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# Modular Design of Processing and Storage Facilities for Small Volumes of Low and Intermediate Level Radioactive Waste including Disused Sealed Sources

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# MODULAR DESIGN OF PROCESSING AND STORAGE FACILITIES FOR SMALL VOLUMES OF LOW AND INTERMEDIATE LEVEL RADIOACTIVE WASTE INCLUDING DISUSED SEALED SOURCES

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IAEA NUCLEAR ENERGY SERIES No. NW-T-1.4

# MODULAR DESIGN OF PROCESSING AND STORAGE FACILITIES FOR SMALL VOLUMES OF LOW AND INTERMEDIATE LEVEL RADIOACTIVE WASTE INCLUDING DISUSED SEALED SOURCES

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# FOREWORD

One of the IAEA's statutory objectives is to "seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world." One way this objective is achieved is through the publication of a range of technical series. Two of these are the IAEA Nuclear Energy Series and the IAEA Safety Standards Series.

According to Article III.A.6 of the IAEA Statute, the safety standards establish "standards of safety for protection of health and minimization of danger to life and property". The safety standards include the Safety Fundamentals, Safety Requirements and Safety Guides. These standards are written primarily in a regulatory style, and are binding on the IAEA for its own programmes. The principal users are the regulatory bodies in Member States and other national authorities.

The IAEA Nuclear Energy Series comprises reports designed to encourage and assist R&D on, and application of, nuclear energy for peaceful uses. This includes practical examples to be used by owners and operators of utilities in Member States, implementing organizations, academia, and government officials, among others. This information is presented in guides, reports on technology status and advances, and best practices for peaceful uses of nuclear energy based on inputs from international experts. The IAEA Nuclear Energy Series complements the IAEA Safety Standards Series.

There are a number of IAEA Member States generating relatively small quantities of radioactive waste, including disused sealed sources from nuclear applications and research. This publication addresses a continuing need to support such Member States in establishing new facilities or in upgrading existing facilities for the processing and storage of their radioactive waste in a safe and cost effective manner. It presents a modular approach to the design of such facilities that is flexible and appropriate for relatively small volumes of waste having a variety of characteristics, and provides guidance on the selection of technical options, and formulation of design specifications and operational procedures. The publication is based on work carried out by Nuvia Ltd, an engineering company in the United Kingdom contracted by the IAEA. It is hoped that this modular design approach will be useful for Member States planning to establish or upgrade facilities for the processing and storage of radioactive waste, mainly from non-power nuclear applications.

The IAEA thanks those who took part in the development and review of this work, particularly D. Keene (United Kingdom), who coordinated the work for Nuvia Ltd. Useful inputs were obtained from several workshops that were conducted to present the modular design approach to Member States in the framework of the IAEA's technical cooperation programme. Special thanks are due to V. Tsyplenkov and Z. Drace for their contributions. The IAEA officer responsible for this publication was S.K. Samanta of the Division of Nuclear Fuel Cycle and Waste Technology.

## *EDITORIAL NOTE*

# CONTENTS

# 1. INTRODUCTION

## 1.1. BACKGROUND

A number of IAEA Member States generate relatively small quantities of radioactive waste and/or disused sealed sources in the application of nuclear techniques in medicine, industry and research, and in nuclear research centres having small research reactors. As part of its activities to support these Member States to manage their radioactive waste in a safe and cost effective manner, the IAEA developed a reference design for construction of a centralized waste processing and storage facility (WPSF) in the 1990s [1.1]. At about the same time, the IAEA also developed a reference design for a centralized spent sealed source facility [1.2]. This design, consisting of a conditioning facility and an interim storage building, was intended for countries generating small amounts of mainly sealed sources and other solid waste from nuclear applications.

These reference designs have since been used as input by some Member States in their process to establish national facilities for processing and storage of radioactive wastes including disused sealed sources. However, the situation at present is that some IAEA Member States still do not have adequate facilities for processing and storing their radioactive waste, notably in those countries with very small quantities of generated radioactive waste. In other Member States the existing waste processing and storage facilities are in need of varying degrees of upgrading so as to address new waste streams, incorporate new waste processing technologies, or expand interim storage capacities. Thus, there is a need to continue to support such Member States in establishing new WPSFs or upgrading existing WPSFs.

Because of the wide variation in the types and quantities of radioactive waste, fixed designs like the ones developed earlier may not be adequate to meet the different needs of these Member States. One very effective way to achieve the required waste processing flexibility is to develop a WPSF design that is based on a variety of modules for different waste stream treatment and conditioning processes. Each module can be constructed locally or pre-fabricated and delivered as skids and then combined with other modules to meet country specific needs. Similarly for storage, different storage module concepts are available, ranging from simple storage cabinets to a purpose designed storage building. Depending on the volume of waste to be stored, the most appropriate concept can be selected.

The present publication is the result of an effort to address the needs of Member States with a modular design approach that is more flexible and appropriate for the relatively small volumes of waste having a variety of characteristics than the previous two reference designs. It is primarily intended for use by waste management professionals responsible for selecting, designing and deploying waste processing and storage systems. It could also assist regulators responsible for reviewing and licensing waste processing and storage systems in these Member States.

## 1.2. OBJECTIVE

The main objective of this publication is to present a modular design approach for waste processing and storage facilities for the relatively small volumes of waste having a variety of characteristics that are generated from nuclear applications and research. It presents guidance on the overall requirements for setting up such facilities, selection of technical options for processing and storage, and formulation of design specifications and operational procedures.

## 1.3. SCOPE

This publication is aimed at Member States that generate small volumes of low and intermediate level radioactive waste, including disused sealed radioactive sources. In particular, it is addressed to:

— Member States that do not have facilities for processing and storing their radioactive waste;

— Other Member States that may have existing WPSFs, but that are in need of varying degrees of upgrading so as to address new waste streams, incorporate new waste processing technologies, or expand interim storage capacities.

The design and specification information presented in this publication should enable users to: determine their requirements; specify those requirements to allow the procurement of the appropriate processing and storage modules; install those modules; and eventually operate them. It does not provide detailed engineering designs of modular waste treatment plant or waste storage modules.

Special waste occurring in a limited number of countries and waste occurring in large quantities (such as naturally occurring radioactive material (NORM) waste, waste from mining and milling and waste from nuclear power plants) are not addressed in this design package.

## 1.4. STRUCTURE

Following this introduction, Section 2 provides a summary of the types and quantities of liquid and solid waste streams, including disused sealed sources that have been used as the basis for developing treatment and conditioning module specifications and concept designs for the modules.

A short description of the various processing module options considered in this work is provided in Section 3. Section 4 provides guidance on the selection of appropriate processing modules for particular applications with the help of decision flow charts.

Section 5 provides detailed guidance on design and specification of the different processing modules. Information is included on the basis of design, process flow diagrams (PFDs), equipment lists and descriptions, facility requirements, process descriptions, etc., and is presented in descriptions that can be adapted to procurement specifications. For each module the presented information can be used on stand-alone basis.

Section 6 provides guidance on process module integration.

The types and quantities of conditioned waste packages resulting from processing and requiring storage are summarized in Section 7.

A short description of the various storage module options considered in this work is provided in Section 8, and guidance is provided in Section 9 on the selection of appropriate storage options for particular applications with the help of decision flow charts.

Section 10 provides detailed guidance on the design and specification of storage modules with new, purpose built storage building as an example. Information is included on building functional requirements and requirements for operation, mechanical handling, mechanical and electrical equipment, environmental control, seismicity, radiation and industrial safety, maintenance and inspection, physical protection, etc., and is presented in descriptions that can be adapted to procurement specifications.

An overview of operating guidelines for a waste processing and storage facility is provided in Section 11, and Section 12 provides an overview of the major requirements for setting up such facilities. Section 13 presents the conclusions.

Annex I summarizes the typical headings and content of a technical procurement specification. Annex II presents guidance to the user on how to specify the requirements for the procurement of individual modules, with a sample procurement specification for a processing module.

## 1.5. KEY DEFINITIONS

Some key definitions of terms used in this publication are given below [1.3].

**Conditioning.** Those operations that produce a waste package suitable for handling, transport, storage and/or disposal. Conditioning may include the conversion of the waste to a solid waste form, enclosure of the waste in containers and, if necessary, provision of an over pack.

**Disused source.** A radioactive source that is no longer used, and is not intended to be used, the practice for which an authorization has been granted.

**Immobilization.** Conversion of waste into a waste form by solidification, embedding or encapsulation. Immobilization reduces the potential for migration or dispersion of radionuclides during handling, transport, storage and/or disposal.

**Over pack.** A secondary (or additional) outer container for one or more waste packages, used for handling, transport, storage and/or disposal.

**Processing.** Any operation that changes the characteristics of waste, including pretreatment, treatment and conditioning.

**Sealed source.** Radioactive material that is: (a) permanently sealed in a capsule; or (b) closely bonded and in a solid form.

**Segregation.** An activity where types of waste or material (radioactive or exempt) are separated or are kept separate on the basis of radiological, chemical and/or physical properties, to facilitate waste handling and/or processing.

**Storage.** The holding of radioactive sources, spent fuel or radioactive waste in a facility that provides for their/its containment, with the intention of retrieval.

**Treatment.** Operations intended to benefit safety and/or economy by changing the characteristics of the waste. Three basic treatment objectives are: (a) volume reduction; (b) removal of radionuclides from the waste; (c) change of composition. Treatment may result in an appropriate waste form. If treatment does not result in an appropriate waste form, the waste may be immobilized.

**Volume reduction.** A treatment method that decreases the physical volume of a waste. Typical volume reduction methods are mechanical compaction, incineration and evaporation.

**Waste form.** Waste in its physical and chemical form after treatment and/or conditioning (resulting in a solid product) prior to packaging. The waste form is a component of the waste package.

**Waste package.** The product of conditioning that includes the waste form and any container(s) and internal barriers (e.g. absorbing materials and liner), as prepared in accordance with requirements for handling, transport, storage and/or disposal.

## REFERENCES TO SECTION 1


[1.1] INTERNATIONAL ATOMIC ENERGY AGENCY, Reference Design for a Centralized Waste Processing and Storage Facility, IAEA-TECDOC-776, IAEA, Vienna (1994).

[1.2] INTERNATIONAL ATOMIC ENERGY AGENCY, Reference Design for a Centralized Spent Sealed Sources Facility, IAEA-TECDOC-806, IAEA, Vienna (1995).

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

# 2. TYPES AND QUANTITIES OF WASTE STREAMS

As mentioned in Section 1, this publication addresses the needs of Member States that generate relatively small quantities of low and intermediate level waste and disused sealed sources. Previous work by the IAEA has reviewed typical waste streams generated by such Member States and identified their principal characteristics. Table 2.1 summarizes these waste streams. It is assumed that these waste streams will require processing to produce conditioned waste packages for storage if no other management option is available. It should be noted that not all Member States will necessarily produce all of these waste streams.

The waste stream information provided in this table has been used as a basis for developing the waste treatment and conditioning process module specifications and the concept designs for these modules. Each waste stream is identified by a letter (A: low volume aqueous liquid; B: high volume aqueous liquid, etc.); these letters are also used to identify the individual waste treatment and conditioning process modules.

This publication does not specifically address waste and disused sealed sources with very short lived radionuclides that are suitable for decay storage and, therefore, are not included in Table 2.1. Such waste can be safely stored until clearance levels have been reached.

TABLE 2.1. WASTE STREAM DESCRIPTION

| Matrix cross-reference number[a] | Waste stream | Annual quantity to be processed | Waste origin and waste type[b] | Waste characteristics |
|---|---|---|---|---|
| A | Low volume aqueous liquid. | Typically up to 0.5 $m^3$; for the reference design 0.1 $m^3$ should be used. | Laboratories, hospitals, etc. | Mainly low levels of activity, single or multiple radionuclides, simple to complex chemical composition. |
| B | High volume aqueous liquid. | Typically in the range 0.5–10 $m^3$; for the reference case 5 $m^3$ should be used. | Laboratories, hot cells, research reactor spent fuel storage pool, decontamination, sump and rinsing collection, etc. | Mainly low levels of activity, single or multiple radionuclides, simple to complex chemical composition. |
| C | Organic liquid. | Typically less than 0.3 $m^3$; for the reference case 0.1 $m^3$ should be used. | Scintillation solutions, oil (e.g. from pumps), extraction solvent, etc. | Mainly low levels of activity, single or multiple radionuclides. |
| D | Compactable solid. | Typically less than 20 $m^3$; for the reference case 5 $m^3$ should be used. | Paper, cardboard, plastics, rubber, gloves, etc. | Total activity typically <50 GBq and not containing significant quantities of long lived radionuclides. |
| E | Non-compactable solid. | Typically less than 5 $m^3$; for the reference case 1 $m^3$ should be used. | Glassware, metallic items, scrap, etc.; disused sealed sources are included as a separate waste stream. | Total activity typically <10 GBq and not containing significant quantities of long lived radionuclides. |
| F | Ion exchange (IX) resin. | Typically less than 0.5 $m^3$; for the reference case 0.1 $m^3$ should be used. | Ion exchange resins: research reactor tank and spent fuel storage pool, as secondary waste from treatment by IX, etc. | Total activity typically <1 GBq and not containing significant quantities of long lived radionuclides. |

TABLE 2.1. WASTE STREAM DESCRIPTION (cont.)

| Matrix cross-reference number[a] | Waste stream | Annual quantity to be processed | Waste origin and waste type[b] | Waste characteristics |
|---|---|---|---|---|
| G | Sludge. | Typically less than 0.5 $m^3$; for the reference case 0.1 $m^3$ should be used. | Sludge: secondary waste from evaporation and chemical treatment, etc. | Total activity typically <1 GBq and not containing significant quantities of long lived radionuclides. |
| H | Disused sealed source — short lived isotope.[c] | Large variation of number of sources; for the reference case 20 should be used. | Medical, industrial and research applications, etc. | Short lived in this connection is a half-life of ≤30 years. |
| J | Disused sealed source — long lived isotope.[b] | Large variation in number of sources; for the reference case 20 should be used. | Medical, industrial and research applications, etc. | Long lived in this connection is a half-life of >30 years. |
| K | Biological (carcasses). | Typically up to 0.5 $m^3$; for the reference case 0.1 $m^3$ should be used. | Medical applications and research. Type: animal carcasses, tissues and body fluids. | Typically, small quantities of $^3$H or $^{14}$C. Hazards mainly due to biological and pathological material. |
| L | High activity disused sealed source. | Typically, 1 or 2 sources per year. | Medical, industrial and research applications, etc. | Typically, Category 1 and 2, as defined in IAEA Safety Standards Series No. RS-G-1.9 [2.2]. Common radionuclides include $^{137}$Cs and $^{60}$Co. |

[a] See Section 3.

[b] More details about some of these waste streams can be found in Ref. [2.1].

[c] Higher activity sources, typically Category 1 and 2 as defined in IAEA Safety Standards Series No. RS-G-1.9 [2.2], are dealt with separately under waste stream L and therefore are not considered for these waste streams.

## REFERENCES TO SECTION 2

[2.1] INTERNATIONAL ATOMIC ENERGY AGENCY, Handling and Processing of Radioactive Waste from Nuclear Applications, Technical Reports Series No. 402, IAEA, Vienna (2001).

[2.2] INTERNATIONAL ATOMIC ENERGY AGENCY, Categorization of Radioactive Sources, IAEA Safety Standards Series No. RS-G-1.9, IAEA, Vienna (2005).

# 3. PROCESSING MODULE OPTIONS

Eleven different process modules have been identified for the treatment and conditioning of the range of waste streams discussed in Section 2. The waste stream and process matrix illustrated in Table 3.1 identifies the most common waste processing technologies or ‘processing modules’ that are likely to be used by Member States and the matrix correlates those processes with the waste streams.

It should be noted that each waste stream has the letter designator in the left hand column that was used in Table 2.1 for the description of the waste stream. Similarly, each process module is identified with both the waste stream letter designator and a process numeric designator (e.g. Module A6 is waste stream A, Module 6, which designates the ‘Solidification’ processing technology).

A wide range of waste processing technologies are available [3.1–3.6]. However, not all of these technologies are considered suitable for the applications covered in the design package presented in this publication. For example, some technologies, such as evaporation and incineration, that may be used for treating radioactive waste elsewhere have been reviewed and assessed as being unsuitable, generally because they are too costly and too complex to implement for the relatively small volumes of waste that are anticipated.

From the waste stream and process matrix, the individual process modules have been summarized in Table 3.2, below, identifying the principal waste stream for which they are intended.

It can be noted that a number of the waste processing technologies could be applied to several different waste streams, e.g. the ‘Encapsulation’ module for non-compactable waste will also be able to encapsulate disused sealed sources and animal carcasses. Therefore, it is not necessary to have a different process module for each waste stream. Table 3.2 summarizes the waste streams for which each processing module may be suitable.

TABLE 3.1. WASTE STREAM AND PROCESS MATRIX

| | | Processing module | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Liquid and wet solid waste | | | | | | Solid waste | | | |
| | | 1 | 2 | 3 | 4 | 5 | 6 | 1 | 2 | 3 | 4 |
| Cross-ref. No. | Waste stream | Chemical treatment | Ion exchange | Reverse osmosis | Cross-flow filtration | Filtration | Solidification | Encapsula-tion | Low force compaction | Use of unshielded booth | Use of hot cell module |
| A | Low volume aqueous liquid | | | | | | A6 | | | | |
| B | High volume aqueous liquid | B1 | B2 | B3 | B4 | B5 | B6 | | | | |
| C | Organic liquid | | | | Same as B4 | Same as B5 | Same as A6 | | | | |
| D | Compressible/compacta-ble solid | | | | | | | | D2 | D3 | |
| E | Non-compactable solid | | | | | | | E1 | | Same as D3 | |
| F | Ion exchange resins | | | | | | Same as A6 | | | | |
| G | Sludge | | | | | | Same as A6 | | | | |
| H | Disused sealed source — short lived isotope (half-life ≤30 a) | | | | | | | Same as E1 | | Same as D3 | |
| J | Disused sealed source — long lived isotope (half-life >30 a) | | | | | | | Same as E1 | | Same as D3 | |
| K | Biological (carcasses) | | | | | | | Same as E1 | | | |
| L | High activity disused sealed source | | | | | | | | | | L4 |

TABLE 3.2. SUMMARY DESCRIPTION OF PROCESSING MODULES AND THEIR APPLICATION TO A WASTE STREAM

| Module No. | Processing module | Principal waste stream | Additional compatible waste streams |
|---|---|---|---|
| A1 | **Solidification**<br>Cementation of limited quantities of liquid waste within small containers (typically <20 L). | Sludge (small volumes);<br>Low volume aqueous liquid;<br>Ion exchange resin (small volumes). | Organic liquid. |
| B1 | **Chemical treatment**<br>Batch treatment (typically <500 L) of aqueous liquid to adjust pH or decontaminate by precipitation of radionuclides. | High volume aqueous liquid. | |
| B2 | **Ion exchange**<br>Batch treatment (typically <500 L) of aqueous liquid to decontaminate by removal of soluble radionuclides by ion exchange. | High volume aqueous liquid. | |
| B3 | **Reverse osmosis**<br>Batch treatment (typically <500 L) of aqueous liquid to decontaminate by removal of soluble and insoluble radionuclides by reverse osmosis. | High volume aqueous liquid. | |
| B4 | **Cross-flow filtration**<br>Batch treatment (typically <500 L) of aqueous liquid to decontaminate by removal of soluble and insoluble radionuclides by membrane filtration. | High volume aqueous liquid. | Organic liquid. |
| B5 | **Filtration**<br>Batch treatment (typically <500 L) of aqueous liquid to decontaminate by removal of solids by cartridge filtration. | High volume aqueous liquid. | Organic liquid. |
| B6 | **Solidification**<br>In-drum cementation of liquid or sludge waste to produce a solid waste product. | High volume aqueous liquid. | Sludge (large volumes)<br>Ion exchange media (large volumes). |
| D2 | **Low force compaction**<br>In drum compaction of ‘soft’ compactable waste to reduce waste volume. | Compactable solid. | |
| D3 | **Unshielded booth**<br>Enclosure for manual sorting and segregating of solid waste prior to further processing or conditioning. | Compactable solid. | Non-compactable solid.<br>Disused sealed source (low dose rates). |
| E1 | **Encapsulation**<br>Encapsulation of waste within a cement grout. | Non-compactable solid. | Disused sealed source under special conditions. |
| L4 | **Hot cell module**<br>Shielded cell with remote handling facility for the dismantling and repackaging of high activity sources. | High activity disused sealed sources. | |

## REFERENCES TO SECTION 3

[3.1] INTERNATIONAL ATOMIC ENERGY AGENCY, Handling and Processing of Radioactive Waste from Nuclear Applications, Technical Reports Series No. 402, IAEA, Vienna (2001).

[3.2] INTERNATIONAL ATOMIC ENERGY AGENCY, Selection of Efficient Options for Processing and Storage of Radioactive Waste in Countries with Small Amounts of Waste Generation, IAEA-TECDOC-1371, IAEA, Vienna (2003).

[3.3] INTERNATIONAL ATOMIC ENERGY AGENCY, Treatment and Conditioning of Radioactive Organic Liquids, IAEA-TECDOC-656, IAEA, Vienna (1992).

[3.4] INTERNATIONAL ATOMIC ENERGY AGENCY, Treatment and Conditioning of Radioactive Solid Wastes, IAEA-TECDOC-655, IAEA, Vienna (1992).

[3.5] INTERNATIONAL ATOMIC ENERGY AGENCY, Handling and Treatment of Radioactive Aqueous Wastes, IAEA-TECDOC-654, IAEA, Vienna (1992).

[3.6] INTERNATIONAL ATOMIC ENERGY AGENCY, Techniques and Practices for Pretreatment of Low and Intermediate Level Solid and Liquid Radioactive Wastes, IAEA Technical Reports Series No. 272, IAEA, Vienna (1987).

# 4. SELECTION OF APPROPRIATE PROCESSING MODULES

Section 3 has identified several possible processing options that may be suitable for the waste streams under consideration in this publication. A series of decision flow charts have been developed in order to provide guidance in determining possible management options for these waste streams. Figure 4.1 is a decision flow chart to determine if processing, storage and eventual disposal are necessary, or if an alternative option is available. Decision flow charts in Figs 4.2, 4.3 and 4.5–4.7 provide guidance to determine the most appropriate waste processing technology to apply to a particular waste stream. The following discussion should be read in conjunction with these figures.

## 4.1. RADIOACTIVE WASTE MANAGEMENT STRATEGY CONSIDERATIONS

It is important to establish the waste management strategy prior to embarking on a waste management processing activity. The strategy has to be consistent with the objectives and constraints of the waste producing facility. It should also be consistent with the national policy and strategy unless exceptional circumstances mean that a variation from the national position is acceptable in a particular instance. The national policy and strategy would ideally include the regulatory framework through which a local waste management strategy could be developed and approvals for designs, construction and operation would be obtained [4.1].

In developing a waste management strategy it is important to consider the entire life cycle, from waste generation to waste disposal including decommissioning liabilities. Key considerations in formulating a strategy include:

(a) Safety — optimization of the dose to operators and the public, industrial safety;
(b) Environmental protection — liquid and gaseous discharges, volumes of waste, secondary waste volumes, availability of disposal facilities;
(c) Regulatory regime — existing or emerging regulatory framework;
(d) Technology — flexibility and robustness, ease of operation and maintenance, availability of existing equipment or facilities, including in other Member States;
(e) Economics — purchase cost, operating costs, decommissioning liabilities, timing of costs;
(f) Timescales — safety case and safety assessment, licensing, technology development, implementation.

The generic waste management objectives are:

(i) To make waste safe because of:
   - Its intrinsic radiotoxicity (alpha emitters, beta, high energy gammas):
     - By containment and shielding;
   - The poor condition of the waste:
     - By containment and shielding;
   - The mobility of the waste, e.g. liquids and sludges:
     - By immobilization and stabilization of the waste form;
   - Other physical, chemical or biological properties, e.g. corrosive, pyrophoric, explosive, putrescible, pathogenic:
     - By immobilization and stabilization of the waste form.

(ii) To improve security of the waste:
   - Non-proliferation and counterterrorism.

(iii) To reduce/minimize the volume of the waste:
   - Optimize storage and disposal facilities.

(iv) To reduce/control radiological discharges to the environment:
   - Minimize environmental impact and radiation exposures.

(v) To prepare waste for:
   - Interim storage;
   - Transport to/from the storage area;
   - Transport to the disposal site;
   - Long term storage;

— Disposal;
— Disposal or long term storage following a period of interim storage;
— To optimize handling, transport and emplacement.

The flow chart in Fig. 4.1 starts by asking the reader to consider the national radioactive waste strategy, the regulatory strategy and the supporting standards and guidelines. In the absence of these, advice should be sought from the appropriate national bodies; the IAEA could also be approached for support.

Having determined a suitable and relevant strategy for waste management the next question is to consider whether the waste has been adequately characterized. It is essential to understand the type of waste being considered so that appropriate solutions can be identified. The flow chart suggests the type of information which would be required in order to consider whether any of the existing waste management infrastructures might be suitable given the relevant constraints and limitations on these facilities. For example, it is possible that the waste might be exempted from radiological regulatory controls because it is of sufficiently low radionuclide activity. Most countries have such exemptions to their radiological regulations. An example is the disposal of certain categories of smoke detectors, many of which contain radioactive sources. Similarly, many countries allow the incineration of large volumes of low active waste. In some cases, the waste could be transferred back to their original producers.

Only if the waste cannot be treated by any existing arrangements or routes should a new facility be considered.

## 4.2. RADIOACTIVE WASTE CATEGORIZATION

Having decided that further waste treatment and conditioning are required, it is necessary to categorize and classify the waste in order to determine the appropriate treatment and conditioning options. The flow chart in Fig. 4.2 and the following sections provide a methodology to assess each type of waste in order to determine the most appropriate treatment required.

Some characterization of the waste has previously been required so that the need for radioactive waste treatment and conditioning facilities could be established. It will now be necessary to demonstrate that the waste will meet the acceptance criteria for the waste processing facility and to determine how to process the waste. The waste acceptance criteria will be established during the facility design as part of the safety case such that the facility can handle the waste safely (e.g. packages are not too large or too heavy, external dose rates are acceptable; the waste is appropriately packaged (not leaking or contaminated); and that the technical solutions adopted by the facility can in fact treat this waste (chemical and physical nature, other hazardous materials, etc.).

Nevertheless, it is recognized that the design of the WPSF will not be able to anticipate all possible waste that may be received. If waste is identified that does not meet the existing waste acceptance criteria, then the WPSF should still be prepared to receive this waste and store it safely while advice is sought on the best means of dealing with that waste. Therefore, before the waste is received at the WPSF it is expected that it will have been adequately characterized to ensure that it meets the WPSF waste acceptance criteria. The waste stream descriptions in Table 2.1 illustrate some of the key characteristics that have been assumed in developing the concept designs of the process modules.

Ideally waste should be segregated at source to suit the planned waste management regime, i.e.:

(a) Soft, compressible/compactable waste segregated from non-compactable waste and from biological waste.
(b) Containers of liquid waste separated from solid waste.
(c) Organic liquid segregated from aqueous liquids.
(d) Long lived sources (half-life >30 years) segregated from short lived (half-life ≤30 years) sources. (The intent on the value of half-life is to place $^{137}Cs$ sources in the short lived category).

However, it is recognized that this is not always possible, nor reliable. Therefore it is expected that further inspection and segregation of wastes will be needed on receipt at the WPSF. If the wastes are of low activity, this can be performed in an unshielded booth (Module D3). Here waste is sorted and segregated by hand, or with hand-held tongs and placed into appropriate waste drums.

Waste with higher dose rates, especially disused sealed sources, will require shielding for handling and inspection. It may also be necessary to repackage such waste, e.g. into more appropriate shielded containers, or if the sources are leaking or contaminated. For this purpose, the IAEA has developed a mobile hot cell module.

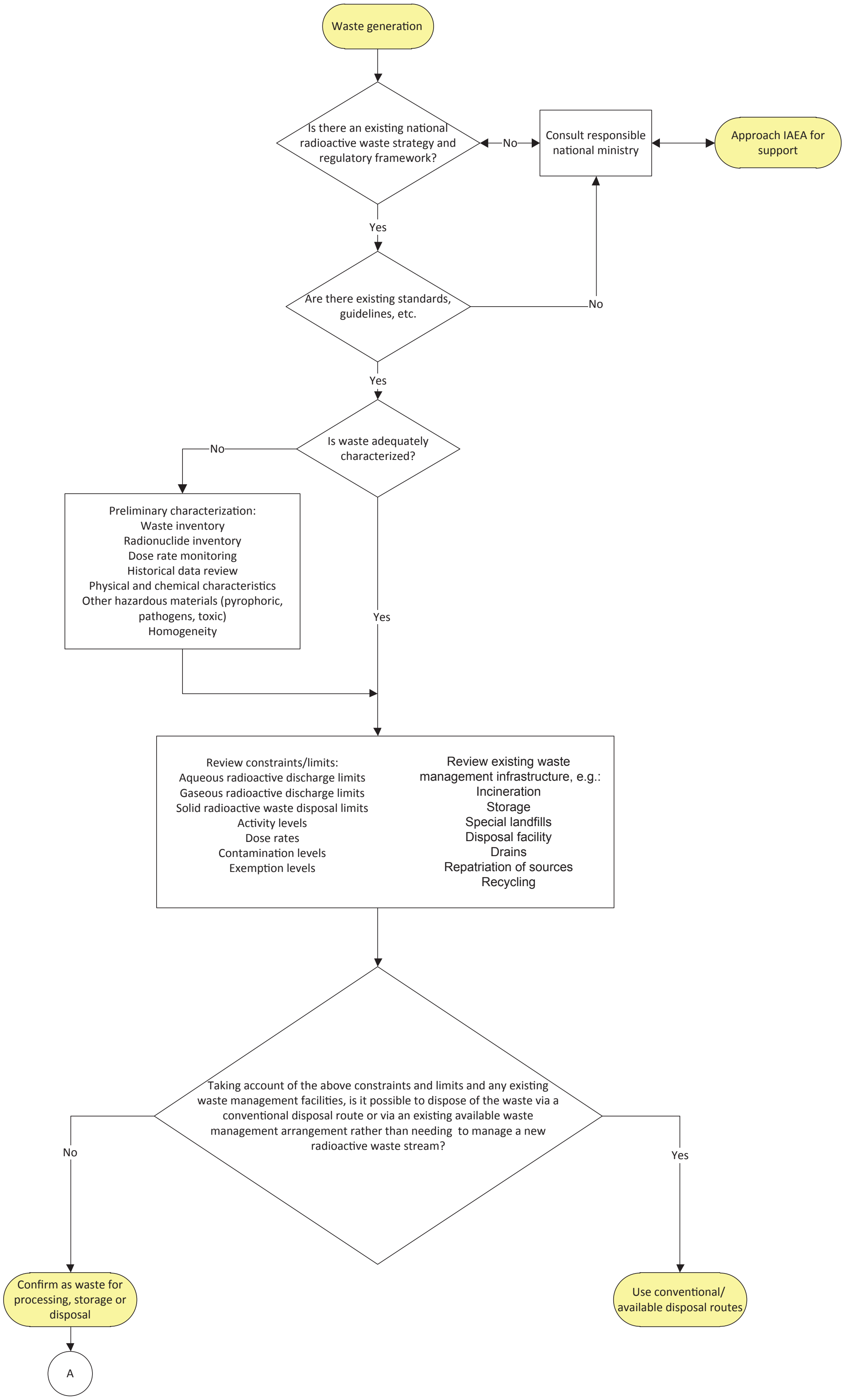


*FIG.4.1. Radioactive waste management strategy considerations.*

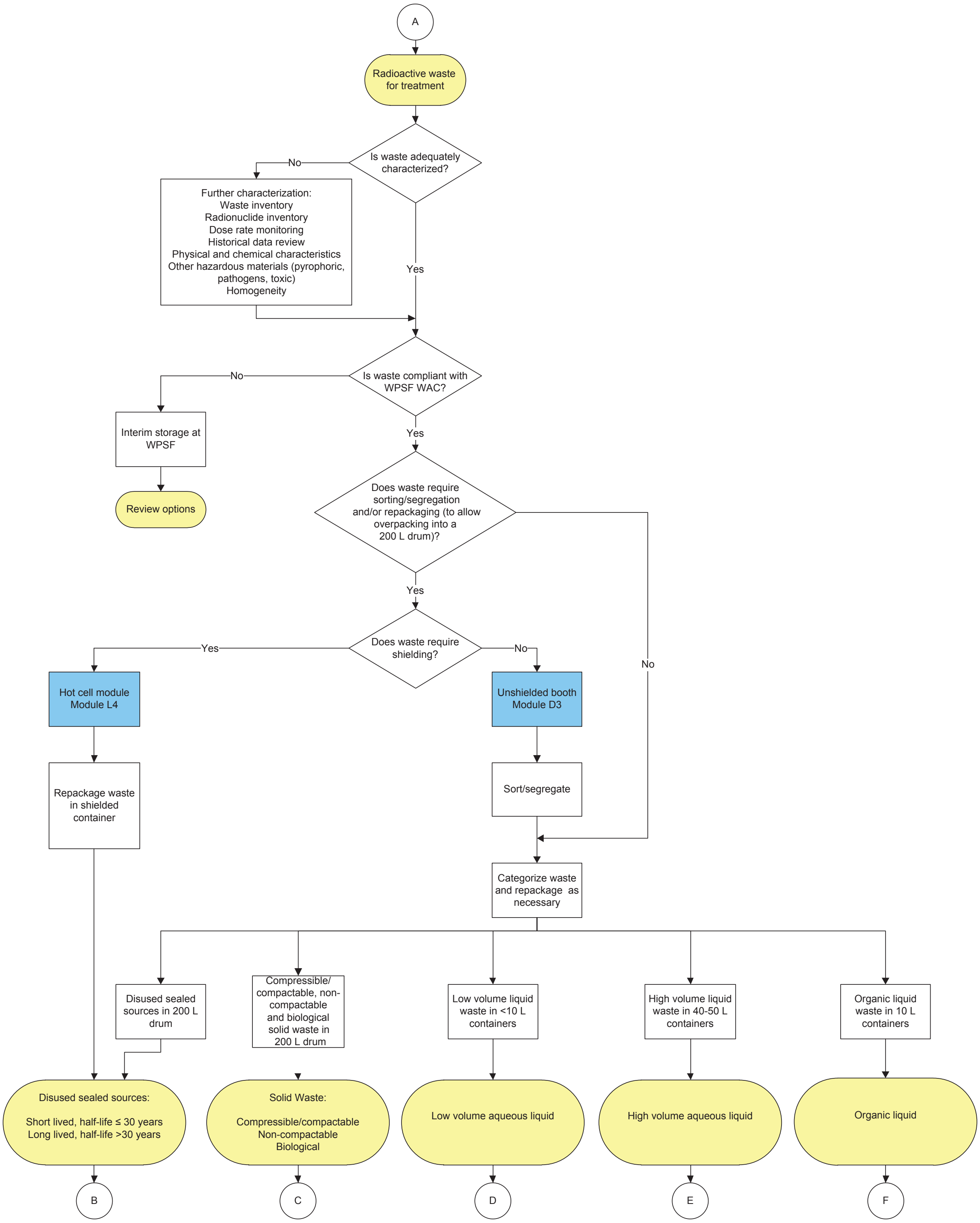


*FIG.4.2. Radioactive waste categorization.*

## 4.3. DISUSED SEALED SOURCES MANAGEMENT

The previous flow chart stipulated that disused sealed sources should be segregated according to their half-life, and if necessary repackaged into appropriate containers. Figure 4.3 shows the flow chart for the management of disused sealed sources.

The short lived sources are considered first and the long lived source second.

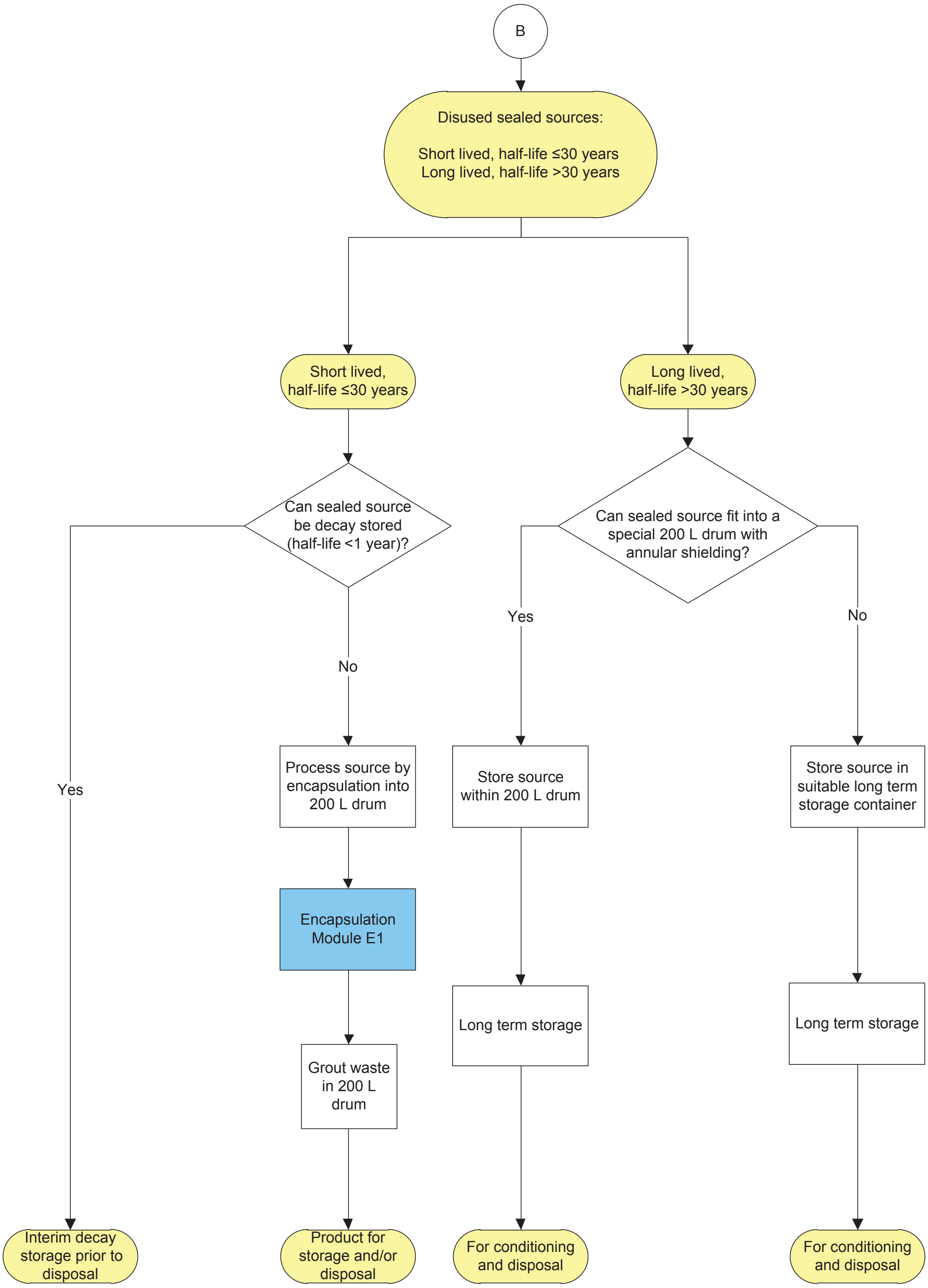


*FIG. 4.3. Management of disused sealed sources.*

### 4.3.1. Short lived sources

As highlighted earlier, the best route for very short lived radionuclides (half-life <1 year) is decay storage.

Short lived sources that do not fall into this category will be placed into 200 L drums with a pre-cast annular concrete lining (Fig. 4.4) and encapsulated with cement using a grouting process module (Module E1). It is important to note that encapsulation by mixing with grout amounts to irretrievable conditioning and should be considered only if an operational disposal facility is available and the conditioned package meets the acceptance criteria for disposal.

FIG. 4.4. Placement of disused sealed sources in a 200 L drum with annular shielding.

#### 4.3.2. Long lived sources

Ideally, all long lived sources will be packaged into 200 L drums for long term storage. The previous flow chart identified that sources may require repacking from their original source holders into long term storage shields in the mobile hot cell module.

If the long lived sealed sources are of adequate physical size, they will be placed into a special 200 L drum with a pre-cast annular shielding similar to the one shown in Fig. 4.4. Packaging in this way will enable the recovery of the source in the future for further conditioning prior to final disposal, probably in a geological disposal facility.

If the long lived sealed sources are too large to be packaged into 200 L drums, they will have to be stored in their long term storage containers.

### 4.4. SOLID WASTE MANAGEMENT

As noted in the categorization flow chart above, solid waste will be sorted and segregated into a number of discrete categories depending upon their characteristics and proposed treatment. A flow chart for the management of solid waste streams is shown in Fig. 4.5.

#### 4.4.1. Waste containing compressible or compactable material

Compressible or compactable waste will be placed into a 200 L drum and in-drum compacted to maximize the waste loading within the drum.

#### 4.4.2. Waste containing biological matter

Biological matter may be more hazardous because of its biological content than its radionuclide content. Pretreatment of the biological matter, e.g. immersion in 4% formaldehyde solution or bagging with lime) will be necessary prior to being encapsulated within a 200 L drum using the encapsulation module.

#### 4.4.3. Waste containing non-compactable material

Non-compactable waste will be placed into a 200 L drum and then encapsulated in cement grout using the encapsulation module (E1).

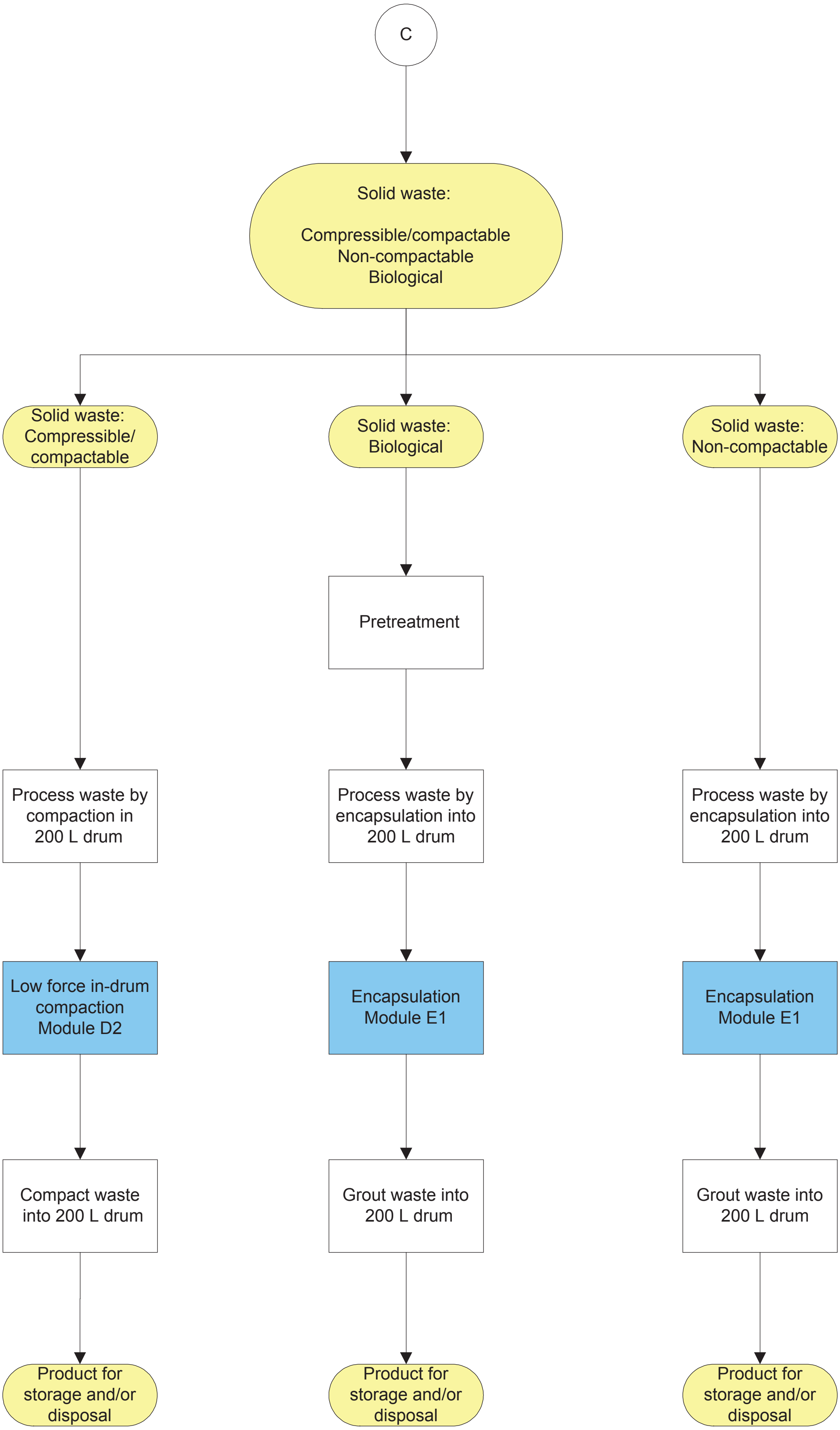


*FIG. 4.5. Solid waste management.*

## 4.5. LOW VOLUME LIQUID WASTE MANAGEMENT

The flow chart for the management of low volume liquid waste is shown in Fig. 4.6.

### 4.5.1. Is there sufficient volume to process immediately?

It is assumed that low volume aqueous liquid waste will be received in suitable containers, such as UN certified plastic bottles, that typically hold up to 10 L. Although the solidification module (Module A6) is designed to process liquid waste from these containers one at a time, it is recommended that several similar containers are collected together so that they can be processed at the same time, thereby saving the number of times the process module needs to be recommissioned and then shut down and washed out after operation.

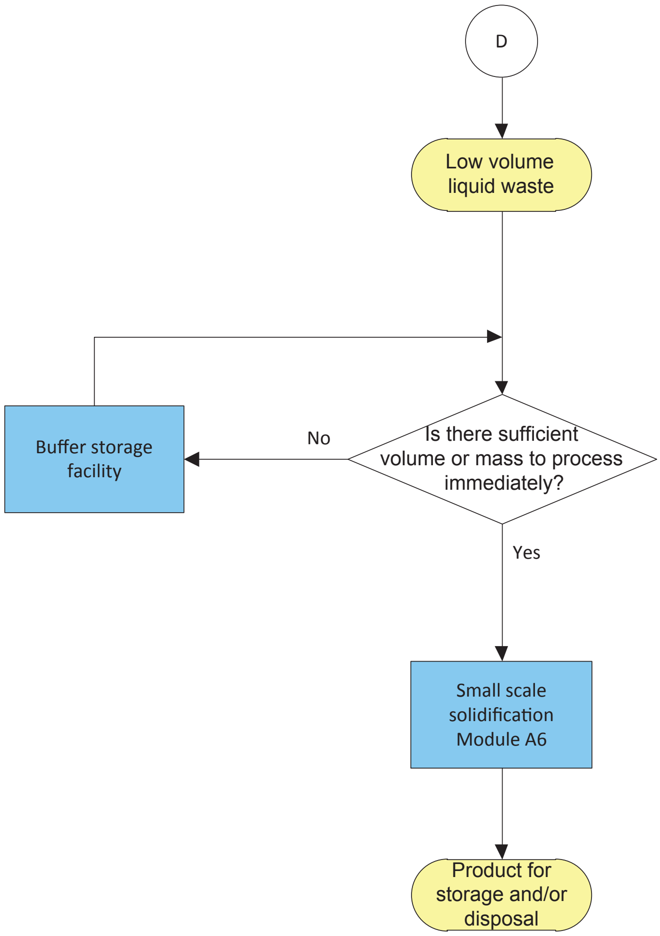


*FIG. 4.6. Low volume aqueous liquid waste management.*

In general, it is recommended that quantities of liquid waste are not accumulated for extended periods of time because of the risk of loss of containment and spread of contamination. Liquid waste containers should be stored within bunded areas that are able to contain the contents of the waste containers in the event of a breach of the containers.

As the rate of generation of liquid waste is small, the liquid waste should be treated by direct solidification. This is because the volume of the waste does not merit the additional equipment and operator exposure in processing it in order to decontaminate it.

## 4.6. HIGH VOLUME LIQUID WASTE MANAGEMENT

Figure 4.7 shows the flow chart for the management of high volume liquid waste.

### 4.6.1. Is there sufficient volume to process immediately?

It is assumed that high volume aqueous liquid waste will be received in suitable containers, such as UN Group I certified carboy, that typically hold 45 L. Although the aqueous waste process modules are designed to process liquid waste from these containers one at a time, it is recommended that several similar carboys are collected together so that they can be processed at the same time, thereby saving the number of times the process module needs to be re-commissioned and then shut down and washed out after operation.

In general, it is recommended that quantities of liquid waste are not accumulated for extended periods of time because of the risk of loss of containment and spread of contamination. Liquid waste containers should be stored within bunded areas that are able to contain the contents of the waste containers in the event of breach of the containers.

If the rate of generation of liquid waste is small (for example <1 of 45 L container per month), then the liquid waste should be treated as a low volume liquid waste stream, i.e. it should be solidified directly. This is because the volume of the waste does not merit the additional equipment and operator exposure in processing it.

