer of schistose material designed to create the basic slope of the disposal cap and contribute to the global imperviousness of the cover;
- A drainage layer made of fine-grain sand to collect water beneath the bituminous geotextile;
- A bituminous geomembrane made of a bitumen saturated geotextile;
- A drainage layer made of fine-grain sand to collect water that penetrates the biological barrier above;
- A semi-impermeable layer of schist to minimise the amount of water infiltration and to protect the membrane against root systems and burrowing animals;
- A layer of topsoil to promote grass growth.

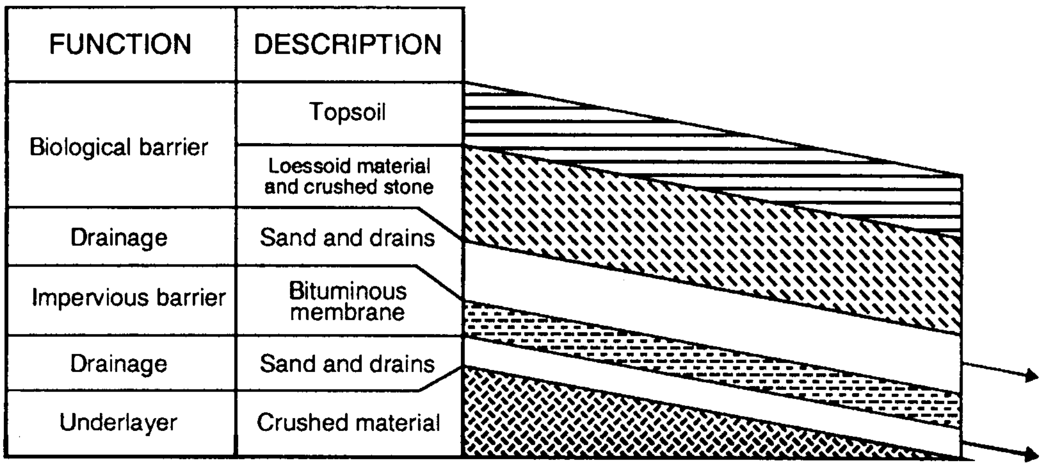


FIG. D.2. Cross-section through the final cap at Centre de la Manche.

D.2.2.2. Water collection system for the covered zone

Runoff water is separated from infiltration water by: a system of large pipes for surface water located underneath the site perimeter road; and a system of smaller pipes for infiltration water drained from the cap. Runoff water is collected at the bottom of each roof panel. All surface water is diverted through concrete channels to a 1000 mm drainage pipe.

Two drainage systems above and beneath the bituminous geomembrane collect all infiltration water. The upper drainage system consists of a layer of sand in which the drains are placed. Their purpose is to minimise the hydraulic head on the geomembrane. The lower drainage system consists of a layer of sand and two drains. There is one drain for each cap panel so that the source of a failure of the geomembrane can be located.

All drains are connected to monitoring chambers located along the side of the perimeter road. All monitoring chambers are linked to a main pipe, as shown in Figure D.3.

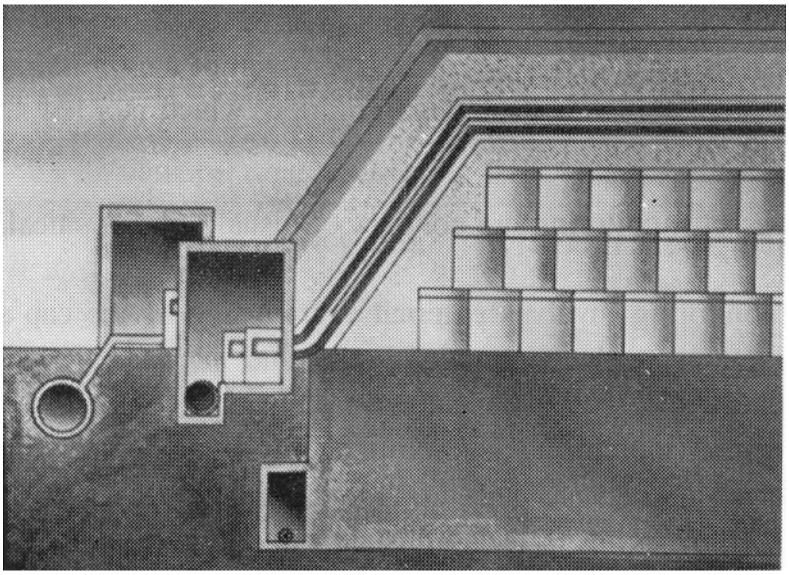


FIG. D.3. Monitoring chambers for infiltration water at Centre de la Manche.

The two surface water collection systems, one on the east side of the disposal site and one on the west side, drain water into the main monitoring station, which is equipped with flow meters, radioactivity monitoring equipment and pH meters. The monitoring station is connected to a storm basin that regulates the flow of water downstream to the Sainte Hélène stream.

The two drainage water collection systems, also to the east and west of the disposal site, will drain northwest into the drainage monitoring station, which is equipped with flow meters and radioactivity monitors.

REFERENCES TO APPENDIX D

[D-1] CHARLESWORTH, D.H., CHAMP, D.R., "Transition from storage to disposal of LLW at Canada's Chalk River Laboratories", Planning and Operation of Low Level Waste Disposal Facilities (Proc. Symp. Vienna, 1996), IAEA, Vienna (1997) 79–88.

[D-2] RATTAN, D.S., STEPHENS, M.E., ROWAT, J.H., DOLINAR G.M., "Uncertainty and sensitivity analysis in the post-closure performance assessment of a Canadian LLW disposal facility", Planning and Operation of Low Level Waste Disposal Facilities (Proc. Symp. Vienna, 1996), IAEA, Vienna (1997) 313–328.

[D-3] POTIER, J.-M., "Final closure of a low level waste disposal facility Planning and Operation of Low Level Waste Disposal Facilities (Proc. Symp. Vienna, 1996), IAEA, Vienna (1997) 243–247.

CONTRIBUTORS TO DRAFTING AND REVIEW

Bell, M.J.	International Atomic Energy Agency
Champ, D.R.	AECL, Chalk River Laboratories, Canada
Dayal, R.	International Atomic Energy Agency
Fernique, J.	ANDRA, France
Han, K.W.	International Atomic Energy Agency
Kawakami, Y.	JAERI, Japan
Kostelnik, K.	Lockheed Martin Idaho Technologies, USA
Iimura, H.	JNFL, Japan
Lange, B.	AECL, Chalk River Laboratory, Canada
Little, R.H.	Quintessa, United Kingdom
Loubrieu, B.	ANDRA, France
Löwendahl, B.	OKG Aktiebolag, Sweden
Matsuzuru, H.	JAERI, Japan
Nachmilner, L.	RAWRA, Czech Republic
Potier, J.M.	ANDRA, France
Seo, J.M.	KAERI, Republic of Korea
Tamborini, J.	ANDRA, France
Wang, X.	Beijing Institute of Nuclear Engineering, China
Wisbey, S.	UK Nirex, United Kingdom
Zuloaga, P.	ENRESA, Spain

Consultants Meetings

Vienna, Austria: 28 September–2 October 1992

Vienna, Austria: 21–25 March 1994

Advisory Group Meeting

Vienna, Austria: 10–14 May 1993

01-02863