### 4.6.2. Is a liquid waste discharge route with authorized discharge limits available?

The aim of treatment is to concentrate the radioactive material and to make the bulk volume of the liquid waste suitable for discharge to, for example, a public sewer. If a discharge route with authorized discharge limits is not available, then there is no merit in treating the liquid waste. In this case it is preferred to directly solidify the liquid waste.

### 4.6.3. Can the liquid waste be decontaminated sufficiently by treatment to allow it to meet the authorized discharge limits?

If a discharge route with an authorized discharge limit is available, the next step is to determine whether treatment of the liquid waste will be able to decontaminate the bulk of the liquid sufficiently to make it acceptable for discharge. The answer to this question will be based on detailed knowledge of the liquid waste characteristics and the authorized discharge limits.

### 4.6.4. Does the liquid waste contain trace oils or solvents?

If the liquid waste contains trace oils or solvents, these could interfere with the treatment processes, e.g. oils could blind filters or ion exchange media, solvents may hold radionuclides in a form that prevents removal by ion exchange or chemical treatment.

If trace oils or solvents are present then pretreatment by filtration on a cartridge filter with hydrophobic fibres followed by adsorption onto activated charcoal or other suitable sorbents in a column should be explored.

### 4.6.5. Is the activity mainly insoluble, or does the liquid waste have a very complex chemical and radionuclide composition?

If the activity is present mainly as insoluble species, or there are solids within the liquid waste then filtration should be used.

Alternatively, if the waste is of complex chemical and radionuclide composition, then reverse osmosis (RO) should be considered. RO must be preceded by filtration and cross-flow filtration to ensure that the liquid does not contain any solids that would block the RO filters.

Filtration by cartridge filtration (Module B5) and then cross-flow filtration (Module B4) may decontaminate the liquid waste sufficiently to enable discharge. Or it will remove the solids that might otherwise cause problems in subsequent treatment such as ion exchange or sorption.

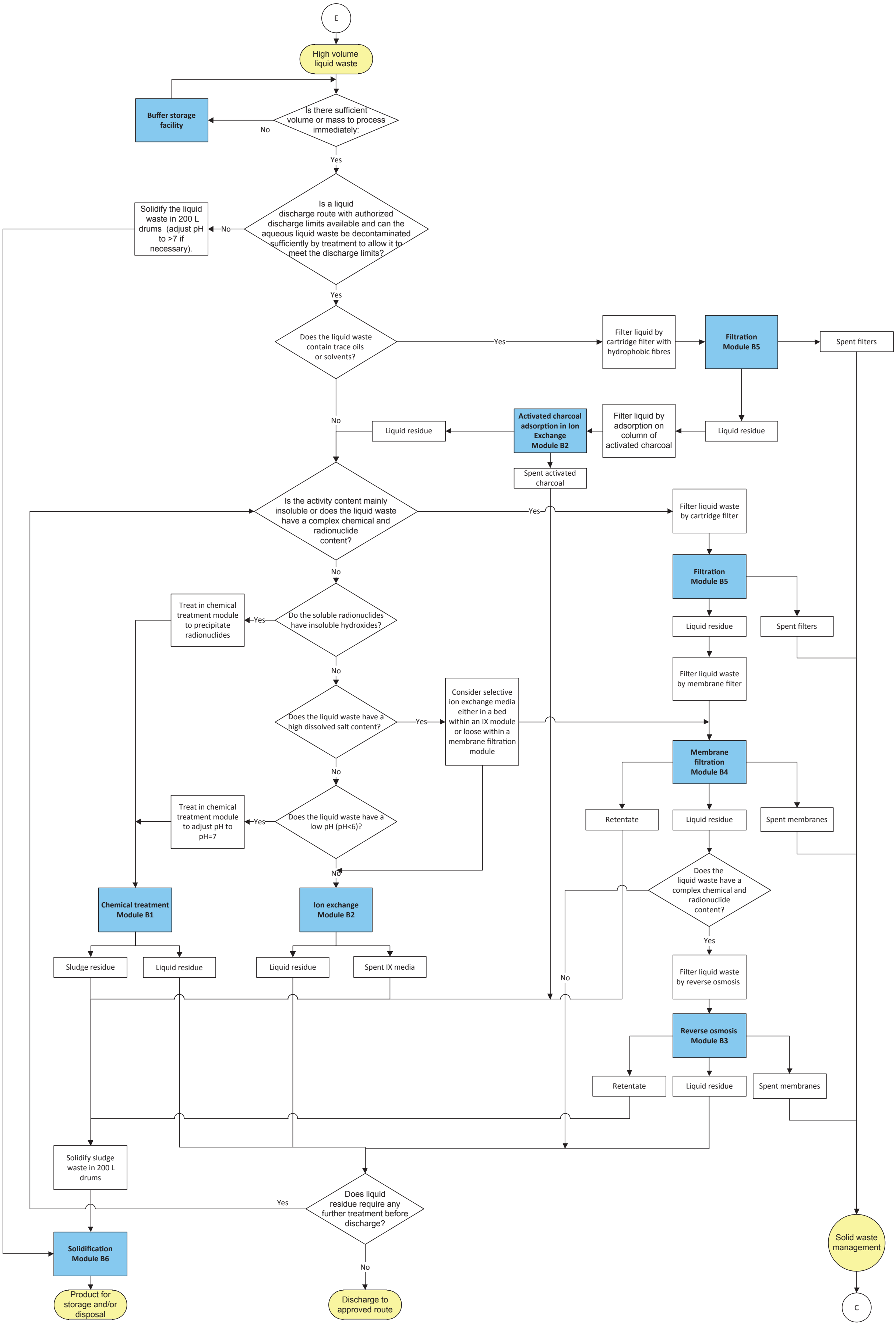


FIG. 4.7. High volume aqueous liquid waste management.

The type of filter and filter pore size will be determined by the particle size range in the liquid waste. The filtration module will be able to accept cartridge filters, typically from 2 μm up to 100 μm. It should be noted that the smaller pore size filters can blind very quickly. After cartridge filtration the liquid will then treated by cross-flow filtration to remove fine particulates.

#### 4.6.6. Does the liquid waste have a very complex chemical and radionuclide composition?

Reverse osmosis is an option when surfactants (anionic or non-ionic), complexing agents and many types of radionuclides are present in the waste stream, because of which chemical treatment and ion exchange are ineffective. If the treated liquid is not meeting the authorized discharge limits, in spite of repeated chemical treatment, RO can be considered.

#### 4.6.7. Do the soluble radionuclides have insoluble hydroxides?

If the radionuclides present in the liquid waste have insoluble radionuclides (e.g. $^{90}$Sr, actinides), then the simplest treatment will be a chemical treatment that includes raising the pH to precipitate the soluble radionuclides.

#### 4.6.8. Does the liquid waste have a high dissolved salt content?

If the radionuclides present in the liquid waste have soluble radionuclides, then ion exchange will be the preferred treatment. However, if the liquid waste has a high salt content, e.g. sodium or calcium ions, then these will also be removed by the ion exchange process, rapidly exhausting the ion exchange media. In this case, selective ion exchange media may be available, e.g. nickel hexa-cyanoferrate for $^{137}$Cs removal. This can either be used as an ion exchange bed in a column, or as finely divided particulates mixed with the liquid within a container and then filtered via a cross-flow filter.

#### 4.6.9. Does the liquid waste have a low pH (pH $<6$)?

If conventional cation exchange resins are to be used, then it is important that the liquid pH is in a suitable range, typically pH 7–9. If the pH is low, then the activity already on the ion exchange resins can be eluted and the treated liquid waste can then contain significantly more activity than before treatment.

If the pH is low, then the pH should be adjusted first either in the chemical treatment module or by recirculation in the storage container, in the absence of a chemical treatment module. It is to be noted that waste streams with high pH would require adjustment when anion exchange resins are used.

#### 4.6.10. Does the liquid residue require any further treatment?

After treatment, the liquid waste will be analysed to confirm whether it meets the authorized discharge limits. If not, for example if the liquid waste has been pretreated by chemical treatment to raise the pH or filtered to remove solids, then further treatment will be necessary.

### 4.7. ORGANIC LIQUID WASTE MANAGEMENT

The flow chart for the management of organic liquid waste is shown in Fig. 4.8.

#### 4.7.1. Is there sufficient volume to process immediately?

As noted earlier, it is assumed that organic liquid waste will be received in suitable containers, such as UN certified plastic bottles that typically hold up to 10 L. Although the process modules are designed to process liquid waste from these containers one at a time, it is recommended that several similar containers are collected together so that they can be processed at the same time, thereby saving the number of times the process module needs to be recommissioned and then shut down and washed out after operation.

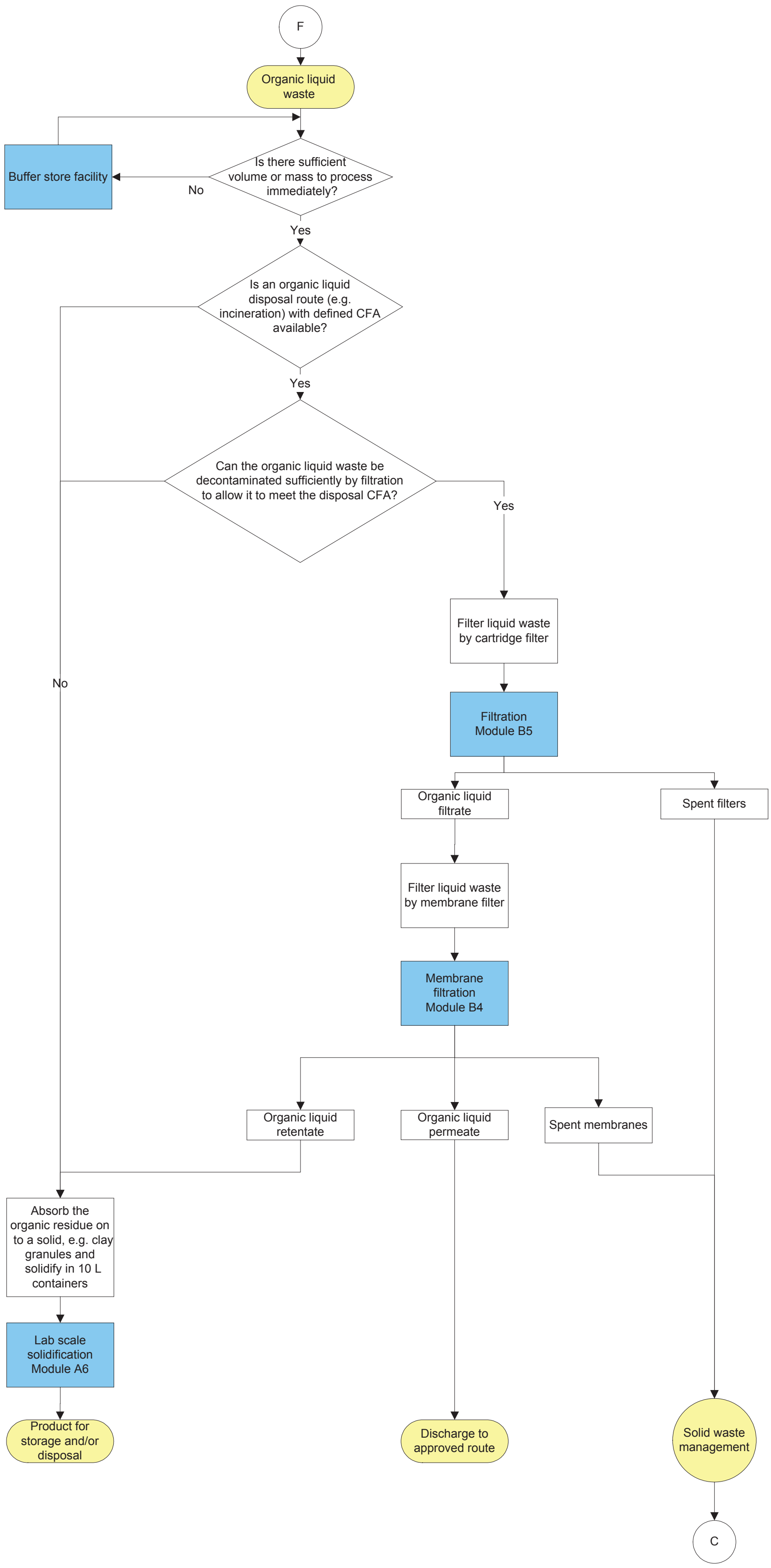


*FIG. 4.8. Organic liquid waste management.*

In general, it is recommended that quantities of organic liquid waste are not accumulated for extended periods of time because of the risk of loss of containment and spread of contamination. Liquid waste containers should be stored within bunded areas that are able to contain the contents of the waste containers in the event of breach of the containers.

### 4.7.2. Is an organic liquid waste discharge route with defined authorized discharge limits available?

The aim of treatment is to make the bulk volume of the organic liquid waste suitable for disposal (e.g. to an existing incinerator) or solidification in cement. If a discharge route with authorized discharge limits is not available, then there is no merit in treating the organic liquid waste. In this case, it is preferred to directly solidify the organic liquid waste.

### 4.7.3. Can the organic liquid waste be decontaminated sufficiently by filtration to allow it to meet the authorized discharge limits?

If a discharge route with authorized discharge limits is available, the next step is to determine whether filtration of the liquid waste will be able to decontaminate the bulk of the liquid sufficiently to make it acceptable for discharge. No treatment other than filtration (by cartridge filtration (Module B5) and then cross-flow filtration (Module B4)) is considered appropriate here because of the relatively small volumes of organic liquid to be treated and the complexity of other treatment technologies.

If filtration is unlikely to decontaminate the organic liquid waste sufficiently for discharge, then it is preferred to directly solidify the organic liquid waste.

## REFERENCE TO SECTION 4

[4.1] INTERNATIONAL ATOMIC ENERGY AGENCY, Policies and Strategies for Radioactive Waste Management, IAEA Nuclear Energy Series No. NW-G-1.1, IAEA, Vienna (2009).

# 5. DESIGN AND SPECIFICATION INFORMATION FOR PROCESSING MODULES

A key part of this publication is the provision of design and specification information for each of the processing modules identified in Section 3 and selected for implementation according to the decision process presented in Section 4.

The aim of these specifications is to enable the user to determine their requirements, specify those requirements to allow the procurement of the appropriate processing modules, to install those processing modules and to eventually operate those processing modules. Design and specification information for each of the process modules is presented in the following sections. For each process module, the following information is provided:

- A basis of design identifying the key parameters and assumptions used in determining the design of the processing module;
- A schematic PFD to illustrate the process module, where appropriate;
- Equipment lists identifying the main equipment items, valves and instrumentation, where appropriate;
- Equipment description providing further details on the major equipment items;
- Photographs of similar processing modules or module equipment (where available) or simple models to illustrate a possible arrangement of the module;
- Identification of facility requirements that need to be taken into account in incorporating the process module into a facility;
- Process description providing further details on how the module will be operated including prerequisites prior to start of operation.

The modules are described in Sections 5.1–5.11.

The majority of the process modules will be skid mounted to simplify installation and any future relocation of the plant. This approach also allows the modules to be built and tested in a factory so that only final connection of services (power, possibly water) is required by the end user.

In general, the layout of equipment on the process module should allow access to all components (and in particular valves and instruments) for commissioning, testing, maintenance and replacement. Detailed design should ensure that there is sufficient space for removal and replacement of items; wherever possible access should be provided to at least two sides of a piece of equipment.

## 5.1. MODULE A6–SOLIDIFICATION

### 5.1.1. Module A6 — General

One of the possible stages in treatment of small quantities of liquid or wet solid waste (waste streams A, C, F and G in Table 2.1) will be to solidify it. Such solidification is aimed at immobilizing the waste and its radioactive contamination to prevent dispersion. The waste will be placed into 10 L waste containers and cement grout added. For the reference case of 0.1 $m^3$ per year, this will generate between 20 and 30 small waste containers per year, depending on the volume of liquid or wet solid waste that goes into the mix. It should be possible to solidify five waste containers per operating day so less than six operating days per year will be required. In the design information presented below, organic liquid (scintillation solutions, oil from pumps, extraction solvents, etc.) has been assumed as the target waste stream in the basis of design.

This solidification module will mix organic liquid waste with a pretested cement mixture in a 10 L container using a 'total loss' paddle mixer. The lost paddle technique is a common design in which the mixing paddle remains in the container after mixing and becomes part of the solid waste package. It is employed to reduce the risk of the spread of contamination. The waste and cement matrix will solidify and a capping grout will be put on the top to provide additional protection against the escape of contamination. Due to the small volumes involved, the equipment used can be proprietary equipment of a type used on a laboratory bench-top.

The waste and cement can be mixed using a standard power drill or laboratory mixer with a removable paddle drill bit. The paddles can be disposed of after use to reduce the risk of the spread of contamination. They can be disposed of either as non-compactable waste (see module E1) or as a ‘total loss’ paddle that remains in the waste container after mixing. In outline, this module features the following bench-top equipment:

(a) Ten-litre waste containers.
(b) Waste container filling station with container splash guard, drip tray, high torque mixer and (possibly ‘total loss’) mixing paddle.
(c) Chemical containers for dosing chemicals in small quantities by hand (if necessary), e.g. caustic.
(d) Cement powder containers filled with measured quantities of pre-blended cement for adding to the waste containers.
(e) Curing area where waste containers that have been solidified can stand and cure.
(f) Grout mixing equipment to prepare small volumes of grout for grout capping the completed waste container. This will comprise a grout mixing container, a reusable mixing paddle and a high torque mixer.

The module’s equipment can be housed within containment such as a Module D3–Unshielded booth or a fume cupboard.

#### 5.1.2. Module A6 — Basis of design

Table 5.1 summarizes the basis of design identifying the key parameters and assumptions used in determining the design of this processing module.

TABLE 5.1. BASIS OF DESIGN FOR MODULE A6–SOLIDIFICATION

| Waste feed characteristics | |
|---|---|
| Total liquid volume | Typically, less than 0.3 $m^3$ per year; for the reference case, 0.1 $m^3$ per year should be used. |
| Timing | Arrives periodically in batches of about 50 L. |
| Peak treatment rates | 50 L of waste per waste drum. |
| Feed activity content | Low levels of activity, single or multiple radionuclides. |
| Physical form | Organic liquid — scintillation solutions, oil (from pumps, etc.), extraction solvents, etc. |
| Solids content | Could have solids content up to 20%. |
| Chemical content | No significant chemical content except potential for presence of small quantities of complexing agents. |
| **Treated effluent characteristics** | |
| Activity content | N/A |
| pH | N/A |
| Other constituents | N/A |

TABLE 5.1. BASIS OF DESIGN FOR MODULE A6–SOLIDIFICATION (cont.)

| Services availability | |
|---|---|
| Services | The schematic design should identify options for connections to existing services or the need for dedicated services. |
| Water | Required. |
| Power | Required. |
| Building heating | Required if the temperature falls below 5°C. |
| HVAC | Required. |
| Chemical reagents | Required. |
| Drainage | None. Any leaks or spillages that do occur to be captured in a drip tray and returned to a waste container by pouring. |

### 5.1.3. Module A6 — Process flow diagram

Figure 5.1 illustrates the equipment in a PFD.

### 5.1.4. Module A6 — Equipment list

The following equipment can be identified from this PFD (Table 5.2).

### 5.1.5. Module A6 — Equipment description

The equipment comprises the following:

(a) Feed containers for the aqueous waste, A6-E-01, in the form of 5 L high integrity, UN certified, reusable containers of polythene construction designed for hazardous liquid chemicals.

(b) A stock of small quantities of dosing chemicals — e.g. caustic — in appropriate approved containers, A6-E-09, contained in their own drip tray, A6-E-16, for pretreatment of the waste by chemical dosing (if necessary).

(c) Cement powder containers, A6-E-07, in stainless steel, polyethylene or polypropylene that are filled with measured quantities of pre-blended cement powder for adding to the waste container.

(d) A curing area with a drip tray, A6-E-15, where waste containers that have been solidified, A6-E-13, can stand and cure for typically 24 h. Typically, five waste containers from one day of operation would be stored together to cure.

(e) A waste container filling station comprising:
   - (i) Waste containers, A6-E-12, of size up to 10 L in mild steel, polyethylene or polypropylene. The nature of the container is not significant as it is intended that ultimately the final product will be over packed by grouting into a 200 L steel drum in Module E1–Encapsulation. It could take the form of a simple plastic bucket or steel can.
   - (ii) A splash guard in mild steel, polyethylene or polypropylene to fit over the waste container during powder addition and mixing.
   - (iii) A mixing paddle in mild steel (similar to that illustrated in Fig. 5.2), which will be used to mix the cement powder into the aqueous organic liquid waste in the container and will:
     – Either remain in the container while the cement sets.
     – Or be disposed of separately as non-compactable waste — see Module E1.

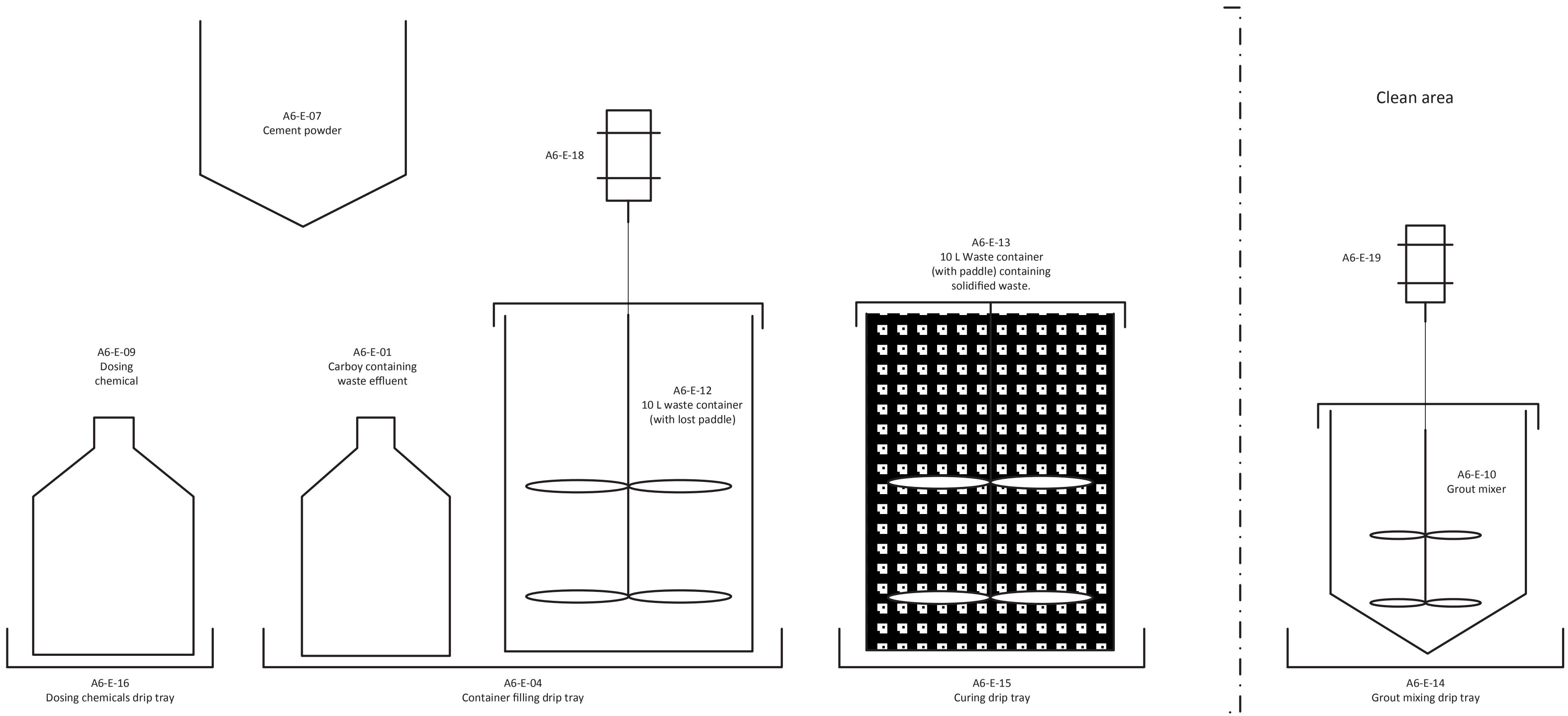


*FIG. 5.1. Process flow diagram for Module A6–Solidification.*

TABLE 5.2. EQUIPMENT LIST FOR MODULE A6–SOLIDIFICATION

| Tag | Description | Material |
|---|---|---|
| A6-E-01 | Untreated waste carboy (5 L) | Plastic |
| A6-E-04 | Container filling drip tray | Plastic or stainless steel |
| A6-E-07 | Cement powder container | Plastic |
| A6-E-09 | Dosing chemical container | Plastic or stainless steel |
| A6-E-10 | Grout mixer | Plastic or steel |
| A6-E-12 | Waste container (10 L) | Plastic or steel |
| A6-E-13 | Curing waste container | Plastic or stainless steel |
| A6-E-14 | Grout mixing drip tray | Plastic or stainless steel |
| A6-E-15 | Curing drip tray | Plastic or stainless steel |
| A6-E-16 | Dosing chemicals drip tray | Plastic or stainless steel |
| A6-E-18 | Waste mixer | Plastic or stainless steel |
| A6-E-19 | Grout mixer | Plastic or stainless steel |


*FIG. 5.2. Mixing paddle.*

*FIG. 5.3. High torque bench top mixer.*

(iv) A high torque mixer, A6-E-18 (possibly similar to the bench top model illustrated in Fig. 5.3), held within a support frame of stainless steel or epoxy painted mild steel that can lower the mixing paddle into the waste container. Typically, the mixer has a drill chuck type device for gripping the end of the mixing paddle. When mixing is complete this can be detached to allow the mixer to be raised, leaving the paddle fixed within the waste container. The mixer support frame should have adjustable feet for levelling.

(v) A drip tray, A6-E-04, in stainless steel, polyethylene or polypropylene located under the waste container to contain any splashes, spillages or leakage during mixing.

(f) Grout mixing equipment to prepare small volumes of grout for grout capping the completed waste container. The need for a grout cap will depend on the national waste acceptance criteria for transport and disposal. The grout mixing equipment is used to cap the solidified waste containers with grout. The equipment selected is again based upon readily available mixing equipment used to prepare plaster and cement based grouts in the building industry. Preparation of the grout will occur in a clean area away from the filling station. The container of grout will then be placed into the containment and the grout poured into the top of the waste container when required.

(g) The equipment will comprise:

(i) A grout mixing container, A6-E-10 (similar to that shown in Fig. 5.4).

*FIG. 5.4. Grout mixing container.*

*FIG. 5.5. Disposable mixing paddle.*


*FIG. 5.6. High torque mixer.*

(ii) A disposable mixing paddle (similar to that shown in Fig. 5.5).
(iii) A high torque mixer, A6-E-19 (similar to that shown in Fig. 5.6).
(iv) A drip tray, A6-E-14, in stainless steel, polyethylene or polypropylene located under the mixing container to contain any splashes or spillages during mixing.

(h) There should be a means to electrically isolate electrical equipment prior to maintenance, e.g. an electrical isolator.
(i) There should be an emergency stop mechanism for all electrical equipment.
(j) Any electrical equipment in the booth should be suitably rated in terms of ingress protection to allow washdown of plant and equipment (e.g. an ingress protection (IP) rating of IP54 or better).

### 5.1.6. Module A6 — Facility considerations

(a) All equipment should fit on a work bench.
(b) The module can be housed in a Module D3–Unshielded booth or in a proprietary fume cupboard.
(c) If an unshielded booth is used, finished solidified waste containers could be placed directly into a 200 L drum for encapsulation with other non-compactable waste, thus avoiding transport — see Module E1.
(d) A proprietary manual trolley for moving multiple waste containers.
(e) Radiochemical laboratory for sample and analysis of the untreated and cemented liquid waste. The results are used to ensure that the correct waste–cement formulation is implemented. Sampling and analysis will also be used to monitor equipment performance.
(f) Testing will be required to develop and test the requisite waste–cement formulation (including the optimum cement powder blend), optimize the waste loading and optimize the performance of the product in terms of cemented waste properties such as compressive strength and leach rate. Equipment required for the testing includes:
   (i) Fume cupboard or small containment for handling active liquids;
   (ii) Samples of active liquids;
   (iii) Liquid radioactive analysis capability;
   (iv) Cement powder;
   (v) Torque/viscosity measurement;
   (vi) Temperature measurement.
(g) Process water is required for chemical make-up and rinsing equipment.
(h) Hand held radiation monitoring equipment is required for monitoring the radiation levels of the incoming carboys of waste and the finished waste containers to confirm that the waste package meets the storage or disposal waste acceptance criteria.
(i) Personnel monitoring equipment is required for operators undertaking maintenance and other activities that present a risk of contamination.
(j) Dry storage for cement powders is required (possibly outside the containment).
(k) Storage for equipment spares, sample bottles and laboratory equipment is required.
(l) A bunded storage area is required for up to five No. 10 L carboys (or equivalent volume) of liquid waste awaiting treatment and sample analysis (similar to that shown in Fig. 5.7). Accumulation of untreated liquid waste should not be encouraged. Therefore, storage space should be limited to a single consignment of containers of up to ten carboys.
(m) Operator personnel protective equipment (PPE) is needed for handling cement powder and grout, i.e. coverall, safety shoes or boots, safety goggles, dust mask (e.g. P3 disposable dust masks) and gloves.

*FIG. 5.7. Storage of liquid waste carboys.*

(n) There should be space to erect temporary shielding around the waste container, e.g. lead bricks. If necessary, following radiation level measurements, lead bricks should be erected around the waste container before waste is introduced into the waste container in order to minimize operator dose rates.

#### 5.1.7. Module A6 — Prerequisites

(a) Appropriate barriers and/or controls must be in place to manage access of personnel to the chemical treatment tank area.
(b) Operators must wear appropriate PPE, e.g. coveralls, safety shoes, goggles or mask and gloves.
(c) A laboratory technician is required for sampling and to calculate any chemicals required for each batch treatment.
(d) A radiation protection supervisor is required to monitor operations, including receipt of waste carboys and dispatch of waste containers; and waste containers during filling, mixing and dispatch.
(e) The cement powder formulation is assumed to be pre-blended so the mix provides the ideal physical and chemical properties for solidifying liquid waste. It is important to get the right mix the first time because recovery is very difficult.
(f) Risk of airborne contamination will be low, so there is no need to monitor for this except during any intrusive maintenance of the equipment.
(g) Storage of untreated and treated waste feed should be in separate areas. The containers should be uniquely tagged for easy identification.

#### 5.1.8. Module A6 — Process description and operation

The following description assumes processing will take place in an unshielded booth, but it applies equally to a fume cupboard:

(a) As carboys of waste, A6-E-01, arrive, they should be monitored and stored in the designated storage area over the bund. Once five carboys have been accumulated, a day’s processing can be organized.
(b) Move the accumulated containers, A6-E-01, adjacent to the booth using the trolley provided for the purpose. Carefully, one at a time, lift up to five containers into the booth.
(c) Position a 10 L waste container, A6-E-12, in the filling station drip tray, A6-E-04, and under the mixer, A6-E-18.
(d) Following sample analysis, a recipe for the untreated effluent is prescribed. Following this recipe, transfer by hand the requisite volume of untreated effluent into the waste container and pretreat the effluent with the chemical(s) or clay granules.
(e) Install the mixer paddle into the mixer chuck. Lower the paddle into the waste container, switch on the mixer, A6-E-18, and mix the organic liquid waste.
(f) Add water and empty the cement powder container, A6-E-07, gradually (typically at 0.5–1.0 kg/min) by hand into the waste container during mixing.
(g) Continue to mix the cemented waste for about 30 min until all cement powder is added. Stop the mixer, A6-E-18. Disconnect the ‘total loss’ paddle from the mixer chuck and lift the mixer, A6-E-18. Transfer the solidifying waste container, A6-E-13, to the curing area and stand it in the drip tray, A6-E-15. Leave the cemented product to cure for 24 h.
(h) Repeat the cementation process for the remaining untreated waste in the batch. Periodically test the setting of the cemented product.
(i) A grout cap will not be required if the solidified containers are to be overpacked immediately by encapsulation within a 200 L steel drum along with other non-compactable waste using Module E1.
(j) If the containers are not to be disposed of immediately, then a grout cap can be added. Grout capping provides a clean top surface to the product in the waste container, thereby minimizing the risk of contamination spreading. Premix a batch of grout in the grout mixer, A6-E-10, located in a clean area. Transfer the grout into the booth and apply a layer to each container. Leave to cure for a further 24 h. The containers can now be stored in controlled storage until disposal.

(k) Empty untreated waste containers can either be washed out with process water and re-used for further collections of untreated waste, or size reduced (cut up) and disposed of into the 200 L drum of non-compactable waste awaiting encapsulation.

#### 5.1.9. Module A6 — Disadvantages of the process

(a) Trials need to be performed to find the right waste-cement formulation and confirm that it meets waste acceptance criteria for interim storage/disposal.
(b) The waste becomes non-recoverable.

#### 5.1.10. Module A6 — Interface and integration requirements

Integration with other process modules covers the following:

— The equipment should be operated within a suitable containment, such as an existing fume cupboard or the unshielded booth (Module D3).

### 5.2. MODULE B1–CHEMICAL TREATMENT

#### 5.2.1. Module B1 — General

Chemical treatment is aimed at separating a significant proportion of the radionuclide contaminants from the bulk volume of the aqueous liquid waste to yield a small volume of liquid containing the radionuclides within a gravity settled sludge. The remaining bulk volume of the aqueous waste will either be suitable for discharge immediately, or will require further ‘polishing’ before discharge. This could be done using ion exchange (see Module B2) or fine filtration (see Modules B4 or B5).

The chemical treatment module will process aqueous waste in batches. Waste will be pumped from its storage container into the module for treatment. The treated liquid and the concentrated waste will be separated by gravity settling and then pumped into different containers for removal from the module.

The main components of the module are an agitated chemical treatment tank with chemical dosing capability and a dip pipe and pump arrangement for decanting the supernate from the treated liquid. The same dip pipe and pump are also used to discharge the sludge.

All equipment in the module is contained in a drip tray that provides containment in the event of leaks or spills. All waste containers connected to the module are also placed in the drip tray.

#### 5.2.2. Module B1 — Basis of design

Table 5.3 summarizes the basis of design identifying the key parameters and assumptions used in determining the design of this processing module.

TABLE 5.3. BASIS OF DESIGN FOR MODULE B1–CHEMICAL TREATMENT

| | |
|---|---|
| Waste feed characteristics | |
| Total liquid volume | Typically 0.5–10 $m^3$ per year, for the reference case 5 $m^3$ per year should be used. |
| Timing | Arrives periodically in containers of about 50 L that are then batched together into 100–500 L batches. |
| Peak treatment rates | Typically 2–8 h per batch depending on sludge settling rate. |
| Feed activity content | Low levels of activity, single or multiple radionuclides. |
| Physical form | Liquid, mainly aqueous, but could have small quantities of oils or other immiscible species. |
| Solids content | Could contain particulates. |
| Chemical content | No significant chemical content except potential for presence of small quantities of complexing agents. |
| Treated effluent characteristics | |
| Activity content | A decontamination factor (DF) between 10 and 100 is expected. Treated effluent activity will depend on initial activity. |
| pH | pH6–9 is assumed. |
| Other constituents | Sludge separated from aqueous stream. |
| Services availability | |
| Services | The schematic designs should identify options for connections to existing services or the need for dedicated services. |
| Water | Required. |
| Power | Required. |
| Building heating | Required if temperatures are likely to fall below 5°C. |
| HVAC | Not required. |
| Chemical reagents | Required. |
| Drainage | None. Any leaks or spillages that do occur should be captured in a drip tray and returned to a waste container using a small pump. |

### 5.2.3. Module B1 — Process flow diagram

Figure 5.8 illustrates the plant and equipment in a PFD.

### 5.2.4. Module B1 — Equipment lists

The following equipment can be identified from this PFD (Table 5.4).

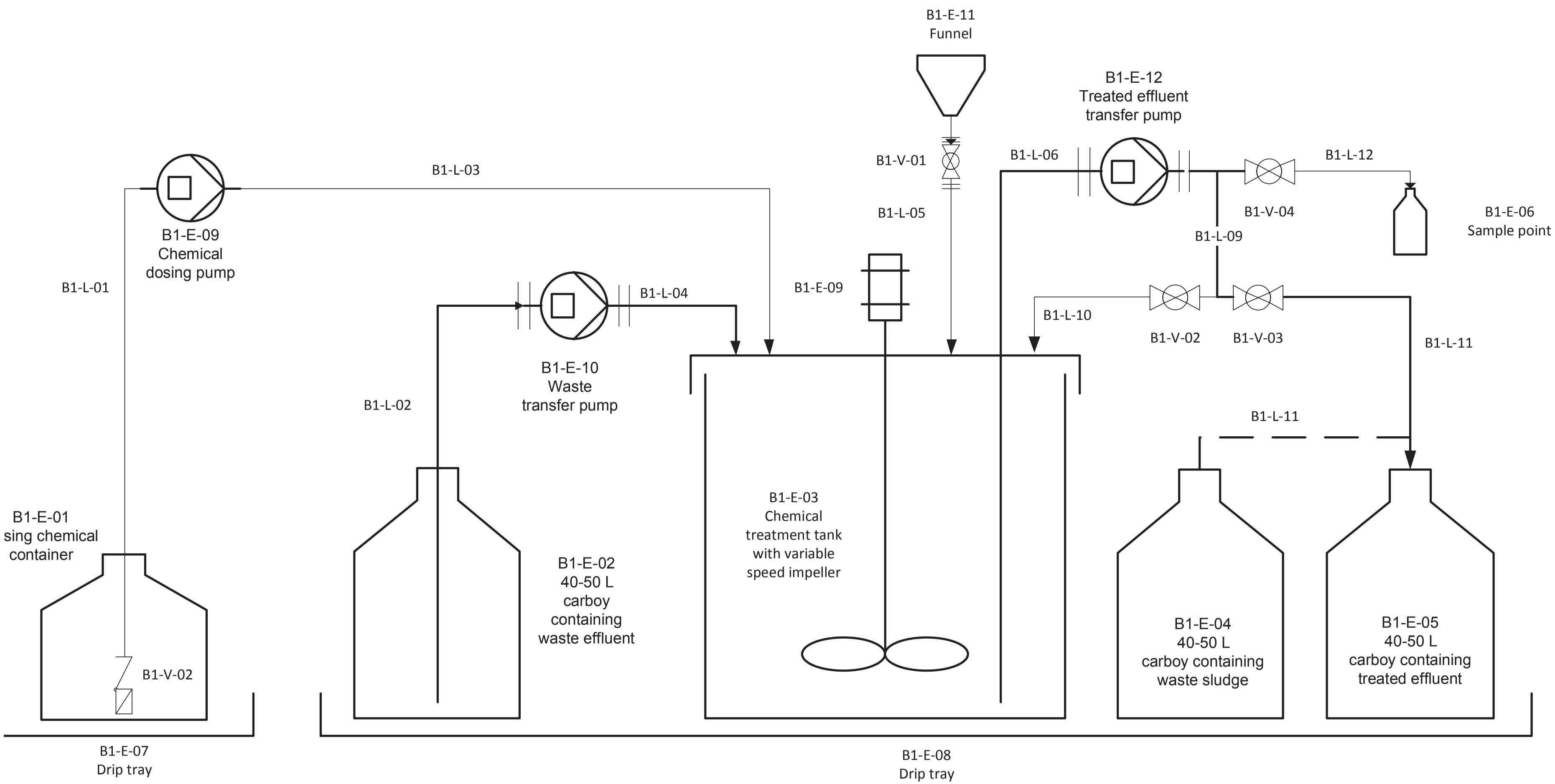


*FIG. 5.8. Process flow diagram for Module B1–Chemical treatment.*

TABLE 5.4. EQUIPMENT LIST FOR MODULE B1–SOLIDIFICATION

| Equipment | | | | |
|---|---|---|---|---|
| Displayed Text | Description | Material | Type | Flow rate |
| B1-E-01 | Dosing chemical container | Plastic or stainless steel | 40–50 L plastic carboy | |
| B1-E-02 | Aqueous waste container | Plastic | 40–50 L carboy | |
| B1-E-03 | Chemical treatment tank | Stainless steel or plastic | Covered roof, agitation | |
| B1-E-04 | Treated effluent container | Plastic | 40–50 L carboy | |
| B1-E-05 | Treated effluent container | Plastic | 40–50 L carboy | |
| B1-E-06 | Sample container | Plastic or glass | Laboratory beaker | |
| B1-E-07 | Drip tray | Plastic or stainless steel | | |
| B1-E-08 | Drip tray | Plastic or stainless steel | | |
| B1-E-09 | Chemical dosing pump | Plastic or stainless steel | Peristaltic (flanged) | 100 L/h |
| B1-E-10 | Waste transfer pump | Plastic or stainless steel | Self-priming/positive displacement (flanged) | 1 000 L/h |
| B1-E-11 | Funnel for dosing solid chemicals | Plastic or stainless steel | Standard industrial | |
| B1-E-12 | Treated effluent transfer pump | Plastic or stainless steel | Self-priming/positive displacement (flanged) | 1 000 L/h |
| Pipelines | | | | |
| Displayed text | Description | Line size | Design pressure | Design temperature |
| B1-L-01 | Chemical dosing pump feed line | 5–15 mm | 2 bar | Ambient |
| B1-L-02 | Waste transfer pump feed line | 15 mm | 2 bar | Ambient |
| B1-L-03 | Chemical dosing line | 5–15 mm | 2 bar | Ambient |
| B1-L-04 | Waste transfer line | 15 mm | 2 bar | Ambient |
| B1-L-05 | Solid chemical dosing line | 25 mm | Atmospheric | Ambient |
| B1-L-06 | Variable height dip pipe | 15 mm | 2 bar | Ambient |
| B1-L-07 | Treated effluent transfer line | 15 mm | 2 bar | Ambient |
| B1-L-08 | Treated effluent transfer line | 15 mm | 2 bar | Ambient |
| B1-L-09 | Treated effluent transfer line | 15 mm | 2 bar | Ambient |
| B1-L-10 | Treated effluent return line | 15 mm | 2 bar | Ambient |
| B1-L-11 | Treated effluent transfer line | 15 mm | 2 bar | Ambient |
| B1-L-12 | Sample point | 15 mm | 2 bar | Ambient |

TABLE 5.4. EQUIPMENT LIST FOR MODULE B1–SOLIDIFICATION (cont.)

| Valves | | | |
|---|---|---|---|
| Displayed text | Description | Line size | Valve class |
| B1-V-01 | Funnel delivery valve | 25 | Ball valve (flanged) |
| B1-V-02 | Treated effluent return valve | 15 | Ball valve (flanged) |
| B1-V-03 | Treated effluent isolation valve | 15 | Ball valve (flanged) |
| B1-V-04 | Sample point isolation valve | 15 | Ball valve (flanged) |

**Note:** Pipelines and valves should be plastic or stainless steel.

### 5.2.5. Module B1 — Equipment description

A simple model to illustrate the chemical treatment module is shown in Fig. 5.9.

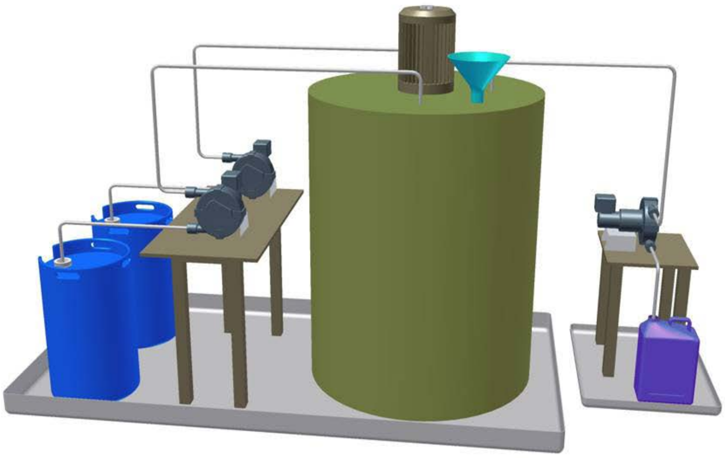

*FIG. 5.9. Model of Module B1–Chemical treatment.*

The module equipment comprises the following:

(a) Storage containers for the aqueous waste, B1-E-02, 04 and 05, in the form of 45 L, high integrity, UN certified reusable containers of double walled polythene construction designed for hazardous liquid chemicals (similar to that shown in Fig. 5.10). The container should incorporate an integral, ergonomically shaped, hand-ring, an offset pouring spout and secure interstacking features. It should have a smooth geometry, thus ensuring easy cleaning.

(b) A feed suction hose, B1-L-02, size 15 mm NB in flexible reinforced plastic, for transferring the aqueous liquid waste from the feed container to the chemical treatment tank.

*FIG. 5.10. Storage containers for aqueous waste.*

(c) A self-priming feed transfer pump, B1-E-10, such as a peristaltic or other progressive cavity (quasi-positive displacement) type or equivalent with wetted part, in stainless steel or plastic. Process connections at 15 mm NB, rated at typically 1000 L/h to transfer the aqueous waste to the chemical treatment tank from the waste storage container. This type of pump allows liquid to be sucked from the top of the storage containers rather than from the bottom, which is better for the integrity of the containers and reduces the risk of leakage from damage to a bottom outlet.

(d) Chemical preparation/storage approved container, B1-E-01, in plastic, in the form of a carboy (similar to the waste containers). The container will be resistant to the chemicals contained, shatterproof and easily cleanable for reuse. Note: the chemicals used for treatment will depend on the chemical and radiochemical inventory of the waste to be treated. This will be determined by a qualified chemist and chemicals will be prepared in a laboratory prior to delivery in the module.

(e) A range of chemical dosing pipe work, B1-L-01, size 5 mm, in stainless steel or plastic, for transferring the dosing chemicals from the dosing chemical container to the chemical treatment tank.

(f) A self-priming chemical dosing pump, B1-E-09, peristaltic, progressive cavity (quasi-positive displacement) type or equivalent with wetted parts, in stainless steel or plastic. Process connections at 15 mm NB, typically rated at 100 L/h, to deliver the treatment chemicals from the preparation/storage tank to the chemical treatment tank.

(g) A chemical treatment tank, B1-E-03, with variable speed impeller to ensure uniform mixing of chemicals:

   (i) The tank capacity will be between 100 and 500 L (depending on the required batch volume specified during the module design). The size of the chemical treatment tank will be dictated by the size of the batch to be treated. In this specification, it has been assumed that individual containers of liquid will have similar contents, i.e. similar chemical and radionuclide content, and that they can be batched together. It has therefore been assumed that the treatment batch size is up to ten containers. If quantities of aqueous liquid waste are smaller, a smaller batch vessel, say, 100 L, should be used. Similarly, if the aqueous liquid waste is more variable from one container to another, it will be better not to mix the contents so that the treatment chemistry and hence performance can be optimized for each batch. Again, in this case a smaller batch vessel, say, 100 L, should be used.

   (ii) The tank should have a lid and have the facility for dosing both liquid and solid (probably in powder form) chemicals.

(h) A range of transfer pipe work (B1-L-06 to B1-L-11), from the chemical treatment tank, size 15 mm in plastic or stainless steel. An adjustable dip pipe (B1-L-06) should be used for:
  (i) Decanting supernate from treated aqueous liquid (after gravity settling of particulates).
  (ii) Discharging waste sludge: The dip pipe should be graduated to enable the measurement of interface/draining of supernate.
(i) A sample line, B1-L-12, size 15 mm NB, in plastic or stainless steel:
  (i) A ball valve, B1-V-04, in stainless steel or plastic to control the flow through the sample line to the sample container.
(j) A transfer pump, B1-E-12, a diaphragm, peristaltic (positive displacement) type or equivalent, in plastic or stainless steel with connections at 15 mm NB to:
  (i) Transfer liquid from chemical treatment tank to sample container, B1-E-06;
  (ii) Decant treated effluent from chemical treatment tank to treated effluent container, B1-E-05;
  (iii) Transfer remaining sludge from chemical treatment tank to sludge waste container, B1-E-04.
(k) A range of return pipe work, B1-L-10, size 15 mm NB, in plastic or stainless steel for returning the treated effluent back to the chemical treatment tank, equipped with a ball valve, B1-V-02, in stainless steel or plastic to control the flow through the return pipe work.
(l) Transfer hose, B1-L-11, size 15 mm NB in flexible reinforced plastic, for transferring the aqueous liquid waste from the outlet valve to the treated effluent container. Equipped with a ball valve, B1-V-03, in stainless steel or plastic to control the flow through the treated effluent transfer hose.
(m) Treated effluent receipt container, B1-E-05, in the form of 45 L, high integrity, UN certified reusable containers of double walled polythene construction designed for hazardous liquid chemicals. The container should incorporate an integral ergonomically shaped hand-ring, an offset pouring spout and secure inter-stacking features. Attention will be paid to a smooth geometry, thus ensuring easy cleaning.
(n) Sludge waste receipt container, B1-E-04, in the form of 45 L, high integrity, UN certified reusable containers of double walled polythene construction designed for hazardous liquid chemicals. The container should incorporate an integral ergonomically shaped hand-ring, an offset pouring spout and secure interstacking features. Attention will be paid to a smooth geometry, thus ensuring easy cleaning.
(o) A framework in stainless steel or epoxy painted mild steel to support all of the equipment:
  (i) The framework is fitted with a drip tray, B1-E-08; a flat bottomed container in stainless steel or plastic to collect any spillages. The drip tray should contain both the waste feed and receipt containers, the chemical treatment tank, the feed and transfer pumps and will, typically, be capable of holding 110% of the total liquid volume held within the containers, and all of the other equipment and pipe-work mounted within or above the drip tray (approximately 40–50 L). A separate drip tray, B1-E-07, in stainless steel or plastic, should contain the dosing chemical tank and will be capable of collecting 110% or the total liquid contained in the container and any pipework above the drip tray.
  (ii) The framework should have adjustable feet for levelling.
(p) Hand held radiation (gamma) instrument to monitor the radiation dose rate from the settled sludge.
(q) A pH probe to assess waste samples and allow the treatment chemistry to be checked.
(r) An electrical control panel (not shown on the model picture), but supported from the module framework that receives the incoming power supply and controls the operation of all electrical equipment on the module. There should also be an emergency stop button to stop all equipment on the module. The control panel should include an electrical isolator to isolate all equipment on the module.
(s) All electrical equipment on the module shall be suitably rated in terms of ingress protection to allow washdown of plant and equipment on the module (with an IP rating of IP54 or better).

### 5.2.6. Module B1 — Facility considerations

The following should be considered for the facility to accommodate this process module:

(a) A waste receipt area for aqueous waste in 45 L carboys.
(b) Storage within a ‘bunded’ area (similar to that shown in Fig. 5.7) for the temporary storage of up to 20 carboys. This is required for liquid effluent awaiting chemical treatment, sludge waste or particulate waste awaiting further processing, or treated aqueous waste awaiting further processing or discharge.

(c) Manual trolley for moving smaller containers (similar to that shown in Fig. 5.11). Waste containers will be lifted into and out of the drip tray by hand (two person lift).

*FIG. 5.11. Manual trolley for moving small containers.*

(d) Forklift for moving large containers.
(e) Storage for treatment chemicals within a 'bunded' area.
(f) Equipment for sampling and analysis of treated waste (during and after treatment).
(g) A simple radiochemical laboratory for analysing waste samples and for planning and preparing treatment chemicals to the correct strength and volume.
(h) Provision of water for washdown of plant and equipment, e.g. prior to maintenance.
(i) A suitable connection to the site sewer or other approved liquid discharge point with appropriate consents will be needed for this option.

#### 5.2.7. Module B1 — Prerequisites

(a) Dosing chemicals are often corrosive or toxic so material safety data sheets should be obtained to ensure appropriate handling of chemicals. Appropriate PPE should be provided.
(b) Appropriate barriers and/or controls must be in place to manage access of personnel to the chemical treatment tank area.
(c) Operators must wear appropriate PPE, e.g. coveralls, safety shoes, goggles or mask and gloves.
(d) A radiation protection supervisor will monitor operations, including waste containers on receipt and dispatch, and at the bottom of treatment tank, when the emptying pipe work is removed from the empty containers.
(e) The aqueous waste should be sampled and analysed by a qualified chemist or technician, following installation and prior to operation of the module.
(f) Based on the sample results the chemical treatment method should be planned by a chemist. If waste in multiple containers has similar characteristics, it could be combined and treated in the same batch.

### 5.2.8. Module B1 — Process description and operation

(a) The chemical treatment module can receive aqueous waste in a variety of containers, typically 45 L plastic carboys. For processing, if necessary, the waste must be transferred to carboys using a manual or electrically powered drum pump.

(b) A small sample of the liquid waste can be taken by an operator using a pipette. Measurements of pH, chemical and radiological composition should be made in the radiochemical laboratory. Suitable chemical treatment should be planned by a chemist, based on the measurements. Chemicals should then be prepared in the laboratory.

(c) A carboy of liquid waste for processing can be lifted into the drip tray by two personnel. Alternatively, specific attachments can be used with a forklift or other mechanical lifting aid to lift and place carboys into the drip tray. A second empty carboy of equal or greater capacity is required for the collection of the treated effluent.

(d) Under radiation protection supervision, insert feed suction pipe B1-L-02, into the feed waste container and secure it. Similarly, insert transfer pipe B1-L-04 into the chemical treatment tank and secure it. Then, using transfer pump B1-E-10, pump the aqueous waste to the chemical treatment tank. When the waste container is empty, stop the pump and start the agitator on the tank.

(e) Transfer the treatment chemicals to the chemical tanks and insert the dosing chemical feed pipe B1-L-01. Using the chemical dosing pump B1-E-09, pump the chemicals into the chemical treatment tank. (Alternatively, chemical dosing could be done manually, depending on the quantities and nature of the chemicals being handled. Appropriate risk assessments should be carried out to ensure that manual handling is acceptable).

(f) Specific chemical treatment will depend on the types of radionuclides present and other chemical constituents of the aqueous waste. Typical steps for the removal of contaminants from solution include the following:
  (i) Acidification.
  (ii) Addition of chemicals to combine with the radionuclides and form a sludge blanket.
  (iii) Addition of alkali to raise the pH and precipitate the radionuclides.
  (iv) Use of chemical treatment of aqueous waste, typically as either a continuous treatment or a batch treatment process. However, given the expected small volumes of liquid to be treated, batch treatment is preferred because it simplifies the equipment and it allows the treatment chemistry to be tailored to individual batches, thereby optimizing treatment.
  (v) Addition of chemical make-up equipment, which may be required for chemical preparation/dilution. This could include small tanks for mixing chemicals with water. Mixing could be by manual stirring or with a small electrical mixer.
  (vi) Use of a chemical flocculating agent (polyelectrolyte), which may be required to aid gravity settling of the precipitate. Again, this chemical will need to be prepared by mixing with water before addition to the chemical treatment tank.

(g) An operator should monitor the pH during chemical dosing.

(h) Leave the chemical treatment tank (with agitator running) for the required period. This may take up to 24 h, depending on treatment. Then switch off the agitation and allow the precipitate to settle. This may take up to 24 h.

(i) Sample and analyse the treated waste in order to determine if the treatment has completed. Place a sample collection container, B1-E-06, at the sample point. When the precipitate has settled, insert the transfer dip pipe, B1-L-06, just below the liquid surface level in the chemical treatment tank. Open the sample valve, B1-V-04, and return valve, B1-V-02. Then start the transfer pump, B1-E-12. Close the sample valve when a sample has been collected, stop the pump and then close the return valve.

(j) Follow the same sample procedures described above. It is assumed that reactions will have finished and chemical treatment will be complete.

(k) Open transfer valve B1-V-03, and start transfer pump B1-E-12. Carefully monitor liquid level and lower dip pipe accordingly. When the dip pipe level approaches the sludge layer, close the transfer isolation valve and stop pump. Withdraw the transfer pipe from the treated effluent container, B1-E-05. Take care to avoid drips and insert the pipe into an empty sludge waste container, B1-E-04. Open transfer valve B1-V-03 again and restart transfer pump B1-E-12. Pump the remaining contents of the chemical treatment tank into the sludge waste container.

(l) Sample the treated effluent container and measure the activity to determine the level of decontamination achieved. This will determine whether further ‘polishing’ is required or if waste can be discharged.
(m) Sample the sludge waste to determine further treatment.
(n) If appropriate, seal and move the container of treated effluent to the appropriate storage area and replace with an empty container. Similarly, move the container of waste sludge to the appropriate storage area and replace with an empty container. Remove the now empty feed waste container and replace with a full container. The empty feed container can be rinsed with clean process water and the washings emptied into a feed waste container.
(o) The equipment should be rinsed through between batches using process water, and the washings collected in a waste container.

#### 5.2.9. Module B1 — Disadvantages of the process

(a) Gravity settling may not remove all solids. Further treatment of the effluent will be required, e.g. filtration (Modules B4 and B5) or ion exchange (Module B2).
(b) The process creates a sludge waste stream that must be processed further to condition it for disposal.
(c) The process requires the handling of toxic or corrosive chemicals.

#### 5.2.10. Module B1 — Interface and integration requirements

Interface requirements for the process module include:

(a) Authorized discharge route for treated aqueous waste required, which may involve further processing (e.g. Modules B2 and B5) to meet discharge criteria.

Integration with other process modules includes the following:

(a) Upstream of Module B2, i.e. ion exchange module that would be used to process the supernate by removing soluble activity;
(b) Upstream of Module B4, i.e. cross-flow module that would be used to process the supernate by removing fine suspended solids;
(c) Upstream of Module B5, i.e. filtration module that would be used to process the supernate by removing suspended solids;
(d) Upstream of Module B6, i.e. solidification module that would be used to cement the precipitated sludge waste.

### 5.3. MODULE B2–ION EXCHANGE

#### 5.3.1. Module B2 — General

Ion exchange is aimed at removing a significant proportion of the soluble radionuclide contaminants from the bulk volume of the aqueous liquid waste to yield a small volume of ion exchange material containing the radionuclides and the remaining bulk volume of the aqueous waste suitable for immediate discharge.

The ion exchange module will be used to pump liquid from a carboy via the ion exchange column, with the treated liquid waste then passing to another carboy.

The main components of the module are a pump, an ion exchange column, and a cartridge filter. The pump draws liquid from a carboy and pumps it through the ion exchange column and then the cartridge filter. The duty of the filter is to remove any ion exchange material fragments that may get flushed from the ion exchange bed. After passing through the filter, the treated liquid drains to another carboy.

The ion exchange column, cartridge filter and the pump are located within a drip tray that provides containment in the event of leaks or spillages. The carboys of aqueous waste feed and treated liquid are lifted into this drip tray for processing.

### 5.3.2. Module B2 — Basis of design

Table 5.5 summarizes the basis of design identifying the key parameters and assumptions used in determining the design of this processing module.

TABLE 5.5. BASIS OF DESIGN FOR MODULE B2–ION EXCHANGE

| | |
|---|---|
| Waste feed characteristics | |
| Total liquid volume | Typically 0.5–10 $m^3$ per year, for the reference case 5 $m^3$ per year should be used. |
| Timing | Arrives periodically in batches of about 50 L. |
| Peak treatment rates | 100 L/h. |
| Feed activity content | Low levels of activity, single or multiple radionuclides. |
| Physical form | Liquid, aqueous. It is assumed that it contains no oils or other immiscible species. |
| Solids content | No solids. |
| Chemical content | No significant chemical content except potential for presence of small quantities of complexing agents. |
| Treated effluent characteristics | |
| Activity content | A decontamination factor between 10 and 100 is expected. Treated effluent activity will depend on initial activity. |
| pH | pH6–9 assumed. |
| Other constituents | None known. |
| Services availability | |
| Services | The schematic designs should identify options for connections to existing services or the need for dedicated services. |
| Water | Required. |
| Power | Required. |
| Building heating | Required if temperatures likely to fall below 5°C. |
| HVAC | Not required. |
| Chemical reagents | Required. |
| Drainage | None. Any leaks or spillages that do occur to be captured in a drip tray and returned to a waste container using a small pump. |

### 5.3.3. Module B2 — Process flow diagram

Figure 5.12 illustrates the plant and equipment in a PFD.

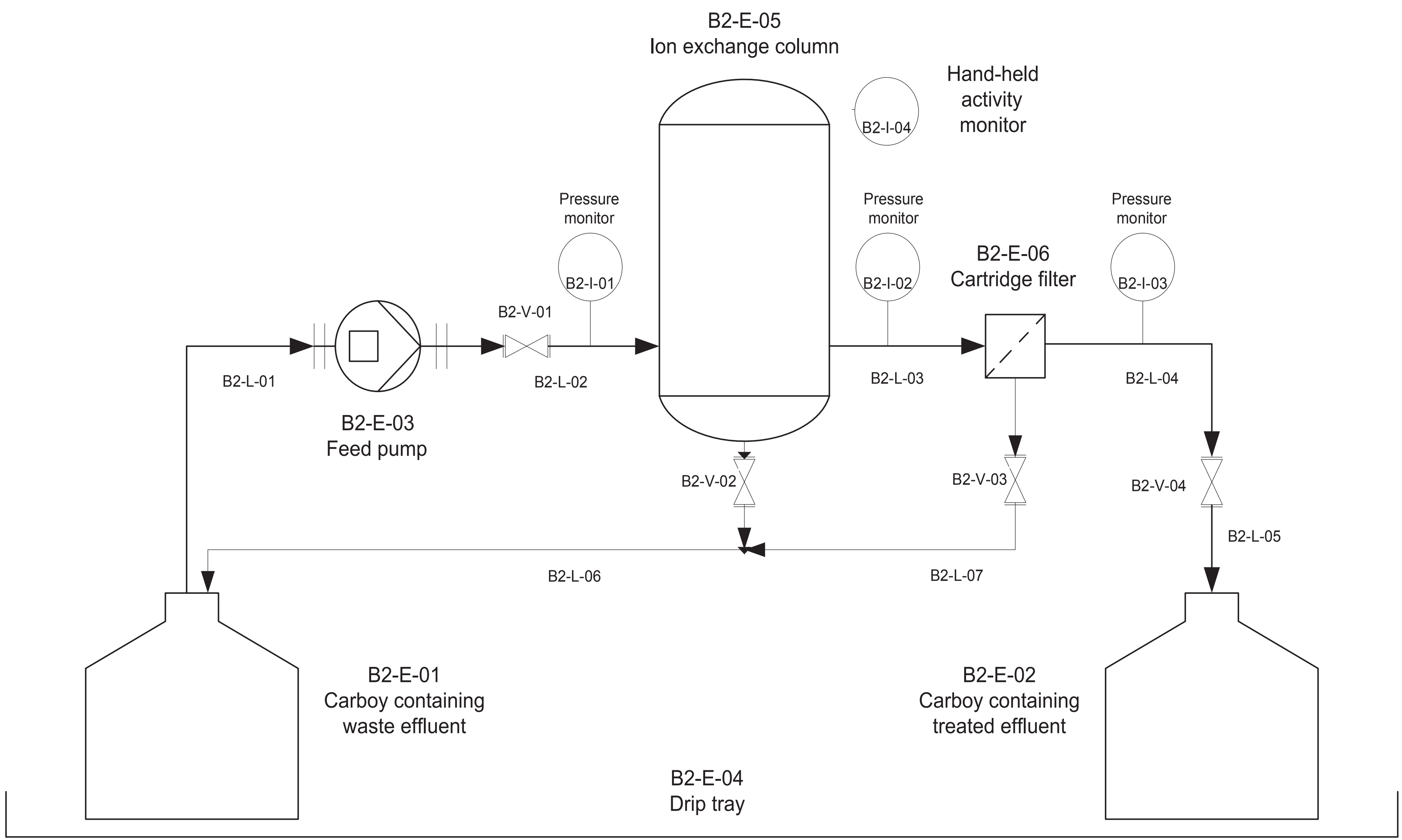


*FIG. 5.12. Process flow diagram for Module B2–Ion exchange.*

### 5.3.4. Module B2 — Equipment lists

The following equipment can be identified from this PFD (Table 5.6).

TABLE 5.6. EQUIPMENT LIST FOR MODULE B2–ION EXCHANGE

| Equipment | | | | |
|---|---|---|---|---|
| Tag | Description | Material | Type | Flow rate |
| B2-E-01 | Carboy containing aqueous waste | Plastic | 40–50 L plastic carboy | |
| B2-E-02 | Carboy containing treated effluent | Plastic | 40–50 L plastic carboy | |
| B2-E-03 | Feed pump | Plastic or stainless steel | Self-priming/positive displacement | 100 L/h |
| B2-E-04 | Drip tray | Plastic or stainless steel | | |
| B2-E-05 | Ion exchange column | Plastic or stainless steel | Mixed resin bed | 100 L/h |
| B2-E-06 | Cartridge filter | Plastic or stainless steel | Cartridge | 100 L/h |
| Pipelines | | | | |
| Tag | Description | Line size | Design pressure | Design temperature |
| B2-L-01 | Feed pump suction line | 15 mm | 2 bar | Ambient |
| B2-L-02 | Feed pump discharge line | 15 mm | 5 bar | Ambient |
| B2-L-03 | Ion exchange column discharge line | 15 mm | 5 bar | Ambient |
| B2-L-04 | Filter discharge line | 15 mm | 2 bar | Ambient |
| B2-L-05 | Discharge line | 15 mm | 2 bar | Ambient |
| B2-L-06 | Drain line | 15 mm | 2 bar | Ambient |
| B2-L-07 | Filter drain line | 15 mm | 2 bar | Ambient |
| Valves | | | | |
| Tag | Description | Line size | | Valve type |
| B2-V-01 | Ion exchange column feed valve | 15 mm | | Diaphragm (flanged) |
| B2-V-02 | Ion exchange column drain valve | 15 mm | | Ball (flanged) |
| B2-V-03 | Cartridge filter drain valve | 15 mm | | Ball (flanged) |
| B2-V-04 | Treated effluent outlet valve | 15 mm | | Diaphragm (flanged) |

TABLE 5.6. EQUIPMENT LIST FOR MODULE B2–ION EXCHANGE (cont.)

| Instruments | | | |
|---|---|---|---|
| Tag | Description | Type | Range |
| B2-I-01 | Ion exchange column inlet pressure | | |
| B2-I-02 | Ion exchange column outlet pressure / filter inlet pressure | | |
| B2-I-03 | Filter outlet pressure | | |
| B2-I-04 | Activity monitor | Hand held | |

**Note:** Pipelines and valves should be plastic or stainless steel.

### 5.3.5. Module B2 — Equipment description

A simple model to illustrate the ion exchange module is shown in Fig. 5.13.

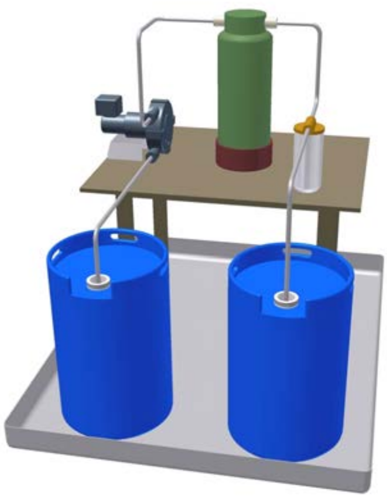

*FIG. 5.13. Model of Module B2–Ion exchange.*

The module equipment comprises the following:

(a) Storage containers for the aqueous waste, B2-E-01, in the form of 45 L, high integrity, UN certified reusable containers of double walled polythene construction designed for hazardous liquid chemicals. The container will incorporate an integral ergonomically shaped hand-ring, an offset pouring spout and secure interstacking features. Attention will be paid to a smooth geometry thus ensuring easy cleaning.
(b) A feed suction hose, B2-L-01, size 15 mm NB in flexible reinforced plastic, for transferring the aqueous liquid waste from the feed container to the feed pump.
(c) A self-priming feed pump, B2-E-03, such as a peristaltic, progressive cavity (quasi-positive displacement) type or equivalent with wetted parts in plastic and/or stainless steel, process connections at 15 mm NB, rated at typically 100 L/h to pump the aqueous liquid waste from the feed waste container through the ion exchange column and filter into a second container.

(d) A range of pump transfer pipework, B2-L-02, size 15 mm NB, in stainless steel or plastic, for transferring the aqueous liquid waste from the feed pump to the ion exchange column equipped with a feed control valve, B2-V-01, nominal size 15 mm NB, diaphragm type, in stainless steel or plastic, for regulating the flow and pressure of liquid waste through the ion exchange column.

(e) A proprietary ion exchange column, B2-E-05, in stainless steel or plastic (which may require integral shielding depending on the nature and level of activity) with process connections sized at 15 mm NB. This column is equipped with:

  (i) Pressure monitoring instruments, B2-I-01 and 02, diaphragm type, to monitor the pressure drop across the ion exchange column to give indication in case the ion exchange column is becoming blocked;

  (ii) Activity build up (gamma) instrument, B2-I-04, hand-held type for periodic monitoring of the build-up of activity within the ion exchange column;

  (iii) A drain valve, B2-V-02, ball type, in stainless steel or plastic, nominal size 15 mm NB, for draining liquid from the ion exchange column.

(f) The materials of construction for the ion exchange column will depend on the nature and level of activity in the aqueous waste. Plastic will not be suitable if high radiation doses are likely from the absorbed radionuclides.

(g) For processing a total of 5000 L/a, based upon a conservative sizing of 3–5 bed volumes per hour, a column of 20–30 L of ion exchange material capable of processing at a flow rate of approximately 100 L/h, will be adequate.

(h) This module can use either mixed ion exchange materials for general service or selective ion exchange materials to remove specific radionuclide species such as caesium and strontium. Hence, the selection of the ion exchange resin will be determined by the target radionuclides.

(i) The ion exchange resin can be loose material or could be contained in a removable cartridge or canister. However, disposal of spent ion exchange material in cartridges may cause a problem because it is not possible to immobilize the resin beads using cementation. Therefore, it is assumed that loose ion exchange material is employed.

(j) Interconnecting pipe-work, B2-L-03, size 15 mm NB, in stainless steel or plastic between the ion exchange column and the filter.

(k) A proprietary filter, B2-E-06, with vessel in stainless steel or plastic and cartridge type filter element in spun polypropylene rated at a nominal 5 μm, to trap any resin bead fragments that may get entrained during the normal operation of the ion exchange column, equipped with:

  (i) Pressure monitoring instruments, B2-I-02 and 03, to monitor the pressure drop across the filter to give indication if the filter is becoming blocked;

  (ii) A drain valve, B2-V-03, ball type, in stainless steel or plastic, nominal size 15 mm NB, for draining liquid from the filter vessel.

(l) A range of drainage pipe work, B2-L-06 and 07, size 15 mm NB, in stainless steel or plastic, for draining the aqueous liquid waste from the ion exchange column and filter vessel back to the waste feed container to permit maintenance operations.

(m) A range of transfer pipe-work, B2-L-04, size 15 mm NB, in stainless steel or plastic, between the filter outlet and the outlet control valve, B2-V-04, diaphragm type, nominal size 15 mm NB in stainless steel or plastic.

(n) A transfer hose, B2-L-05, size 15 mm NB in flexible reinforced plastic, for transferring the aqueous liquid waste from the outlet valve to the treated effluent container.

(o) To receive the aqueous waste after passing through the ion exchange column, a treated effluent receipt container, B2-E-02, in the form of 45 L, high integrity, UN certified, reusable containers of double walled polythene construction designed for hazardous liquid chemicals. The container will incorporate an integral ergonomically shaped hand-ring, an offset pouring spout and secure interstacking features. Attention will be paid to a smooth geometry, thus ensuring easy cleaning. to receive the aqueous waste after passing through the ion exchange column.

(p) Pipe work, valves and pump are arranged so that the pump can pump directly from the waste container and through the ion exchange column.

(q) Pipe work should be designed to keep the module as compact and simple as possible.

(r) There shall be the ability to isolate by valves, wash down and drain down all pipe work, pumps, vessels and other equipment.

(s) Process connections between pipe work and equipment shall be flanged.

(t) A framework, in stainless steel or epoxy painted mild steel, to support all of the equipment:
  (i) The framework is fitted with a drip tray, B2-E-04, a flat bottomed container in stainless steel or plastic to collect any spillages. The drip tray will contain both the feed and receipt containers, the transfer pump, ion exchange column and filter and typically will be capable of holding 110% of the total liquid volume held within the containers and all of the other equipment and pipe work mounted within or above the drip tray (approximately 150 L).
  (ii) The framework will have adjustable feet for levelling.
(u) An electrical control panel (not shown in the model picture), but supported from the module framework that receives the incoming power supply and controls the operation of all electrical equipment on the module. There should also be an emergency stop button to stop all equipment on the module. The control panel should include an electrical isolator to isolate all equipment on the module.
(v) All electrical equipment on the module should be suitably rated in terms of ingress protection to allow washdown of plant and equipment on the module (with an IP rating of IP54 or better).

### 5.3.6. Module B2 — Facility considerations

(a) Storage for untreated and filtered aqueous waste in 45 L carboys. Accumulation of aqueous waste should not be encouraged; therefore, the size of the storage for untreated liquid waste should be adequate for a single consignment of containers, equivalent to one day of operation, or say 20% of the annual volume (i.e. 1 $m^3$) or a nominal 20 carboys. This space should be 'bunded' to contain any spillages or leaks. The containment volume should be 110% of the total volume stored.
(b) A radiochemical laboratory will be required for sampling and analysis of both the treated and untreated liquids. The radionuclide content and pH of samples should be analysed.
(c) Provision of wash water for washdown of the plant and equipment, e.g. prior to maintenance.
(d) Containers of nominal capacity up to 200 L for the collection of spent ion exchange resins and flushing water.
(e) Bunded area for short term storage of containers holding spent ion exchange resins and flushing water. Localized shielding may be required.
(f) A suitable connection to the site sewer or other approved liquid discharge point with appropriate consents will be needed for this option.

### 5.3.7. Module B2 — Prerequisites

(a) Appropriate barriers and/or controls must be in place to manage the access of personnel to the ion exchange processing area.
(b) Operators must wear appropriate PPE, e.g. coveralls, safety shoes, goggles or mask and gloves.
(c) A radiation protection supervisor will monitor all module operations, including the receipt and dispatch of waste containers, the ion exchange column and the removal of pipe work from the liquid waste container.
(d) Following installation of the module and prior to operation with liquid waste, the ion exchange media must be wetted with deionized water. Once wetted, the ion exchange resin is ready to process aqueous waste.
(e) The ion exchange material can be prone to fouling if hard water is used for wetting the material or if it is a component of the aqueous waste being processed. Deionized water should be used to wet the ion exchange material by flushing it through the column. (If possible, ensure that hardness is removed at source from any process water used in the generation of the aqueous waste. This can be easily achieved at low cost if local ion exchange cartridges are fitted upstream of any process water taps.).
(f) It is recommended that any liquid waste is pre-treated to remove any suspended solids or they will foul the ion exchange column quickly. This can be achieved using either Module B4–Cross-flow filtration or B5 – Filtration.
(g) A small sample of the liquid waste can be taken by an operator using a pipette. Measurements of pH and activity can be made locally. At a low pH, absorbed species can be eluted from the cation exchange column, i.e. absorbed species will be removed from the column. Therefore, it is important to check the pH of the liquid waste being processed.

### 5.3.8. Module B2 — Process description and operation

(a) A carboy of liquid waste for processing is lifted into the drip tray by two personnel. Alternatively, specific attachments can be used with a forklift or other mechanical lifting aid to lift and place carboys into the drip tray.
(b) A second empty carboy of equal or greater capacity is positioned for the collection of the treated effluent.
(c) Under radiation protection supervision insert feed suction hose B2-L-01 into the feed waste container and secure it. Similarly, insert transfer pipe B2-L-05 into the empty treated effluent container and secure it. Open inlet and transfer valves, B2-V-01 and B2-V-04, and, using transfer pump B2-E-03, pump the aqueous waste through the ion exchange column.
(d) Observe the pressure instruments, B2-I-01 and B2-I-02 , to monitor the pressure drop across the ion exchange column, and B2-I-02 and B2-I-03 to monitor the pressure drop across the filter in case either the ion exchange column or filter is becoming blocked. Continue until either:
   (i) The treated effluent container is full; or
   (ii) The feed waste container is empty.
(e) Stop feed pump B2-E-03 and close isolation valves B2-V-01 & B2-V-04. Carefully, under radiation protection supervision, disconnect and withdraw pipes B2-L-01 B2-L-05 from their respective containers.
(f) Sample the treated effluent container and measure the activity to determine the level of decontamination achieved.
(g) If appropriate, seal and move the container of treated effluent to the appropriate storage area and replace with an empty container. Similarly, remove the now empty feed waste container and replace with a full container. The empty feed container can be rinsed with clean process water and the washings emptied into a feed waste container.
(h) If the treated liquid waste is not sufficiently decontaminated after one pass, it can be processed a second time through the ion exchange column. However, it is assumed that each container of liquid waste will be processed sufficiently with one pass through the ion exchange column. This minimizes the time to process a container.
(i) The buildup of activity radiation levels in the ion exchange resin after the processing of each container of waste should be monitored. Activity buildup as liquid waste is processed starts at the top of the column where the liquid is introduced. Monitoring will ensure that:
   (i) Dose rates remain acceptable where manual work is carried out;
   (ii) The activity level of the ion exchange resin does not exceed that of low level radioactive waste.
(j) It is likely that the ion exchange material and column will need to be changed because of a buildup of dose rate, before it is chemically exhausted:
   (i) Ion exchange materials will be loose, held between distribution plates within the column. Spent loose ion exchange material should be flushed from the column and collected in a suitable container (e.g. a 45 L plastic carboy). Excess water can be removed by decanting.
   (ii) The flushing system should also be capable of making up a batch of fresh ion exchange resin in water and then pumping that into the column.

### 5.3.9. Module B2 — Disadvantages of the process

(a) Pretreatment of process water is required, e.g. to wet the ion exchange material.
(b) Ion exchange material for selective radionuclide removal may be expensive.
(c) The process can be less effective in the presence of high salt levels.
(d) Low effluent pH can elute cations, i.e. absorbed species will be removed from the column.
(e) It creates a secondary waste stream (spent ion exchange) that must be processed.

### 5.3.10. Module B2 — Interface and integration requirements

Interface requirements for process module include the following:

(a) Spent ion exchange material is secondary waste and requires further treatment before disposal, e.g. solidification in Module B6.
Integration with other process modules involves the following:

(a) Use downstream of Module B4–Cross-flow to process the permeate by removing soluble activity in the effluent waste.
(b) Use downstream of Module B5–Filtration to remove soluble activity in the effluent waste.

## 5.4. MODULE B3–REVERSE OSMOSIS

### 5.4.1. Module B3 — General

Reverse osmosis is aimed at removing from the aqueous radioactive waste a major part (more than 99% on a spot sample basis, although more typically 90–95% with retentate recycle) of all the insoluble and soluble components, including radionuclide contaminants to yield a concentrated retentate (containing the major part of insoluble and soluble components) and a permeate (the remaining bulk volume of the aqueous waste).

The raw effluent must be pre-filtered using Module B5–Filter before treatment with a spiral RO filter. The permeate may be suitable for discharge immediately or require further 'polishing' by, for example, ion exchange (see Module B2).

Reverse osmosis is an option when surfactants, complexing agents and many types of radionuclides are present in the waste stream, because of which chemical treatment and ion exchange are ineffective. If the treated liquid is not meeting the authorized discharge limits, in spite of repeated chemical treatment, RO can be considered.

The RO module will pump aqueous waste out of the carboy and re circulate it through a spiral RO filter. The concentrated waste (i.e. retentate) will be directed back into the same carboy and the treated water which has been desalted (i.e. permeate) will be directed into a second carboy.

The main components of the module are the spiral RO filter, a feed pump and a high pressure pump. The feed pump draws liquid from a carboy to feed the high pressure pump, which pumps it through the spiral RO filter. A manually adjustable back pressure needle valve on the outlet ensures the liquid within the spiral RO filter is at the required pressure (typically 30–40 bar). Permeate passes through the RO membrane and drains from the spiral RO filter housing to another carboy. Retentate returns to the waste feed carboy to be pumped through the spiral RO filter again.

The spiral RO filter and the pump are located within a drip tray that provides containment in the event of leaks or spillages. The carboys of aqueous waste feed and permeate are lifted into this drip tray for processing.

As an example of an RO module, Fig. 5.14 shows a bench top unit in testing. A two chamber vessel is used in this unit instead of two carboys and two RO filters instead of one.

### 5.4.2. Module B3 — Basis of design

Table 5.7 summarizes the basis of design identifying the key parameters and assumptions used in determining the design of this processing module.

*FIG. 5.14. Bench top Module B3–RO.*

TABLE 5.7. BASIS OF DESIGN FOR MODULE B3–RO

| | |
|---|---|
| Waste feed characteristics | |
| Total liquid volume | Typically 0.5–10 $m^3$ per year, for the reference case 5 $m^3$ per year should be used. |
| Timing | Arrives periodically in batches of about 50 L. |
| Peak treatment rates | Up to 100 L/h. |
| Feed activity content | Low levels of activity, single or multiple radionuclides. |
| Physical form | Liquid, mainly aqueous. Assumed no oils or other immiscible liquids present. |
| Solids content | Expected to contain small quantities of fine particulates (size less 0.1 μm). |
| Chemical content | No oxidizing agents, salt content less 25 g/L. |
| Treated effluent characteristics | |
| Activity content | A DF of up to 100 is expected. Treated effluent activity will depend on initial activity. |
| pH | pH4–5 assumed. |
| Other constituents | No solids and salt content less than 1 g/L in treated waste stream. |
| Services availability | |
| Services | The schematic designs should identify options for connections to existing services or the need for dedicated services. |
| Water | Required. |
| Power | Required. |
| Building heating | Required if temperature falls below 5°C. |
| HVAC | Not required. |
| Chemical reagents | Required. |
| Drainage | None. Any leaks or spillages that do occur to be captured in a drip tray and returned to a waste container using a small pump. |

### 5.4.3. Module B3 — Process flow diagram

Figure 5.15 illustrates the plant and equipment in a PFD.

### 5.4.4. Module B3 — Equipment lists

The following equipment can be identified from this PFD (Table 5.8).

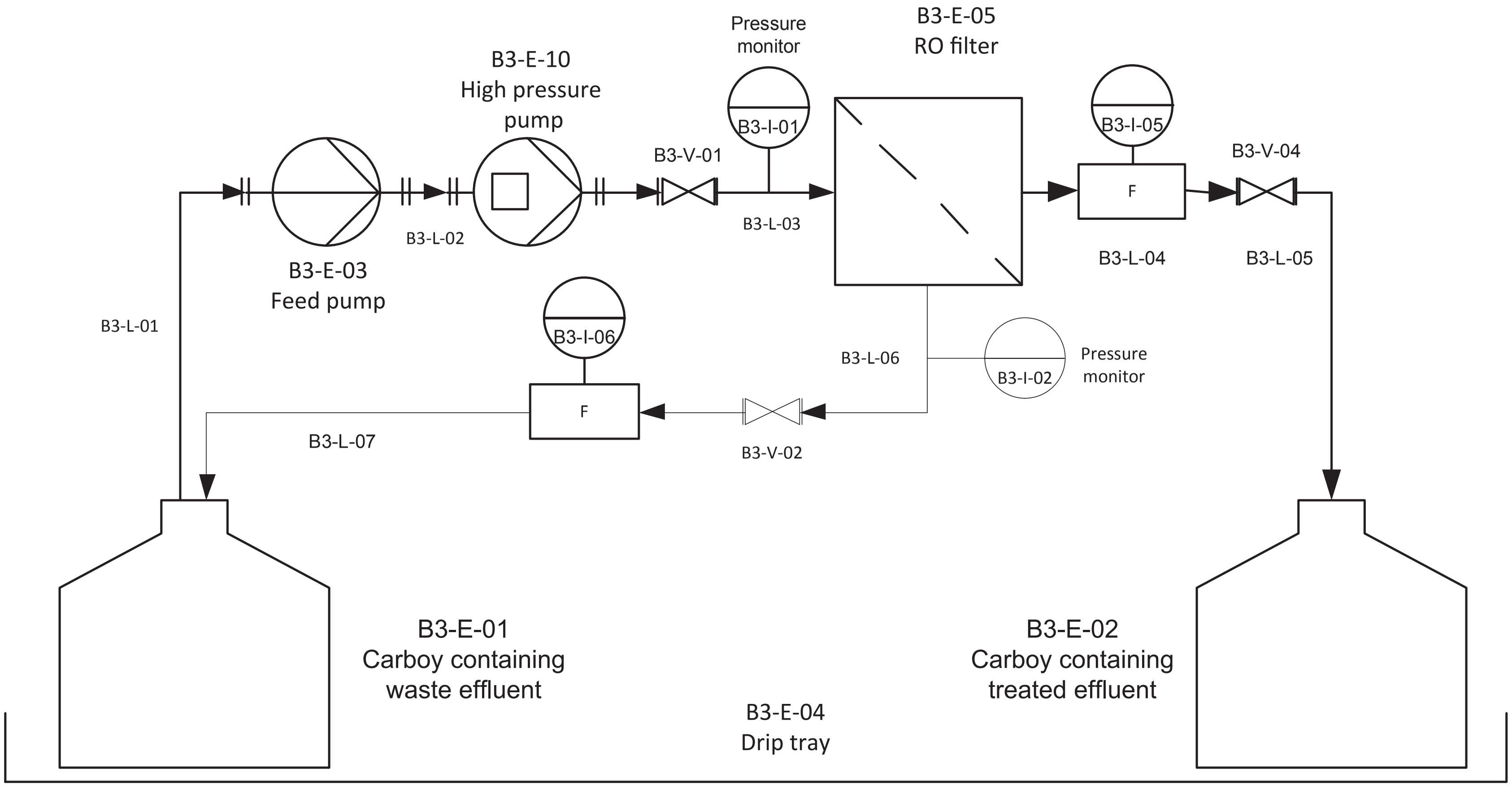


FIG. 5.15. Process flow diagram for Module B3–Reverse osmosis.

TABLE 5.8. EQUIPMENT LIST FOR MODULE B3–REVERSE OSMOSIS

| Equipment | | | | |
|---|---|---|---|---|
| Tag | Description | Material | Type | Flow rate |
| B3-E-01 | Aqueous waste container | Plastic | 45 L carboy | |
| B3-E-02 | Treated effluent container | Plastic | 45 L carboy | |
| B3-E-03 | Feed pump | Plastic or stainless steel | Self-priming | 1000 /h |
| B3-E-04 | Drip tray | Plastic or stainless steel | | |
| B3-E-05 | RO filter | Plastic or stainless steel casing | Membrane | 1000 L/h |
| B3-E-10 | High pressure pump | Stainless steel | Piston | 1000 L/h |

| Pipelines | | | | |
|---|---|---|---|---|
| Tag | Description | Line size | Design pressure | Design temperature |
| B3-L-01 | Feed pump suction line | 15 mm | 2 bar | Ambient |
| B3-L-02 | Feed pump discharge line | 15 mm | 5 bar | Ambient |
| B3-L-03 | High pressure pump discharge line | 15 mm | 40 bar | Ambient |
| B3-L-04 | Filter permeate outlet line | 15 mm | 2 bar | Ambient |
| B3-L-05 | Effluent discharge line | 15 mm | 2 bar | Ambient |
| B3-L-06 | Filter retentate outlet line | 15 mm | 40 bar | Ambient |
| B3-L-07 | Retentate return line | 15 mm | 2 bar | Ambient |

| Valves | | | | |
|---|---|---|---|---|
| Tag | Description | Line size | Type | Model |
| B3-V-01 | Filter feed control valve | 15 mm | Ball valve (flanged) | |
| B3-V-02 | Filter retentate control valve | 10 mm | Needle (flanged) | |
| B3-V-03 | Not used | — | — | |
| B3-V-04 | Permeate outlet valve | 15 mm | Ball valve (flanged) | |

| Instruments | | | | |
|---|---|---|---|---|
| Tag | Description | | Type | Range |
| B3-l-01 | Filter inlet pressure | | Gauge | 0–40 bar |
| B3-l-02 | Filter outlet pressure | | Gauge | 0–40 bar |
| B3-l-03 | Not used | | | |
| B3-l-04 | Not used | | | |

TABLE 5.8. EQUIPMENT LIST FOR MODULE B3–REVERSE OSMOSIS (cont.)

| Instruments | | | |
|---|---|---|---|
| Tag | Description | Type | Range |
| B3-I-05 | Permeate flow | Variable area | |
| B3-I-06 | Retentate flow | Variable area | |

**Note:** Pipelines and valves should be stainless steel.

### 5.4.5. Module B3 — Equipment description

Figure 5.16 illustrates a simple model of the RO module.

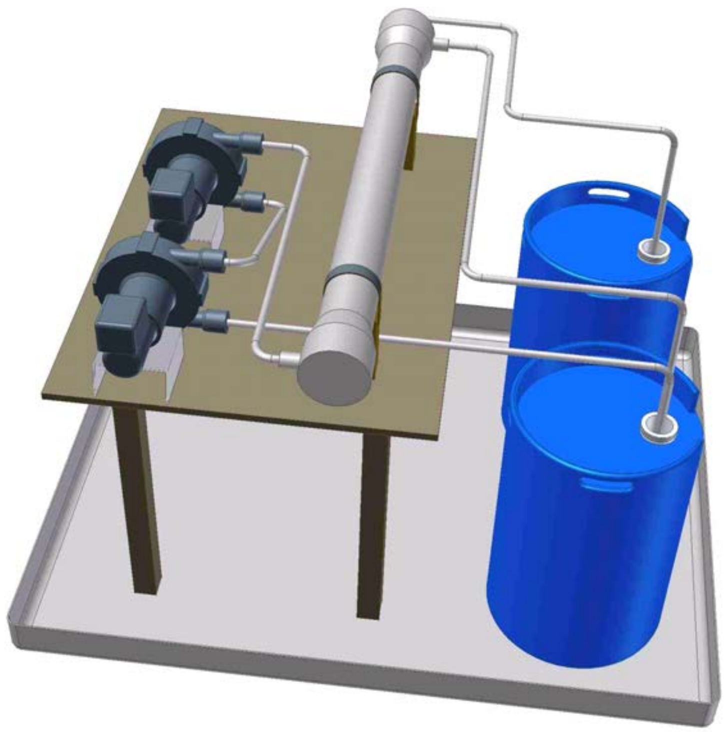

*FIG. 5.16. Model of Module B3–Reverse osmosis.*

The module equipment comprises the following:

(a) A feed container for the aqueous waste, B3-E-01, in the form of 45 L, high integrity, UN certified, reusable containers of double walled polythene construction designed for hazardous liquid chemicals. The container will incorporate an integral ergonomically shaped hand-ring, an offset pouring spout and secure interstacking features. Attention will be paid to a smooth geometry thus ensuring easy cleaning.
(b) A feed suction hose, B3-L-01, size 25 mm NB in flexible reinforced plastic, for transferring the aqueous liquid waste from the feed container to the feed pump.
(c) A self-priming feed pump, B3-E-03, with wetted parts in plastic and/or stainless steel, rated at typically 1000 L/h to pump the aqueous liquid waste from the feed waste container to a second high pressure pump, B3-E-10.

(d) An interconnecting pipe, B3-L-02, in stainless steel, incorporating a flexible hose in flexible reinforced plastic or rubber, size 25 mm NB.

(e) A high pressure pump, B3-E-10, a multistage centrifugal, positive displacement plunger or diaphragm pump, or equivalent, with wetted parts in stainless steel, rated at typically 1000 L/h at pressures up to 40 bar to pump the aqueous liquid waste through the RO filter, B3-E-05.

(f) A range of pump transfer pipe work, B3-L-03, size 15 mm NB, in stainless steel, incorporating a high pressure hose in stainless steel braided rubber or PTFE for transferring the aqueous liquid waste from the high pressure pump to the RO filter equipped with an isolating valve, B3-V-01, nominal size 15 mm NB, ball type, in stainless steel, for stopping the flow of liquid waste through the RO filter when the pumps are switched off.

(g) A proprietary RO filter, B3-E-05, in a stainless steel or plastic housing. Relevant observations include:
  (i) For processing a total of 5000 L/a; an RO module capable of processing at a flow rate up to about 100 L/h is adequate.
  (ii) This RO module is equipped with pressure monitoring instruments, B3-I-01 and B3-I-02, to monitor the operating pressure and the pressure drop along the RO filter, to indicate whether the membrane filter is becoming blocked.
  (iii) A spiral RO membrane element is recommended. Water molecules are driven through the membrane by a pressure differential, leaving fine particulates, larger and small molecules and ions on the retentate side. The retentate is recycled until the desired degree of concentration is achieved (controlled by the flow rates within the process). The dissolved solids content in the retentate at the end of processing is typically 40–50 g/L.
  (iv) The RO membrane itself can be made from different polymeric materials depending on the required separation characteristics.
  (v) The selection of the RO membrane will depend on the nature and content of salts in the aqueous waste and can only be established through trials. A nanofiltration (NF) membrane may be a better choice than an RO membrane for some applications.

(h) A range of permeate transfer pipe work, B3-L-04, size 15 mm NB, in stainless steel or plastic, between the RO filter permeate outlet and the permeate outlet control valve equipped with:
  (i) Permeate outlet control valve, B3-V-04, ball type, nominal size 15 mm NB, in stainless steel or plastic. This valve must be kept open whenever the plant is operating. It can only be closed when the pumps are switched off.
  (ii) Permeate flow meter, B3-I-05, variable area type, nominal size 15 mm NB, in stainless steel and/or plastic, range 0–100 L/h.
  (iii) A permeate transfer hose, B3-L-05, size 15 mm NB, in flexible reinforced plastic, for transferring the aqueous liquid waste from the outlet valve to the treated effluent container, B3-E-02.

(i) A range of retentate outlet pipe work, B3-L-06 in stainless steel, size 15 mm NB, for transferring the aqueous liquid waste from the RO filter to the waste feed container equipped with:
  (i) A control valve, B3-V-02, nominal size 10 mm NB, needle type, in stainless steel, for regulating the flow and pressure of liquid waste through the RO filter;
  (ii) A retentate flow meter, B3-I-06, variable area type, nominal size 10 mm NB, in stainless steel and/or plastic.

(j) A range of retentate return pipe work, B3-L-07, size 15 mm NB in flexible reinforced plastic, for transferring the aqueous liquid waste from the retentate outlet valve, B3-V-02, to the feed container, B3-E-01.

(k) To receive the aqueous waste after passing through the RO membrane, a treated effluent receipt container, B3-E-02, in the form of 45 L high integrity, UN certified, reusable container of double walled polythene construction designed for hazardous liquid chemicals. The container will incorporate an integral, ergonomically shaped, hand-ring, an offset pouring spout and secure interstacking features. Attention will be paid to a smooth geometry, thus ensuring easy cleaning.

(l) A framework, in stainless steel, to support all of the above equipment:
  (i) The framework is fitted with a drip tray, B3-E-04, a flat bottomed container in stainless steel or plastic to collect any spillages. The drip tray should contain both the feed and receipt containers, both of the pumps and RO filter and typically will be capable of holding 110% of the total liquid volume held within the containers and all of the other equipment and pipe work mounted within or above the drip tray (approximately 150 L).
  (ii) The framework will have adjustable feet for levelling.

(m) A waste container for the periodic discharge of the retentate (some shielding may be required, depending on the activity levels in the waste stream) in the form of a 45 L, high integrity, UN certified, reusable container of double walled polythene construction designed for hazardous liquid chemicals. The container will incorporate an integral, ergonomically shaped hand-ring, an offset pouring spout and secure interstacking features. Attention should be paid to a smooth geometry, thus ensuring easy cleaning.

(n) An electrical control panel (not shown on the model picture) supported from the module framework that receives the incoming power supply and controls the operation of all electrical equipment on the module. There should also be an emergency stop button to stop all equipment on the module. The control panel should include an electrical isolator to isolate all equipment on the module.

(o) All electrical equipment on the module should be suitably rated in terms of ingress protection to allow washdown of plant and equipment on the module (with an IP rating of IP54 or better). Particular points to note:
   (i) Pumps with flow meters are employed to transfer aqueous waste to the RO filter. This delivers controlled and uninterrupted flow, important for effective membrane separation performance.
   (ii) This module requires a wash water supply to provide water for plant flushing and for the addition of cleaning chemicals to make up cleaning solutions.

### 5.4.6. Module B3 — Facility considerations

(a) Storage for untreated and treated aqueous waste in 45 L carboys. Accumulation of aqueous waste should not be encouraged; therefore, the size of the storage for untreated liquid waste should be adequate for a single consignment of containers, equivalent to one day of operation, or say 20% of the annual volume, i.e. 1 $m^3$ or a nominal 20 carboys. This space should be bunded to contain any spillages or leaks. The containment volume should be 110% of the total volume stored.

(b) A radiochemical laboratory will be required for sampling and analysis of both the treated and untreated liquids. The radionuclide content and pH of samples should be analysed.

(c) Provision of wash liquors for washdown of plant and equipment, e.g. prior to maintenance.

(d) Bunded area for short term storage of containers holding and flushing water. Localized shielding may be required.

(e) A suitable connection to the site sewer or other approved liquid discharge point with appropriate consents will be needed for this option.

### 5.4.7. Module B3 — Prerequisites

(a) The operator or technician requirements are as follows:
   (i) One operator required to operate the equipment and for occasional monitoring and sampling duties;
   (ii) A lab technician or chemist for sampling and analysis of untreated and treated aqueous waste;
   (iii) A radiation protection supervisor to monitor all operations, including the receipt and dispatch of waste containers, the removal of pipe work from the liquid waste containers, the monitoring of the accumulated concentrated aqueous waste, and to assist the operator with occasional lifting operations.

(b) The RO membrane element can be prone to fouling if hard water is used either for flushing the RO membrane element, or as a component of the aqueous waste being processed. Deionized water should be used to wet the membrane by flushing through the RO membrane element.

(c) Also, if possible, ensure that hardness is removed at source from any process water used in the generation of the aqueous waste. This can be easily achieved at low cost if local ion exchange cartridges are fitted upstream of any process water taps.

(d) A RO process is suitable for the removal of dissolved solids only. A spiral RO membrane element is not suitable for handling gross solids which could block the end face of the membrane element and damage the membrane. For large quantities of solids, chemical treatment and gravity settling (in Module B1) or cartridge filtering (in Module B5) is advisable. This is then followed by the cross-flow filtration module (Module B4) as necessary. If further decontamination is required for meeting the authorized discharge levels, RO (Module B3) can be adopted as a polishing step after gravity settling (Module B1), cartridge filtration (Module B5) and cross-flow filtration (Module B4).

(e) Once wetted, the RO filter:
   (i) Is ready to process aqueous waste;
   (ii) Must remain wetted at all times.

(f) Prior to the arrival of any such waste:
   (i) Appropriate barriers and/or controls must be in place to manage the access of personnel to the RO processing area;
   (ii) The operator(s) must put on appropriate PPE, e.g. coveralls, safety shoes, goggles or mask and gloves.

(g) A small sample of the liquid waste can be taken and measurements made locally of pH and activity.

### 5.4.8. Module B3 — Process description and operation

(a) A carboy of liquid waste for processing is lifted into the drip tray by both personnel. Alternatively, specific attachments can be used with a forklift or other mechanical lifting aid to lift and place carboys into the drip tray. A second empty carboy of equal or greater capacity is required for the collection of the treated effluent.

(b) Under radiation protection supervision, insert the feed suction hose B3-L-01 into the feed waste container B3-E-01 and secure it. Similarly, insert the retentate return pipe B3-L-07 into the feed waste container and secure it. Insert the transfer pipe B3-L-05 into the empty treated effluent container and secure it. Open the inlet and transfer valves B3-V-01, B3-V-02 and B3-V-04. Using the transfer pump B3-E-03 and high pressure pump B3-E-10 pump the aqueous waste through the RO membrane housing. Gradually apply pressure to the RO filter using the retentate outlet valve B3-V-02 in accordance with the membrane manufacturer's instructions.

(c) Within the RO filter the flow is separated into two streams:
   (i) Permeate which passes through the membrane, deficient in solids and salts which have been rejected by the membrane, is discharged to the treated effluent container;
   (ii) Retentate, rich in salt and solids which do not pass through the membrane, is returned to the aqueous waste feed tank.

(d) The permeate flow rate will decrease as the retentate concentration increases through the repeated recycling of retentate, so monitoring flow rates is important in controlling the process. Observe the pressure instruments, B3-I-01 and 02, to monitor the pressure drop along the filter housing to indicate whether the filter is becoming blocked. Continue until either:
   (i) The treated effluent container is full;
   (ii) The required degree of concentration has been achieved in the feed waste container; or
   (iii) The permeate flow rate is lower than the minimum recommended by the membrane supplier.

(e) Stop the feed pump B3-E-10, followed by B3-E-03 and close the isolation valves B3-V-01, B3-V-02 and B3-V-04. Carefully, under radiation protection supervision, withdraw pipes B3-L-01, B3-L05 and B3-L-07 from their respective containers and keep them in the drip tray.

(f) Sample the treated effluent container and measure the activity to determine the level of decontamination achieved. Sample the feed effluent container (now containing concentrated retentate) and measure the activity to determine the degree of concentration achieved.

(g) If appropriate, seal and move the container of treated effluent to the appropriate storage area and replace with an empty container. Similarly, remove the feed waste container and replace with a full container. The concentrated waste in the feed container can be transferred to a separate concentrate storage vessel (which may require shielding), the feed container rinsed with clean process water and the washings emptied into a feed waste container.

(h) It is assumed that each container of liquid waste will be processed by passing once through the RO filter. This minimizes the time to process a container. However, if the treated liquid waste is not sufficiently decontaminated after one pass, it can be processed a second time through the RO filter.

### 5.4.9. Module B3 — Additional operational considerations

(a) To prevent sludge build up in pipes and equipment, the entire system will require periodic cleaning. Flushing with deionized water/suitable reagent solution and soaking of the membrane in chemical solutions are required to maintain optimum performance as after many operations the RO filter may become fouled. Fouling is recognized as low permeation rates accompanied by high operating pressures during operation on aqueous effluent. This washing generates secondary aqueous waste, which should be kept to a minimum in volume (for example, by repeated use).
(b) Once wetted, the RO filter must remain wetted at all times. If the filter is not used for long periods, it may be susceptible to biological attack. To prevent this, it is recommended that a solution of a mild biocide chemical is circulated through the filter and left in the filter for the duration of any shutdown lasting more than one day.
(c) A disposal route for spent contaminated cleaning chemicals is also required, e.g. Module B1–Chemical treatment or Module B6–Solidification.
(d) The RO membrane elements will require replacement during the life of the plant (typically after one year), but this depends on usage, the volume of waste treated, the presence of abrasive solids and frequency of cleaning.

### 5.4.10. Module B3 — Disadvantages of the process

Disadvantages of the RO process include the following:

(a) It is prone to fouling.
(b) Surfactants (cationic) and some complexing agents can irreversibly foul the membrane;
(c) It does not handle suspended solids well.
(d) It needs periodic cleaning to restore permeability.
(e) Chemical dosing for the preparation of cleaning solutions will need to be carried out manually.
(f) Once the membrane material is specified, the unit will only work effectively for certain chemical compositions of liquid radioactive waste.
(g) Sampling will need to be carried out manually.
(h) The special high pressure pumps are costly and complex and require specialist maintenance.
(i) Permeate flow rate will decrease as retentate concentration increases so continuous monitoring of the flow rate is important for controlling the process.
(j) It creates secondary waste streams (retentate, used cleaning solution and spent RO filters) that must be processed.
(k) It requires additional space for making up chemical solutions for cleaning the RO module.

### 5.4.11. Module B3 — Interface and integration requirements

The interface requirements for process module include the following:

(a) Retentate will require further processing (see Module B6–Solidification, or Module B2–Ion exchange).
(b) A disposal route for spent contaminated cleaning chemicals is also required, e.g. Module B1–Chemical treatment or Module B6–Solidification.
(c) A disposal route for spent RO filter elements is also required, e.g. Module B6–Solidification.

Integration with other process modules includes the following:

— Downstream of Module B1–Chemical treatment and Module B5–Filtration for solids removal and Module B4–Cross-flow, i.e. to process permeate or effluent from this module.

## 5.5. MODULE B4–CROSS-FLOW FILTRATION

### 5.5.1. Module B4 — General

Cross-flow filtration (either microfiltration or ultrafiltration) is aimed at removing a significant proportion of the insoluble radionuclide contaminants from the bulk volume of the aqueous liquid waste to yield a retentate containing the particulates and the remaining bulk volume of the aqueous waste suitable for discharge immediately or requiring further 'polishing' by, for example, ion exchange (see Module B2).

The cross-flow filtration module will pump aqueous waste out of the carboy and recirculate it through a cross-flow filter. The concentrate (i.e. retentate) will be directed back into the same carboy and the treated liquid which has been filtered (i.e. permeate) will be directed into a second carboy.

The main components of the module are the cross-flow filter unit and the pump. The pump draws liquid from a carboy and pumps it through the cross-flow filter. A manually adjustable back pressure valve on the outlet ensures the liquid within the filter is at the required pressure (typically 2–4 bar). Permeate passes through the cross-flow membrane and drains from the filter housing to another carboy. The retentate returns to the waste feed carboy to be pumped through the filter again.

The cross-flow unit and the pump are located within a drip tray that provides containment in the event of leaks or spillages. The carboys of aqueous waste feed and permeate are lifted into this drip tray for processing.

Figure 5.17 shows a similar cross-flow filtration module in works testing. This module is not yet located within a drip tray. The cross-flow filter itself is mounted directly on the pump discharge.

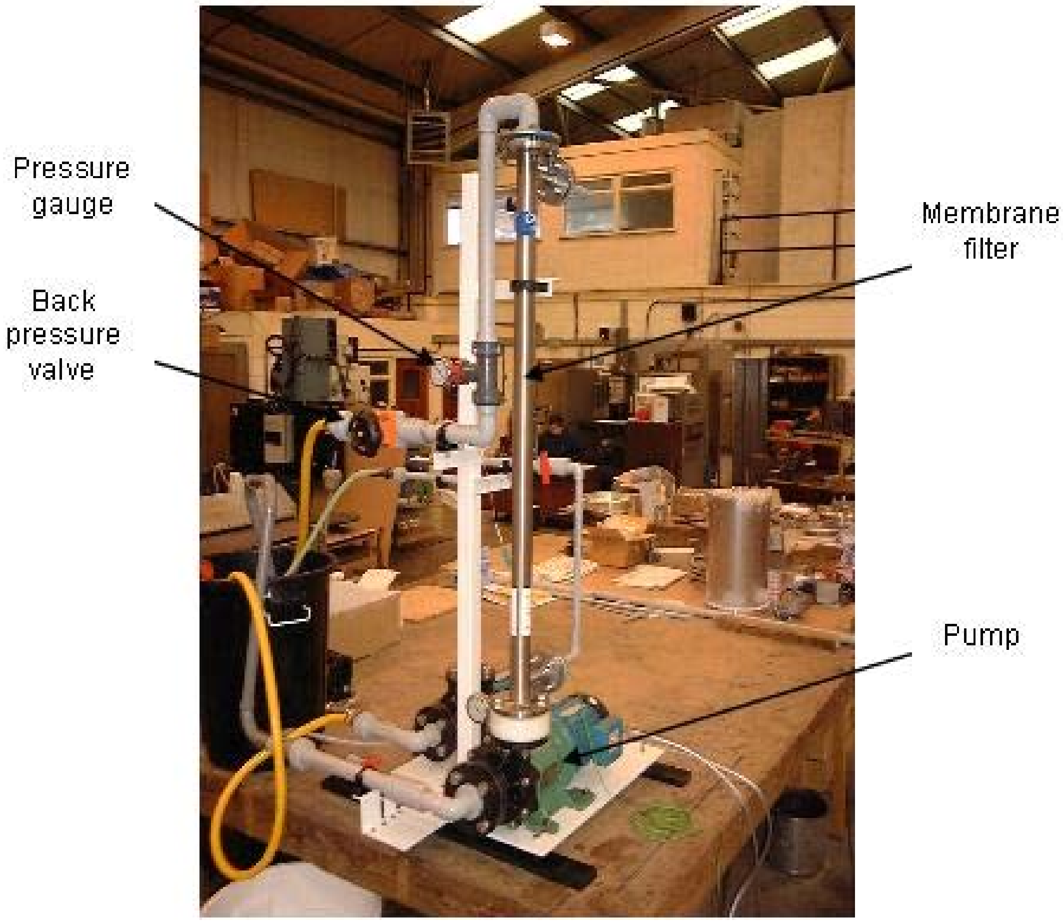


*FIG. 5.17. Example of Module B4–Cross-flow filtration.*

### 5.5.2. Module B4 — Basis of design

Table 5.9 summarizes the basis of design identifying the key parameters and assumptions used in determining the design of this processing module.

TABLE 5.9. BASIS OF DESIGN FOR MODULE B4–CROSS-FLOW FILTRATION

| | |
|---|---|
| Waste feed characteristics | |
| Total liquid volume | Typically 0.5–10 $m^3$ per year, for the reference case 5 $m^3$ per year should be used. |
| Timing | Arrives periodically in batches of about 50 L. |
| Peak treatment rates | 10 to 20 L/h. |
| Feed activity content | Low levels of activity, single or multiple radionuclides. |
| Physical form | Liquid, mainly aqueous. Assumed no oils or other immiscible liquids present. |
| Solids content | Expected to contain small quantities of fine particulates. |
| Chemical content | No significant chemical content except potential for presence of small quantities of complexing agents. |
| Treated effluent characteristics | |
| Activity content | A DF of 10 to 100 is expected. Treated effluent activity will depend on initial activity. |
| pH | pH6–9 is assumed. |
| Other constituents | No solids in treated waste stream. |
| Services availability | |
| Services | The schematic designs shall identify options for connections to existing services or the need for dedicated services. |
| Water | Required. |
| Power | Required. |
| Building heating | Required if temperature falls below 5°C. |
| HVAC | Not required. |
| Chemical reagents | Required. |
| Drainage | None. Any leaks or spillages that do occur to be captured in a drip tray and returned to a waste container using a small pump. |

### 5.5.3. Module B4 — Process flow diagram

Figure 5.18 illustrates the plant and equipment in a PFD.

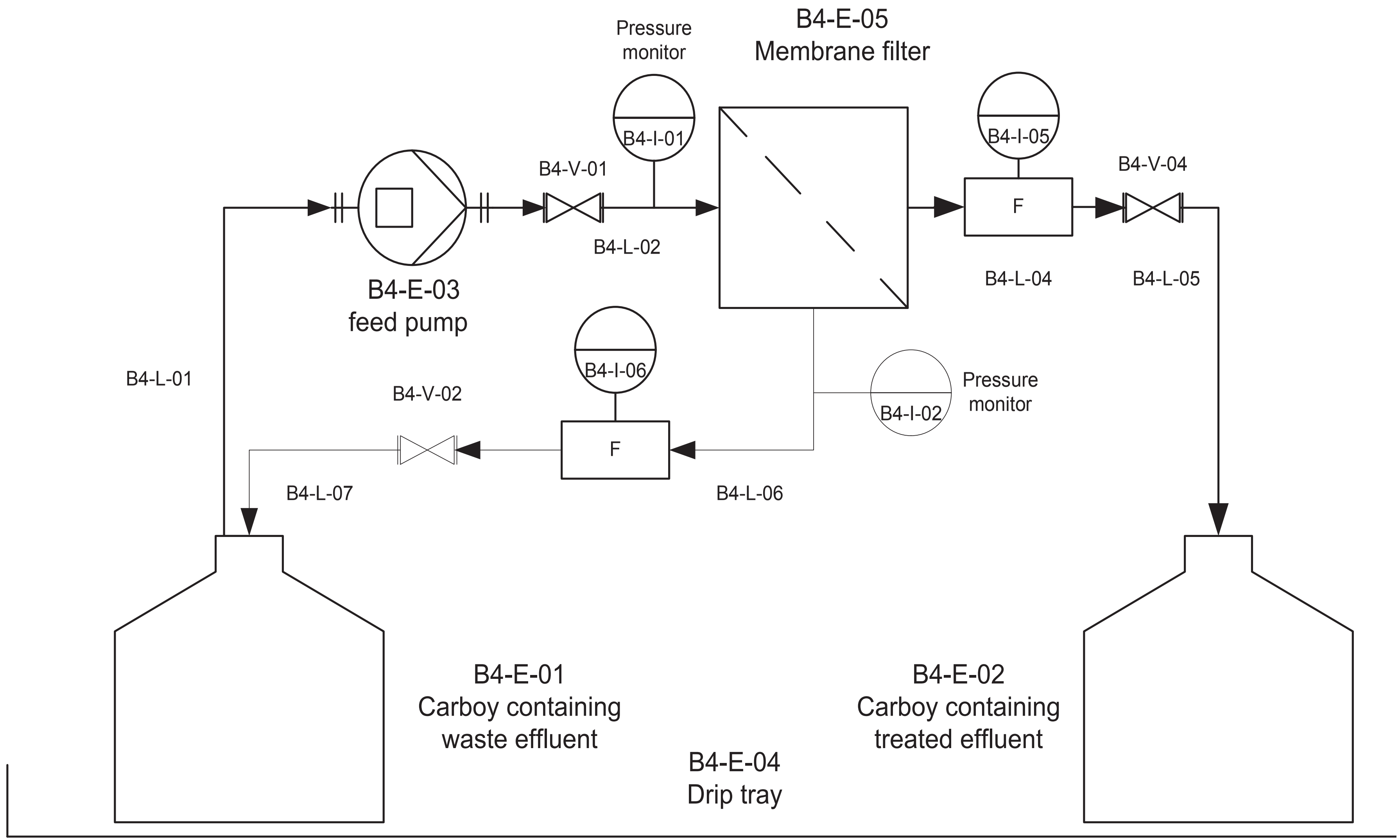


*FIG. 5.18. Process flow diagram for Module B4–Cross-flow filtration.*

### 5.5.4. Module B4 — Equipment lists

The following equipment can be identified from this PFD (Table 5.10).

TABLE 5.10. EQUIPMENT LIST FOR MODULE B4–CROSS-FLOW FILTRATION

| | | Equipment | | |
|---|---|---|---|---|
| Tag | Description | Material | Type | Flow rate |
| B4-E-01 | Aqueous waste container | Plastic | 45 L carboy | |
| B4-E-02 | Treated effluent container | Plastic | 45 L carboy | |
| B4-E-03 | Feed pump | Plastic or stainless steel | Self-priming positive displacement | 2000 L/h |
| B4-E-04 | Drip tray | Plastic or stainless steel | | |
| B4-E-05 | Cross-flow membrane filter | Plastic or stainless steel casing | Microfilter or ultrafilter membrane | 20 L/h |
| | | Pipelines | | |
| Tag | Description | Line size | Design pressure | Design temperature |
| B4-L-01 | Feed pump suction line | 15 mm | 2 bar | Ambient |
| B4-L-02 | Feed pump discharge line | 15 mm | 5 bar | Ambient |
| B4-L-04 | Filter permeate outlet line | 15 mm | 2 bar | Ambient |
| B4-L-05 | Effluent discharge line | 15 mm | 2 bar | Ambient |
| B4-L-06 | Retentate return line | 15 mm | 2 bar | Ambient |
| B4-L-07 | Retentate return line | 15 mm | 2 bar | Ambient |
| | | Valves | | |
| Tag | Description | Line size | Type | Model |
| B4-V-01 | Filter feed control valve | 15 mm | Diaphragm (flanged) | |
| B4-V-02 | Filter retentate control valve | 15 mm | Diaphragm (flanged) | |
| B4-V-03 | Not used | — | — | |
| B4-V-04 | Permeate outlet valve | 15 mm | Diaphragm (flanged) | |
| | | Instruments | | |
| Tag | Description | | Type | Range |
| B4-I-01 | Filter inlet pressure | | | |
| B4-I-02 | Filter outlet pressure | | | |

TABLE 5.10. EQUIPMENT LIST FOR MODULE B4–CROSS-FLOW FILTRATION (cont.)

| Instruments | | | |
|---|---|---|---|
| Tag | Description | Type | Range |
| B4-l-03 | Not used | | |
| B4-l-04 | Not used | | |
| B4-l-05 | Permeate flow | Variable area | |
| B3-l-06 | Retentate flow | Variable area | |

**Note:** Pipelines and valves should be stainless steel.

### 5.5.5. Module B4 — Equipment description

Figure 5.19 illustrates a simple model of the cross-flow filtration module.

*FIG. 5.19. Model of Module B4–Cross-flow filtration.*

The process module comprises the following:

(a) A feed container for the aqueous waste, B4-E-01, in the form of 45 L high integrity, UN certified, reusable containers of double walled polythene construction designed for hazardous liquid chemicals. The container will incorporate an integral, ergonomically shaped, hand-ring, an offset pouring spout and secure interstacking features. Attention should be paid to a smooth geometry, to ensure easy cleaning.

(b) A feed suction hose, B4-L-01, size 15 mm NB, in flexible reinforced plastic, for transferring the aqueous liquid waste from the feed container to the feed pump.

(c) A self-priming feed pump, B4-E-03, peristaltic or progressive cavity type (quasi positive displacement) or equivalent with wetted parts in plastic and/or stainless steel, process connections at 15 mm NB, rated at typically 2000 L/h to pump the aqueous liquid waste from the feed waste container through the cross-flow filter into a second container.

(d) A range of pump transfer pipe work, B4-L-02, size 15 mm NB, in stainless steel or plastic, for transferring the aqueous liquid waste from the feed pump to the cross-flow filter equipped with a feed control valve, B4-V-01, nominal size 15 mm NB, diaphragm type, in stainless steel or plastic, for regulating the flow and pressure of liquid waste through the cross-flow filter.

(e) A proprietary cross-flow filter, B4-E-05, in stainless steel or plastic housing, capable of processing 10–20 L/h waste. This is suitable for a total waste volume of approximately 5000 L/a:

  (i) This filter is equipped with pressure monitoring instruments, B4-I-01 and B4-I-02, to monitor the operating pressure and the pressure drop along the cross-flow filter to indicate whether the cross-flow filter is becoming blocked.

  (ii) The cross-flow filter typically comprises a bundle of cross-flow filter membrane tubes within a shell. Water molecules are driven through the cross-flow membrane by a pressure differential, leaving fine particulates and/or larger molecules on the retentate side. The retentate is recycled until the desired degree of concentration is achieved (controlled by the flow rates within the process).

  (iii) The filter membrane itself can be sintered steel or ceramic, depending on the required filtration characteristics. Care is needed when handling ceramic or graphite type membranes as they are fragile. Sintered stainless steel membranes are generally more robust and so these types of membranes are the preferred option.

  (iv) Selection of membrane pore size will depend on the nature and content of solids in the aqueous waste and can only be established through trials. Pilot testing will be required to select the most suitable filter pore size to optimize filter performance in terms of filtration efficiency and throughput, e.g. a small pore size may have high filtration efficiency but have low throughput; a large pore size may have lower filter efficiency but a higher throughput. One cross-flow tube and associated filter housing for one tube can be used for pilot scale testing. The tube can then be used in the full scale plant, along with additional tubes to take it up to scale. A larger filter housing will then be required as well.

  (v) The cross-flow filter will require replacement during the life of the plant (typically after five years), but this depends on usage, volume of waste treated, presence of abrasive solids and frequency of cleaning.

  (vi) To prevent sludge build up in pipes and equipment the whole system will require periodic cleaning. Flushing with deionized water and soaking of the cross-flow filter membrane in chemical solutions are required to maintain optimum performance as after many operations the cross-flow membrane may become fouled. Fouling is recognized as low permeation rates accompanied by high operating pressures during operation on aqueous effluent. This washing generates secondary aqueous waste, which should be kept to a minimum in volume (for example, by repeated use).

(f) A range of permeate transfer pipe work, B4-L-04, size 15 mm NB, in stainless steel or plastic, between the filter permeate outlet and the permeate transfer control valve equipped with:

  (i) Permeate outlet control valve, B4-V-04, diaphragm type, nominal size 15 mm NB in stainless steel or plastic;

  (ii) Permeate flow meter, B4-I-05, variable area type, nominal size 15 mm NB in stainless steel and/or plastic.

(g) A permeate transfer hose, B4-L-05, size 15 mm NB in flexible reinforced plastic, for transferring the aqueous liquid waste from the outlet valve to the treated effluent container.

(h) A range of retentate return pipe work, B4-L-06, size 15 mm NB in stainless steel or plastic, for returning the concentrated aqueous liquid waste from the cross-flow filter back to the waste feed container equipped with:

  (i) A filter concentrate outlet modulating valve, B4-V-02, nominal size 15 mm NB in stainless steel or plastic, to control the cross-flow filter operating pressure;

  (ii) Retentate flow meter, B4-I-06, variable area type, nominal size 15 mm NB in stainless steel and/or plastic.

(i) A retentate transfer hose, B4-L-07, size 15 mm NB in flexible reinforced plastic, for transferring the aqueous liquid waste from the retentate outlet valve to the treated effluent container.

(j) To receive the aqueous waste after passing through the filter, a treated effluent receipt container, B4-E-02, in the form of 45 L high integrity UN certified reusable container of double walled polythene construction designed for hazardous liquid chemicals. The container will incorporate an integral, ergonomically shaped hand-ring, an offset pouring spout and secure interstacking features. Attention should be paid to a smooth geometry, thus ensuring easy cleaning, to receive the aqueous waste after passing through the ion exchange column.

(k) The pipe work, valves and pump are arranged so that the pump can pump directly from the waste container and through the filter.

(l) The pipe work should be designed to keep the module as compact and simple as possible.

(m) There should be the ability to isolate by valves, and to wash down and drain down all pipe work, pumps, vessels and other equipment.

(n) The process connections between the pipe work and equipment should be flanged.

(o) A framework, in stainless steel or epoxy painted mild steel, to support all of the equipment:
   (i) The framework is fitted with a drip tray, B4-E-04; a flat bottomed container in stainless steel or plastic to collect any spillages. The drip tray should contain both the feed and receipt containers, the feed pump and cross-flow filter, and typically will be capable of holding 110% of the total liquid volume held within the containers and all of the other equipment and pipe work mounted within or above the drip tray (approximately 150 L).
   (ii) The framework will have adjustable feet for levelling.

(p) A waste container for the periodic transfer of the retentate (some shielding may be required, depending on the activity levels in the waste stream.) in the form of a 45 L, high integrity, UN certified reusable container of double walled polythene construction designed for hazardous liquid chemicals. The container should incorporate an integral, ergonomically shaped hand-ring, an offset pouring spout and secure interstacking features. Attention should be paid to a smooth geometry, thus ensuring easy cleaning.

(q) An electrical control panel (not shown on the model picture) supported from the module framework that receives the incoming power supply and controls the operation of all electrical equipment on the module. There should also be an emergency stop button to stop all equipment on the module. The control panel should include an electrical isolator to isolate all equipment on the module.

(r) All electrical equipment on the module should be suitably rated in terms of ingress protection to allow washdown of plant and equipment on the module (with an IP rating of IP54 or better).

### 5.5.6. Module B4 — Facility considerations

(a) The bunded storage area for containers of treated and untreated liquid, plus accumulated concentrate equivalent to five days of operation.

(b) This module requires a water supply to provide water for plant flushing and for the addition of cleaning chemicals to make up cleaning solutions.

(c) Radiochemical laboratory for sampling and analysis of aqueous liquid for the expected solids content in both the treated and untreated liquids.

(d) A disposal route for spent contaminated cleaning chemicals is also required, e.g. Module B1–Chemical treatment or Module B6–Solidification.

(e) A suitable connection to the site sewer or other approved liquid discharge point, with appropriate consents, will be needed for this option.

### 5.5.7. Module B4 — Prerequisites

(a) Appropriate barriers and/or controls must be in place to manage the access of personnel to the cross-flow filter processing area.

(b) The operator(s) must wear appropriate PPE, e.g. coveralls, safety shoes, goggles or mask and gloves.

(c) A radiation protection supervisor should monitor all module operations, including the receipt and dispatch of waste containers and the removal of pipe work from the liquid waste container.

(d) Deionized water should be used to wet the cross-flow filter membrane by flushing through the filter. The cross-flow filter can be prone to fouling if hard water is used to flush it, or if it is a component of the aqueous waste being processed. If possible, ensure that hardness is removed at the source from any process water used in the generation of the aqueous waste. This can be easily achieved at low cost if local ion exchange cartridges are fitted upstream of any process water taps.

(e) A cross-flow filter plant is only suitable for the removal of very fine particulate (<0.1 μm) and high molecular weight dissolved solids. Cross-flow filters are not suitable for handling gross solids, which could block tubes and damage the cross-flow membrane. For large quantities of solids, gravity settling (in Module B1) or cartridge filtering (in Module B5) is advisable prior to cross-flow filtration treatment.

(f) Following installation of the module and prior to operation with liquid waste, the cross-flow membrane must be wetted with deionized water. Once wetted, the cross-flow membrane filter is ready to process aqueous waste.

(g) A small sample of the liquid waste can be taken and measurements made locally of pH and activity.

### 5.5.8. Module B4 — Process description and operation

(a) A carboy of liquid waste for processing is lifted into the drip tray by two personnel. Alternatively, specific attachments can be used with a forklift or other mechanical lifting aid to lift and place carboys into the drip tray. A second empty carboy of equal or greater capacity is required for the collection of the treated effluent.

(b) Under radiation protection supervision, insert the feed suction hose B4-L-01 into the feed waste container B4-E-01 and secure it. Similarly, insert the retentate return pipe, B4-L-07, into the feed waste container and secure. Insert the transfer pipe B4-L-05 into the empty treated effluent container and secure it. Open inlet and transfer valves, B4-V-01, B4-V-02 and B4-V-04. Using feed pump B4-E-03, pump the aqueous waste through the cross-flow filter housing. Gradually apply pressure to the cross-flow filter using retentate outlet valve B4-V-02 in accordance with the cross-flow filter manufacturer's instructions.

(c) Within the filter, the flow is separated into two streams:
   (i) Permeate, which passes through the membrane, deficient in solids and large dissolved molecules which have been rejected by the cross-flow filter, is discharged to the treated effluent container;
   (ii) Retentate, rich in solids and rejected dissolved constituents which do not pass through the cross-flow filter, is returned to the aqueous waste feed tank.

(d) The permeate flow rate will decrease as the retentate concentration increases through the repeated recycling of retentate so monitoring flow rates is important in controlling the process. Observe the pressure instruments, B4-I-01 and B4-I-02, to monitor the pressure drop along the filter housing to indicate whether the filter is becoming blocked. Continue until either:
   (i) The treated effluent container is full;
   (ii) The required degree of concentration has been achieved in the feed waste container; or
   (iii) The permeate flow rate is lower than the minimum recommended by the cross-flow filter supplier.

(e) Stop feed pump B4-E-03 and close isolation valves B4-V-01, B4-V-02 and B4-V-04. Carefully, under radiation protection supervision, withdraw pipes B4-L-01, B4-L05 and B4-L-07 from their respective containers and keep in the drip tray.

(f) Sample the treated effluent container and measure the activity to determine the level of decontamination achieved. Sample the feed effluent container (now containing concentrated retentate) and measure the activity to determine the degree of concentration achieved.

(g) If appropriate, seal and move the container of treated effluent to the appropriate storage area and replace with an empty container. Similarly, remove the feed waste container and replace with a full container. The concentrated waste in the feed container can be transferred to a separate concentrate storage vessel (which may require shielding), the feed container rinsed with clean process water and the washings emptied into a feed waste container.

(h) It is assumed that each container of liquid waste will be processed by passing once through the cross-flow filter. This minimizes the time to process a container. However, if the treated liquid waste is not sufficiently decontaminated after one pass, it can be processed a second time through the filter.

#### 5.5.9. Module B4 — Disadvantages of the process

(a) It is prone to fouling.
(b) It needs periodic cleaning to restore permeability.
(c) Once the cross-flow filter material is specified, the unit will only work effectively for certain particle sizes.
(d) Sampling will need to be carried out manually.
(e) Chemical dosing for the preparation of cleaning solutions will need to be carried out manually.
(f) The permeate flow rate will decrease as the retentate concentration increases, so continuous monitoring of the flow rate is important for controlling the process.
(g) It creates a secondary waste streams (retentate and used cleaning solution) that must be processed.
(h) It requires additional space for making up chemical solutions for cleaning the cross-flow membrane module.

#### 5.5.10. Module B4 — Interface and integration requirements

Interface requirements for process module include the following:

(a) The retentate will require further processing (see Module B6–Solidification);
Integration with other process modules:
  (i) Downstream of Module B1, i.e. to process supernate or effluent from the chemical treatment module (after bulk solids have been taken out using a settling process);
  (ii) Downstream of Module B5 (Filtration) that will be used to pre-filter the liquid waste before cross-flow filtration;
  (iii) Upstream of Module B3 (RO) to filter the liquid waste to avoid blockage of the RO membranes.

### 5.6. MODULE B5–FILTRATION

#### 5.6.1. Module B5 — General

One of the possible stages in treatment is filtration. Filtration is aimed at removing a significant proportion of the insoluble radionuclide contaminants from the bulk volume of the aqueous liquid waste. The filtered stream will usually require further ‘polishing’ by, for example, cross-flow filtration (see Module B4) or ion exchange (see Module B2).

The filtration module pumps aqueous waste out of the carboy and recirculates it through a filter. The particulates are trapped in the filter and the treated liquid which has been filtered (i.e. permeate) is directed into a treated waste carboy.

The main components of the module are the filter unit and the pump. The pump draws liquid from a carboy and pumps it through the filter. A manually adjustable back pressure valve on the outlet ensures the liquid within the filter is at the required pressure (typically 2–4 bar). Permeate passes through the filter and drains from the filter housing to a carboy. Particulates are retained within the filter (cartridge or bag).

The filter unit and the pump are located within a drip tray that provides containment in the event of leaks or spillages. The carboys of aqueous waste feed and filtered liquid are lifted into this drip tray for processing.

#### 5.6.2. Module B5 — Basis of design

Table 5.11 summarizes the basis of design identifying the key parameters and assumptions used in determining the design of this processing module.

TABLE 5.11. BASIS OF DESIGN FOR MODULE B5–FILTRATION

| | |
|---|---|
| Waste feed characteristics | |
| Total liquid volume | Typically 0.5–10 $m^3$ per year, for the reference case 5 $m^3$ per year should be used. |
| Timing | Arrives periodically in batches of about 50 L. |
| Peak treatment rates | 100 L/h. |
| Feed activity content | Low levels of activity, single or multiple radionuclides. |
| Physical form | Liquid, mainly aqueous. Assumed no oils or other immiscible liquids present. |
| Solids content | Expected to contain small quantities of fine particulates. |
| Chemical content | No significant chemical content, except potential for presence of small quantities of complexing agents. |
| Treated effluent characteristics | |
| Discharge activity content | DF of 10–100 is expected. Treated effluent activity will depend on initial activity. |
| pH | pH6–9 assumed. |
| Other constituents | No solids in the treated waste stream. |
| Services availability | |
| Services | The schematic designs should identify options for connections to existing services or the need for dedicated services. |
| Water | Required. |
| Power | Required. |
| Building heating | Required if the temperature falls below 5°C. |
| HVAC | Not required. |
| Chemical reagents | Not required. |
| Drainage | None. Any leaks or spillages that do occur to be captured in a drip tray and returned to a waste container using a small pump. |

### 5.6.3. Module B5 — Process flow diagram

Figure 5.20 illustrates the plant and equipment in a PFD.

### 5.6.4. Module B5 — Equipment lists

From this PFD the following equipment can be identified (Table 5.12).

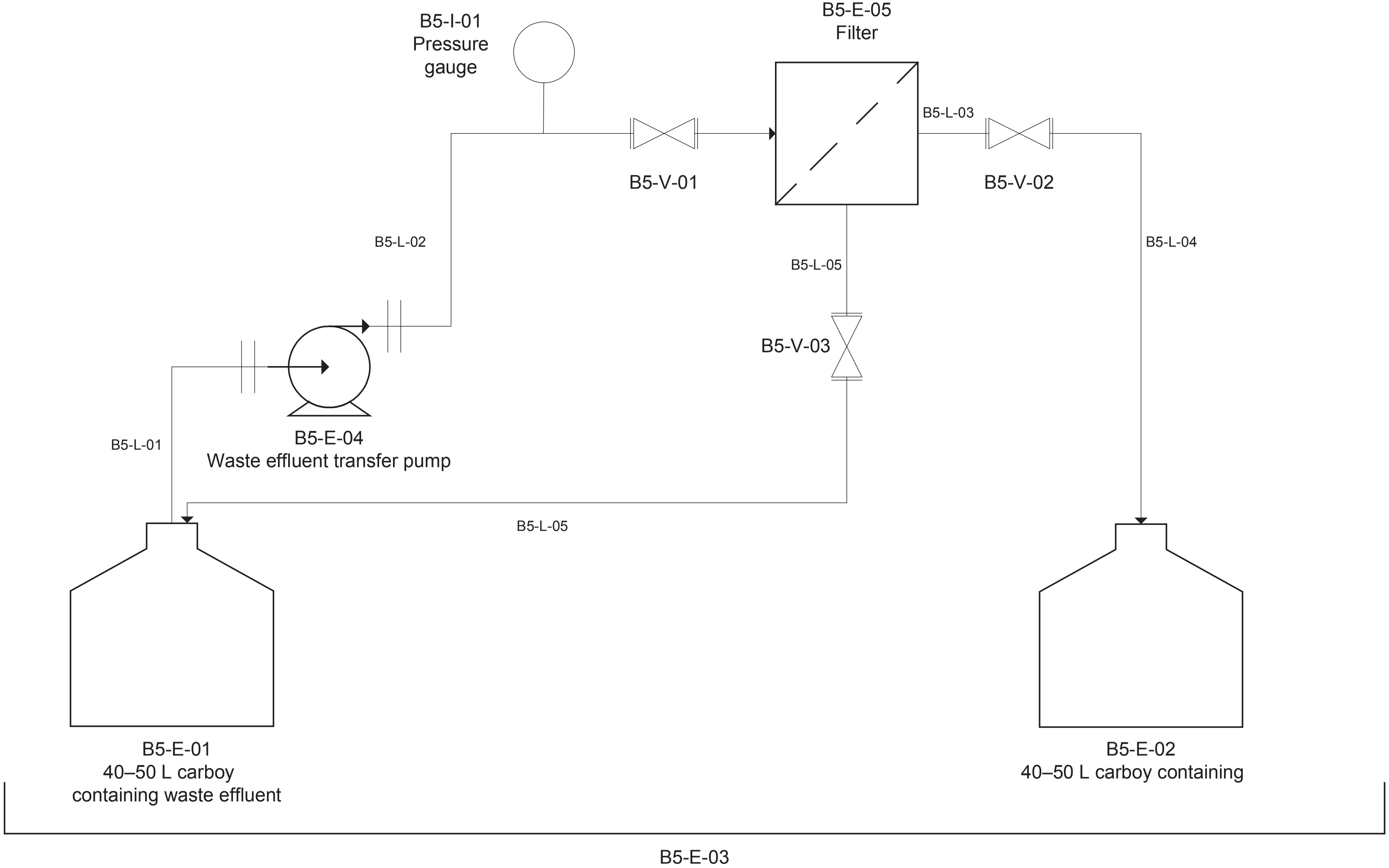


*FIG. 5.20. Process flow diagram for Module B5–Filtration.*

TABLE 5.12. EQUIPMENT LIST FOR MODULE B5–FILTRATION

| Equipment | | | | |
|---|---|---|---|---|
| Displayed text | Description | Material | Type | Flow rate |
| B5-E-01 | Aqueous waste container | Plastic | 40–50 L carboy | |
| B5-E-02 | Treated effluent container | Plastic | 40–50 L carboy | |
| B5-E-03 | Drip tray | Plastic or stainless steel | | |
| B5-E-04 | Waste feed pump | Plastic or stainless steel | Self-priming positive displacement (flanged) | 100 L/h |
| B5-E-05 | Filter | Plastic or stainless steel | Cartridge filter | 100 L/h |
| Pipelines | | | | |
| Displayed text | Description | Line size | Design pressure | Design temperature |
| B5-L-01 | Feed suction hose | 15 mm | 2 bar | Ambient |
| B5-L-02 | Pump outlet line | 15 mm | 2 bar | Ambient |
| B5-L-03 | Treated effluent line | 15 mm | 2 bar | Ambient |
| B5-L-04 | Treated effluent hose | 15 mm | 2 bar | Ambient |
| B5-L-05 | Filter drain line/return line | 15 mm | 2 bar | Ambient |
| Valves | | | | |
| Displayed text | Description | Line size | Type | Model |
| B5-V-01 | Filter isolation valve | 15 mm | Diaphragm valve (flanged) | Plastic or stainless steel |
| B5-V-02 | Filter isolation valve | 15 mm | Diaphragm valve (flanged) | Plastic or stainless steel |
| B5-V-03 | Filter drain valve | 15 mm | Diaphragm valve (flanged) | Plastic or stainless steel |
| Instruments | | | | |
| Displayed text | Description | Connection size | | |
| B5-I-01 | Filter inlet pressure monitor | 15 mm | | |

**Note:** Pipelines and valves will be in plastic or stainless steel.

### 5.6.5. Module B5 — Equipment description

Figure 5.21 illustrates a simple model of the filtration module.

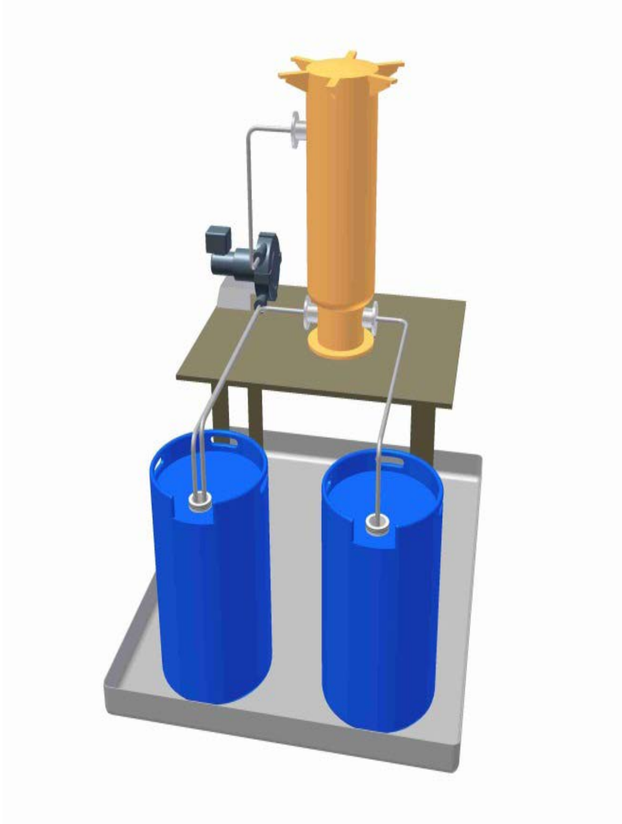

FIG. 5.21. Model of Module B5–Filtration.

The process module comprises the following:

(a) A feed container for the aqueous waste, B5-E-01, in the form of 45 L, high integrity, UN certified, reusable containers of double walled polythene construction designed for hazardous liquid chemicals. The container should incorporate an integral, ergonomically shaped, hand-ring, an offset pouring spout and secure interstacking features. Attention should be paid to a smooth geometry, thus ensuring easy cleaning.

(b) A feed suction hose, B5-L-01, size 15 mm NB in flexible reinforced plastic, for transferring the aqueous liquid waste from the feed container to the feed pump.

(c) A self-priming feed pump, B5-E-04, peristaltic or progressive cavity type (quasi-positive displacement) or equivalent with wetted parts in plastic and/or stainless steel, process connections at 15 mm NB, rated at typically 100 L/h to pump the aqueous liquid waste from the feed waste container through the filter into a second container.

(d) A range of feed pump transfer pipe work, B5-L-02, size 15 mm NB, in stainless steel or plastic, for transferring the aqueous liquid waste from the feed pump to the filter equipped with a feed control valve, B5-V-01, nominal size 15 mm NB, diaphragm type, in stainless steel or plastic, for regulating the flow and pressure of liquid waste through the filter.

(e) A proprietary cartridge or bag filter, B5-E-05, in a stainless steel or plastic housing. It will be capable of processing 100 L/h of waste and a total of 5000 L/a. In addition:
   (i) This filter is equipped with a pressure monitoring instrument, B5-I-01, to monitor the operating pressure and the pressure drop across the filter to indicate whether the filter is becoming blocked;
   (ii) The filter could be a bag or cartridge filter. Bag filters are cheaper and easier to replace than cartridges filters and they offer a broad range of micrometre sizes, from 1 to 800 µm.

(f) A filtrate transfer line, B5-L-03, size 15 mm NB, in stainless steel or plastic, to transfer the filtrate to the treated waste container, B5-E-02.

(g) A filtrate transfer hose, B5-L-04, size 15 mm NB in flexible reinforced plastic, for transferring the aqueous liquid waste from the outlet valve to the treated effluent container.

(h) A range of filtrate return pipe work, B5-L-05, size 15 mm NB in stainless steel or plastic, for returning the filtered aqueous liquid waste from the filter outlet back to the waste feed container, or to drain the filter between batches.
(i) An outlet modulating valve, B5-V-03, nominal size 15 mm NB in stainless steel or plastic, to control the filter operating pressure.
(j) A container to receive the aqueous waste after passing through the filter, B5-E-02, in the form of 45 L high integrity, UN certified, reusable containers of double walled polythene construction designed for hazardous liquid chemicals. The containers should incorporate an integral, ergonomically shaped, hand-ring, an offset pouring spout and secure interstacking features. Attention should be paid to a smooth geometry, thereby ensuring easy cleaning to receive the aqueous waste after passing through the filter.
(k) Pipe work, valves and pump arranged so that the pump can pump directly from the waste container and through the filter.
(l) Pipe work designed to keep the module as compact and simple as possible.
(m) Ability to isolate by valves, washdown and drain down all pipe work, pumps, vessels and other equipment.
(n) Process connections between pipe work and equipment should be flanged.
(o) Pumps should be a positive displacement, e.g. a peristaltic or air operated diaphragm pump. This allows liquids to be sucked from the top of the storage containers instead of having bottom outlets on the containers. This is better for the integrity of the liquid storage containers.
(p) Pipe work, valves and pumps should be arranged so that the pump can be used to pump directly from the waste container through the filter.
(q) The pump should also be used to recirculate the contents of the storage container on the module so that a representative sample can be taken.
(r) If the filter housing does not self-drain when flow has stopped, a drain should be fitted with an isolation valve to allow the filter housing to be drained prior to filter change.
(s) A framework, in stainless steel or epoxy painted mild steel, to support all of the equipment:
    (i) The framework is fitted with a drip tray, B5-E-03, as well as a flat bottomed container in stainless steel or plastic to collect any spillages. The drip tray should contain both the waste feed and receipt containers, the filter, and the feed pump and will, typically, be capable of holding 110% of the total liquid volume held within the containers, and all of the other equipment and pipe work mounted within or above the drip tray (approximately 150 L).
    (ii) The framework will have adjustable feet for levelling.
(t) An electrical control panel (not shown on the model picture) supported from the module framework that receives the incoming power supply and controls the operation of all electrical equipment on the module. There should also be an emergency stop button to stop all equipment on the module. The control panel should include an electrical isolator to isolate all equipment on the module.
(u) All electrical equipment on the module should be suitably rated in terms of ingress protection to allow washdown of plant and equipment on the module (with an IP rating of 54 or better).

#### 5.6.6. Module B5 — Facility considerations

(a) A ‘bunded’ waste receipt area with a capacity of up to 20 containers of liquids, assumed to be 40–50 L carboys.
(b) A proprietary manual trolley for moving containers.
(c) Hand held radiation monitoring equipment for monitoring radiation levels from the filter housing.
(d) Storage in a bunded area for spent filters. Localized shielding may be required.
(e) Storage in a bunded area for filtered aqueous waste, assumed to be 40–50 L carboys.
(f) Radiochemical laboratory for sampling and analysis of aqueous liquid for the expected solids content in both the treated and untreated liquids.
(g) Provision of water for washdown of plant and equipment, e.g. prior to maintenance.
(h) Storage area for spare filters, pump, valve and instrument spares, sample bottles and laboratory equipment.
(i) A suitable connection to the site sewer or other approved liquid discharge point with appropriate consents.

### 5.6.7. Module B5 — Prerequisites

(a) Appropriate barriers and/or controls must be in place to manage the access of personnel to the filter processing area.
(b) The operator(s) must wear appropriate PPE, e.g. coveralls, safety shoes, goggles or masks and gloves.
(c) A radiation protection supervisor should monitor all module operations, including the receipt and dispatch of waste containers and the removal of pipe work from the liquid waste container.
(d) The filtration module is suitable for the removal of fine particulates (1–100 µm). For large quantities of solids, gravity settling (in Module B1) is advisable prior to filtration treatment to remove bulk solids and prevent early filter blocking.

### 5.6.8. Module B5 — Process description and operation

(a) Following installation of the module and prior to operation, the aqueous waste should be sampled and analysed. A small sample of the liquid waste can be taken and measurements made locally of pH and activity.
(b) A carboy of liquid waste for processing is lifted into the drip tray by two personnel. Alternatively, specific attachments can be used with a forklift or other mechanical lifting aid to lift and place the waste carboy, B5-E-01, and an empty carboy, B5-E-02, for the collection of the treated effluent, into the drip tray.
(c) Under radiation protection supervision, insert the feed suction pipe, B5-L-01, into the waste feed container, B5-E-01. Similarly, insert filtrate return line, B5-L-05, into the waste feed container and secure it. Insert transfer pipe, B5-L-04, into the empty treated effluent container and secure it. Open inlet and outlet valves, B5-V-01 and B5-V-03. Using transfer pump, B5-E-04, pump the aqueous waste through the filter housing. When the filtrate becomes transparent it is necessary to open valve B5-V-02 and close valve B5-V-03.
(d) Filtrate, which passes through the filter and is deficient in solids that have been trapped by the filter, is discharged to the treated effluent container, B5-E-02.
(e) The filtrate flow rate will decrease as the filter cartridge becomes blocked through repeated batch processing, so monitoring flow rates is important in controlling the process. Observe the pressure instrument, B5-I-01, to monitor the pressure drop along the filter housing to indicate whether the filter is becoming blocked. Refer to filter manufacturer specifications for acceptable pressure drop.
(f) Continue filtration until the waste effluent container is empty and the treated effluent container is full.
(g) The pressure drop across the filter will indicate when it needs to be replaced.
(h) The activity buildup on the filter should also be monitored. There may be a need to change the filter early (i.e. before the pressure drop measurement indicates that the filter is becoming blocked) for safe handling or to meet disposal site acceptance requirements.
(i) Stop the feed pump, B5-E-04, and close the isolation valves, B5-V-01, B5-V-02 and B5-V-03. Carefully, under radiation protection supervision, withdraw pipes B5-L-01, B5-L-04 and B5-L-05 from their respective containers.
(j) Sample the treated effluent container and measure the activity to determine the level of decontamination achieved.
(k) If appropriate, seal and move the container of treated effluent to the appropriate storage area and replace with an empty container. Similarly, remove the feed waste container and replace with a full container. The concentrated waste in the feed container can be transferred to a separate concentrate storage vessel (which may require shielding), the feed container rinsed with clean process water and the washings emptied into a feed waste container.
(l) It is assumed that each container of liquid waste will be processed by passing once through the filter. This minimizes the time needed to process a container.

### 5.6.9. Module B5 — Disadvantages of the process

(a) Creates a secondary waste stream (spent filters), which may have high dose implications for operators.
(b) It can only handle liquids with relatively low solid content.
(c) Pretreatment such as gravity settling may be required to remove high volumes of suspended solids.

#### 5.6.10. Module B5 — Interface and integration requirements

Interface requirements for the process module include the following:

(a) Filtered solids that collect within the filter will need to be treated as non-compactable solid waste (see Module E1) once replaced.

Integration with other process modules includes the following:

(i) Downstream of Module B1;
(ii) Upstream of Module B4, i.e. the cross-flow module to remove gross particulates prior to cross-flow filtration;
(iii) Upstream of Module B2, i.e. the ion exchange module as filtrate may also require further processing before disposal, e.g. ion exchange to remove soluble ions not removed by filter.

This module is suitable with other waste streams such as: organic liquids.

### 5.7. MODULE B6–SOLIDIFICATION

#### 5.7.1. Module B6 — General

The solidification module will mix aqueous waste with a pre-tested cement mixture in a 200 L steel drum using a 'lost paddle' agitator. The lost paddle technique is a common design in which the mixing paddle remains in the drum after mixing and becomes part of the solid waste package. It is employed to reduce the risk of the spread of contamination. The waste and cement matrix will solidify and a capping grout will be put on the top to provide additional protection against the escape of contamination.

Solidification could be applied to the bulk aqueous waste volume or to the concentrated waste arising from treatment of the bulk aqueous waste in the form of, for example:

(a) Precipitated sludge from chemical treatment (Module B1);
(b) Spent ion exchange resins from ion exchange treatment (Module B2);
(c) Retentate from RO (Module B3) or cross-flow filtration treatment (Module B4).

A relatively simple cementation module with mixing using a lost paddle in-drum agitator is shown in operation in Fig. 5.22.

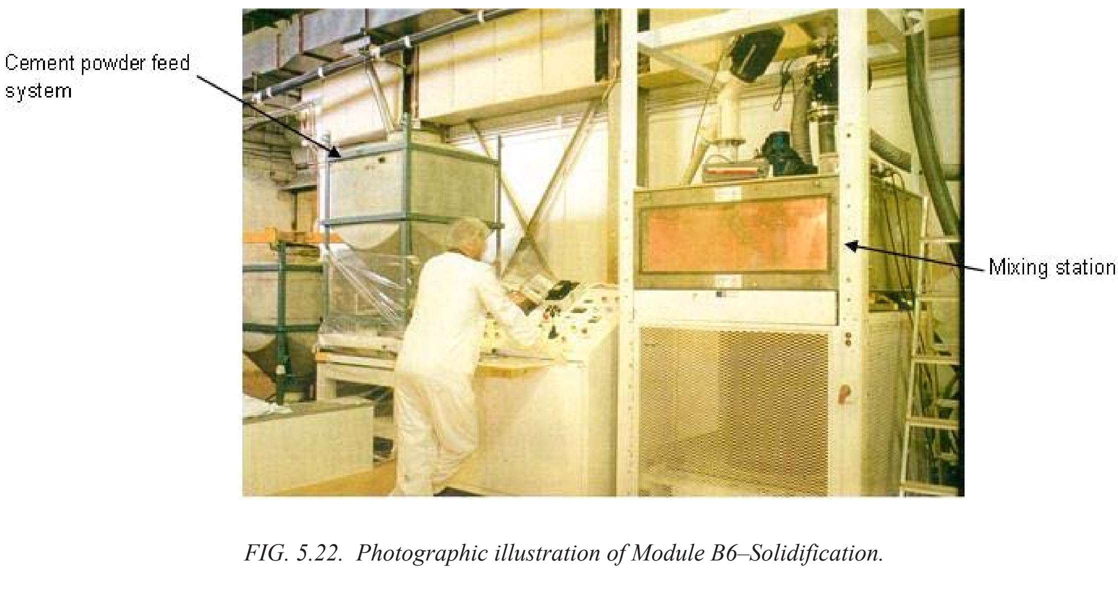


*FIG. 5.22. Photographic illustration of Module B6–Solidification.*

This module features:

(i) A ventilated mixing station to provide containment during the mixing process;
(ii) A cement powder feed system to accurately meter cement powders into the drum during mixing;
(iii) A control station where the process is controlled and monitored;
(iv) A ventilation extract plant (not shown in the photo) with fan and filter for ventilating the mixing station.

A typical drum with a lost paddle agitator is shown in Fig. 5.23. The paddle is fabricated from mild steel, and the drum has simple locating points welded at the top and bottom to support the paddle in the centre of the drum.

*FIG. 5.23. Typical drum with a lost paddle agitator.*

Figure 5.24 shows a completed drum after mixing. An inactive grout cap can be added if required. The grout will be prepared using a grout mixer (Module E1–Encapsulation).

*FIG. 5.24. Completed drum after mixing.*

### 5.7.2. Module B6 — Basis of design

Table 5.13 summarizes the basis of design identifying the key parameters and assumptions used in determining the design of this processing module.

TABLE 5.13. BASIS OF DESIGN FOR MODULE B6–SOLIDIFICATION

| | |
|---|---|
| Waste feed characteristics | |
| Total liquid volume | Typically 0.5–10 $m^3$ per year, for the reference design, 5 $m^3$ should be used. |
| Timing | Arrives periodically in batches of about 50 L. |
| Peak treatment rates | 50 L of waste per waste drum. |
| Feed activity content | Not known. |
| Physical form | Liquid, mainly aqueous. |
| Solids content | Could have solids content up to 20%. |
| Chemical content | No significant chemical content except for the potential for the presence of small quantities of complexing agents. |
| Treated effluent characteristics | |
| Discharge activity content | N/A |
| pH | N/A |
| Other constituents | N/A |
| Services availability | |
| Services | The schematic designs shall identify options for connections to existing services or the need for dedicated services. |
| Water | Required. |
| Power | Required. |
| Building heating | Required if temperature falls below 5°C. |
| HVAC | Required. |
| Chemical reagents | Required. |
| Drainage | None. Any leaks or spillages that do occur to be captured in a drip tray(s) and returned to a waste container using a small pump. |

### 5.7.3. Module B6 — Process flow diagram

Figure 5.25 illustrates the plant and equipment in a PFD.

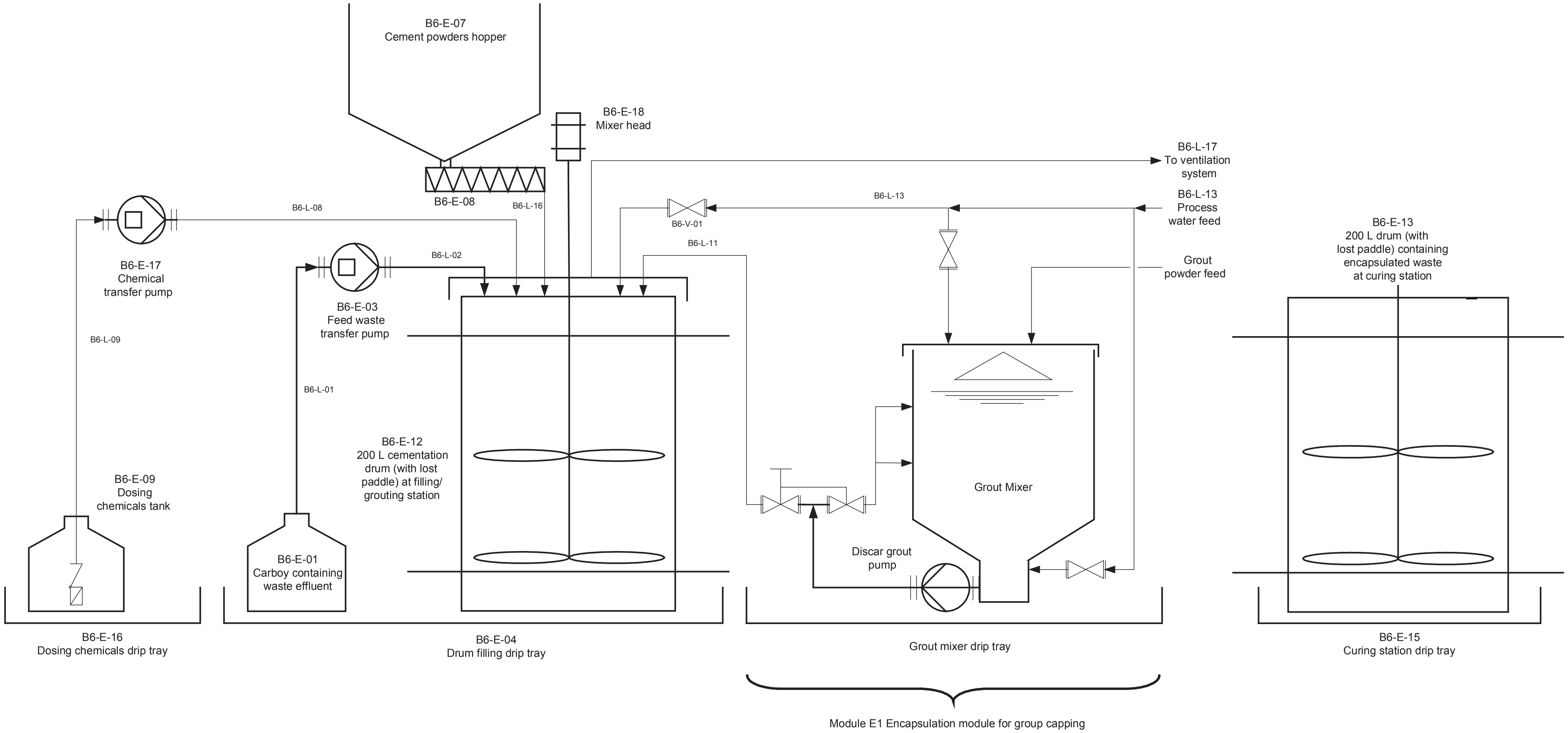


*FIG. 5.25. Process flow diagram for Module B6–Solidification.*

### 5.7.4. Module B6 — Equipment lists

The following equipment can be identified from this PFD (Table 5.14).

TABLE 5.14. EQUIPMENT LIST FOR MODULE B6–SOLIDIFICATION

| Equipment | | | | |
|---|---|---|---|---|
| Tag | Description | Material | Type | Flow rate |
| B6-E-01 | Untreated waste container | Plastic | 45 L carboy | |
| B6-E-02 | Not used | — | — | — |
| B6-E-03 | Waste transfer pump | Plastic or stainless steel | Self-priming positive displacement | 100 L/h |
| B6-E-04 | Drum filling drip tray | Plastic or stainless steel | | |
| B6-E-07 | Cement powders hopper | stainless steel | | |
| B6-E-08 | Screw feed | stainless steel | | |
| B6-E-09 | Dosing chemicals tank | Plastic | Closed or lidded | |
| B6-E-12 | Solidification drum | Mild steel of stainless steel | 200 L drum (with lost paddle) | |
| B6-E-13 | Solidification drum (curing) | Mild steel of stainless steel | 200 L drum (with lost paddle) | |
| B6-E-15 | Curing station drip tray | Plastic or stainless steel | | |
| B6-E-16 | Dosing chemicals drip tray | Plastic or stainless steel | | |
| B6-E-17 | Chemical transfer pump | Plastic or stainless steel | Self-priming, positive displacement | 50 L/h |
| B6-E-18 | Solidification drum mixer | Mild steel | | |
| Pipelines | | | | |
| Tag | Description | Line size | Design pressure | Design temperature |
| B6-L-01 | Waste transfer pump suction line | 15 mm | 2 bar | Ambient |
| B6-L-02 | Waste transfer pump discharge line | 15 mm | 2 bar | Ambient |
| B6-L-09 | Chemical dosing feed line | 15 mm | 2 bar | Ambient |
| B6-L-11 | Grout mix feed line to drum | 50 mm | 2 bar | Ambient |
| B6-L-13 | Process water feed to drum | 15 mm | 2 bar | Ambient |
| B6-L-16 | Cement powders feed line | 50 mm | 2 bar | Ambient |
| B6-L-17 | Drum hood vent line | 50 mm | 2 bar | |

TABLE 5.14. EQUIPMENT LIST FOR MODULE B6–SOLIDIFICATION (cont.)

| Valves | | | |
|---|---|---|---|
| Tag | Description | Line size | Valve class |
| B6-V-01 | Filter isolation valve | 15 mm | Ball valve (flanged) |

### 5.7.5. Module B6 — Equipment description

The solidification equipment can be built into a single module. The cutaway illustration in Fig. 5.26 shows the equipment built into an ISO freight container.

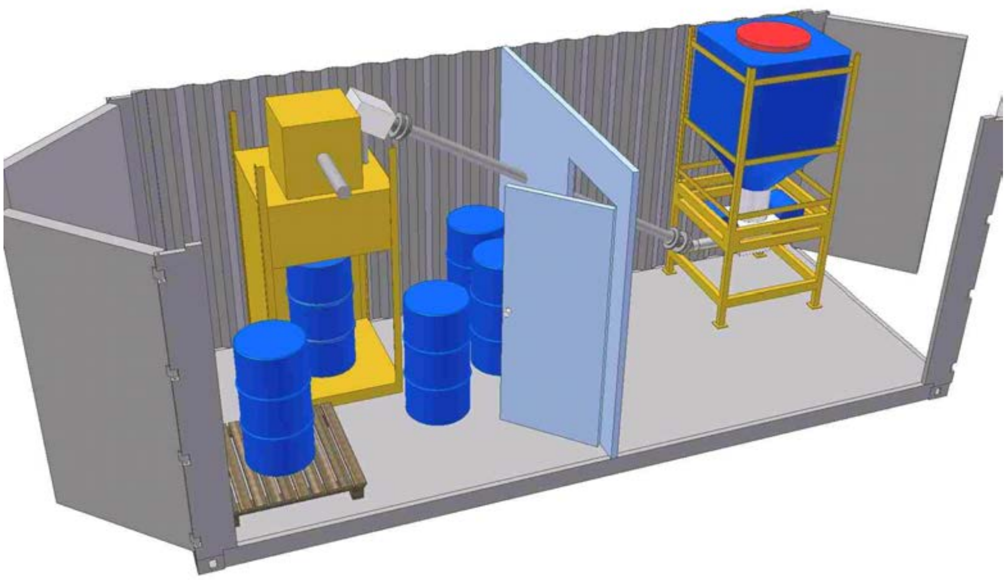

*FIG. 5.26. Model illustration of Module B6–Solidification in an ISO freight container.*

The process module comprises:

(a) Feed containers for the aqueous waste, B6-E-01, in the form of 45 L, high integrity, UN certified, reusable containers of double walled polythene construction designed for hazardous liquid chemicals. The container should incorporate an integral, ergonomically shaped, hand-ring, an offset pouring spout and secure interstacking features. Attention should be paid to achieving a smooth geometry, thus ensuring easy cleaning.
(b) A feed suction hose, B6-L-01, size 15 mm NB in flexible reinforced plastic, for transferring the aqueous liquid waste from the feed container to the feed pump.
(c) A self-priming feed pump, B6-E-03, peristaltic or progressive cavity (quasi-positive displacement) type or equivalent with wetted parts in plastic and/or stainless steel, process connections at 15 mm NB, rated at typically 100 L/h to pump the aqueous liquid waste from the feed waste container into the 200 L steel cementation drum, delivering approximately 100–120 L of liquid waste per drum.

(d) A pump transfer pipe, B6-L-02, size 15 mm NB, in stainless steel or plastic, for transferring the aqueous liquid waste from the feed pump into the cementation drum.

(e) A container, B6-E-12, for solidifying the aqueous liquid waste by cementation in the form of a 200 L mild steel or stainless steel drum with:
   (i) An internal lost paddle agitator and supports in mild steel.
   (ii) A containment hood to prevent splashing during mixing.
   (iii) A through hood mixing head, B6-E-18, to power the in-drum lost paddle agitator;
   (iv) A vent connection to the hood connected via duct B6-L-17, size 50 mm NB, in stainless steel to the module active ventilation system to prevent airborne contamination. The ventilation system will comprise a fan, ductwork and a HEPA filter. This is a dedicated ventilation system for this module.

(f) A 200 L stainless steel hopper mounted above and to one side of the cementation drum to hold the pre-blended cement powders, equipped with:
   (i) A powder screw feeder, B6-E-08, size 50 mm NB, in stainless steel to deliver a controlled transfer of cement powders to the cementation drum (at typically 10 kg/min);
   (ii) Pipe work B6-E-16 in stainless steel, size 50 mm NB, from the screw feeder to the drum through the containment hood.

(g) A range of process water pipe work, B6-L-13, size 15 mm NB, in plastic to deliver process water to the cementation drum and the grout mixer, equipped with an isolation valve, B6-V-01, a ball valve size 15 mm NB, in plastic, to control flow to the cementation drum.

(h) A framework, in stainless steel or epoxy painted mild steel, to support the above equipment.

(i) The framework is fitted with a drip tray, B6-E-04, a flat bottomed container in stainless steel or plastic, to collect any spillages. The drip tray will contain the feed waste container, the transfer pump and the cementation drum, and typically will be capable of holding 110% of the total liquid volume held within the containers and all of the other equipment and pipe work mounted within or above the drip tray (approximately 200 L):
   (i) There should be space to erect temporary shielding around the cementation drum if required, e.g. lead bricks.
   (ii) The framework should have adjustable feet for levelling.

(j) A proprietary feed container for the dosing chemical, B6-E-09, which can be the plastic or stainless steel container in which the chemical — e.g. caustic — is supplied by the chemical manufacturer.

(k) A range of chemical dosing pipe work, B6-L-09, size 15 mm NB, in stainless steel or plastic, fitted with a foot valve and strainer, for dosing the aqueous liquid waste in the 200 L drum (B6-E-12) with chemical.

(l) A self-priming, positive displacement, chemical dosing pump, B6-E-17, with wetted parts in plastic and/or stainless steel, process connections at 15 mm NB, rated at typically 50 L/h.

(m) A framework, in stainless steel or epoxy painted mild steel, to support all of the chemical dosing equipment:
   (i) The framework is fitted with a drip tray, B6-E-16; a flat bottomed container in stainless steel or plastic to collect any spillages. The drip tray will contain the chemical feed container and the dosing pump and typically will be capable of holding 110% of the total liquid volume held within the container and all of the other equipment and pipe work mounted within or above the drip tray (approximately 50 L).
   (ii) The framework should have adjustable feet for levelling.

(n) A proprietary 150 L batch grout mixing plant for grout capping. This is described more fully under Module E1–Encapsulation. The need for a grout cap will depend on the waste acceptance criteria for drum transport and disposal.

(o) A curing area where drums that have been solidified can stand and cure for typically 24 h. Typically, five drums from one day of operation would be stored together to cure. The curing area should also be fitted with a drip tray, B6-E-15, to contain up to 110% of the total liquid volume held (up to five drums).

(p) An electrical control panel (not shown in the model picture), but supported from the module framework that receives the incoming power supply and controls the operation of all electrical equipment on the module. There should also be an emergency stop button to stop all equipment on the module. The control panel should include an electrical isolator to isolate all equipment on the module.

(q) All electrical equipment on the module should be suitably rated in terms of ingress protection to allow washdown of the plant and equipment on the module (with an IP rating of IP54 or better).

### 5.7.6. Module B6 — Facility considerations

(a) The solidification Module B6 could be located and operated adjacent to the encapsulation Module E1, so the grouting equipment can be easily shared.
(b) The radiochemical laboratory required for sampling and analysis of the liquid waste prior to treatment in order to ensure the correct waste-cement formulation is implemented.
(c) The provision of water for the washdown of plant and equipment, e.g. prior to maintenance.
(d) Manual trolley for moving carboys and empty drums.
(e) Fork lift for moving loaded drums.
(f) Bunded storage area for drums, adequate for up to five days of operation.

### 5.7.7. Module B6 — Prerequisites

(a) Appropriate barriers and/or controls must be in place to manage the access of personnel to the solidification processing area.
(b) The operators must put on appropriate PPE, e.g. coverall, safety shoes or boots, goggles or mask, respirator and gloves.
(c) A lab technician and/or chemist for sampling and analysis of untreated liquid waste to confirm the acceptability of this treatment and to tailor the dosing chemistry for individual drums if required.
(d) A radiation protection supervisor per operating day to monitor operations including the waste containers on receipt and dispatch, drums during filling, mixing and dispatch, and when the emptying pipe work is removed from an empty container.
(e) Pilot testing to develop and test the waste-cement formulation (including the optimum cement powder blend), optimize the waste loading and optimize the performance of the product in terms of cemented waste properties such as compressive strength and leach rate. Site requirements for pilot testing include:
   (i) Fume cupboard or small containment for handling active liquids;
   (ii) Samples of active liquids;
   (iii) Liquid radioactive analysis capability;
   (iv) Cement powder;
   (v) Torque/viscosity measurement;
   (vi) Calorimeter for temperature measurement.
(f) The cement powder formulation finally chosen is assumed to be pre-blended so that the mix provides the best physical and chemical properties for solidifying liquid waste. It is important to get the right mix first time because reworking the cementation process is very difficult in practice.
(g) A small sample of the actual liquid waste can be taken by the chemist/lab technician and measurements made locally to confirm the acceptability of the formulation and to tailor the dosing chemistry for individual waste drums if required.

### 5.7.8. Module B6 — Process description and operation

(a) It should be possible to solidify up to five drums of waste per operating day. The reference design is for 5 $m^3$ of liquid waste per year that will generate 40–50 drums/year, so less than ten operating days per year will be required.
(b) An empty 200 L cementation drum is lifted into position below the cement mixer head by two personnel. Alternatively, specific attachments can be used with a forklift or other mechanical lifting aid to lift and place the steel drum in position. The lost paddle agitator is engaged with its drive in the mixing head.
(c) The cement hopper is filled with an appropriate blend of cement powder. If necessary, a carboy of the chosen dosing chemical — e.g. caustic solution — is placed into the drip tray and the suction hose of the dosing pump, B6-E-17, carefully lowered into it and secured.
(d) A carboy of liquid waste for processing is lifted into the drip tray by two personnel. Alternatively, specific attachments can be used with a forklift or other mechanical lifting aid to lift and place carboys into the drip tray.

(e) Under radiation protection supervision insert the feed suction hose, B6-L-01, into the feed waste container, B6-E-01, and secure it.
(f) A feed pump, B6-E-03, is used to transfer a measured volume of aqueous liquid waste into the cementation drum. As typically 100–120 L will be required, up to three feed waste containers will be needed.
(g) As each container is emptied, stop the transfer pump, B6-E-03, and under radiation protection supervision remove the feed suction pipe, B6-L-01, from the feed waste container, B6-E-01. Fully empty the used feed container and rinse it with process water into another feed waste container. Remove the empty container from the drip tray and set aside. Repeat with a fresh feed waste container as necessary to give the required volume of liquid waste within the drum.
(h) If an error is made, excess waste can be decanted from the drum back into the feed container to adjust the waste content as required using the feed pump.
(i) The liquid waste is mixed with the drum paddle driven by the mixing head, B6-E-18. If necessary, chemically condition the liquid waste in the drum, e.g. by the addition of caustic solution using a chemical transfer pump, B6-E-17.
(j) When thoroughly mixed, a small sample of the liquid waste can be taken and measurements made locally to confirm the acceptability of this treatment.
(k) Ensure the mixing hood ventilation system is switched on and operational. Using the screw feeder, B6-E-08, meter a batch of cement powder into the drum while continuing to mix. Continue to mix the cemented liquid waste for about 30 min until all the cement powder is dispersed.
(l) Switch off the mixer, B6-E-18, and allow the contents of the drum to set solid. When set, disengage the lost paddle agitator from its drive and remove the drum from the mixing station. All operator personnel will be needed for this operation. Alternatively, specific attachments can be used with a forklift or other mechanical lifting aid to lift the drum from the mixing station.
(m) Place the cemented product in the drum in the bunded curing area and leave it to cure for at least 24 h. Test the setting of the cemented product.
(n) Once the product has cured, a grout cap can be added on the top of the cured cemented waste drum. Additional grout capping provides a clean top surface to the product in the drum, thereby minimizing the risk of the spread of contamination. The need to grout cap will depend on the waste acceptance criteria for transport and disposal. Return the cemented drum to the mixing station (which is at least a two person operation). Either use pre-mixed grout or mix a fresh batch using Module E1.
(o) Once thoroughly mixed, transfer the grout as necessary to the cementation drum via line B6-L-11.
(p) Finally, lid the cemented drum and put aside to await approved transportation to its final destination.

### 5.7.9. Module B6 — Disadvantages of the process

(a) Trials need to be performed to find the correct waste-cement formulation and confirm that it meets waste acceptance criteria for interim storage/disposal.
(b) Waste becomes non-recoverable.
(c) Cement powder handling needs adequate provisions for ventilation and introduces dust inhalation hazard.

### 5.7.10. Module B6 — Interface and integration requirements

This module is compatible with other waste streams such as:

(a) Ion exchange resins (from Module B2 or other sources);
(b) Sludges.

5.8. MODULE D2–LOW FORCE COMPACTION

### 5.8.1. Module D2 — General

Low force compaction is aimed at reducing the volume of dry, compactable waste such as paper and plastic by compressing the waste in a 200 L drum. The compressed waste is ready for long term storage at an appropriate storage facility. A small quantity of liquid waste may be generated due to the release of absorbed liquids from the waste when compressed. Equipment will be rinsed periodically between batch treatments.

The compaction module compresses the waste in the drum, adds more waste to the drum, compresses it again and repeats the process until the drum is full. The process is repeated until the drum is full.

The main components of the module are waste drums and a low force in-drum compactor.

### 5.8.2. Module D2 — Basis of design

Table 5.15 summarizes the basis of design, identifying the key parameters and assumptions used in determining the design of this processing module.

TABLE 5.15. MODULE D2–BASIS OF DESIGN FOR LOW FORCE COMPACTION

| | |
|---|---|
| Waste characteristics | |
| Total waste volume | Typically less than 20m$^3$ per year, for the reference case 5m$^3$ per year should be used. |
| Timing | Arrives periodically in batches of about 200 L. |
| Peak treatment rates | X batches per day. |
| Feed activity content | The total activity of these wastes is <50 GBq. These wastes will not contain significant quantities of long lived radionuclides. |
| Physical form | Typically, the types of waste will be soft solid waste containing paper, cardboard, plastics, rubber, gloves, etc. |
| Liquids content | Wastes should not contain liquids. Trace liquids could be absorbed into the waste. |
| Chemical content | Trace chemicals could be absorbed into the waste. |
| Treated effluent characteristics | |
| Discharge activity content | N/A |
| pH | N/A |
| Other constituents | Some liquids could be released from waste during compaction. These should be collected in a drip tray and processed appropriately. |
| Services availability | |
| Services | The schematic designs should identify options for connections to existing services or the need for dedicated services. |
| Water | Required. |
| Power | Required. |

TABLE 5.15. MODULE D2–BASIS OF DESIGN FOR LOW FORCE COMPACTION (cont.)

| Services availability | |
|---|---|
| Building heating | Not required. |
| HVAC | Not required. |
| Chemical reagents | Not required. |
| Drainage | None. |

### 5.8.3. Module D2 — Equipment description

Figure 5.27 shows the photograph of a typical low force compactor.

*FIG. 5.27. Photograph of Module D2–Low force compactor.*

(a) A low force compactor has the following features:
  - (i) Typically, for a low force compactor, the compaction force can range from a few tonnes to 40 t. For soft waste (paper, cardboard, plastics, rubber), a lower compaction force is adequate because the waste will reassert itself in any case (spring back) when the compaction force is removed. Higher compaction forces allow the compaction of empty tins, cartridge filters, bottles (empty) and plastic components. The lower force compactor unit will be easier to accommodate inside the unshielded booth (Module D3).
  - (ii) The low force compaction module can receive dry, lightweight, pre-sorted waste in a variety of containers, typically 200 L steel drums, or polycotton bags. For processing, if necessary, the waste must be transferred into polycotton bags prior to compaction.
  - (iii) The in-drum low force compactor can be purchased direct from the manufacturer.

(b) Key equipment specifications include the following:
   (i) A compaction force of up to 40 t hydraulic force for inside drum compaction, suitable for compacting lightweight materials such as paper and plastic. Stainless steel compaction head, to prevent corrosion.
   (ii) Able to withstand rinsing with water between batches.
   (iii) Large drum clearance for material overfill.
   (iv) Exhaust collar for chamber ventilation.
   (v) Regenerative hydraulic circuit for fast cycle.
   (vi) The in-drum compactor can use pneumatic or hydraulic power to compress waste. Hydraulic is preferred and more widely used.
   (vii) Integral drip tray for collecting liquids that may be expelled from the drum.

(c) Waste containers for compactable waste: 200 L mild steel or stainless steel drums, with lids (Fig. 5.28).

*FIG. 5.28. Waste container for compactable waste (200 L drum).*

(d) Polycotton bags to contain presorted waste and prevent airborne dust during compaction.

(e) Drum weighing equipment to weigh the final compacted waste and drum to be disposed of. It should be a standard industry pallet or drum weighing platform, and should be skid mounted in the module. Consideration must be given to ease of cleaning.

(f) Drum handling equipment, particularly for loading the drum into and out of the compactor. A manual fork lift truck with drum grab will be suitable.

(g) Equipment for monitoring radioactivity:
   (i) Hand held contamination monitoring equipment;
   (ii) Hand held radiation monitoring equipment.

(h) Dedicated HVAC equipment to ventilate the compactor (or unshielded booth if the compactor is integral to this), comprising fan, HEPA filter, isolation dampers, filter differential pressure instrumentation, flow instrumentation, discharge sampler, ductwork, and discharge stack.

(i) An electrical control panel supported from the module framework that receives the incoming power supply and controls the operation of all electrical equipment on the module. There shall also be an emergency stop button to stop all equipment on the module. The control panel shall include an electrical isolator to isolate all equipment on the module.

(j) All electrical equipment on the module should be suitably rated in terms of ingress protection to allow wash down of plant and equipment on the module (with an IP rating of IP54 or better).

### 5.8.4. Module D2 — Facility considerations

(a) Storage for compactor equipment spares.

(b) Storage for up to ten standard 200 L drums awaiting compaction and five compacted waste drums.

(c) Storage area for waste identified as unsuitable for compaction.

(d) Waste receipt for containers of compactable waste assumed to be 200 L drums.
(e) Adequate storage space for non-compacted and compacted waste required, equivalent to one day of operation.
(f) Module should be located adjacent to the waste sorting area — the unshielded booth (see Module D3).
(g) Disposal route is required for fully loaded compacted waste drums. Further processing may be required (see Module E1) prior to disposal.
(h) It is expected that the compactor will be operated in conjunction with an unshielded booth (see Module D3) where the waste can be sorted/segregated and added into the 200 L drums. Ideally, the compactor would be located within the unshielded booth.
(i) Filling of the drum may involve several cycles of filling, compaction and then further filling to make use of the space created by compaction. Therefore, the module should provide a means of containment to prevent the spread of contamination during filling and compaction. One way of achieving this will be to locate the compactor within the unshielded booth (Module D3). Alternatively, the compactor could incorporate a ventilated enclosure that houses the drum during compaction, with an access door for loading and unloading the drum and for adding more waste to the drum.

### 5.8.5. Module D2 — Prerequisites

(a) Appropriate barriers and/or controls must be in place to manage the access of personnel to the processing area.
(b) The operator(s) must put on appropriate PPE, e.g. coveralls, safety shoes, goggles or masks and gloves.
(c) Preparation of aerosols (i.e. piercing and draining) should take place prior to arrival at compaction module (see Module D3).
(d) Waste is sorted (e.g. in conjunction with Module D3) to remove non-compactable waste items before delivery to the compactor and placed in 200 L drums.
(e) It is recommended that compactable waste is packed in polycotton sacks before loading into 200 L drums for compaction. This prevents waste from releasing powder or dust during the compaction process.
(f) Waste should be dry; however, there is the possibility that some moisture is released on compaction. This will stay in the drum.

### 5.8.6. Module D2 — Process description and operation

(a) Remove the lid of an empty 200 L drum and load the drum into the compactor respiratory protective equipment (RPE) may be required during certain stages of operation such as loading and unloading the low force compactor when containment is not being maintained by the ventilation system.
(b) Polycotton sacks containing pre-sorted waste should be loaded into an empty drum and compressed. Additional sacks will be loaded and compressed until the drum is at full capacity.
(c) When at full capacity, remove the drum from the compactor and replace the lid. The radiation protection supervisor should check the drum surface for contamination. If clean, the drum can be transferred to short term storage prior to disposal. Otherwise, the drum should be cleaned under radiation protection supervision.
(d) Operators may have to swab clean the external surfaces of the drum after the waste has been compacted — as a guide, the limit for low specific activity (LSA) material is 4 $Bq/cm^2$ for beta/gamma emitters and 0.4 $Bq/cm^2$ for alpha emitters).
(e) Operators will have to monitor the full waste package and ensure that the surface dose rate of the drum meets the requirements for transport [5.1] and the waste acceptance criteria for storage and disposal.
(f) The module equipment is cleaned prior to further processing. This reduces the risk of contamination.

### 5.8.7. Module D2 — Disadvantages of the process

(a) Presorting and compaction of waste is labour intensive.
(b) There is risk of airborne contamination.
(c) The dose rate in the area will need to be monitored to ensure that it remains acceptable.

### 5.8.8. Module D2 — Interface and integration requirements

The interface requirements for the process module include:

— Ventilation discharge via an external stack.

Integration with other process modules:

— With Module D3–Unshielded booth.

## 5.9. MODULE D3–UNSHIELDED BOOTH

### 5.9.1. Module D3 — General

The unshielded booth will be used for the sorting of dry solid waste into compactable and non-compactable waste streams. The booth can also be used for the handling of low activity disused sealed sources and placing them into a 200 L drum prior to encapsulation (not compaction). The booth is a cabinet fabricated in stainless steel, painted mild steel or possibly even glass reinforced plastic (GRP) material. It has windows and a sash opening for the operator to reach in and handle/sort the solid waste. Figure 5.29 illustrates a typical booth, although in this instance quite a large booth is depicted; a smaller (shorter) unit may be more appropriate for Member States.

The booth has a horizontal drum loading port at the rear. The raw waste drum is offered up to this port and pushed through partly into the booth. The lid is then removed and waste is pulled out on to the table by the operator for sorting and segregation. An in-drum waste compactor can be built into the booth (as shown in the figure) so that compactable waste can be compacted into the drum as the drum is filled.

Typically, it should be possible to sort and segregate approximately 1 $m^3$ of compactable waste each day, hence a minimum of five days of operation per year.

The booth is served by an extract ventilation system that provides a degree of contamination control during operation.

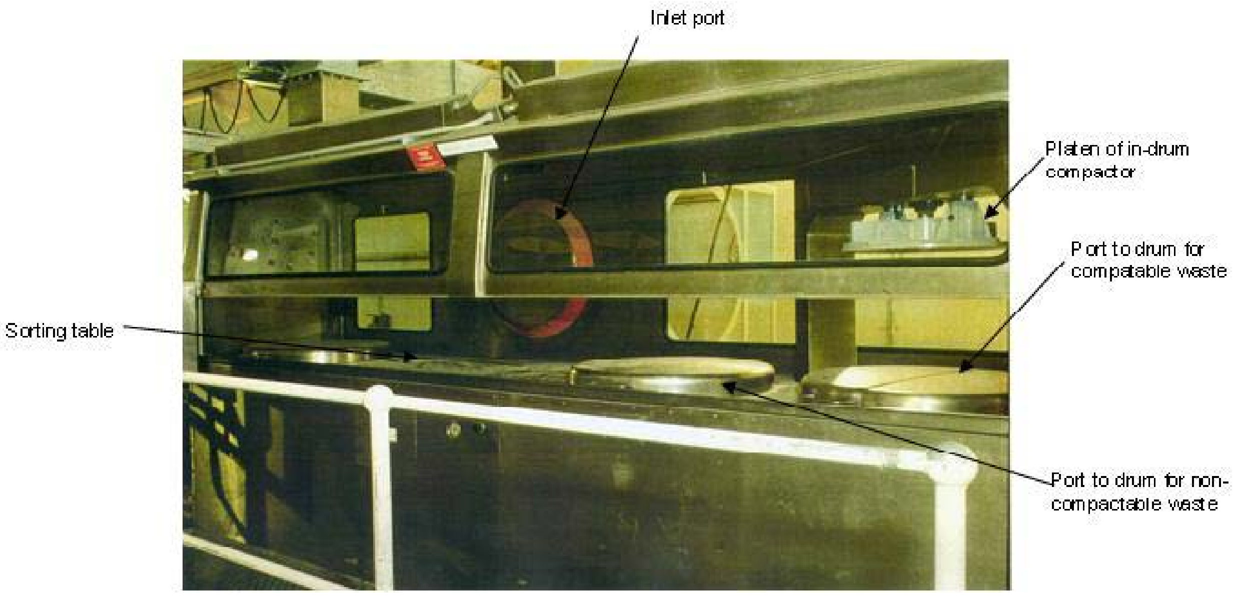


*FIG. 5.29. Typical unshielded booth for sorting of solid waste.*

### 5.9.2. Module D3 — Basis of design

Table 5.16 summarizes the basis of design identifying the key parameters and assumptions used in determining the design of this processing module.

TABLE 5.16. BASIS OF DESIGN FOR MODULE D3–UNSHIELDED BOOTH

| | |
|---|---|
| Waste characteristics | |
| Total waste volume | Less than 25 $m^3$ per year, for the reference case 5 $m^3$ per year should be used. |
| Timing | Arrives periodically in batches of about 200 L. |
| Peak treatment rates | Typically up to five drums per day. |
| Feed activity content | The total activity of these wastes is <50 GBq. These wastes will not contain significant quantities of long-lived radionuclides. |
| Physical form | Typically, the types of waste will be a mixture of light and heavyweight solid waste including paper, cardboard, plastics, rubber, gloves, glassware, metallic items, scrap, etc. |
| Liquids content | Trace liquids could be absorbed into waste. |
| Chemical content | Trace chemicals could be absorbed into waste. |
| Treated effluent characteristics | |
| Activity content | N/A |
| pH | N/A |
| Other constituents | N/A |
| Services availability | |
| Services | The schematic designs should identify options for connections to existing services or the need for dedicated services. |
| Water | Required. |
| Power | Required. |
| Building heating | Dependent on application. |
| HVAC | Required. |
| Chemical reagents | Not required. |
| Drainage | None. |

### 5.9.3. Module D3 — Equipment description

Figure 5.30 shows Module D3–Unshielded booth processing fitted with an in-drum compactor.

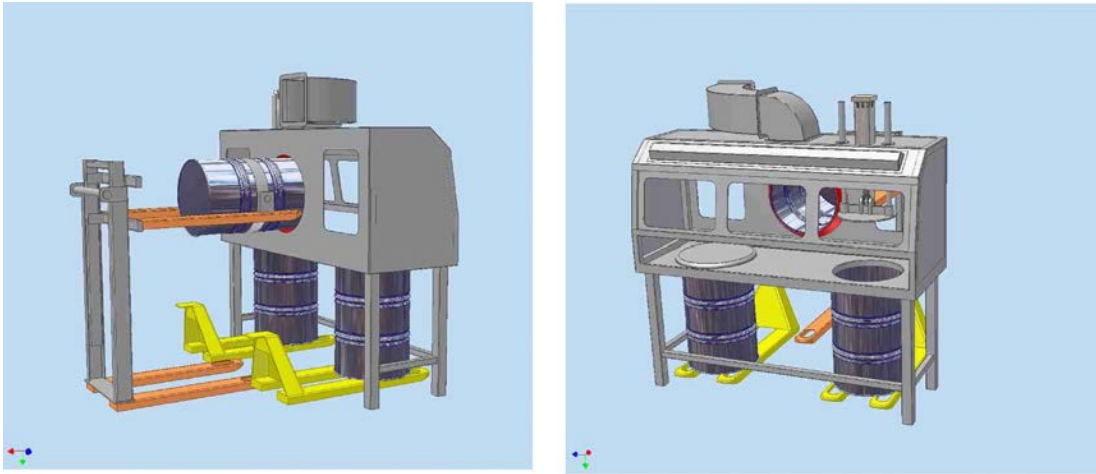

*FIG. 5.30. Model pictures of Module D3–Unshielded booth with in-drum compactor.*

The unshielded booth process module comprises the following:

(a) Compactable waste storage containers, such as 200 L drums. For the subsequent encapsulation of low activity disused sealed sources, the drums will have been pre-fabricated with annular cement linings to enhance the shielding.

(b) Storage containers/bags for sorted compactable waste — polycotton bags (essential for containing dust during compaction, see Module D2).

(c) Cabinet, constructed in stainless steel, painted mild steel or glass reinforced plastic, with the following specifications:
   (i) Windows to view the sorting table.
   (ii) Opening for operator to put hands into the cabinet to sort waste. This could be the full length of the cabinet as shown above or there could be a number of sliding glove ports to cut down the opening area, and hence the volume of air movement required to maintain containment.
   (iii) Dedicated HVAC equipment to ventilate the booth and provide containment, comprising fan, HEPA filter, isolation dampers, filter differential pressure instrumentation, flow instrumentation, discharge sampler, ductwork and discharge stack. Air velocity of approximately 0.5 m/s is required to maintain containment in the cabinet.
   (iv) The sorting table inside the cabinet, in stainless steel, at a comfortable height to work at and with smooth surfaces for ease of cleaning.
   (v) Inlet port for unsorted waste. This should be compatible to connect to a 200 L waste drum and should be positioned so that waste can easily be placed onto the sorting table. In the picture above the inlet port is situated vertically at the back of the cabinet so the operator can pull waste out directly onto the sorting table.
   (vi) Port to drum containing sorted compactable waste, with seal and removable lid to provide airtight connection or cover port when not in use.
   (vii) Port to drum containing sorted non-compactable waste, with seal and removable lid to provide airtight connection or cover port when not in use.

(d) Hand held contamination monitoring equipment.

(e) Hand held radiation monitoring equipment.

(f) Hand held tools for handling waste. Tools could include rakes for separating the waste, tongs for picking up individual items, hand held cutters for size reducing waste.

(g) Local portable beta in air monitor.

(h) An electrical control panel (not shown on the model pictured), but supported from the module framework that receives the incoming power supply and controls the operation of any electrical equipment on the module. There shall also be an emergency stop button to stop all equipment on the module. The control panel shall include an electrical isolator to isolate all equipment on the module.

(i) All electrical equipment on the module shall be suitably rated in terms of ingress protection to allow wash down of plant and equipment on the module (with an IP rating of IP54 or better).

#### 5.9.4. Module D3 — Facility considerations

(a) Internal surfaces to be smooth and easy to decontaminate, avoiding features that would be difficult to decontaminate by swabbing.
(b) The unshielded booth module can receive dry, heavy and lightweight waste in a variety of containers, typically 200 L steel drums. For processing, if necessary, the waste must be transferred into 200 L steel drums prior to sorting in the booth.
(c) Ventilation discharge via an external stack is required.
(d) Dry storage area for waste — for protection against the weather.
(e) The module should be able to receive a wide range of compactable waste, including clothing, shoes, gloves and sharp objects.
(f) Waste may arrive with a degree of sorting, for example sharp objects such as needles could arrive in a special disposal container.
(g) A route for processing of the sorted waste is required, i.e. non-compressible waste (see Module E1) and compressible waste (see Module D2).
(h) Preparation of waste may include size reduction by dismantling or cutting, or removal of pressurized gases from aerosols.
(i) Module could be integrated with the low force compactor and grouting plant (see Modules D2 and E1). The advantage of integration of the booth with this other equipment is that it minimizes handling of the waste and hence reduces the risk of contamination spreading.
(j) Specialized aerosol compaction tools are available, which can combine piercing, draining and compaction in one step. Alternatively, draining could be done manually in a controlled environment, such as a glove box.
(k) The module should also be able to handle and sort all types of non-compactable waste, such as spent filter cartridges.

#### 5.9.5. Module D3 — Prerequisites

(a) Appropriate barriers and/or controls must be in place to manage the access of personnel to the processing area.
(b) The operator(s) must put on appropriate PPE, e.g. coveralls, safety shoes, goggles or masks and gloves.
(c) Activity levels in the work area should be monitored as each time the booth is opened there is a risk of loss of contamination.
(d) Wet compactable waste is not suitable for compaction and may require further treatment to remove moisture prior to compaction.

#### 5.9.6. Module D3 — Process description and operation

(a) Turn on the cabinet ventilation system to start the flow of air and provide containment of airborne contamination.
(b) Place empty 200 L drums into the drum ports for compactable and non-compactable waste.
(c) Lift the waste drum and insert at the drum inlet port, ensuring it is sealed correctly. Remove the lid of the drum and empty the waste onto the sorting table.
(d) Begin sorting the waste. Put non-compactable waste (such as glassware, metallic items and scrap, etc.) into the designated waste drum. Put compactable waste (such as paper, cardboard, plastics, rubber, gloves) into polycotton sacks and then into the designated drum.
(e) When sorting of waste is complete, or when the unsorted waste drum is empty, disconnect the drum from the drum inlet port and remove it. Sorting should cease during disconnection of drum inlet port when it is open to the atmosphere, in order to reduce the risk of airborne contamination through loss of containment.
(f) When sorted waste drums are full, close the drum ports, remove the drums for further processing (see Module D2–Compaction or Module E1–Encapsulation) and replace with empty drums.
(g) Equipment should be cleaned between batches.

#### 5.9.7. Module D3 — Disadvantages

(a) Labour intensive.
(b) May require some pre-sorting at source (for example, separate collection containers for sharp objects).
(c) There is risk of airborne contamination.
(d) Dose rate in the area will need to be monitored to ensure that dose rates remain acceptable.

#### 5.9.8. Module D3 — Integration with other process modules

This module is suitable for use with other waste processing modules such as:

(a) With Module E1, i.e. encapsulation module;
(b) With Module D2, i.e. low force compactor.

High activity disused sealed sources are dealt with separately (Module L4–Mobile hot cell).

### 5.10. MODULE E1–ENCAPSULATION

#### 5.10.1. Module E1 — General

Encapsulation is aimed at immobilizing the waste and its radioactive contamination to prevent dispersion.

The module can be used for the encapsulation of non-compactable wastes and disused sealed sources (if acceptable in an operational disposal facility), and for the grout capping of drums of solidified liquid wastes. The wastes will have been placed into 200 L drums and the cement grout will then be added.

It is assumed the non-compactable waste arrives in 200 L drums already sorted and segregated to meet the required waste acceptance criteria. This sorting and segregation will probably take place in an unshielded booth (see Module D3). Therefore, this module is aimed at preparing fresh cementitious grout batches and then discharging the grout into the drum to immobilize the non-compactable waste. The grouting could take place with the waste drum still within the unshielded booth, but this is not essential. This module specification also includes the preparation of the drum to receive the waste and the grout.

The module will be capable of preparing up to five batches of grout per day, sufficient to encapsulate five 200 L drums per day.

Figure 5.31 shows a typical proprietary grout batch mixer. This is able to mix a single batch of grout and then pump it into a 200 L drum to encapsulate the waste.

*FIG. 5.31. Grout batch mixer.*

The advantage of this type of mixer compared with mixing by hand or by a tumble mixer is that it produces a very fluid (low viscosity) grout that flows, fills and fully encapsulates the waste, leaving no voids.

It is suggested that this unit be operated in conjunction with the unshielded booth. The drum is filled with non-compactable waste following sorting within the booth. Grout is prepared in the grout batch mixer and then pumped into the drum whilst the drum is located beneath the drum port in the unshielded booth.

### 5.10.2. Module E1 — Basis of design

Table 5.17 below summarizes the basis of design identifying the key parameters and assumptions used in determining the design of this processing module.

TABLE 5.17. BASIS OF DESIGN FOR MODULE E1–ENCAPSULATION

| Waste feed characteristics | |
|---|---|
| Total waste volume | Less than 5 $m^3$ per year, for the reference case 1 $m^3$ per year should be used. |
| Timing | Arrives periodically in batches of about 50 L. |
| Peak treatment rates | Typically, five batches per day. |
| Feed activity content | The total activity of these wastes is <10 GBq. These wastes will not contain significant quantities of long lived radionuclides. |
| Physical form | Typically, the types of waste will be heavyweight solid laboratory waste, including glassware, metallic items, scrap, etc. |
| Liquids content | Trace liquids could be on waste. |
| Chemical content | Trace chemicals could be on waste. |
| **Treated effluent characteristics** | |
| Activity content | N/A |
| pH | N/A |
| Other constituents | N/A |
| **Services availability** | |
| Services | The schematic designs should identify options for connections to existing services or the need for dedicated services. |
| Water | Required. |
| Power | Required. |
| Building heating | Required if the temperature falls below 5°C. |
| HVAC | Required. |
| Chemical reagents | Required. |
| Drainage | None. Any leaks or spillages that do occur to be captured in a bunded area to prevent spread. These should be clean, i.e. not radiologically contaminated. |

### 5.10.3. Module E1 — Process flow diagram

Figure 5.32 illustrates the plant and equipment in a PFD.

### 5.10.4. Module E1 — Equipment lists

The following equipment can be identified from this PFD (Table 5.18).

TABLE 5.18. MODULE E1–EQUIPMENT LIST FOR ENCAPSULATION

| Equipment | | | | |
|---|---|---|---|---|
| Tag | Description | Material | Type | Flow rate |
| E1-E-10 | Grout mixer. | Mild steel. | Agitation, lidded. | |
| E1-E-11 | Discar grout pump. | Cast iron. | | |
| E1-E-12 | Empty waste drum (with internal cage). | Steel. | | |
| E1-E-13 | Curing waste drum. | Steel. | | |
| E1-E-14 | Grout mixing drip tray. | Plastic or stainless steel. | | |
| E1-E-15 | Curing drip tray. | Plastic or stainless steel. | | |
| Pipelines | | | | |
| Tag | Description | Line size | Design pressure | Design temperature |
| E1-L-08 | Grout powder feed. | N/A | N/A | N/A |
| E1-L-10 | Grout recirculation line. | 50 mm | 2 bar | Ambient |
| E1-L-11 | Grout feed to waste drum. | 50 mm | 2 bar | Ambient |
| E1-L-12 | Grout recycle to mixer. | 50 mm | 2 bar | Ambient |
| E1-L-13 | Process water feed line. | 15 mm | 2 bar | Ambient (<12ºC) |
| E1-L-14 | Process water feed to grout mixer. | 15 mm | 2 bar | Ambient (<12ºC) |
| E1-L-17 | Vent. | 50 mm | 2 bar | Ambient |
| Valves | | | | |
| Tag | Description | Line size | Valve class | |
| E1-V-05 | Process water to grout mixer control valve. | 15 mm | Ball valve (flanged) | |
| E1-V-06 | Process water to grout pump control valve. | 15 mm | Ball valve (flanged) | |
| E1-V-07 | Grout discharge to waste container control valve. | 50 mm | Pinch valve (flanged) | |
| E1-V-08 | Grout recycle to mixer control valve. | 50 mm | Pinch valve (flanged) | |

**Note:** Pipelines and valves will be in plastic, rubber or stainless steel.

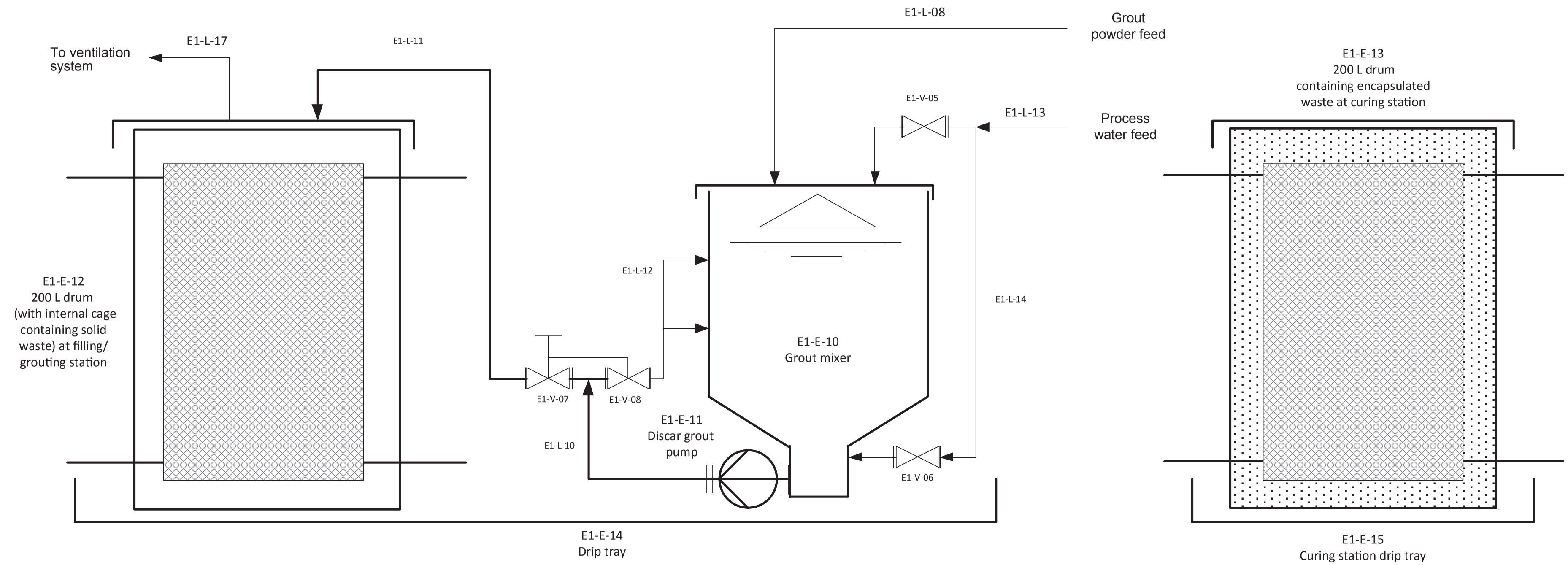


FIG. 5.32. Process flow diagram for Module E1–Encapsulation.

### 5.10.5. Module E1 — Equipment description

The encapsulation process Module E1 comprises:

(a) A container for encapsulating the solid waste, E1-E-12, in the form of a 200 L mild steel or stainless steel drum with:
   (i) In-drum support cages of steel reinforcement mesh (as used for concrete reinforcement in the civil engineering industry) and fixing wire (Fig. 5.33). These help to locate the waste centrally within the drum and can help prevent lighter waste floating to the top of the drum.

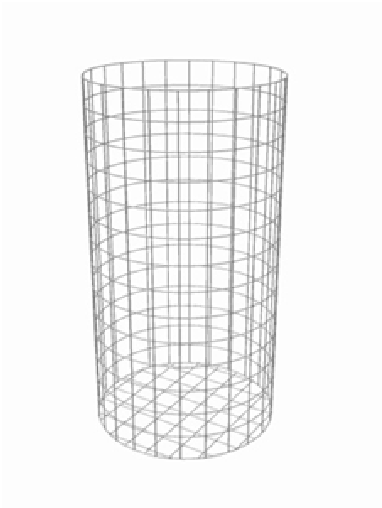

*FIG. 5.33. Steel reinforcement mesh.*

   (ii) For higher activity waste, the drum can also have a pre-fabricated annular cement liner that distances the waste from the side of the drum and provides additional shielding.
(b) Proprietary grout mixing equipment as illustrated in Fig. 5.32:
   (i) The key element of the colloidal mixer is the colloidal mill, E1-E-11. The mill comprises a high speed rotor (or Discar) operating at 2100 rev./min coupled with a close fitting chamber housing immediately below the mixer vessel, all in cast iron. The Discar colloidal mill also acts as a centrifugal pump rated at flows of up to 700 L/min at 200 kPa (2 bar).
   (ii) The grout mixing tank, E1-E-10, in epoxy painted mild steel, of nominal capacity 150 L. The mixing unit tank is equipped internally with a cone, which distributes the pre-mixed grout powder evenly into the circulating water.
   (iii) A range of grout discharge pipe work, E1-L-10, E1-L-11 and E1-L-12, size 50 mm NB in steel, that permits either pumped recirculation or discharge to be achieved by means of two pinch type valves, E1-V-07 and E1-V-08, which are linked and operated by a single lever. The recirculated stream splits into two and enters the vessel tangentially to improve mixing.
   (iv) A process water feed to the top of the vessel, E1-L-13, size 15 mm NB, in plastic with isolation ball valve, E1-V-05, and a second water feed direct to the colloidal mill at the base of the vessel, E1-L-14, with isolation valve, E1-V-06.
   (v) The mixing equipment is built on to a transportable framework that will have adjustable feet for levelling.
(c) There should be a means to electrically isolate electrical equipment on the module prior to maintenance, e.g. an electrical isolator.
(d) There should be a means to stop all electrical equipment on an emergency basis on the module.
(e) All electrical equipment on the skid should be suitably rated in terms of ingress protection to allow wash down of plant and equipment on the skid (e.g. an IP rating of IP54).

### 5.10.6. Module E1 — Facility considerations

(a) This module could be located and operated adjacent to Module B6–Solidification, so this grouting equipment can be shared. It could also be operated adjacent to the unshielded booth (Module D3) to minimize transportation of waste.
(b) The grout mixer could be housed in a building, a full height ISO freight container, or it could be wheel mounted to move between this encapsulation module (E1) and the solidification module (B6).
(c) A storage area for untreated waste drums, curing waste drums and encapsulated waste drums, each holding up to five 200 L drums.
(d) The curing area is where drums that have been solidified can stand and cure for typically 24 h. Typically, five drums from one day of operation would be stored together to cure. The curing area should also be fitted with a drip tray, E1-E-15, capable of containing 110% of the total liquid volume held (in up to five drums).
(e) Provision will need to be made for the receipt and storage of the cement powders as small quantities, e.g. 25 kg bags of Ordinary Portland Cement (OPC) and pulverized fuel ash (PFA) can be used for grouting and capping the drums.
(f) The storage of untreated and treated waste feed should be in separate areas. The containers should be uniquely tagged for easy identification.
(g) The use of chilled water between 4°C and 10°C is recommended. This will ensure that the grout prepared does not cure too quickly.
(h) A suitable non-active waste route will be needed for the discharge of washings from the clean out of the grout mixer.
(i) Manual drum handling will be by means of a proprietary hand operated trolley for moving drums, e.g. a pallet truck.
(j) A forklift will be required for moving grouted containers, e.g. using a drum grab.
(k) Provision of water for washdown of plant and equipment, e.g. prior to maintenance.

### 5.10.7. Module E1 — Prerequisites

(a) Appropriate barriers and/or controls must be in place to manage the access of personnel to the processing area.
(b) The operator(s) must put on appropriate PPE, e.g. coveralls, safety shoes, goggles or mask and gloves.
(c) Pilot testing will be required to develop and demonstrate the grout properties using the available cement powders (PFA and OPC). Pilot testing will need:
  (i) Samples of cement powders;
  (ii) Torque/viscosity measurement;
  (iii) Temperature measurement;
  (iv) Samples of inactive materials;
  (v) Grout flow test apparatus.
(d) Non-compressible waste should arrive at the encapsulation module ready to be grouted. (For example, buoyant waste material may be enclosed in a mesh within the drum to prevent it all floating to the top of the drum).
(e) Cement powder formulation is assumed to be a pre-blended mix that has suitable physical and chemical properties (see above). It is important to get the correct mix the first time because waste recovery is very difficult in practice.
(f) A laboratory technician or chemist for occasional sampling and analysis of cement material.
(g) A radiation protection supervisor to monitor operations, including waste containers, on receipt and dispatch.
(h) A hand held radiation monitor for monitoring radiation levels emitted from incoming waste drums and completed waste drums.
(i) Test equipment for occasional sampling and analysis of the cement grout mix.
(j) A grout washings drum for receipt of washings from the grout mixing equipment. Grout is allowed to settle and solidify in the drum so any water can be decanted off and discharged to a suitable drain as inactive process effluent.
(k) Storage provision for spares, cement powders, empty waste drums and reinforcement mesh.
(l) Wire cutters for cutting reinforcement mesh and pliers for twisting wire to hold the mesh into the required shape for making ‘baskets’ to contain the waste in the drum.

### 5.10.8. Module E1 — Process description and operation

(a) The cement needed to make up the grout should be weighed and pre-blended by the operators and carried to the tote bin or hopper (mounted directly above the grout mixer). The lid of the tote bin or hopper should be removed and the pre-blended cement powders manually added to the tote bin or hopper (if the powders are not pre-blended, then the PFA should be added to the hopper before the OPC is added). The lid on the hopper or tote bin should then be replaced.
(b) A known volume of water should then be added to the chilled water tank from the chilled water unit. The water in the chilled water tank should then be pumped into the mixer vessel, E1-E-10. The mixer will be set to recycle mode by opening recycle valve E1-V-08 and starting the colloidal mill, E1-E-11.
(c) The pre-blended cement should be discharged into the mixer via a short length screw conveyor and the grout mixer starts batch mixing the cement, additives and water.
(d) Once mixing is complete after approximately 15– 25 min, depending on the power of the mixer unit (at this point the surface of the vortex has a smooth, uniform appearance), it is important to recirculate the grout to prevent the heavier constitutes from settling to the bottom of the mixer.
(e) A sample should be taken and a flow test carried out to ensure the grout's fluidity is within the required range.
(f) When ready, the grout mixer has the capability to pump the prepared grout into the waste drum in a controlled manner via the discharge take off. Use the lever operator to simultaneously open valve E1-V-07 and close E1-V-08. This should be done gradually to limit the flow of grout into the drum. For the controlled discharge of grout for encapsulation and capping, in order to give good penetration around non-compactable waste, the pumping rate should be approximately 20 L/min (a small fraction of the full capacity of the pump).
(g) It is important not to completely fill the 200 L drum at this stage as a grout cap must be added once the first grout pour has cured. This is done because the initial grout pour can pick up activity from the waste as it rises up the drum, resulting in the potential for contamination on the top surface of the grout. A non-active cap seals this in and is good practice in the event that the lid of the drum fails in an accident. It is assumed that a further 10–15 L of grout will be needed to cap the encapsulated waste drum. Return the grout mixer to recycle mode. Use the lever operator to simultaneously open valve E1-V-08 and close E1-V-07.
(h) Allow the grout to set. Once set, use a forklift truck with suitable attachment to carefully remove the encapsulated drum from the module and transport the drum to the drum cure area, and allow the grout to cure overnight.
(i) Test that the grout has cured.
(j) Return the cured drum to the module drip tray using the forklift, prepare and add a second pour of 10–15 L of capping grout to the top of the drum. Then return the drum to the curing area and leave overnight.
(k) Re-lid the drum.
(l) Clean out the grout mixing equipment using a batch of process water and put the washings into the grout washings drum.
(m) Operators will have to monitor the full waste package and ensure that the surface dose rate of the drum meets the requirements for transport and the waste acceptance criteria for storage and/or disposal.

### 5.10.9. Module E1 — Disadvantages of the process

(a) Equipment is costly compared with mixing by hand or using a tumble type mixer.
(b) A non-radioactive waste route will be needed for washings from cleaning the grout mixer.
(c) Waste becomes non-recoverable.
(d) Work needs to be conducted in a well ventilated area because of the risk from cement dust.

### 5.10.10. Module E1 — Interface and integration requirements

Interface requirements for this process module:
(a) Filtered solids that collect from Module B5–Filtration can be treated as non-compactable solid waste.
(b) Ideally, Module E1–Encapsulation will be operated in conjunction with Module D3–Unshielded booth.
Integration with other process modules:

(i) Downstream of Module D3–Unshielded booth used for waste segregation and low activity source repackaging (e.g. fume hood or glove box);
(ii) Downstream of solidification Module B6 for grout capping.

This module is suitable for the encapsulation of other waste streams such as:

— Disused sealed sources;
— Animal carcasses;
— Grout capping drums of solidified liquid waste from Module B6.

It is noted here that encapsulation of disused sealed sources by mixing with grout amounts to irretrievable conditioning and should be considered only for those sources that can be accepted in an operational disposal facility. In general, long lived sources and sources with higher activity would require disposal in a borehole or a deep geological facility for which acceptance requirements may call for retrieval and reconditioning of the sources in future. When size and activity permits, such sources can be placed in a shielded container and then placed inside cement lined 200 L steel drum and securely closed. In this case, the grout mixer can be used for preparing the cement lining inside the drum following procedures that are outlined in other IAEA publications.

## 5.11. MODULE L4–HOT CELL

### 5.11.1. Module L4 — General

Sealed radioactive sources have found diverse applications in many agricultural, industrial and medical uses, as well as other technical and scientific research areas. Some of these areas and applications require high levels of radioactivity. Examples of equipment containing sealed radioactive sources include: industrial irradiators, teletherapy equipment, research irradiators, industrial radiography equipment, brachytherapy equipment, nuclear logging equipment and industrial gauges.

The handling of high activity disused sealed sources requires the use of a hot cell equipped with remote handling, ventilation and other auxiliary systems. Such hot cells can be designed for stationary or mobile configuration. The design information presented in this section is for the IAEA disused sealed sources (high activity) conditioning facility, which is a mobile hot cell that can be disassembled, packaged and transported to a site where it is needed [5.2–5.4]. The development and deployment of this facility has been carried out in cooperation with the Nuclear Energy Corporation of South Africa (Necsa). The facility consists of a biological shield with a window for viewing work in progress inside the shield. It makes use of master–slave manipulators (MSMs) and an internal crane to handle and lift various objects within the cell. There is a crane outside the shield for use in lifting heavy objects in and out of the biological shield. A ventilation system maintains a negative pressure within the cell to contain the spread of possible contamination. The long term source storage container will be coupled to the side of the biological shield for easy and safe transfer of the sources from the cell. Figure 5.34 shows a mobile hot cell facility assembled at a site.

### 5.11.2. Module L4 — Basis of design

Table 5.19 below summarizes the basis of design identifying the key parameters and assumptions used in determining the design of this processing module.


*FIG. 5.34. Disused sealed sources conditioning facility assembled at site.*

TABLE 5.19. BASIS OF DESIGN FOR MODULE L4–HOT CELL

| | |
|---|---|
| Waste feed (high activity disused sealed radioactive source) characteristics | |
| Total waste volume | Up to 20 sources per year. |
| Timing | N/A. |
| Peak treatment rates | 1 or 2 sources per day. |
| Feed activity content | The nature and quantity of the radionuclides utilized depend on the intended purpose of the source. While most sources are of relatively low activity, there are some of high or very high activity. |
| Physical form | Radioactive material that is: (a) permanently sealed in a capsule; or (b) closely bounded and in a solid form. Typically, the capsule or material of a sealed source is strong enough to be leak proof under the conditions of use and for which the source was designed and also under foreseeable mishaps. |
| Solids content | Source is in solid form. |
| Chemical content | No significant chemical content. |
| Treated effluent characteristics | |
| Discharge activity content | N/A. |
| pH | N/A. |
| Other constituents | Original source casing may be disposed of separately as non-radioactive material. |
| Services availability | |
| Services | The schematic designs should identify options for connections to existing services or the need for dedicated services. |
| Water | Required. |
| Power | Required. |
| Building heating | For operator comfort. |
| HVAC | Required. |
| Chemical reagents | Not required. |
| Drainage | None. |

### 5.11.3. Module L4 — Equipment description

*5.11.3.1. Biological shield*

This is the hot cell wall, which protects operators, the public and environment from ionizing radiation and prevents the spread of contamination. It is typically designed to handle radiation levels up to the equivalent of 1000 Ci $^{60}$Co source at a time. The biological shield provides a platform for mounting the MSMs, internal crane, ventilation system and source transfer port, etc.

The biological shield comprises a double walled cavity, 1.55 m wide, in mild steel, filled with sand as a shielding material. The shielding material should have a density of at least 1.6 kg/L. This density reduces radiation from a 1000 Ci source inside the biological shield to 0.03 mSv/h on the outside wall surface. The working volume of the biological shield is 2.5 m long, 1.6 m wide and 3.0 m high. Figure 5.35 shows a section view of the biological shield.

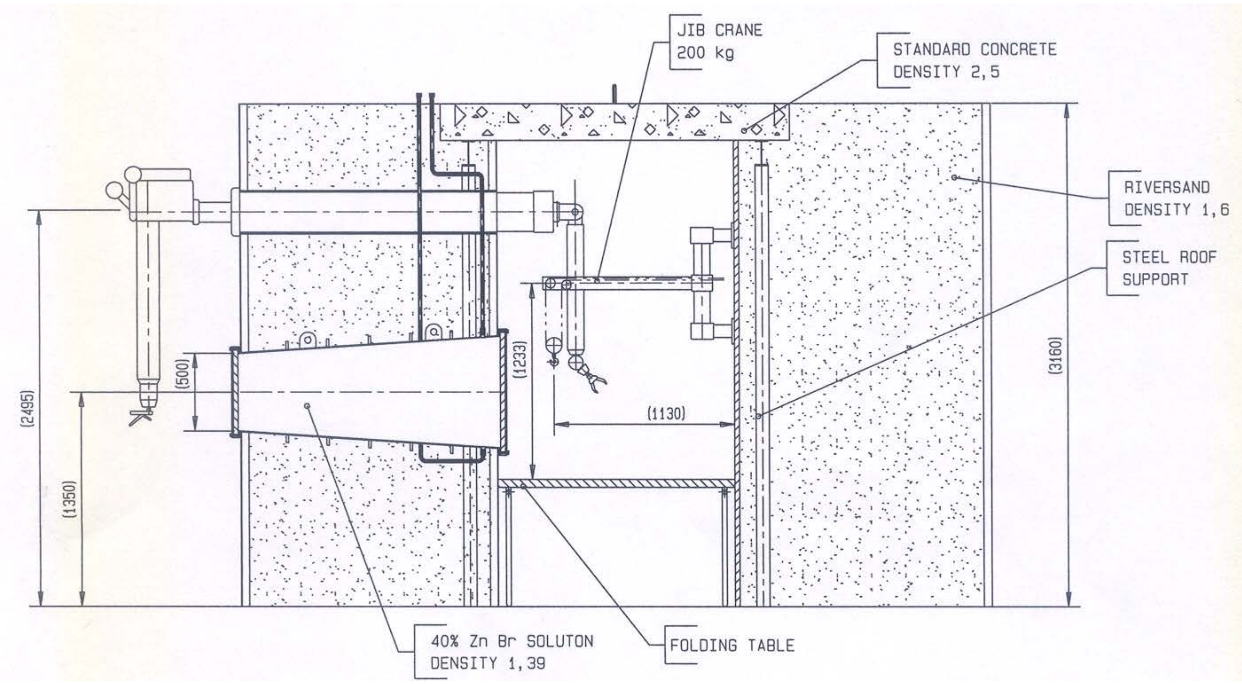


*FIG. 5.35. Section view of the biological shield.*

All joints of adjacent shuttering panels are filled with silicon glue to provide airtight smooth surfaces. The internal surface of the biological shield is painted with epoxy paint for ease of decontamination.

*5.11.3.2. Workbench*

A table, filling the internal dimensions of the cell at 800 mm from the floor, provides a working surface. The table is indicated in Fig. 5.35. Its height should be adjustable for a better view of the work area. It should be covered in plastic sheeting during operations for ease of decontamination. The manipulators are able to access any point on the workbench surface.

*5.11.3.3. Biological shield roof*

The roof is made up of three 23 cm thick slabs of concrete cast with mild steel corner protection and standard reinforcing bars. The concrete provides shielding and reduces skyshine. The roof reduces skyshine from an effective dose equivalent of 0.215 mSv/h to 0.036 mSv/h to operators of the facility. The total weight of the roof is about 4 t. This means that each slab is about 1.3 t, well below 2 t design lifting capacity for the crane.

*5.11.3.4. Window*

The polycarbonate window provides shielding, equivalent to that provided by the walls of the biological shield (Fig. 5.36). The window is positioned such that the operator can view the operation area from a standing position.

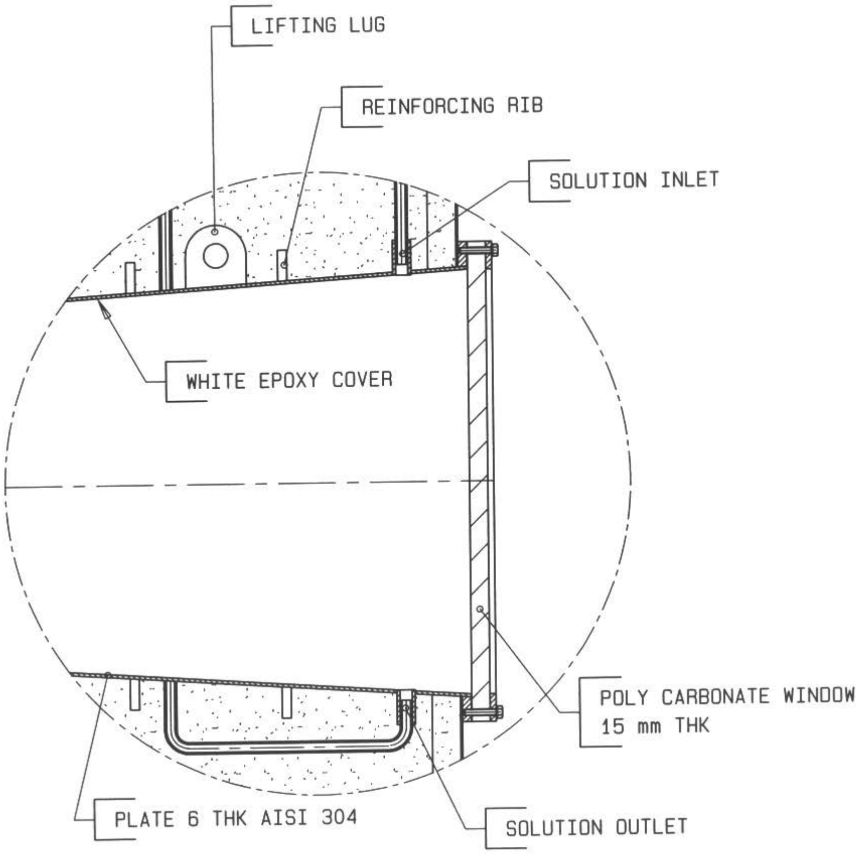


*FIG. 5.36. Sketch of viewing window.*

The window comprises a container filled with a transparent heavy liquid and having transparent end panels. For the window to have the same depth as the cavity while still providing the same level of shielding, the shielding liquid will be a 50% zinc bromide solution. The solution reduces dose due to a 1000 Ci source inside the biological shield to an effective dose equivalent of 0.062 mSv/h on the outer wall. A lead skirt on the bottom section of the window will provide added shielding in case the sand settles and creates voids through which there could be radiation steaming.

The window has two transparent end panels through which the cell is viewed. The end panels are shatter proof and made of polycarbonate. The window is installed empty and is then filled with a zinc bromide solution through the filling pipe. To empty the window, the shielding solution is drained using the siphon tube accessible from the top of the biological shield. The window is held in place by a set of two custom made shuttering panels on both sides of the biological shield wall.

*5.11.3.5. Master–slave manipulators*

The main function of MSMs is to perform the final dismantling of the working shield in order to expose the unshielded sealed source. They cover the entire cell area so that they can handle objects anywhere within the cell to a height of 1.2 m above the workbench (Fig. 5.37).

The telescopic MSMs are capable of lifting up to 20 kg of weight. Some modifications to these manipulators are necessary to ensure that the wall tube covers the 1.5 m thickness of the biological shield wall. They should be supplied with booting for airtightness and are easily dismantled into their three components for transportation.

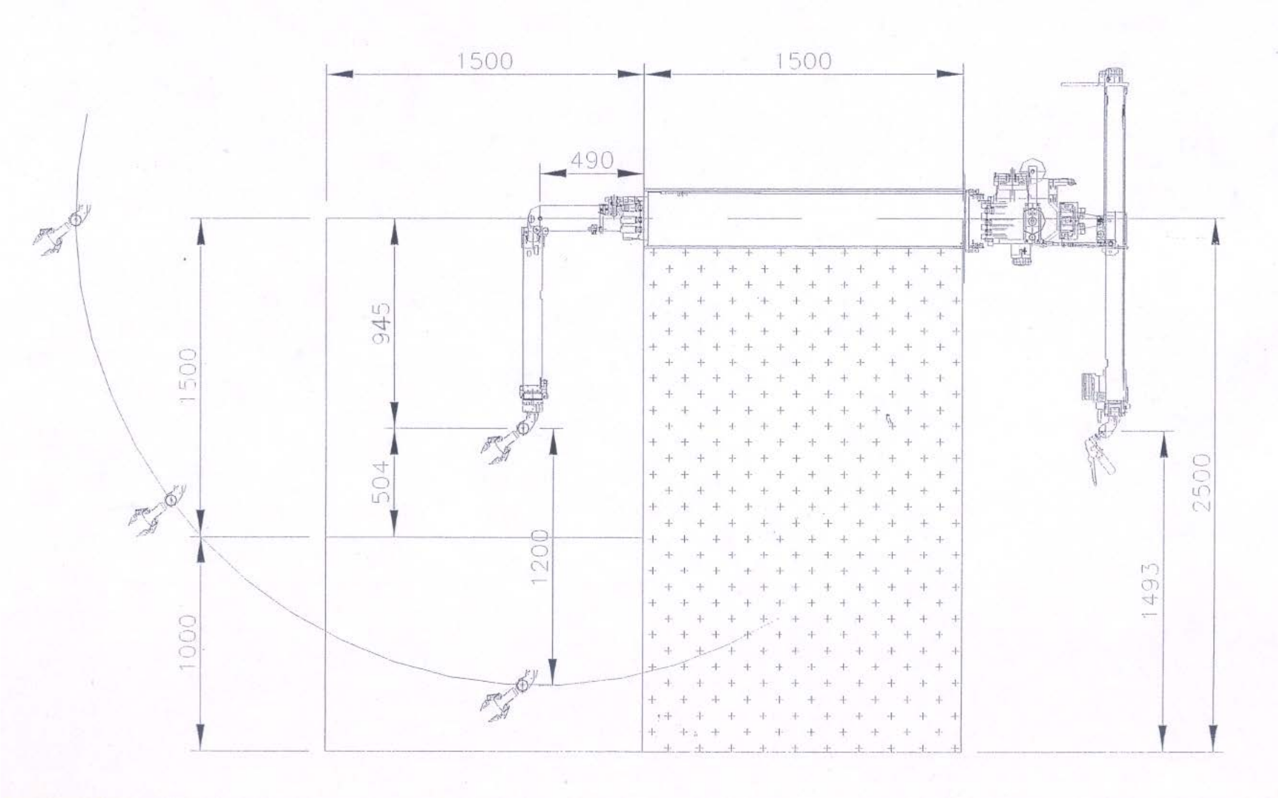


*FIG. 5.37. Telescopic MSMs.*

### *5.11.3.6. Internal crane*

An internal crane is designed to lift objects too heavy for the master slave manipulators. It covers as much of the cell as possible, especially the rear of the cell where most of the work will be done. It is a jib crane type mounted on the internal wall of the biological shield. The crane arm can swivel through 180º about its mounting. The crane hoist travels the length of the crane arm and is electrically operated. It has a total lifting height of 1.2 m above the workbench. The lifting capacity of the crane is 200 kg.

### *5.11.3.7. External crane*

The external crane's main purpose is to lift heavy objects such as the source's working shield into and out of the biological shield. It is also used during assembly of the biological shield, window, and placing of roof panels.

The external crane is a gantry crane type shown in Fig. 5.38. It has four large rubber wheels for moving across even surfaces. The hoist has a capacity of 2 t. It moves along the cross-beam by means of a motorized pinion on a rack mounted on the cross-beam. The crane needs an overhead clearance of 5.5 m. It has a lifting height of 3.9 m from the ground. This gives it a working clearance of 750 mm above the biological shield.

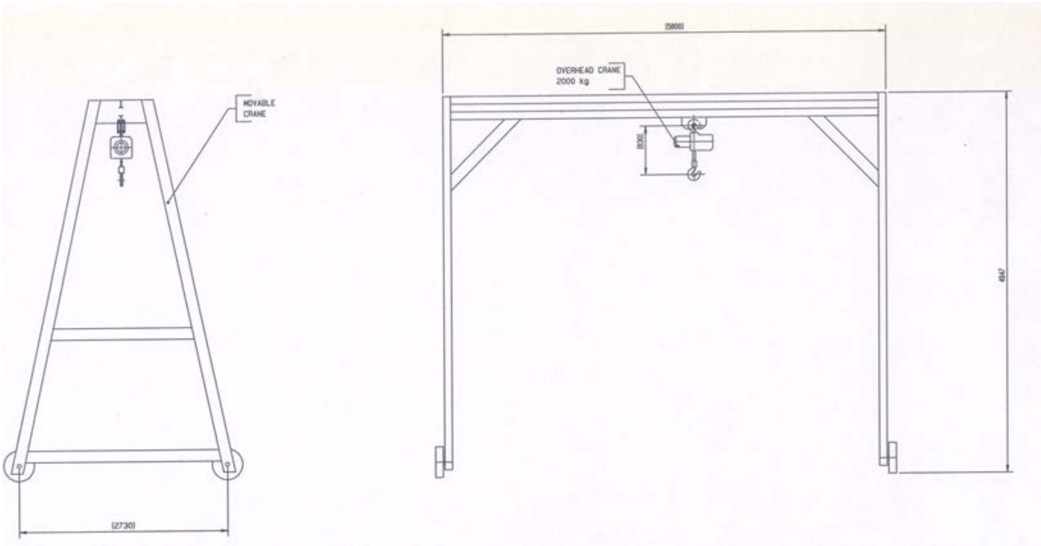


*FIG. 5.38. External crane.*

A ratchet should be installed on the external crane so that it can be accurately placed over the identified point.

*5.11.3.8. Ventilation system*

The ventilation system is designed to prevent contamination from migrating to areas outside the biological shield by maintaining a negative pressure within the cell. All potential sources of airborne contamination will be trapped on HEPA filters to the outside. Personnel working inside the biological shield will not need ventilation, as the roof will be open at this stage. Hence, ventilation is to cater for accident scenarios involving a leaking source.

The ventilation system is a stand-alone system that is coupled to the biological shield through a specially designed duct (Fig. 5.39). The system consists of a fan, pre-filters fitted with fire arrestors, HEPA filters, and an exhaust hose. The system maintains an internal cell pressure of –200 Pa and 5 air changes per hour (ACH).

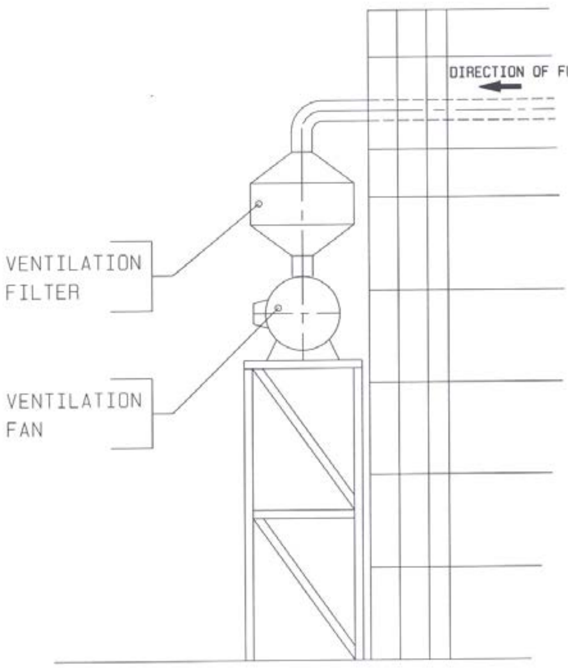


*FIG. 5.39. Mobile hot cell conditioning facility ventilation system.*

In addition to the equipment described and illustrated above, provision should be made for:

(a) Fully automatic welding equipment.
(b) Leak testing equipment.
(c) Radiation protection equipment.
(d) Sand loading equipment.
(e) Tools for stripping of teletherapy heads, building and stripping of biological shield, and other general applications.
(f) Transport container. It will be modified and adapted for the transportation of the facility.
(g) Vibrators.
(h) Vacuum cleaner.
(i) Emergency battery operated lights, installed inside the biological shield, in case power to the main lights is lost. Two closed circuit cameras will be installed inside the cell and connected to two independent monitors outside.
(j) Power supply with sufficient redundancy.
(k) Long term storage shield:
    (i) The long term storage shield is a container based on, and compatible to, the design of the F147 source transport container by MDS Nordion. The container is coupled to the transfer port of the biological shield. The source drawer is then pushed into the cell. The source is placed into the drawer and the loaded source drawer retracted into the long term storage shield. The shield has a locking mechanism that makes it very difficult for unauthorized access of the stored source. Special knowledge and authorization is required to open the shield once the sources have been introduced. Figure 5.40 shows a sketch of the long term storage shield with the drawer in loading position inside the cell.
    (ii) It is designed to have four drawers capable of holding sources with a total activity of about 10 kCi. The dose rate on the outer surface of the shield should not exceed 2.0 mSv/h.
    (iii) Allowance is made for about two–three teletherapy sources and about five–ten blood irradiator pencils. The blood irradiator pencils must fit into the drawer in a horizontal position.

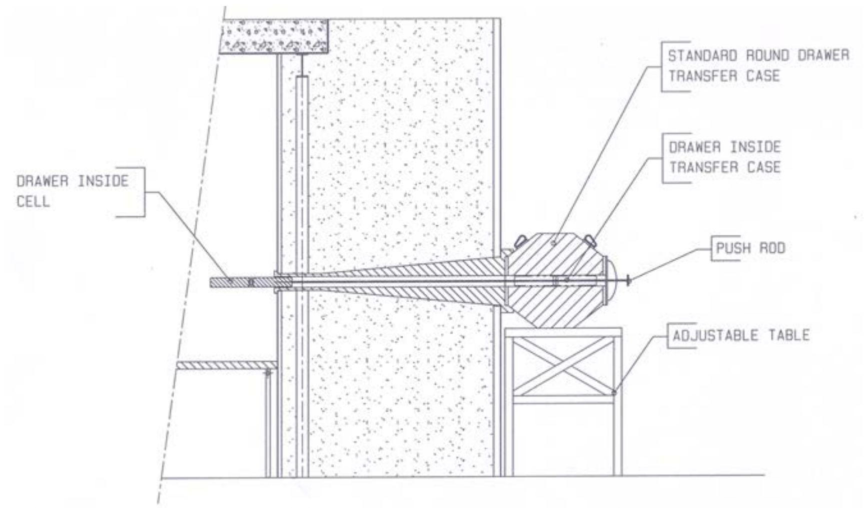


*FIG. 5.40. Long term storage shield coupled to the transfer port.*

### 5.11.4. Module L4 — Process description and operation

The requirements for operators or technicians should be:

(a) A designated person trained in radiation safety identified as being in charge of administrative control of the conditioning facility temporary storage site;
(b) A designated person trained in the use of MSMs and lifting operations.

#### 5.11.4.1. Assembling the conditioning facility

The conditioning facility should be assembled inside a building with an overhead clearance of at least 5.2 m. The floor of the building should be strong and even. A pre-mission to the host should identify a suitable location for the conditioning facility.

The biological shield, which is in a modular form, should be assembled largely by hand with the assistance of the external gantry crane. The shielding material should be loaded into the biological shield cavity manually. About 90 $m^3$ of sand will be required for shielding.

#### 5.11.4.2. Retrieving source from working shield

A radiation protection supervisor should monitor this operation at all times.

The working shield containing the source should be partially dismantled outside the biological shield to loosen the holding bolts. The shield should then be transferred into the biological shield using the external crane through the open roof. Then, operators should make sure that all connections and holding bolts and nuts are loose enough to allow disassembly by using manipulators.

The roof should be closed and final dismantling of the working shield undertaken. The source should be checked for leaking, retrieved, encapsulated and transferred into the storage container.

#### 5.11.4.3. Placing source into a long term container

The storage container should be coupled to the source transfer aperture on the outside of the biological shield. This coupling, which is done prior to final dismantling of the working shield, should be radiation tight.

To transfer the source into the storage container, the source drawer is pushed into the cell through the source transfer aperture. The source is placed and secured in the drawer and the drawer retracted back into the storage container.

### 5.11.5. Additional operation considerations

(a) As mentioned above, a designated person trained in radiation safety should be identified as being in charge of administrative control of the temporary storage site. A written plan should be developed for such administration that should require, but not necessarily be limited to, performing the following:
  - (i) Checks of the storage area security systems;
  - (ii) Any special tests required to ensure integrity of the source holder;
  - (iii) Wipe tests, radiation surveys, and testing of the functioning of the radiation monitors;
  - (iv) Checks that all signs and labels are present and readable;
  - (v) Checks that all persons authorized to enter the storage area are appropriately trained;
  - (vi) Efforts to minimize the period of temporary storage;
  - (vii) Ensuring that responsibility does not lapse with a change of personnel or facility ownership.

(b) Information in the documentation retained for each source in temporary storage should be included in the national inventory of sealed sources.

(c) All official documentation pertaining to the source and the device must be retained for reference and transfer when the source is moved to interim storage. The documentation should be retained in an obvious but secure location under the control. It should include, but not necessarily limited to:
  - (i) The source certificate or other pertinent information about the source;
  - (ii) Procedures related to source handling, such as loading and unloading instructions;
  - (iii) Identification of suitable shipping and storage containers;
  - (iv) Drawings and other technical information about the source and the device;
  - (v) Information about administrative checks performed during storage.

## REFERENCES TO SECTION 5


[5.1] INTERNATIONAL ATOMIC ENERGY AGENCY, Regulations for the Safe Transport of Radioactive Material, IAEA Safety Standards Series No. TS-R-1, IAEA, Vienna (2005).

[5.2] INTERNATIONAL ATOMIC ENERGY AGENCY, Management of Spent High Activity Radioactive Sources (SHARS), IAEA-TECDOC-1301, IAEA, Vienna (2002).

[5.3] POTIER, J.-M., AL-MUGHRABI, M., SHARS: A shared solution for risky radioactive sources, IAEA Bull. 49 **1** (2007).

[5.4] LIEBENBERG, G., AL-MUGHRABI, M., “The development of a mobile hot cell facility for the conditioning of spent high activity radioactive sources (SHARS)”, Waste Management ’08 (Proc. Int. Conf. Phoenix), (2008).

# 6. PROCESSING MODULE INTEGRATION

In many cases, it is unlikely that the process modules will be used in isolation. Instead, as can be seen from the waste management flow charts, two or more process modules will be needed to manage a waste stream. For example, to manage solid radioactive waste might require:

— The unshielded booth (Module D3) to receive, sort and segregate the waste into, say, compactable and non-compactable waste and disused sealed sources;
— The low force compaction (Module D2) to compact the compactable waste into 200 L drums;
— The encapsulation module (Module E1) to encapsulate non-compactable waste into 200 L drums.

The processing modules can be considered in three basic groups when considering how they will be used together or integrated to process specific waste streams:

— To process solid waste streams requires two or more of the following process modules to be integrated: the unshielded booth (Module D3), low force compaction (Module D2) and encapsulation module (Module E1);
— To process high volume aqueous waste streams requires two or more of the following process modules to be integrated: chemical treatment (Module B1), ion exchange (Module B2), reverse osmosis (Module B3), cross-flow filtration (Module B4), filtration (Module B5) and solidification (Module B6).

In addition, there is the special group of wastes, i.e. high activity disused sealed sources, that may require the hot cell module for their repackaging prior to placing in special shielded containers.

Integration can involve physical co-location and sequential operation of the process modules with the benefits of:

— Minimizing double handling of waste, and hence reduced dose uptake by the operators;
— More efficient and effective use of staff and resources as wastes can be processed in short campaigns;
— Reduced interim storage of unconditioned or incompletely treated waste because waste streams are processed from their raw form to final conditioned form in one campaign.

The following sections discuss how the processing modules can be integrated.

## 6.1. SOLID WASTE PROCESSING MODULES

Unless solid waste is received at the WPSF already sorted and segregated, it will be necessary to undertake sorting and segregation. This is the fundamental purpose of the unshielded booth that provides the ability to empty the contents of a waste package on to a sorting table and sort and segregate the waste into compactable and non-compactable categories and also, if found, isolate sources and liquid waste containers for separate treatment.

To avoid double handling of waste, the low force compactor can be built into the unshielded booth so that sorted compactable waste can be placed into a drum and compacted as the waste is received. At the same time, the non-compactable waste can be also placed into an adjacent drum. When the drum is full, the waste can solidified while still at the unshielded booth by pumping grout from the encapsulation module.

Thus, these three modules can be integrated to provide a single location for all solid waste operations. They can be constructed within an existing or new permanent structure. Alternatively, they could be housed together within an ISO freight container (Fig. 6.1).

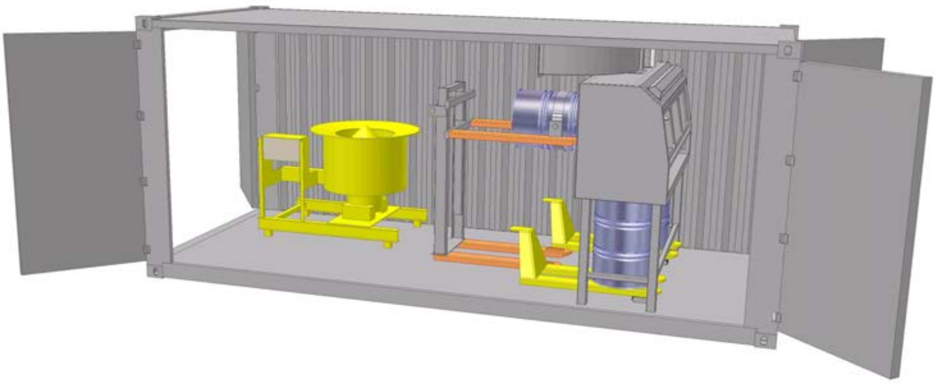

*FIG. 6.1. Integration of unshielded booth, low force compactor and encapsulation equipment inside an ISO freight container.*

The unshielded booth is shown located across the width of the ISO freight container, with access to one side for bringing in waste drums, picking them up, rotating them horizontally and then pushing the lid of the drum in through the port at the back of the booth. The encapsulation module is also housed on this side of the cabinet. A delivery pipe from the encapsulation module is pushed through a guide tube in the back of the booth and can then be manipulated by the operator to direct grout into a waste drum.

On the other side of the booth, the operator can access the waste drum, remove the lid and then pull the contents of the drum on to the sorting area of the booth and then place the waste into the appropriate waste drum. The waste compactor is operated from this side of the booth.

The unshielded booth will be ventilated by a small filtered extract system. This can be located in the end of the freight container.

## 6.2. LOW VOLUME AQUEOUS AND ORGANIC LIQUID WASTE PROCESSING MODULES

The processing modules for low volume aqueous and organic liquid treatment are small laboratory type equipment that would be housed within a proprietary fume cupboard with integral ventilation. The fume cupboard can be housed within an existing permanent structure or again could be installed within an ISO freight container.

## 6.3. HIGH VOLUME AQUEOUS WASTE PROCESSING MODULES

The high volume aqueous waste processing modules may be used individually or combined for the treatment of aqueous liquid waste. One of the more complicated combinations is: chemical treatment (Module B1), followed by cross-flow filtration (Module B4), followed by ion exchange (Module B2) of the liquid and solidification (Module B6) of the precipitated sludge from chemical treatment, and eventually of the spent ion exchange media.

The layout of these treatment modules adjacent to one another is illustrated in Fig. 6.2. Transfer of liquid from one processing stage to the next is by lifting the container of liquid out of one module and placing it in the next module.

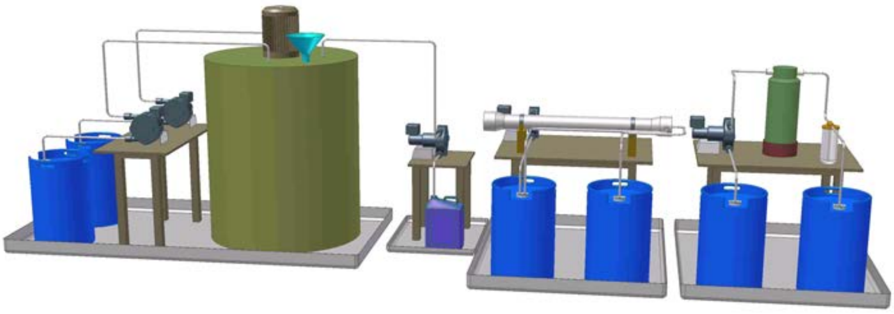

*FIG. 6.2. Combination of chemical treatment (Module B1), followed by cross-flow filtration (Module B4), followed by ion exchange (Module B2).*

Alternatively, the treatment equipment can be housed within an ISO freight container as illustrated in Fig. 6.3.

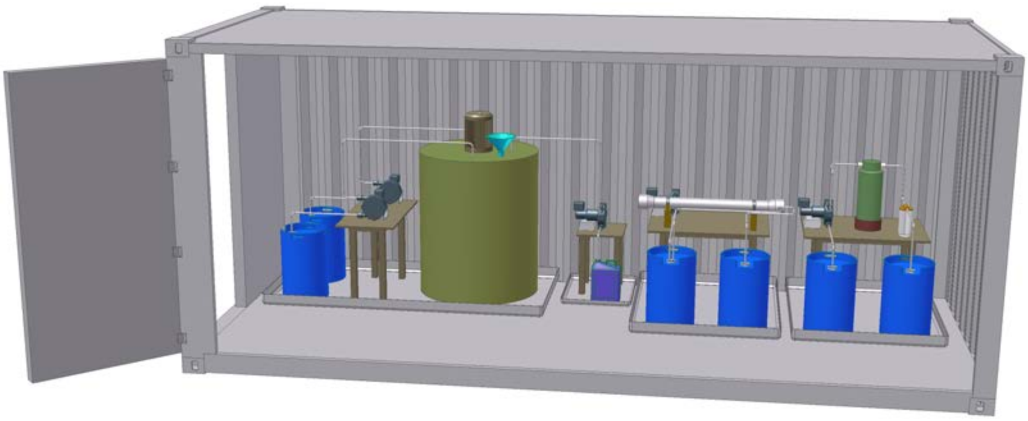

*FIG. 6.3. Housing of modules for chemical treatment (Module B1), followed by cross-flow filtration (Module B4), followed by ion exchange (Module B2) within the ISO freight container.*

This ISO container can then be located adjacent to the containerized Module B6–Solidification. In the illustration, the central dividing wall is omitted for clarity (Fig. 6.4). A doorway could be provided in this wall between the two modules for transferring containers of waste sludge from the treatment modules to the solidification module.

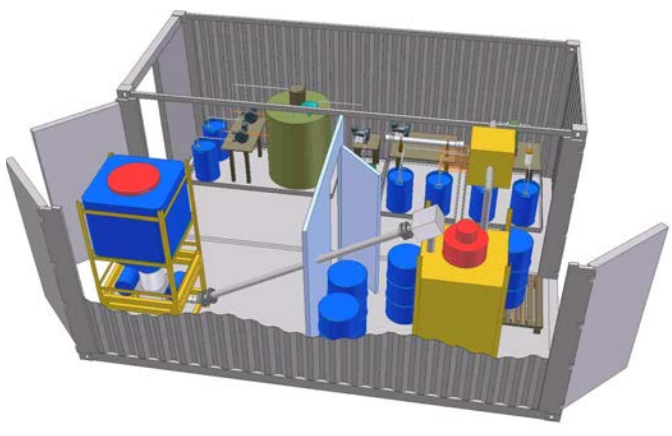

*FIG. 6.4. Housing of modules for chemical treatment (Module B1), followed by cross-flow filtration (Module B4), followed by ion exchange (Module B2) and solidification (Module B6) of the precipitated sludge from chemical treatment and eventually of spent ion exchange media within two adjacent ISO freight containers.*

Another likely, but simpler, combination is filtration (Module B5), followed by ion exchange (Module B2) of the liquid and eventual solidification (Module B6) of spent ion exchange media.

Each of the processing modules include space to locate waste containers to feed waste into the process and receive treated waste; tanks, pumps, valves and instruments are all supported on a steel framework and contained within drip trays for containment of spillages or leaks. Pipe work and vessels should be fabricated in a combination of stainless steel and plastics.

The processing modules can be located adjacent to one another so that the receiving container of the first module acts as the feed container for the second module.

The combination of filtration and ion exchange modules is illustrated in Fig. 6.5. These process modules can be constructed within an existing or new permanent structure.

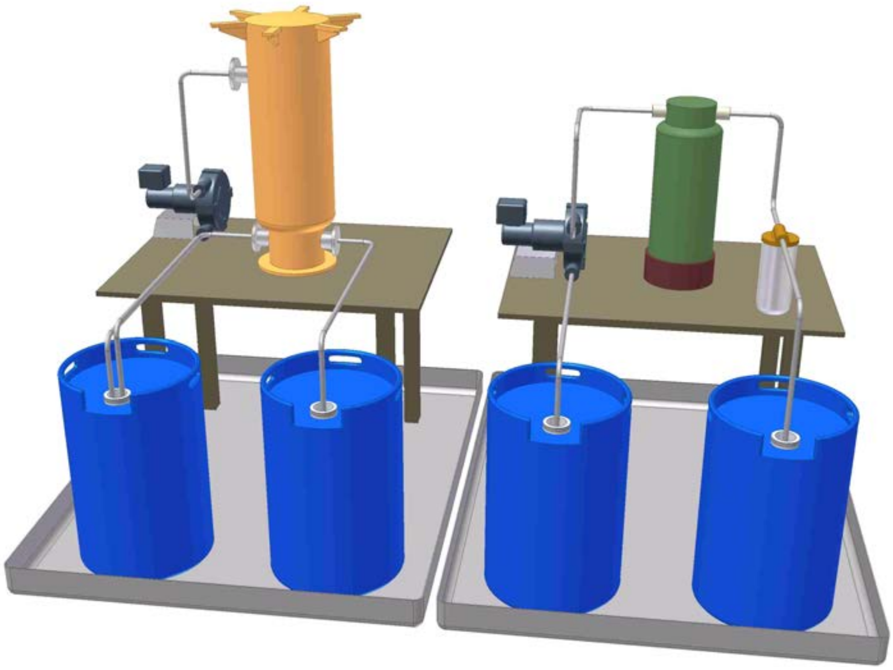

*FIG. 6.5. Combination of filtration (Module B5) followed by ion exchange (Module B2).*

Alternatively, with the exception of the solidification module that will need its own ISO freight container, they could be housed together within an ISO freight container as illustrated in Fig. 6.6.

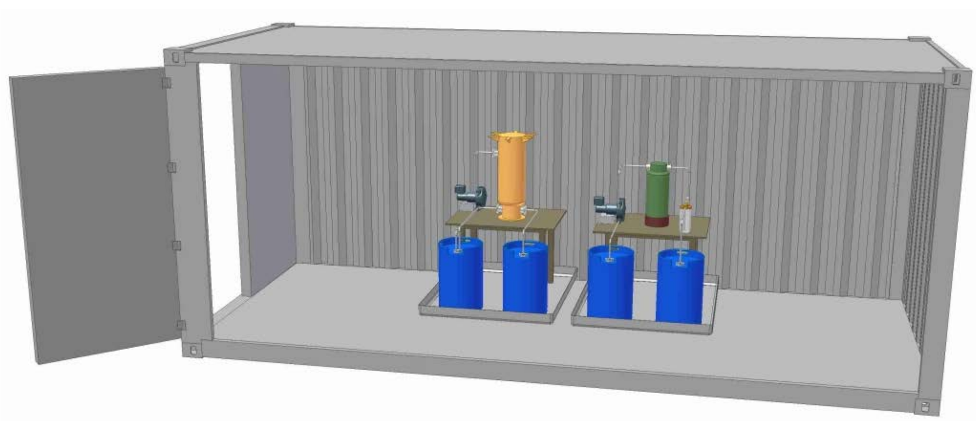

*FIG. 6.6. Housing of modules for filtration (Module B5) followed by ion exchange (Module B2) in an ISO freight container.*

Another layout (Fig. 6.7) shows how there will be space for temporary storage of containers of liquid waste awaiting treatment in bunded trays.

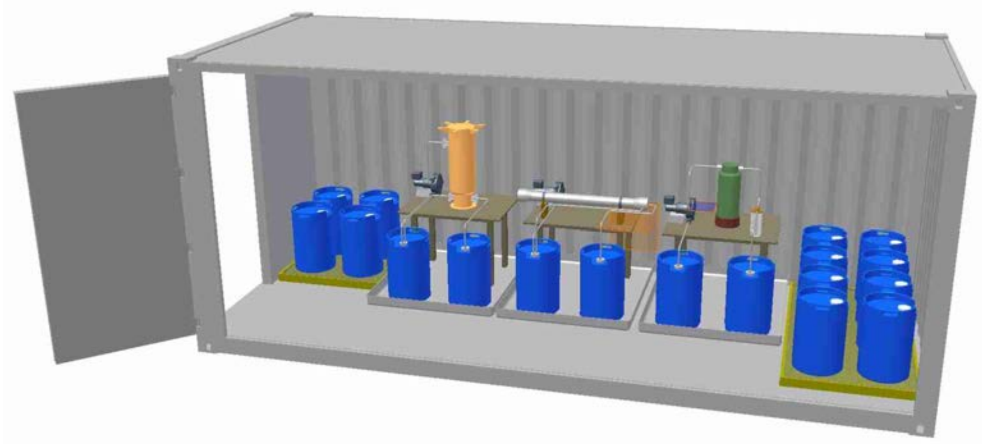

*FIG. 6.7. Housing of modules for filtration (Module B5) followed by ion exchange (Module B2) in an ISO freight container with bunded storage areas for waste containers.*

## 6.4. ISO FREIGHT CONTAINERS

ISO freight containers are a practical, low cost method of providing a weather proof enclosure for the process modules. The external dimensions of standard 20 ft ISO containers are 20 ft (length) × 8 ft (width) × 8–9 ft 6 in (height) (6.06 m (length) × 2.44 m (width) × 2.44–2.89 m (height). The containers are normally supplied with full width double doors at one end of the container, but many other options are available, including double doors at both ends of the container and personnel access doors on the side of the container.

There are a large number of companies that can supply special purpose containers, either built from new or refurbished/converted from pre-used freight containers. For use as weather proof enclosures for process modules, the containers should be:

(a) Supplied with CSC certification;
(b) In wind and water tight condition;
(c) Fitted with a steel floor (or steel cladding of the existing wooden floor, sealed to the walls) to provide a decontaminable surface;
(d) Fitted with lock boxes on the doors to improve security;
(e) Finished with a good paint finish outside and inside.

A very large number of organic paint systems will provide excellent protection to the freight container mild steel construction, provided the necessary care is taken with the surface preparation, a suitable inhibitive primer is used, and a sufficiently high dry film thickness of paint is applied. If a full protective organic paint system is applied over an inorganic treatment, i.e. hot dip galvanizing or metal spray, then a long protective life under almost all service conditions is assured. The degree of surface preparation required will be dependent on the form of the mild steel, cold rolled thin section plate will be easier to prepare than hot rolled plate covered, or partially covered, with mill scale, but badly pitted steel requires extra attention. Blast cleaning conforming to applicable standards (e.g. Sa.2½, Swedish Standards Institution, SS 05 59 00 or equivalent) is generally the best option.

For maximum corrosion resistance and ease of decontamination the following is recommended:

| | | |
|---|---|---|
| Primer: | Two pack zinc rich epoxy primer | 45–50 μm; |
| Finish: | Two pack solvent free epoxy topcoat | 200–250 μm; |
| | Total dry film thickness | 245–300 μm |

As well as using the ISO freight containers to house the process modules as illustrated above, they can also be used to house support modules such as offices (Fig. 6.8), change rooms, radiation protection services room and ventilation plant and equipment.

ISO containers can also be used as storage modules, as discussed in Section 8.2.4.

*FIG. 6.8. ISO freight container providing office accommodation.*

# 7. TYPES AND QUANTITIES OF CONDITIONED WASTE PACAKAGES FOR STORAGE

Interim storage of conditioned waste packages will be required pending disposal. The packaged waste arises from the treatment and conditioning of the different waste types identified in Section 3 using the processing modules described in Section 6. It is expected that wastes requiring storage will be packaged as follows:

(a) General solid and liquid wastes conditioned into 200 L drums;
(b) Disused sealed sources in their shielded transport and storage containers and overpacked into 200 L drums.

Typically, no other package types are expected if the waste originates from the waste processing facility/modules. The exception to this may be the case when there are only very small numbers and volumes of waste packages, e.g. in Member States that have limited use of a relatively small numbers of radioactive sources. In this case, the disused sources may be sealed in smaller packages (e.g. cans) and stored within cabinets. Another type of package that may arise is the long term storage shield containing high activity disused sealed sources.

The criteria for waste acceptance for storage, number of waste packages, period of storage and functional and other requirements are summarized below. For more information on these topics the reader is referred to related IAEA publications.

## 7.1. WASTE ACCEPTANCE CRITERIA

Key assumed waste acceptance criteria are identified below. Wastes that do not meet these acceptance criteria will first be processed and/or repackaged via the waste processing facility/modules.

### 7.1.1. Size/weight of packages

The majority of packages are based upon the 200 L drum. Typical dimensions are 610 mm (outer diameter) and 880 mm (height). Drum weight could vary from 50 kg (in-drum compacted soft waste) up to 400 kg for encapsulated and solidified wastes. Sources in shielded containers, e.g. radium sources in storage shields that have been overpacked into 200 L drums could weigh 500 kg.

Drums should be in good condition, either in mild steel with a protective coating, e.g. paint system, to prevent corrosion from the outside of the drum, or stainless steel, especially if prolonged storage is anticipated. Figure 7.1 illustrates different types of drums in common use.


Mild steel drum with clamp lid — Mild steel drum with bolted lid — Stainless steel drum

*FIG. 7.1. Examples of drums commonly used for waste packaging.*

### 7.1.2. Radiological characteristics

As the waste has originated from the waste processing facility/modules it can be assumed that:

(a) The drum radiation dose rates are sufficiently low because of integral shielding to allow manual handling rather than remote handling. This does not remove the requirement that some packages may require additional shielding within the storage facility to allow facility operations and ensure that operator dose rates are optimized.
(b) The drums are clean, i.e. they are sealed and free of external contamination when received.

## 7.2. NUMBER OF PACKAGES

Previous work by the IAEA has reviewed typical wastes generated by Member States from nuclear applications and research and identified their principal characteristics and quantities. These are summarized in Table 7.1, together with an estimate of the number of 200 L drum waste packages that will be generated by conditioning of these waste streams each year.

TABLE 7.1. WASTE VOLUMES

| Waste stream | Annual quantity to be processed | Estimated annual conditioned waste volume for reference design | Equivalent number of 200 L drums per annum |
|---|---|---|---|
| Low volume aqueous liquid | Typically up to 0.5 $m^3$, for the reference design, 0.1 $m^3$ should be used | 200 L | 1 |
| High volume aqueous liquid | Typically in the range 0.5–10 $m^3$, for the reference case 5 $m^3$ should be used | 10 $m^3$ if directly solidified. If bulk volume is treated and discharged then 500 L of conditioned residue. | 3–50 |
| Organic liquid | Typically less than 0.3 $m^3$, for the reference case 0.1 $m^3$ should be used | 1 $m^3$ if directly solidified. | 5 |
| Compactable solid | Typically less than 20 $m^3$, for the reference case 5 $m^3$ should be used | 1 $m^3$ after compaction | 5 |
| Non-compactable solid | Typically less than 5 $m^3$, for the reference case 1 $m^3$ should be used | 1 $m^3$ when encapsulated | 5 |
| Ion exchange resins | Typically less than 0.5 $m^3$, for the reference case 0.1 $m^3$ should be used | 250 L when encapsulated | 1–2 |
| Sludge | Typically less than 0.5 $m^3$, for the reference case 0.1 $m^3$ should be used | 200 L when encapsulated | 1 |
| Disused sealed source — short lived isotope | Large variation of number of sources, for the reference case 20 should be used | Depends on physical size of source in shielded container. Assumed 1–4 $m^3$ when encapsulated | 5–20 |
| Disused sealed source — long lived isotope | Large variation of number of sources, for the reference case 20 should be used | Depends on physical size of source in shielded container. Assumed 1–4 $m^3$ when encapsulated | 5–20 |

TABLE 7.1. WASTE VOLUMES (cont.)

| Waste stream | Annual quantity to be processed | Estimated annual conditioned waste volume for reference design | Equivalent number of 200 L drums per annum |
|---|---|---|---|
| Biological (Carcasses) | Typically up to 0.5 $m^3$, for the reference case 0.1 $m^3$ should be used | Assumed 400 L when encapsulated | 2 |
| Waste and disused sealed sources suitable for decay storage (very short lived radionuclides) | Typically less than 0.5 $m^3$ of solid and liquid waste and less than ten disused sources, for the reference case 0.2 $m^3$ of solid and liquid waste and five disused sources should be used | Interim decay storage | 1 for solid waste<br>1 for liquid waste<br>1 for sealed sources |

Not all of these waste streams will be generated by all Member States and not necessarily at these rates of generation. In addition Member States may have quantities of historical or legacy waste to be conditioned, packaged and stored. Consideration should also be given to any expected future use of nuclear materials in the Member States and the impact that will have on future waste generation.

From the table, assuming all of the waste streams are generated and that the high volume aqueous liquid waste is treated and discharged, there will be approximately 30–40 drums produced each year. This will be taken as the maximum annual volume of packaged waste to be received at the storage facility.

The number of packages expected and the rate at which they are received will determine the storage facility size and whether, for example, the full facility needs to be provided from the start, or whether it can be expanded over a period of time.

# 8. STORAGE MODULE OPTIONS

## 8.1. IDENTIFICATION OF OPTIONS

A wide variety of storage options are available [8.1–8.4]. For example:

(a) Shielded cabinet;
(b) Dedicated room;
(c) Concrete container;
(d) ISO freight container;
(e) Concrete pipe;
(f) Concrete bunker or trench;
(g) Below ground tubes or vaults;
(h) Caves, mines and tunnels;
(i) Purpose built industrial building;
(j) Existing building;
(k) Outdoors on a hard standing (dry climates).

## 8.2. REVIEW AND EVALUATION OF OPTIONS

Each of the storage options are discussed below in more detail, taking account of the requirements identified in Section 8 for the storage facility.

### 8.2.1. Shielded cabinet

Security cabinets and safes are ideal for the storage of small waste packages and small quantities of waste packages. Shielded cabinets and thick walled safes require no other support systems such as ventilation or waste package handling. The cabinet can be located within an existing facility, e.g. where radioactive material is being used such as a hospital or research facility. Cabinets are lockable, and therefore provide a degree of security. Two examples are shown in Fig. 8.1.


*FIG. 8.1. Shielded cabinets.*

However, a key assumption is that the majority of waste packages produced from the waste processing facility will be based upon a 200 L drum. Because of the size and weight of this package, shielded cabinets will not be suitable.

### 8.2.2. Dedicated room

It may be possible to use a room in an existing facility for the purpose of waste storage if waste volumes are relatively small. A room should be able to receive larger waste packages than a shielded cabinet. If necessary, higher dose rate packages can be shielded within a room using concrete blocks, lead bricks or other waste packages of low dose rates.

However, in considering such a room the following should be taken into account:

(a) Access into the room carrying waste packages as large as drums with fork lift truck or pallet trucks will require a double door. Normal personnel access single doors will not be wide enough.
(b) The access route to the room from where the waste drums are received will need reasonable flat, smooth floors for fork lift truck or pallet truck movement and as well as being sufficiently wide for manoeuvring.
(c) The room should have adequate ventilation.

### 8.2.3. Concrete containers

Concrete containers have been widely used as transport, storage and disposal containers. They are particularly suitable for higher dose rate waste packages as the box provides a degree of shielding. Again, a concrete container should be able to receive larger waste packages than a shielded cabinet (including 200 L drums). A number of proprietary designs are available. An example is shown in Fig. 8.2.


*FIG. 8.2. Concrete container.*

Most, if not all, designs have a removable lid for loading waste packages from above. This requires a crane and grab for handling and positioning the waste packages and for removal and replacement of the lid. This adds complexity to drum handling.

### 8.2.4. ISO freight containers

ISO freight containers are widely available throughout the world (Fig. 8.3). They have been used as radioactive transport packages and as final disposal containers. They can also be used as storage modules. Some of the basic construction and surface protection features of ISO freight containers have been described in Section 6.4.

*FIG. 8.3. ISO freight container.*

Typical dimensions and weights of ISO freight containers are given in Table 8.1.

TABLE 8.1. TYPICAL ISO FREIGHT CONTAINER DIMENSIONS AND WEIGHTS

| | | 20 ft container | | 40 ft container | |
|---|---|---|---|---|---|
| | | Imperial | Metric | Imperial | Metric |
| External dimensions | Length | 20 ft 0 in | 6.096 m | 40 ft 0 in | 12.192 m |
| | Width | 8 ft 0 in | 2.438 m | 8 ft 0 in | 2.438 m |
| | Height | 8 ft 6 in | 2.591 m | 8 ft 6 in | 2.591 m |
| Interior dimensions | Length | 18 ft 10 5⁄16 in | 5.758 m | 39 ft 5 45⁄64 in | 12.032 m |
| | Width | 7 ft 8 19⁄32 in | 2.352 m | 7 ft 8 19⁄32 in | 2.352 m |
| | Height | 7 ft 9 57⁄64 in | 2.385 m | 7 ft 9 57⁄64 in | 2.385 m |
| Door aperture | Width | 7 ft 8 ⅛″ | 2.343 m | 7 ft 8 ⅛ in | 2.343 m |
| | Height | 7 ft′ 5 ¾ in | 2.280 m | 7 ft 5 ¾ in | 2.280 m |
| Volume | | 1169 $ft^3$ | 33.1 $m^3$ | 2385 $ft^3$ | 67.5 $m^3$ |
| Maximum gross mass | | 66 139 lb | 30 400 kg | 66 139 lb | 30 400 kg |
| Empty weight | | 4850 lb | 2200 kg | 8380 lb | 3800 kg |
| Net load | | 61 289 lb | 28 200 kg | 57 759 lb | 26 600 kg |

ISO freight containers are a flexible, modular low cost method of providing a weather proof enclosure for waste storage. Being portable, they are flexible in their location and can be relocated if required. They can accommodate a wide range of waste package sizes and weights. The model in Fig. 8.4 shows standard 200 L drums stacked inside an ISO freight container. With the arrangement shown, some manoeuvring will be required for carrying out periodic inspection of the stored drums. Depending on the situation users may prefer other arrangements that require less manoeuvring for inspection.

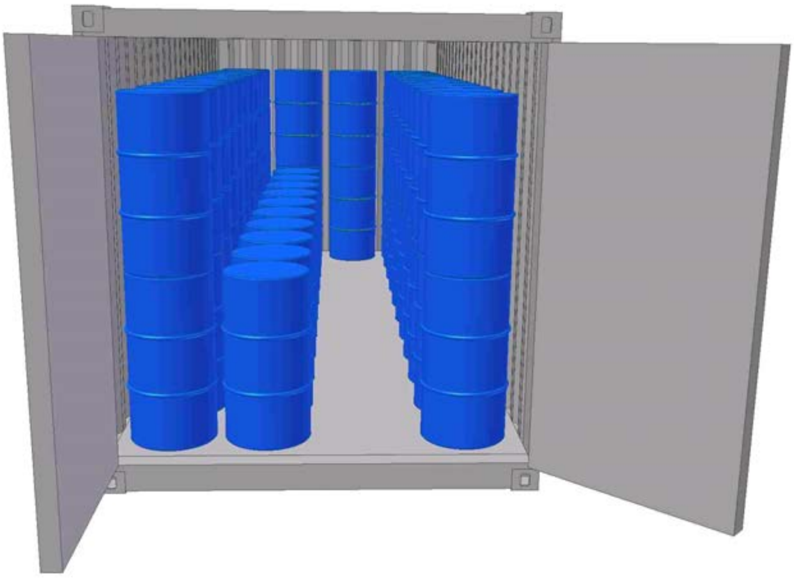

*FIG. 8.4. Drums stacked inside an ISO freight container.*

Being of metal construction, ISO containers are liable to corrosion and ultimately their design life will be limited by environmental conditions.

A suitable foundation is required for the placement of the ISO freight container(s). A full ISO freight container can weigh up to 30 t, so the slab should provide a load bearing capacity of 20 kN/m$^2$. A basic design for the slab would be a simple, ground bearing, reinforced concrete raft. Resistance to water penetration from the ground should be provided by a polyethylene damp proof membrane on the underside of the slab. The floor of the slab should be sloped to encourage rain water runoff.

Individual drums can be shielded by other waste drums or by concrete blocks within an ISO freight container. If larger numbers of drums require shielding, then individual ISO freight containers could be surrounded with an external shield wall of interlocking concrete blocks or stacked sand bags to limit the operator dose rate around the ISO freight containers and the dose rate from adjacent containers. Figure 8.5 illustrates possible shielding arrangements.

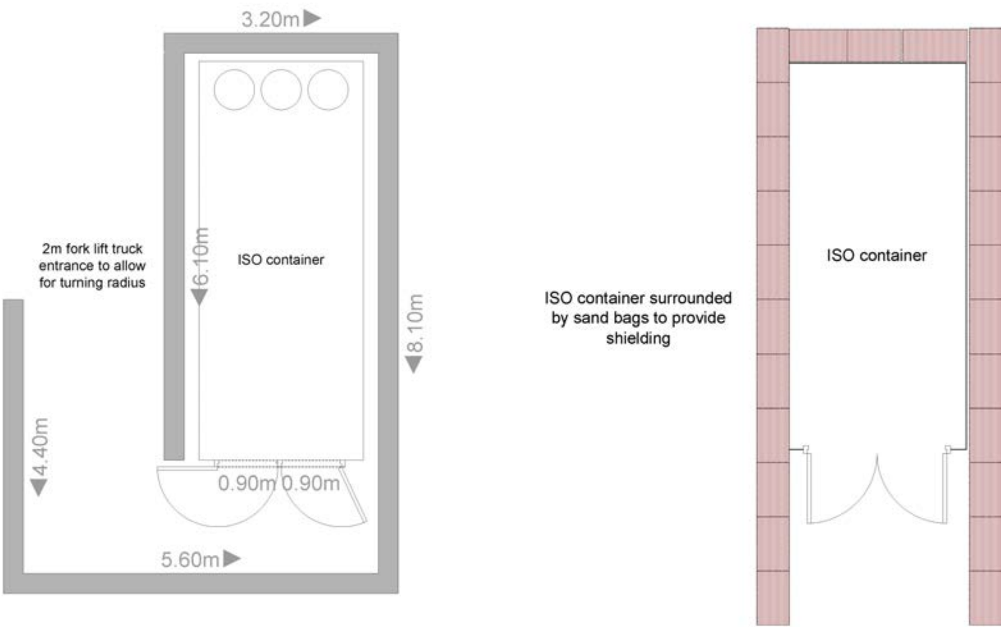


*FIG. 8.5. Shielding arrangements for ISO freight containers.*

### 8.2.5. Concrete pipe

A number of existing radwaste stores have used concrete pipes as a means of segregating and supporting drums in vertical stacks (Fig. 8.6). They are particularly suited to large stores where high vertical stacks reduce the floor area required for the store. They are suitable for high radiation waste packages.

However, this type of storage requires drums to be handled from above using slings or finger grabs from overhead cranes. This adds complexity and cost to drum handling and store design. Inspection and monitoring is difficult with such storage.

The waste packages also need to be uniform so that they are stable when stacked and are compatible with the specialized handling equipment.

Vertical concrete pipes offer no significant benefits for the storage of small volumes of waste and will not be considered further.

*FIG. 8.6. Concrete pipe storage.*

### 8.2.6. Concrete bunker or trench

In ground concrete bunkers or trenches have been used for storage of waste (Fig. 8.7). In some cases they have been used for the collection of unconditioned operational wastes, e.g. from power reactors, where waste is tipped into the bunker via small access ports. There are often difficulties later in the retrieval of this waste. They are particularly suited to high dose rate wastes as they do not require shielding to the walls. They are also suited to high activity disused sealed sources, again because of the shielding, but also because of the improved security.

Bunkers and trenches require careful site selection for suitability for excavation as well as consideration of water ingress and drainage.

Loading the bunker or trench with drums from above requires more complex cranes and grabs. Loading drums using fork lift trucks via an access ramp requires careful design to ensure rain water/surface water cannot enter the store. Personnel entry and emergency exits can also pose problems and for this reason access for inspection of waste packages will be difficult.

It is worth noting that concrete trenches are used as the basis for final shallow land burial facility designs in several countries, including France and the United Kingdom. However, consideration of a storage facility that could eventually become the waste disposal facility is outside the scope of this report.

*FIG. 8.7. Concrete bunker or trench.*

### 8.2.7. Below ground tubes or vaults

A number of existing storage facilities have used below ground tubes or vaults as a means of segregating and supporting drums, usually in vertical stacks. They are particularly suited to high dose rate packages that are loaded into the tube or vault via a flask and gamma gate.

Although flasks and gamma gates would not be required for the waste packages considered here, as noted earlier, this type of storage would still require waste packages to be handled from above using slings or finger grabs from overhead cranes. This adds complexity and cost to waste package handling and store design. An example of below ground storage facility is shown in Fig. 8.8.

*FIG. 8.8. Below ground tubes or vaults.*

Typically, storage tubes have been used for smaller waste packages (typically up to 50 L) than are being considered for this interim storage facility. Small below ground vaults would be suitable for drums and particularly for high activity disused sealed sources because of the shielding, but also because of the improved security.

One or more small vaults could be provided within a storage building allowing the storage of general waste above ground, with the more secure and shielded storage of high activity waste below ground.

### 8.2.8. Caves, mines and tunnels

It is possible that existing caves, mines or tunnels could provide a suitable site for a storage facility. As with other storage options, many issues need to be considered, including location relative to transport routes, accessibility for movement of drums into the cave/tunnel/mine and personnel to inspect and monitor the waste packages, groundwater and flooding as well as more unique problems such as stability.

Although a suitable cave/tunnel/mine could offer an ideal storage facility, this would be a unique solution and it is unlikely to represent a realistic option for the vast majority of Member States. A cave/tunnel/mine is therefore not considered further.

### 8.2.9. Purpose built industrial building

Provision of a purpose built industrial building for dedicated storage of waste packages represents the most common storage solution and one that will be a realistic and practical option in the majority of Member States.

In its simplest form the building (Fig. 8.9) is simply a shell erected on a reinforced concrete slab, with vehicle access doors for a fork lift truck to bring waste packages into the building and personnel doors (a normal entry and possibly one or more emergency exits depending on the size of the building). The building will be illuminated by electric lighting. The slab floor is finished smooth and painted with an easily decontaminated floor paint.

*FIG. 8.9. Purpose built storage building.*

The building design can be tailored to the particular environmental conditions of the country (e.g. rain, snow loading, wind loading, heat, cold) to give a design life of 25 years or more. The building can be sized to hold the total volume of waste that is expected. Alternatively, a modular design that can be expanded in the future to provide additional storage volume can be provided.

In many cases it is expected that the fabric of the building will not need to provide shielding as this will be provided by the waste package construction itself. However, if there are some high dose rate waste packages, then a shielded area can be built within the storage building to house them.

The design of the building can become more sophisticated if required e.g. by the addition of a ventilation system with air conditioning for humidity and temperature control. Suitable material handling systems such as overhead cranes can be part of this sophistication.

Erection of a building will require careful site selection, with many considerations including planning permissions, ground conditions and consultation with the local population.

### 8.2.10. Existing building

It is possible that a building may already exist that can be adapted as a dedicated waste store. The features required for the building will be as described for a new building.

### 8.2.11. Outdoors on a hard standing (dry climates)

An example of outdoor storage is shown in Fig. 8.10. This type of storage is of limited applicability, only in dry climates where there is adequate security of the site. Outdoor storage would be a unique solution and it is unlikely to represent a realistic option for the vast majority of Member States. It is therefore not considered further.

*FIG. 8.10. Outdoor storage.*

## REFERENCES TO SECTION 8


[8.1] INTERNATIONAL ATOMIC ENERGY AGENCY, Reference Design for a Centralized Waste Processing and Storage Facility, IAEA-TECDOC-776, IAEA, Vienna (1994).

[8.2] INTERNATIONAL ATOMIC ENERGY AGENCY, Reference Design for a Centralized Spent Sealed Sources Facility, IAEA-TECDOC-806, IAEA, Vienna (1995).

[8.3] INTERNATIONAL ATOMIC ENERGY AGENCY, Handling, Conditioning and Storage of Spent Sealed Radioactive Sources, IAEA-TECDOC-1145, IAEA, Vienna (2000).

[8.4] INTERNATIONAL ATOMIC ENERGY AGENCY, Storage of Radioactive Wastes, IAEA-TECDOC-653, IAEA, Vienna (1992).

# 9. SELECTION OF APPROPRIATE STORAGE MODULES

Section 8 identified several possible storage options that may be suitable for the conditioned waste packages resulting from the processing of waste streams under consideration in this publication. A series of decision flow charts have been developed in order to provide guidance in determining possible storage solutions, including storage strategy considerations, storage facility type selection, ventilation, shielding and mechanical handling requirements, and implementation of a storage facility project.

The following discussion should be read in conjunction with the decision flow charts presented in Figs 9.1–9.6.

## 9.1. STORAGE STRATEGY CONSIDERATIONS

The product of the waste processing facility will be a conditioned and packaged waste suitable for storage. The first approach when considering how, and where, the conditioned and packaged waste may be stored is to consider the national strategy for radioactive waste storage, the relevant regulatory framework and the supporting standards and guidelines (Fig. 9.1). It is important to note that lack of a national strategy for radioactive waste storage or existing standards or guidelines should not prevent safe radioactive waste storage facilities from being developed. In the absence of these, advice must be sought from the appropriate national bodies, and the IAEA could also be approached for support.

Having considered the requirements of the national strategy and the constraints of the regulatory system the waste owner should then consider whether there are any existing waste management facilities which could be appropriate (for example, decay storage).

### 9.1.1. Are the wastes widely distributed nationally?

The waste owner should consider whether similar types of waste arisings are also being generated in other parts of the country. If this is not the case, then the storage location should be near to the waste packaging facility. If, however, the wastes are produced in significantly different areas of the country, then consideration should be given to a central storage facility, or limited number of local facilities, depending on the availability and adequacy of the national transport infrastructure.

## 9.2. STORAGE FACILITY TYPE SELECTION

The flow chart in Fig. 9.2 assists in selection of the type of storage facility that is suitable for the particular application.

### 9.2.1. Is the total waste inventory and classification known for storage in a new facility?

The waste inventory, its classification and the waste package volume for storage at the existing facility need to be assessed, after which the storage facility design requirements and specifications can be defined.

### 9.2.2. Are high activity radiation sources to be stored?

If there are high activity radiation sources to be stored, these would ideally be stored below ground in a storage bunker, tube or vault. The advantages of storing below ground are that shielding is provided by the ground and security is greatly improved.

If there is only a small volume of other waste, then it too could be stored below ground. However, if there is a larger volume of other waste to be stored, the decision chart should be referred to again for guidance.

It should be noted that the below ground vault(s) could be incorporated into the design of a storage building for other waste.

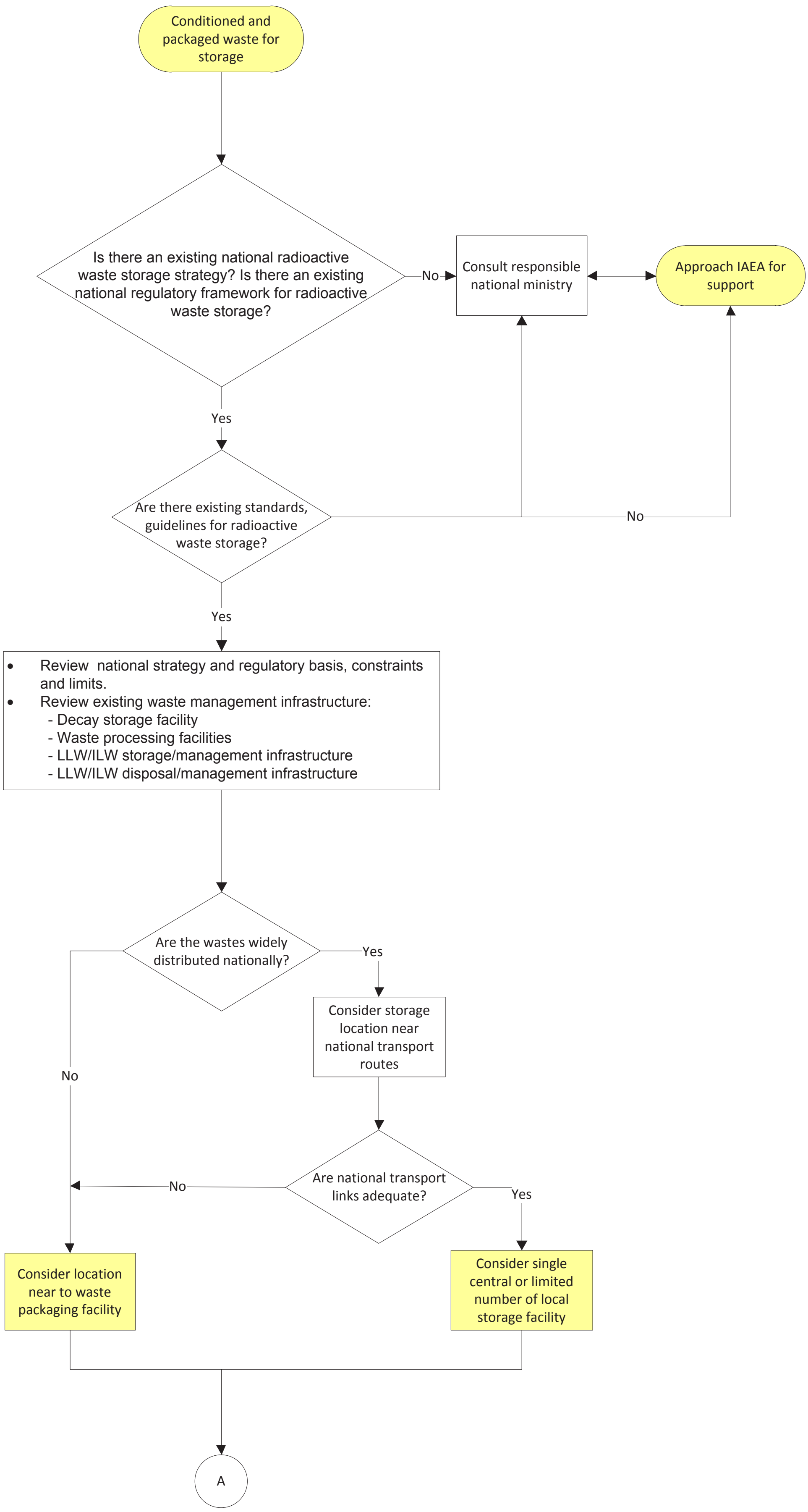


*FIG. 9.1. Storage strategy considerations.*

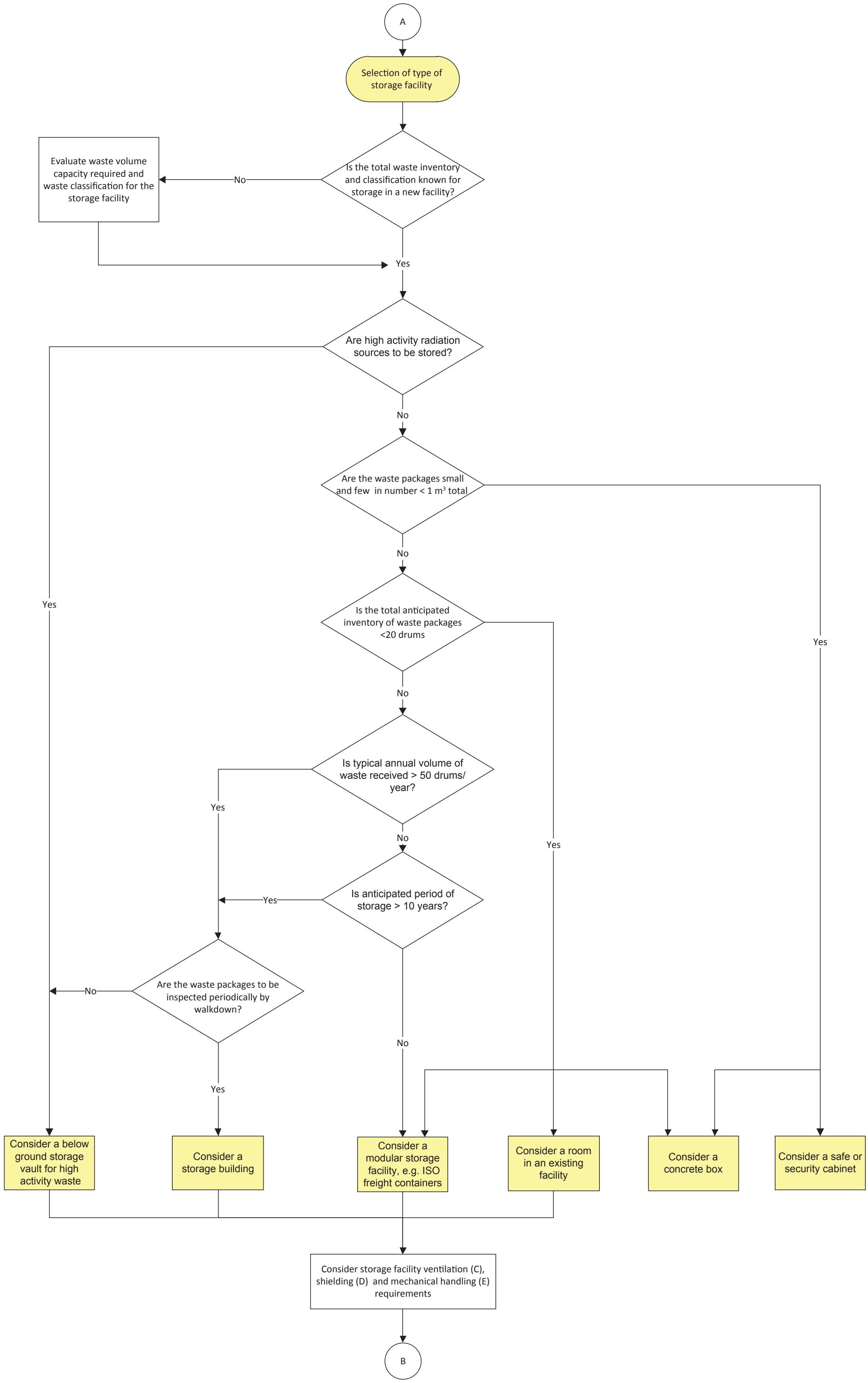


*FIG. 9.2. Storage facility type selection.*

### 9.2.3. Are the waste packages small and few in number?

If the waste packages are small and few in number, they could be stored conveniently and economically in a commercially available security cabinet or cupboard or a concrete container. However, for the WPSF it is expected that packages will be 200 L drums. These are too large to be stored in cabinets.

### 9.2.4. Is the total anticipated inventory of waste packages less than 20 drums?

If there is a relatively small number of drums to be stored it may be possible to use a room in an existing facility or an ISO freight container or a concrete container(s) for the purpose of waste storage. However, if the waste volumes and numbers of drums expected are larger, then this is unlikely to be a practical solution.

### 9.2.5. Is the typical annual volume of waste received more than 50 drums per year?

As noted in Table 7.1, it is unlikely that the number of waste drums for storage will exceed 50 drums per year (unless large volumes of aqueous waste are directly solidified because a disposal route after treatment is not available). With smaller numbers of drums (i.e. less than 50 drums per year) modular storage within, for example, freight containers is a practical solution. Above that figure, the number of freight containers that will be required could become excessive and it may be more practical to design a purpose built storage facility.

### 9.2.6. Is the anticipated period of storage more than 10 years?

A prolonged period of interim storage prior to disposal is not recommended. Freight containers that might be used for a modular storage facility can suffer from corrosion and, over a prolonged period, corrosion could affect the integrity of the waste package. The design life of storage container in temperate conditions is estimated as ten years. In a wet, damp or high humidity environment it could be significantly less.

If periods of storage are expected to exceed ten years, then a storage facility with a greater design life is required, implying the provision of a permanent building or storage bunker rather than using a simple modular design based upon freight containers.

### 9.2.7. Are the waste packages to be inspected periodically by walkdown?

It is required that drums are periodically inspected during storage to monitor the physical condition of the packages and allow early remediation of any problems. Radiological monitoring of the storage facility itself should also take place periodically:

(a) To ensure that radiation levels are acceptable (and to identify packages that may need to be relocated or placed behind shielding if levels are not acceptable).
(b) To monitor airborne and surface contamination levels so that appropriate and timely action can be taken to minimize the spread of contamination and the dose to operators.

For these reasons, it is required that drums are stored so that:

(i) They are relatively easy to access and visually inspect;
(ii) It is not necessary to move a great many drums in order to access any one particular drum.

Operator access is a key consideration and this favours an above ground storage facility (either a dedicated building or room or ISO freight containers) that allows walkdown inspection rather than a below ground storage trench or bunker.

However, if it is determined that the drums do not require frequent periodic inspection by walkdown, then a below ground bunker can be used. In this case, special arrangements will be required to conduct an inspection as and when deemed necessary.

Having determined the type of storage facility required, it is necessary to determine other key facility design requirements. Some design requirements, i.e. ventilation, shielding and mechanical handling, are presented in further decision flow charts and discussed in Sections 9.3–9.5.

## 9.3. VENTILATION REQUIREMENTS

The flow chart in Fig. 9.3 assists in determining whether ventilation will be required within the storage facility.

### 9.3.1. Do local environmental conditions involve extended periods of high relative humidity?

Painted mild steel 200 L drums that are in good condition at the start of the period of storage can be reasonably expected to have a storage life of ten years, provided the drums are stored in a suitable environment, i.e. kept dry. Periodic inspection of the drums will be necessary and, possibly, remediation e.g. repainting, or over packing during the storage period.

If environmental conditions are likely to lead to corrosion of mild steel drums, two options are possible:

(a) Use stainless steel drums;
(b) Control the storage conditions to prolong the waste package life, i.e. humidity control.

### 9.3.2. Can waste be packaged within stainless steel drums?

The use of good quality stainless steel drums should ensure waste drum integrity in difficult environmental conditions and for prolonged drum storage. Stainless steel drums are significantly more expensive than standard open lid mild steel drums, although they can still be a cost effective solution compared to the alternative of controlling the storage conditions within the storage facility.

If stainless steel drums are not available or are judged to be too costly an option, then an alternative approach will be needed for long periods of storage in humid conditions and where condensation is likely. In this case, humidity control will be required using a dehumidifier (in a small storage area) or a mechanical ventilation system. Typically, the ventilation shall maintain the humidity to less than 80% relative humidity (RH).

### 9.3.3. Are volatile nuclides or hazardous gases likely to be released?

Ventilation of the storage facility may be required to assist containment and contamination control, and hence protection of operators and public.

Waste packages may gradually release gaseous contaminants such as $^{222}Rn$, $^{3}H$, $^{14}C$ and $^{131}I$. For radium sources, the requirement will be for them to be sealed into gas-tight containers before overpacking into specially shielded containers. Therefore, radon release will not be an issue.

However, other unsealed materials that are encapsulated within cement could release gaseous contaminants over time. Ventilation will ensure that these species do not build up to a level that is hazardous to the operators.

A suitably designed ventilation system is also called for if there is possibility of accumulation of flammable and/or explosive gases.

If there is no significant release of contaminants or hazardous gases the storage facility needs only to provide a weatherproof closure with sufficient natural ventilation to prevent stagnant air.

### 9.3.4. Is ventilation required to reduce the exposure?

An assessment will need to be made of the rate of release of contaminants and the hazard of external exposure as well as internal contamination to the operators.

### 9.3.5. Can the necessary ventilation be achieved by natural means?

Depending on the rate of release of these contaminants, ventilation may be required to dilute the contaminants to an acceptable level to reduce the exposure to the operators.

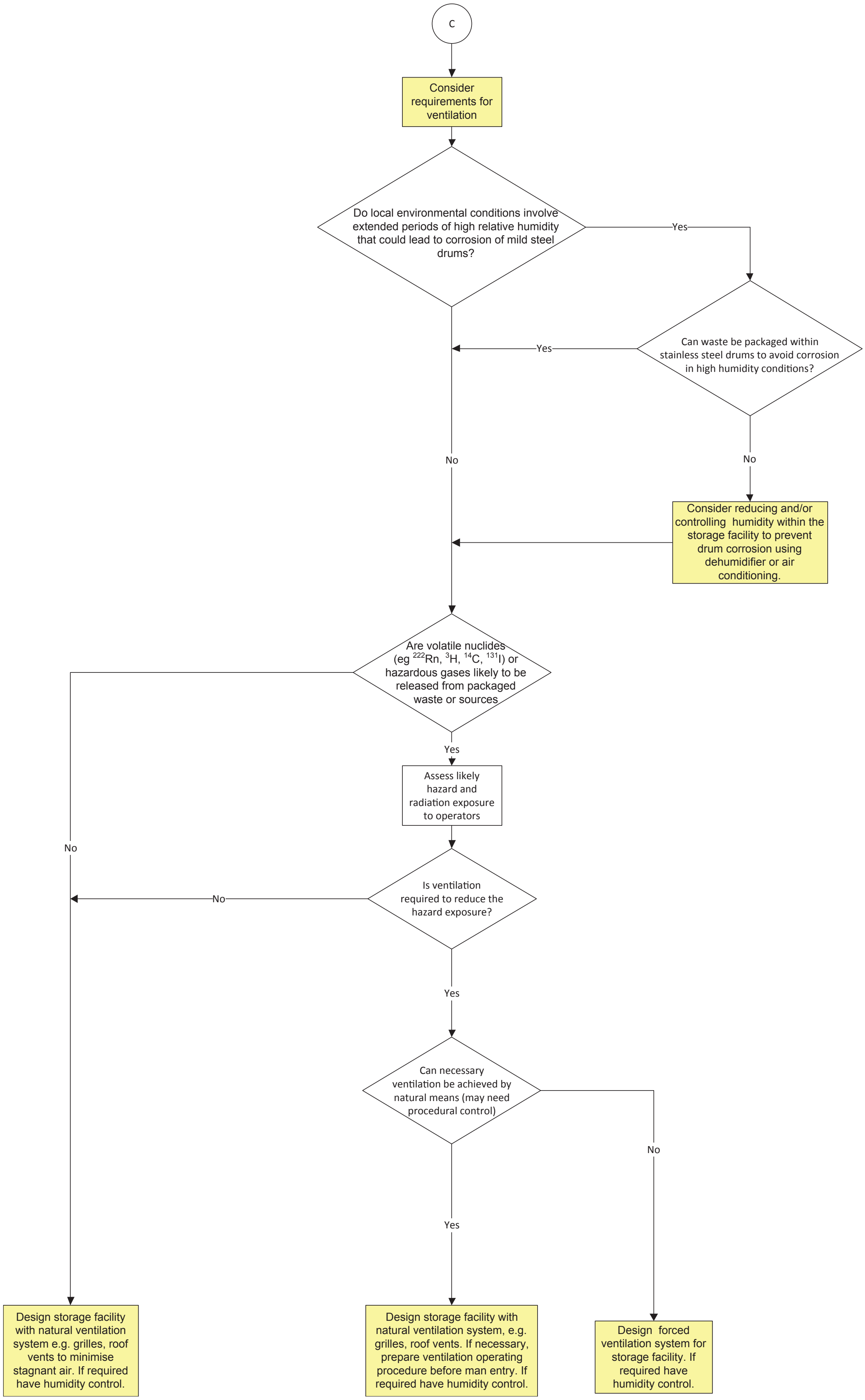


*FIG. 9.3. Ventilation requirements.*

Natural ventilation will in most cases be more than adequate to dilute and disperse contaminants. It may be necessary to have an operating procedure to ensure that the storage facility is opened up to promote ventilation and the air monitored by a health physicist before entering the facility.

In the unlikely event that natural ventilation alone is not adequate, then a forced mechanical ventilation system will be required to control levels of contaminants.

## 9.4. SHIELDING REQUIREMENTS

The storage facility should be designed to provide adequate shielding for protecting the operator and the public from radiation. The flow chart in Fig. 9.4 assesses the need for shielding within the storage facility for protecting the operator. Aspects dealing with shielding design with respect to permitted dose rates at exterior surface of the facility are discussed later in sections dealing with individual storage facility types.

### 9.4.1. Are individual waste package surface dose rates acceptable for contact handling?

As noted earlier, it is expected that individual drums will be adequately self-shielded, or incorporate their own shielding (e.g. the LTSS) to allow contact handling rather than remote handling. Further, the size and weight of packages will require mechanical means (e.g. fork lift trucks) for transferring and positioning drums within the storage facility. This will help in distancing the operator from the drum being moved. Assuming that each waste drum meets the normal transport of radioactive material limits of <2 mSv/h at contact and <0.1 mSv/h at 1 m, the drum can be transported using mechanical handling methods.

However, if individual package dose rates are greater than this consideration will need to be given to over packing the drum into another container that incorporates additional shielding.

### 9.4.2. Are dose rates from operating the storage facility containing a collection of stored waste packages within regulatory requirements?

When drums are collected together within the storage facility in an array the combined dose rate from the drums will be greater than that from individual drums.

It will be necessary to assess the dose budget (an assessment of the duration and dose rate for each and every operation within the storage facility) from all storage facility operations to ensure that operator dose rates are within regulatory limits and, even if they are within regulatory limits, that they are also optimized (see below).

Although the dose rate from individual drums may be acceptable, the accumulated dose rate from a collection of packages may require additional shielding. This can be achieved in a number of ways:

(a) If only a few drums require shielding, it may be possible to shield them behind similar, but lower, dose rate packages.
(b) If temporary shielding is required, e.g. for a short storage duration before drums are dispatched, concrete shielding blocks, positioned using a fork lift truck, can be assembled around single drums or a group of drums.
(c) If a significant number of higher dose rates packages are expected routinely, then a permanent shielded storage area within the storage facility (or a separate dedicated shielded storage facility) can be built using concrete or concrete blocks. A labyrinth entrance should be provided to prevent radiation shine; this avoids the need for complex and costly shield doors.

### 9.4.3. Are dose rates from operating the storage facility containing a collection of stored waste packages optimized?

As noted above, even if operator doses are within regulatory limits it is also essential to ensure that they are optimized. Options will need to be considered for reducing operator dose rates further by the usual methods of increasing shielding (such as those noted in Section 9.4.2), increasing distance or reducing time of exposure.

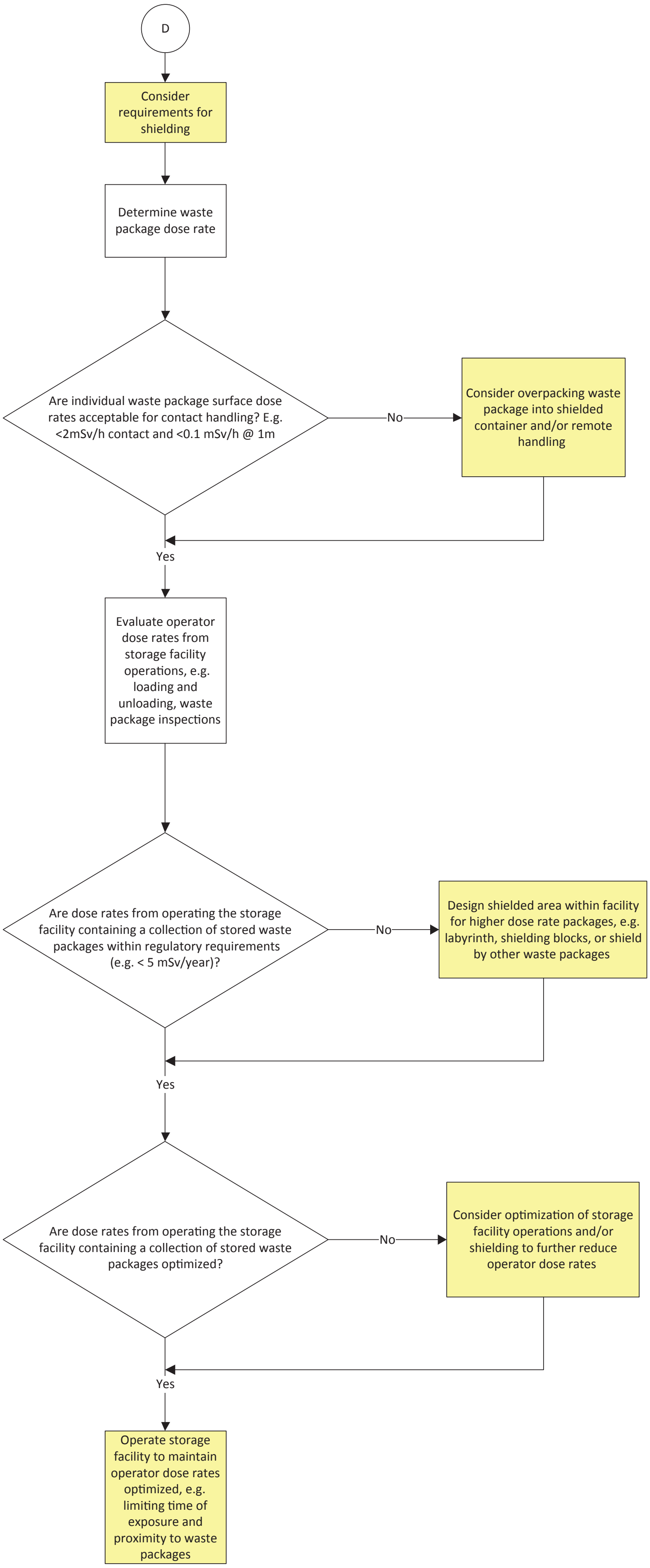


*FIG. 9.4. Shielding requirements.*

## 9.5. MECHANICAL HANDLING REQUIREMENTS

The flow chart in Fig. 9.5 assesses the requirements for waste handling within the storage facility.

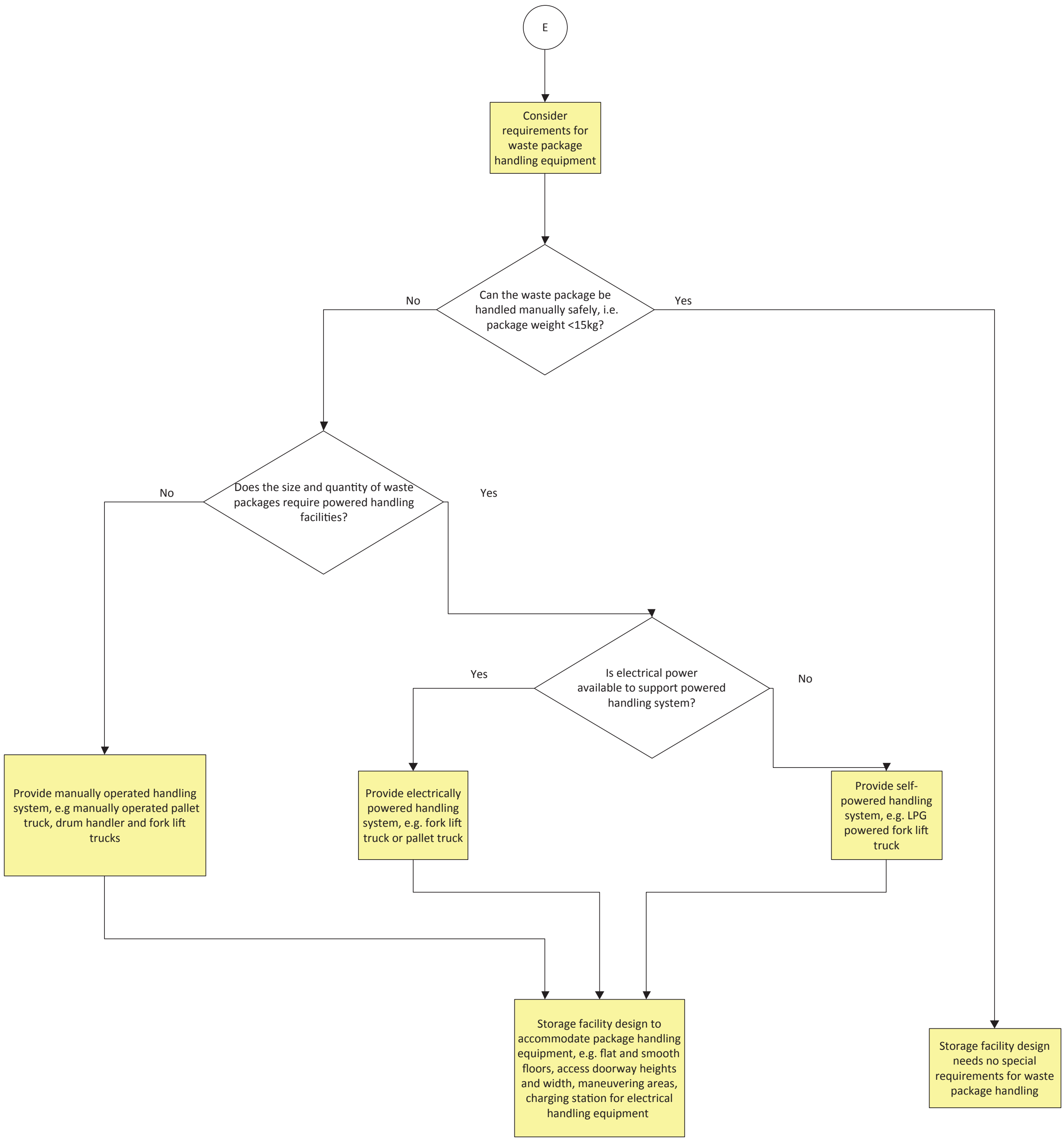


*FIG. 9.5. Mechanical handling requirements.*

### 9.5.1. Can the waste package be safely handled manually?

All drums are expected to be too large for manhandling and therefore handling and lifting equipment will be required.

#### 9.5.2. Does the size and quantity of waste packages require powered handling facilities?

Given the relatively small numbers of drums that are expected (30–40 drums per year, see Section 7) manual fork lift trucks and pallet trucks will be adequate for moving drums into and around the storage facility assuming a good, flat floor slab.

The operation of the handling equipment must be taken into account in the design and layout of the storage facility, including:

(a) The obvious size of access doorways;
(b) The spacing of drums and positioning of adjacent rows of drums;
(c) The segregation of personnel and vehicular access;
(d) Provision of reasonably flat, smooth and load bearing surfaces.

If it is necessary to transport the drums across rougher ground, then a powered fork lift will be necessary. Specialized handling equipment should be avoided in preference for readily available equipment such as fork lifts with drum grabs and pallet trucks.

#### 9.5.3. Is electrical power available to support powered handling equipment?

Ideally, electrically operated equipment should be used as this avoids the fumes associated with internal combustion engines. A charging station should be provided away from the main storage area. This type of commercially available equipment requires access to the drums from the side for picking up and placement. This is compatible with most but not all of the storage concepts identified in Section 9.

If electrical power is not available, self-powered fork lift trucks, e.g. LPG fuelled, can be used. However, consideration will then need to be given to the fire risk and ventilation of fumes within the storage facility.

However, some of the storage concepts in Section 8 require drums to be handled from above using slings or finger grabs from overhead cranes. This can add complexity and cost to drum handling and storage facility design, for example:

(a) Drums may need special lifting features; therefore, drums have to be designed especially for the storage facility.
(b) The storage facility may need special features, e.g. crane rails to accommodate an overhead crane.
(c) Drums will tend to be lifted over greater heights and therefore the consequences of a dropped load can be more significant.

Complex crane installations should be avoided. A simple mobile ‘A’ frame or a fork lift truck fitted with a jib crane attachment should be adequate, for example, for placing waste drums/packages into an in-ground storage vault or bunker from above. This equipment will also be suitable for lifting off the shielded top cover to the in-ground storage facility.

### 9.6. IMPLEMENTATION OF STORAGE FACILITY PROJECT

The flow chart in Fig. 9.6 assesses the requirements for implementation of the storage facility project.

#### 9.6.1. New or existing storage facility

Having identified the storage facility design requirements, including size/capacity now and for the future, and key design requirements, including shielding, mechanical handling and possible ventilation, a decision can be taken on whether it is feasible to adapt an existing facility for waste storage or to site and construct a new storage facility.

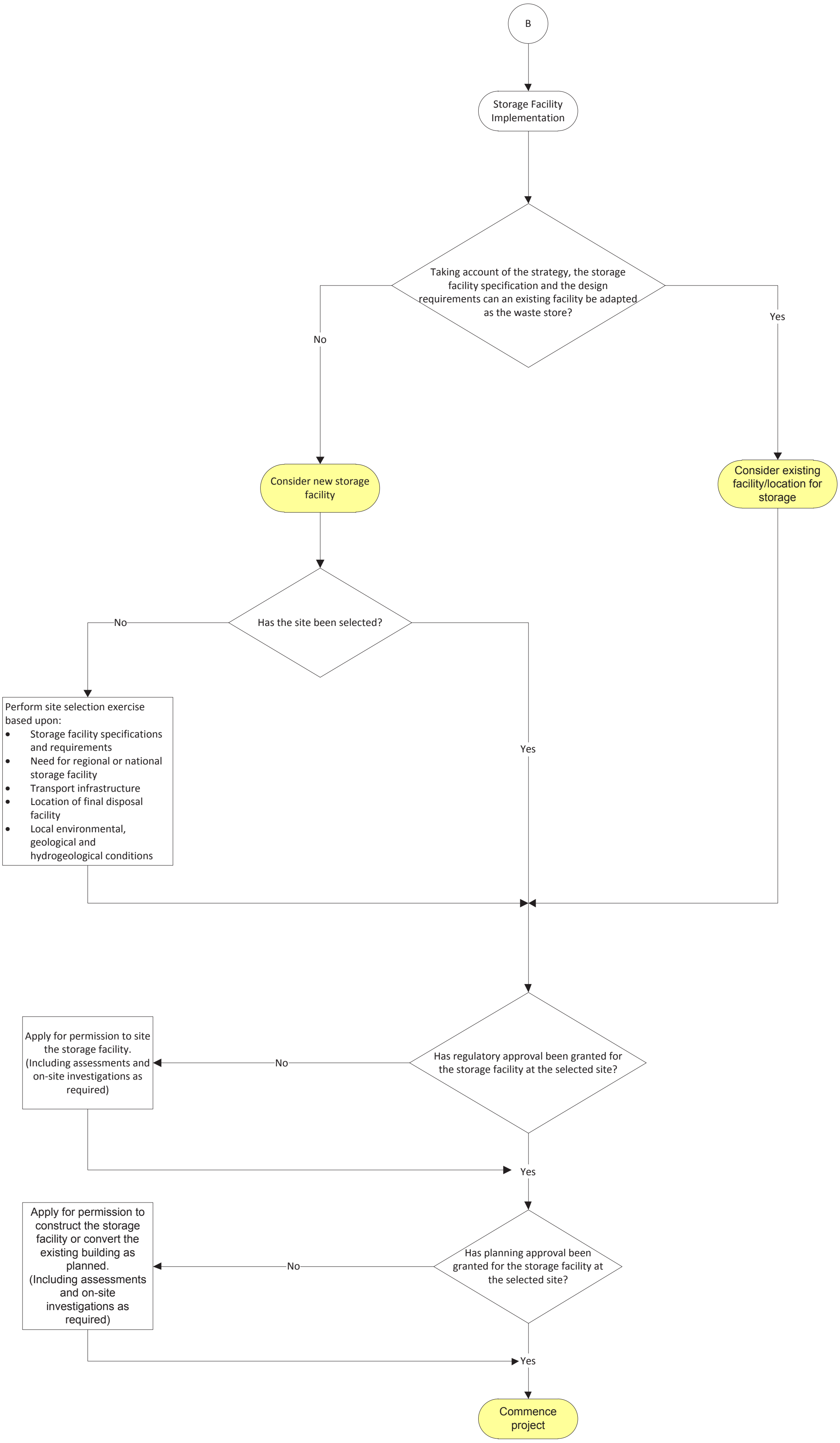


*FIG. 9.6. Implementation of storage facility project.*

#### 9.6.2. Has the site been selected?

The location of the storage facility will depend on a number of factors, for example:

(a) The location of the waste.
(b) The distribution of the waste (e.g. are there many waste producers around the country, or is there just one or two in one major city?).
(c) The availability of suitably qualified and experienced personnel (as noted above).
(d) The security of the site (as noted above).
(e) The accessibility of the site for bringing waste packages to the storage facility and dispatching waste packages to a disposal facility.
(f) Public occupancy factor and traffic in the area outside the facility (both should be low).
(g) The availability of an existing building that could accommodate the storage function.

Local environmental conditions will also impact on the design features of the storage facility e.g.:

(i) Wind loading;
(ii) Snow loading;
(iii) High daytime temperatures;
(iv) Possibility of flooding;
(v) Geological and hydrogeological conditions.

Similarly, the availability of local construction materials will also impact on the design features of the store. For example, it is recognized that the materials for the construction of building with steel portal frames and external cladding (a common industrial and commercial construction technique in many countries) may not be available in some countries.

The issue of site selection is not within the scope of this document. The reader is referred to an Agency publication (and other publications cited therein) for guidance on siting criteria [9.1].

#### 9.6.3. Has regulatory approval been granted for the storage facility at the selected site?

Regulatory approval will be required for permission to site a storage facility for radioactive waste. Assessments and on-site investigations will need to be undertaken to demonstrate the security and safety of the storage facility with respect to the protection of human health and the environment and compliance with regulations in force.

#### 9.6.4. Has planning permission been granted for the storage facility at the selected site?

Planning permission will be required to construct the storage facility or convert the existing building as planned. Again, assessments and on-site investigations will need to be undertaken to support the application for planning permission.

## REFERENCE TO SECTION 9

[9.1] INTERNATIONAL ATOMIC ENERGY AGENCY, Storage of Radioactive Waste, IAEA Safety Standards Series No. WS-G-6.1, IAEA, Vienna (2006).

# 10. DESIGN AND SPECIFICATION INFORMATION FOR STORAGE MODULES

Having selected the appropriate storage module, it is necessary to arrange for procurement or construction of the selected module (e.g. storage cabinet, ISO freight container, new purpose built building, etc.). This section provides design and specification information to assist the user in procurement/construction of appropriate storage modules.

Amongst the storage module options listed in Section 8, the largest and most complex module is the new purpose built storage building. As an example, detailed information is presented here on new purpose built storage building. The information is provided in descriptions that are presented in such a way that they can be adapted into procurement specifications. The aim of these descriptions is to enable the user to determine their requirements, specify those requirements to allow the procurement of the appropriate storage modules and to eventually operate those storage modules.

The example below should serve as guidance on the range of topics that will need to be considered and specified in developing procurement specification for the other storage modules.

## 10.1. NEW PURPOSE BUILT STORAGE BUILDING

### 10.1.1. Overall functional requirement

The key function of the storage building is to provide safe, retrievable, monitorable and secure storage of conditioned radioactive waste packages pending disposal to a suitable disposal facility.

Safety includes the safety of operators who will need to access the storage facility for operational duties and the public. Safety also includes providing an environment such that the waste packages do not degrade during the period of storage so that they are safe to retrieve and transfer to the final disposal facility.

### 10.1.2. Scope

The storage building will comprise the following:

(a) Main building;
(b) Waste package handling systems;
(c) Auxiliary systems.

The main building comprises:

— The foundations and main building slab;
— The walls and roof of the building;
— Access doors;
— Shielding structures;
— Surface finishes.

Waste package handling systems comprise:

— Mechanical handling equipment for offloading from transport vehicles, transferring the waste packages to the storage building and stacking (if required) of the waste packages;
— Waste package monitoring equipment for both radiation and contamination;
— Waste package, equipment and area decontamination equipment.

Auxiliary systems comprise:

— Radiological monitoring system;
— Electrical equipment power supply, electrical lighting, earthing and lightning protection;
— Communication and alarm;
— Fire detection and alarm system;
— Fire fighting/protection system;

— Ventilation system;
— Physical protection/security.

### 10.1.3. Location of the storage building

The proposed location of the storage building should be described here. Reference drawings should be included.

### 10.1.4. Waste description

The types of waste packages, their size, weight and radiological characteristics and quantities per year have been discussed in Section 7. Typically, the majority of packages originating from the waste processing facility/modules will be in the form of 200 L drums, containing either conditioned general solid and liquid wastes or disused sealed sources in their shielded transport and storage containers for over packing. Occasionally, some long term storage shield containers containing high activity sources arising from the hot cell module are expected.

### 10.1.5. Period of storage

Ideally, the storage period of waste packages awaiting disposal should be kept to a minimum. However, in the absence of a disposal facility in a Member State now or for the foreseeable future, it is recognized that prolonged interim storage (>10 years) may be unavoidable.

The absence of a disposal facility is likely to be even more of an issue for long lived radionuclides. Therefore a storage period of several decades should be assumed for long lived radionuclides.

### 10.1.6. Operational requirements (normal and abnormal conditions)

The key operational requirements are:

(a) Receipt of vehicles carrying waste drums/packages;
(b) Radiation and contamination monitoring of the transport vehicle and the waste drums/packages on receipt;
(c) Quarantining and subsequent decontamination of the transport vehicle and the waste drums/packages if contamination is discovered;
(d) Off-loading of the waste drums/packages from the transport vehicle;
(e) Transfer of the waste drums/packages into the storage building;
(f) Acceptance and placing of the waste drums/packages into their storage location within the storage building;
(g) Storage of the waste drums/packages for the total storage time;
(h) Maintenance of storage records;
(i) Periodic inspection and radiological monitoring of the storage building and of the waste drums/packages;
(j) Quarantining of waste drums/packages within the storage building if contamination is discovered;
(k) Wrapping/bagging of the quarantined waste drums/packages and transfer to a suitable area for decontamination if contamination is discovered;
(l) Maintenance of the storage building and all associated equipment;
(m) Ensuring physical protection of the storage building;
(n) Operator radiation safety, e.g. possible monitoring of operating and maintenance staff on exit from the storage building.

The design intent is that the storage building should be available to perform these operational requirements for 250 days of operation per year (although not all of the operations will actually need to be carried out for 250 days per year).

During the storage period it is required that drums are periodically inspected by walkdown during storage to monitor the physical condition of the packages and allow early remediation of any problems. Radiological monitoring of the storage facility itself should also take place periodically:

(1) To ensure that radiation levels are acceptable (and to identify that drums/packages may need to be relocated or placed behind shielding if levels are not acceptable);
(2) To monitor airborne and surface contamination levels so that appropriate and timely action can be taken to minimize the spread of contamination and dose to operators.

For these reasons, it is required that drums are stored so that:

(1) They are relatively easy to access and visually inspect;
(2) It is not necessary to move a great many drums in order to access any one particular drum.

Dry decontamination methods should be used for the decontamination of vehicles, drums/packages, equipment and working areas.

The storage facility should be managed and operated by suitably qualified and experienced personnel. Typically, the storage facility will require:

(1) Operations manager: An experienced radiochemist or a radiophysicist trained to university degree level with experience in radioactive waste management;
(2) Radiation protection supervisor: A person experienced in radiological protection procedures and regulations;
(3) Supervisor: Someone who has practical experience with the handling of radioactive materials and quality control to supervise day to day operations;
(4) Skilled operators: Persons with experience in mechanical handling operations.

#### 10.1.7. Information and records

Information on the waste and the various stages of the conditioning process should be collected and stored. The location of the drums in the interim storage facility should be recorded. Before detailed planning is possible it is necessary to have all relevant facts about the waste such as:

(a) Waste package unique identification number.
(b) Position of waste package in storage facility.
(c) Description of waste package contents:
    (i) Physical characteristics;
    (ii) Chemical characteristics;
    (iii) Biological characteristics;
    (iv) Radioactivity content.
(d) Originator of waste (i.e. the user that generated the waste), name and address.
(e) Results and date of the last waste package inspection.
(f) Measured dose rate (usually at 1 m distance and on contact).

The information on the waste package should be obtained from the operator of the waste processing facility that packaged the waste.

#### 10.1.8. Building functional requirements

All building and civil structures should be designed in accordance with recognized standards, and the building regulations that should be identified in the contractor's basis of design document. The design submission should include calculations, specifications and quality control plans for all aspects of the structural and civil works, for review by the client.

The building should be a simple structure and should have a design life of 50 years. The contractor should undertake any site surveys and should not rely on information provided by the client.

*10.1.8.1. Overall construction*

The storage building should be constructed of non-combustible materials. The method of construction of a storage facility within a Member State depends on a number of factors, including custom and practice to suit the environment, availability of construction expertise and availability of materials. Options could include:

(a) In situ reinforced concrete framed building with walls and flat roof also made of concrete (Fig. 10.1). This would suit a warm, arid climate.
(b) In situ reinforced concrete framed building with concrete walls and pitched roof to improve water runoff (Fig. 10.2). This would suit a warm, humid climate.
(c) Steel framed, metal clad and thermally insulated building with pitched roof (Fig. 10.3). This would suit a cold climate.

*10.1.8.2. Ground conditions*

The particular ground conditions in any specific location may result in the need for more complex foundations. The local construction industry in the Member State should be able to advise on foundation design. Flooded areas should generally be avoided. However, if the facility were to be built in an area susceptible to flash floods, local building tradition may dictate that the floor should be raised above ground level on pillars or piers.

*FIG. 10.1. In situ reinforced concrete frame building with flat roof.*

*FIG. 10.2. In situ reinforced concrete frame building with pitched roof.*

*FIG. 10.3. Steel framed metal clad thermally insulated building with pitched roof.*

*10.1.8.3. Building the base slab/floor*

(a) A basic design for the foundation would be a simple, reinforced concrete raft, which will also constitute the working floor of the storage facility.
(b) Resistance to water penetration from the ground should be provided by a polyethylene damp proof membrane to the underside of the slab.
(c) The storage building should be equipped with an internal floor drain system to direct any internal liquid traces generated to an appropriate sump pit. The floor should be appropriately sloped to facilitate movement of the liquid toward the floor drains. There should be provision for inspection of the sump and sampling of accumulated liquid.
(d) The interior construction of the building should be done in such a way that the risk of any liquids leaking out of the building is minimized.
(e) If required, the floor slab should include one or more below ground storage bunkers or the placement of high activity waste drums/packages. The bunkers should be accessed via removable, interlocking shielded panels.
(f) Particular attention should be paid to the waterproofing of the below ground bunkers to prevent ingress from groundwater.

*10.1.8.4. Building structure*

(a) The building structure and associated civil infrastructure should be designed for external environmental events. For example, these could be for external environmental events with a return frequency of 1 in 50 years using data for the local area.
(b) The foundations, columns, walls and roof should be designed to support all superimposed structural loads as well as all applicable dead loads.
(c) The structure should be designed to withstand all applicable live loads, for example, earthquake, wind and snow.
(d) The floor slab should be able to support the concentrated point loads of the waste containers, any impact loads resulting from accidental dropping of waste containers as well as live loads of vehicles used to load the waste.
(e) If concrete is used for the wall construction, then the slab would be thickened locally all around the building perimeter to support the walls and locally around all internal stanchions.
(f) Rainwater should be prevented from entering any radiologically designated secondary containment areas of the storage building.

*10.1.8.5. Finishes*

(a) The floor slab will be a steel floated finish with an epoxy paint coating to provide a hard wearing and decontaminable surface.
(b) The contractor should propose surface finishes for all plant areas that take account of the potential hazard and the requirement for containment and decontamination.
(c) The contractor should be responsible for the finish painting of all structures, piping and equipment as necessary to prevent corrosion. The painting systems should be consistent with the required design life of the plant and should be in accordance with the manufacturers' recommendations.
(d) Where ducts, pipes or cables pass through walls, floors and fire rated partitions, the contractor should provide a suitable means to accommodate expansion and or compliance with the appropriate fire resistance, and to provide a neat finish. All penetrations through fire rated partitions should be sealed to the same standard as the partition that it breaks and documentation provided to demonstrate this. A proprietary waterproofing should be applied at the entry point to a building. The contractor should ensure, and show, that any pipe entries through the building fabric will not threaten the structural or fire integrity of the building.

*10.1.8.6. Shielding*

The storage building structure should provide radiation shielding to limit exposures outside the building.

Individual drums can be shielded by other waste drums or by concrete blocks. If larger numbers of drums require shielding, then a shielded area within a dedicated storage building with a labyrinth entrance can be provided (Fig. 10.4).

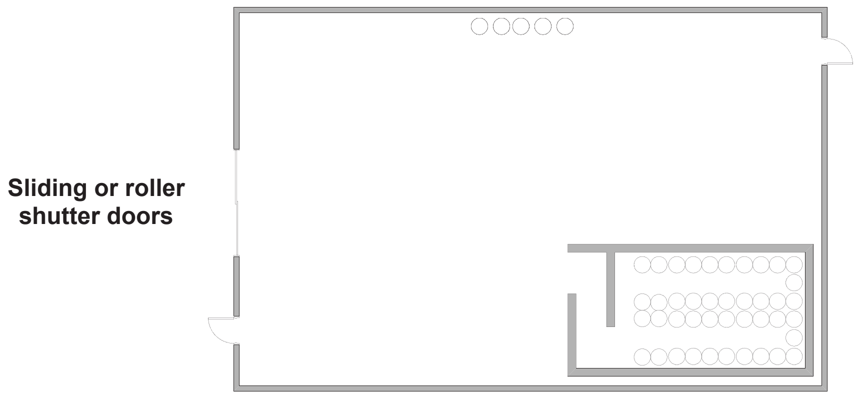


*FIG. 10.4. Labyrinth area with additional shielding for drums within storage building.*

The entire building could be provided with external shield walls and then divided internally into several shielded compartments, each with a labyrinth entrance (Fig. 10.5). Shield walls will be of concrete block or reinforced concrete construction. As a typical example, for radiation from a source or waste package containing $^{137}Cs$, a concrete thickness of 17 cm will reduce the dose rate to one tenth of its original value. Doubling the concrete thickness to 34 cm will reduce the dose rate to one hundredth of its original value.

Alternatively, high activity drums/packages can be stored in below ground bunkers within the storage building (Fig. 10.6). The bunkers will have removable interlocking shielded covers to reduce radiation levels above the bunkers. Waste drums/ packages will be placed into the bunkers using, for example, an overhead mobile crane or a fork lift truck with jib attachment (see mechanical handling section below).

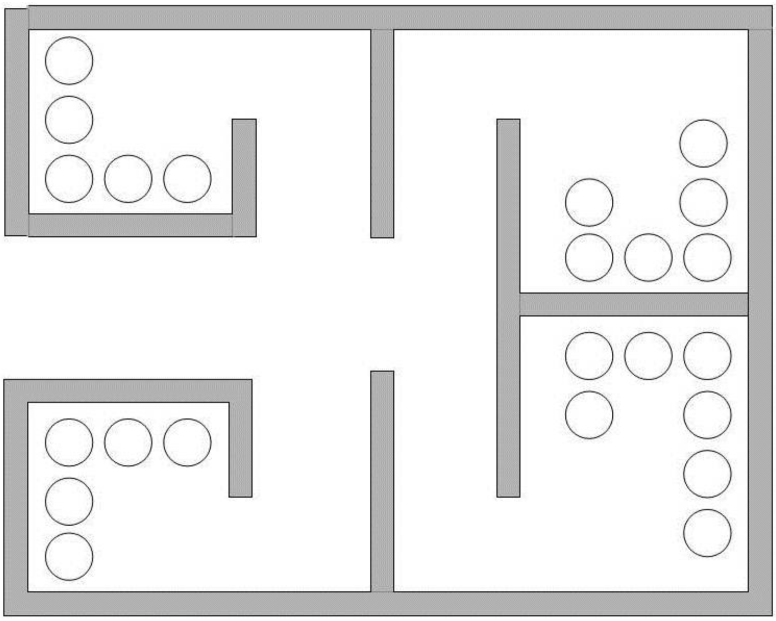

*FIG. 10.5. Storage building divided into four shielded labyrinths.*

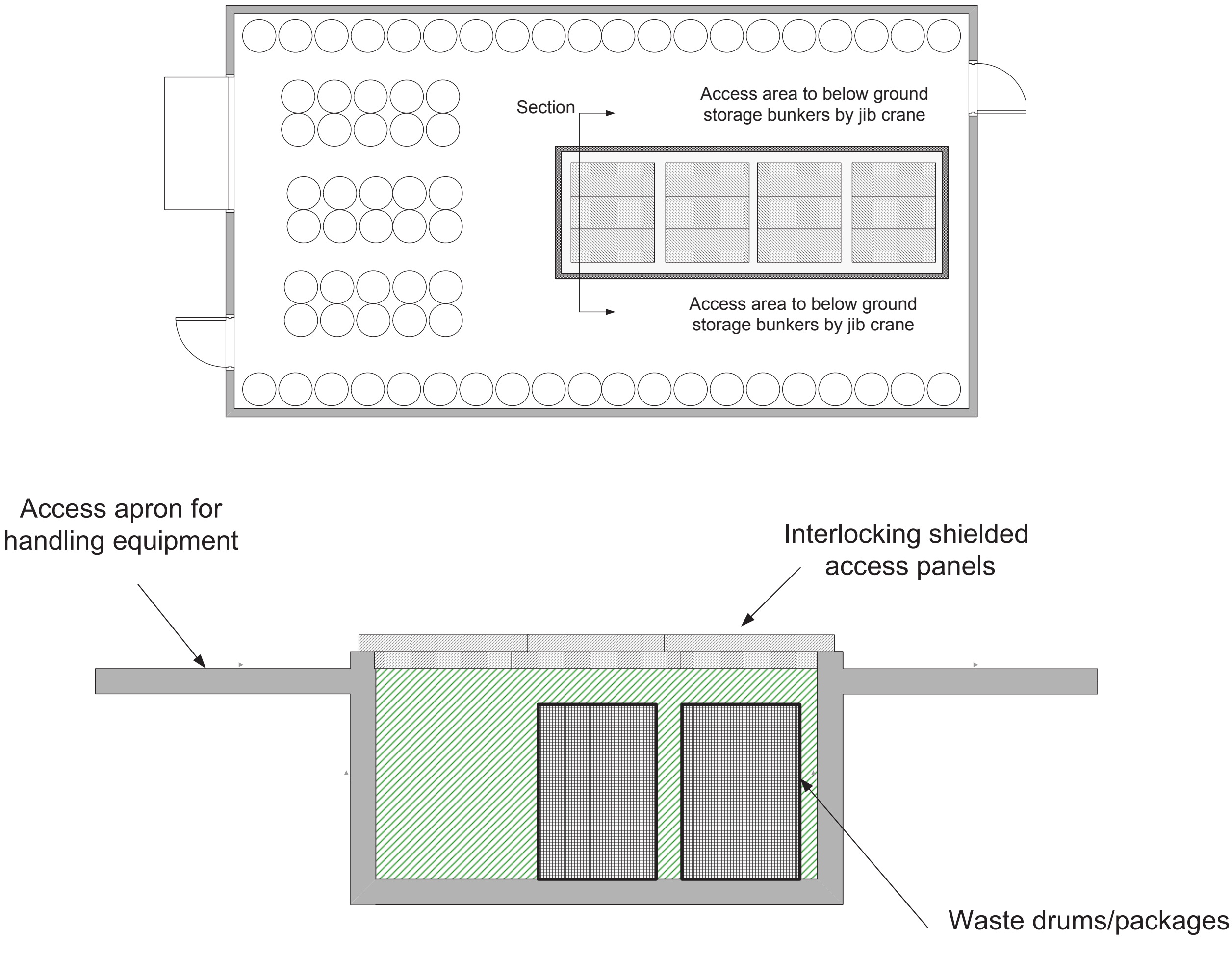


*FIG. 10.6. Below ground bunker within storage building.*

The design concept should allow for the installation and use of local temporary shielding by maintenance staff. Temporary shielding has to take into account the floor slab load limits if applied on top of the waste packages.

*10.1.8.7. Access*

(a) The building will normally have a vehicle access door (typically, a roller shutter or sliding doors) for access by fork lift truck carrying a waste drum. A separate personnel door should also be provided to segregate personnel from vehicle movements. One or more emergency personnel exits may be required. In the interest of security, these emergency exit doors would only be able to be opened from the inside.
(b) Grades of all surfaces should be minimized so as not to restrict vehicular or personnel access to and from the storage building.
(c) The contractor should provide adequate roads and footpaths for safe access to the plant by personnel, service vehicles and waste handling and transport vehicles.
(d) No windows should be provided as these could represent both a shielding and a security weakness.
(e) There will be no penetrations in the roof. In order to reduce occupational exposures the roof should be designed for minimum inspection and maintenance over the lifetime of the facility.
(f) There shall be provision of space and power supply at the main entrance to the building for personnel radiation monitoring equipment.

*10.1.8.8. Modular construction*

Consideration should be given to whether the complete storage facility needs to be constructed from the start, or whether a modular building design, capable of expansion in the future to provide additional waste storage may be more cost effective or at least help to defer capital expenditure.

With a simple building module design (Fig. 10.7), second and subsequent modules can be added, thus increasing the length of the building without disturbing the use of the existing storage area.

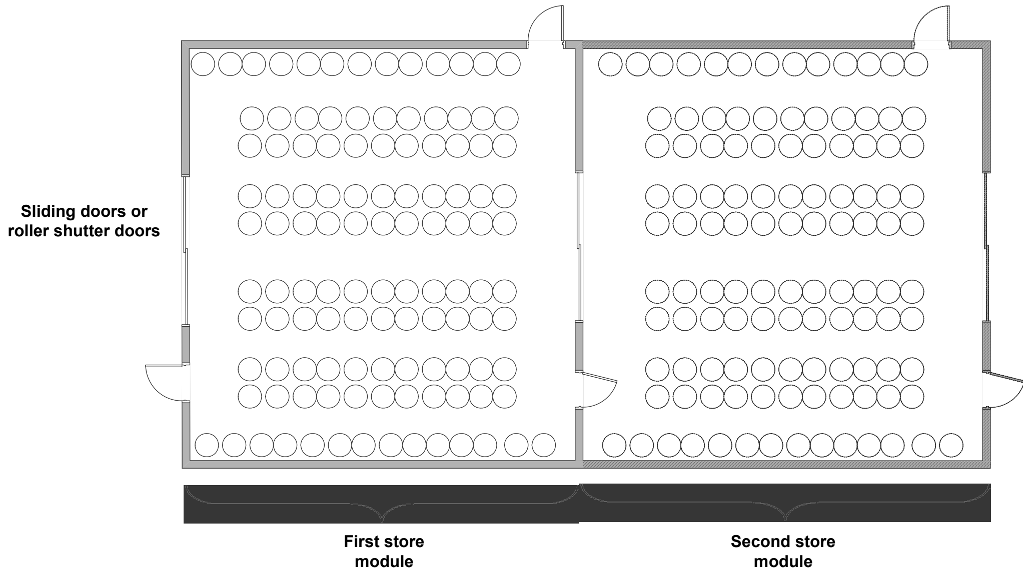


*FIG. 10.7. Modular design of storage building.*

*10.1.8.9. Waste drum/package stacking*

(a) Waste drums/packages shall be stacked in a manner such that packages do not contact the interior surface of the building walls. The design should allow the operator, either directly or remotely, to visually inspect wall surfaces for water leakage, and adjacent waste stacks for packaging degradation.

(b) Drums can be stacked within the storage facility up to two high. Drums can be stacked on one another provided that they are all of a consistent height. Stacking of drums of different heights is not recommended as the stacked drums may not be stable and represent a hazard to the operator. If there are a large number of drums to be stored, the height of stacking could be increased to minimize the floor area of the storage facility. However, consideration should be given to ensuring the stability of the stacked drums.
(c) Drums should be positioned in rows with aisles in between rows to allow access for operators to inspect individual drums and, if necessary, remove individual drums for further inspection, remediation or disposal, without the need to move a significant number of other drums.
(d) Robust racking can be fitted for storage of drums on two levels, although this adds to the cost and reduces the packing efficiency.
(e) Waste package and stacking systems should maintain their physical handling integrity over the 50 year design life.
(f) Storage facility operations like handling and stacking should minimize worker contact with the waste packages in order to reduce radiation exposure and the risk of contamination.

*10.1.8.10. Fire protection*

It will be necessary to give consideration to protection from fire at the time of planning the storage facility layout and building construction. This is a specialist area that the building architect will be able to advise upon in order to meet a particular Member State’s building regulations.

Waste drums that have been conditioned by solidification or encapsulation present no significant hazard of fire. However, compactable wastes are typically paper and plastics and these will have been in-drum compacted rather than encapsulated. They therefore represent more of a fire hazard and will increase the fire loading of the building.

Considerations at the planning stage will include:

(a) Protection of the building structure to withstand a fire;
(b) Escape routes and escape exits for personnel;
(c) Fire detection systems;
(d) Fire fighting systems;
(e) Containment and recovery of contaminated fire suppression media.

Optional clauses:

(1) The storage building should have a fire detection and a non-water based fire suppression system designed to detect and suppress the fire;
(2) The fire detection system and firefighter access panels will be at the main building access point;
(3) Building doors and penetrations should normally be closed, and ventilation systems, if fitted, should be shut off, manually, when the building is not in use.

### 10.1.9. Mechanical handling requirements

Specialized handling equipment should be avoided in preference for readily available equipment such as fork lifts with drum grabs and pallet trucks. Given the relatively small numbers of drums that are expected (30–40 drums per year) manual fork lift trucks and pallet trucks will be adequate for moving drums into and around the storage facility assuming a good flat floor slab.

The operation of the handling equipment must be taken into account in the design and layout of the storage facility including:

(a) The obvious size of access doorways;
(b) The spacing of drums and positioning of adjacent rows of drums;
(c) The segregation of personnel and vehicular access;
(d) Provision of reasonably flat, smooth and load bearing surfaces.

If it is necessary to transport the drums across rougher ground, then a powered fork lift will be necessary.

Ideally, electrically operated equipment should be used as this avoids the fumes associated with internal combustion engines. A charging station should be provided away from the main storage area. If the use of self-powered, e.g. LPG fuelled, fork lift trucks cannot be avoided, consideration should be given to ventilation of fumes within the storage facility.

Below-ground storage in bunkers will require waste drums/packages to be handled from above using slings or finger grabs from overhead cranes. This can add complexity and cost to drum handling and storage facility design, for example:

(1) Drums/packages may need special lifting features; therefore, drums/packages have to be designed, especially for the storage facility.
(2) The storage facility may need special features, e.g. crane rails to accommodate the overhead crane.
(3) Drums/packages will tend to be lifted over greater heights and therefore the consequences of a dropped load can be more significant.

Complex crane installations should be avoided. A simple mobile 'A' frame or a fork lift truck fitted with a jib crane attachment should be adequate, for example, for placing waste drums/packages into an in-ground storage vault or bunker from above. This equipment should also be suitable for lifting off the shielded top cover to the in-ground storage facility.

### 10.1.10. Mechanical equipment requirements

(a) All mechanical structures and equipment should be designed in accordance with recognized standards that should be identified in the contractor's Basis of Design document.
(b) The design submission should include calculations, specifications and quality control plans for all aspects of the mechanical works, for review by the client.
(c) The equipment should have a design life of 25 years, subject to the normal requirements for replacement of items under a maintenance regime.
(d) The amount of process, mechanical, HVAC, electrical and control equipment located in radiologically designated areas should be minimized.
(e) All maintainable items should be ergonomically located such that access can be gained to them without the use of temporary steps or platforms.
(f) Adequate space should be available around all maintainable plant to provide safe access for maintenance and plant removal. Access and egress routes for plant should be pre-defined and the appropriate mechanical handling equipment provided.
(g) Safe and suitable lifting and transport equipment should be provided to allow items of plant to be removed to a defined location for off-line maintenance.
(h) The contractor should supply any special tools that will be required to operate and maintain the equipment.
(i) All mechanical equipment, including pipe work, should be adequately labelled and colour coded in accordance with recognized standards.

### 10.1.11. Electrical equipment requirements

(a) All electrical plant and equipment should be designed in accordance with recognized standards that should be identified in the contractor's Basis of Design document.
(b) The design submission should include calculations, specifications and quality control plans for all aspects of the electrical works for review by the client.
(c) All electrical equipment should be IP rated to suit the environment within which it is located in accordance with recognized standards.
(d) A building earth system should be installed and all plant and equipment including cable trays should be equipotentially bonded and tied back to the building earth system.
(e) Adequate separation and segregation should be maintained between power cables and instrumentation and control cables.

(f) Low smoke and fume (LSF) cables should be used throughout the installation.
(g) All equipment should be fully certified as complying with electromagnetic compatibility (EMC) requirements as defined by regulations and legislation within the Member State.
(h) A risk assessment should be carried out to determine the need for lightning protection in accordance with recognized standards. If required, the contractor shall provide the lightning protection.
(i) All electrical plant and equipment should be adequately labelled and colour coded in accordance with a procedure to be prepared by the contractor and agreed by the client.
(j) All distribution boards and control panels should be fitted with a permanent, non-flammable finish, washable and easily removable circuit list fixed to the inside of the front cover. The details on the circuit list should adequately describe the correct rating of the protective device, the duty and give the location of the source of supply for each circuit.
(k) Electrical drives should be provided with a local lockable means of isolation.
(l) Adequate task lighting will be required for storage facility operations. The contractor should provide building lighting, room lighting levels should comply with recognized standards. All light fittings should be located, or of a design, such that the lamps can be replaced from floor level or using temporary steps or platform of no more than 2 m in height.
(m) Additional portable lighting for periodic visual inspection of drums should also be provided.
(n) Fixed high bay lighting should be avoided because of the difficulty of access for maintenance.

Optional clauses:

(1) A non-maintained emergency lighting system should be installed providing egress lighting and appropriate signage.
(2) The contractor should design, install and test the main power supplies to the building from the agreed termination point.
(3) All electrical distribution equipment and cable routes should include approximately 30% spare capacity for commissioning and future changes.

#### 10.1.12. Environmental control

The storage facility needs to protect the drums from degradation during the period of storage. This means the storage facility needs to protect the drums from the weather so that rain, condensation and damp conditions do not give rise to corrosion of the waste package. In its simplest form, this could be a weatherproof enclosure with some natural ventilation to prevent stagnant air accumulating within the storage facility. In this instance, no forced ventilation and heating is required for the storage building. In more extreme conditions, the storage facility may need to provide heating or cooling plus humidity control.

#### 10.1.13. Environmental conditions

The expected environmental conditions will need to be established for the particular storage facility location and should be specified. For example:

(a) Maximum and minimum temperatures;
(b) Humidity and/or dry bulb and wet bulb temperatures;
(c) Maximum rainfall;
(d) Maximum snowfall;
(e) Maximum wind strength;
(f) Possibility of flooding.

These should be based upon a risk based return frequency, e.g. a return frequency of 1 in 50 years (or greater periods) using data for the local area.

#### 10.1.14. Seismicity

The seismic design requirements will need to be established for the particular storage facility location and the design of the storage facility, and possibly the waste package handling equipment (including stacks or shelves) will need to demonstrate adequate performance in terms of stability and ultimately in terms of dose to operators and the public in the event of a design basis seismic event.

Again, these should be based upon a risk based return frequency, e.g. a return frequency of 1 in 50 years (or greater periods) using data for the local area.

#### 10.1.15. HVAC requirements — optional

(a) The ventilation of radioactive areas should be determined from risk based assessment and should be generally in accordance with recognized standards and safety assessment.
(b) Powered ventilation capability should be provided to reduce airborne contamination levels in the building to an acceptable level.
(c) All ventilation equipment should be designed in accordance with recognized standards that shall be identified in the contractor’s Basis of Design document.
(d) The design submission should include calculations, specifications and quality control plans for all aspects of the HVAC systems, for review by the client.
(e) All HVAC plant and equipment should be adequately labelled in accordance with relevant recognized standards.
(f) Adequate provision should be made for the in situ testing of HEPA filters in accordance with recognized standards.
(g) HEPA filters should be ‘safe-change’ ‘bag type’.
(h) The contractor should identify the measures taken in the design to minimize the levels of noise from fans on the normally occupied areas of the plant. Where practical, the normal noise levels shall be calculated.
(i) Provision should be made to deal with condensation within and on the outside of ductwork.
(j) The requirement for stand-by fans and filters and for auto-change should be determined by safety assessment.
(k) Heating of normally occupied areas of the building should be provided to maintain a minimum of 18ºC during winter assuming a minimum outside air temperature of XºC saturated (the actual temperature experience in the Member State should be confirmed). The maximum temperature in normally occupied areas of the plant should not exceed 25ºC.
(l) The HVAC system should maintain the environment of all other areas within the process plant to allow maintenance activities to be conducted within acceptable environmental conditions.
(m) Ventilation stacks should be provided with continuous stack sampling for radioactivity, as required by recognized standards.
(n) Where HVAC systems pass through fire resistant structures and compartment walls, fire dampers to equivalent fire resistance of the structure should be fitted that comply with recognized standards.

#### 10.1.16. Radiation safety requirements

The storage building is normally unoccupied. Radiation exposure of personnel should be optimized by minimizing the operation time required within the storage facility for all of the facility operations. Once the storage facility is filled, support systems will not be operated continuously but only according to a schedule based on periodic inspection or maintenance requirements.

The following is a set of design requirements that could be specified in respect of radiation safety. All radiation levels quoted below are for illustrative purpose to provide an idea about the magnitudes. The figures should be reviewed and revised in accordance with the waste drum/package characterization and Member States own radiological protection requirements:

(a) The storage building should be designed to store low level solid radioactive material with dose rates at 300 mm of less than 10 mSv/h.

(b) Subject to specific design, radiation safety and licensing approvals, storage buildings may be used for the storage of materials with dose rates greater than 10 mSv/h, or for the storage of radioactive liquid waste.
(c) The interior of the storage building is classified as a controlled area and all relevant requirements as stated in the Member State's radiological protection requirements should govern access control, signage, contamination control, hazard detection, and monitoring and alarms.
(d) For a filled building, dose rates, measured at contact with the exterior surface of the building walls are to be less than or equal to 0.025 mSv/h.
(e) For the storage building in the active loading phase, localized dose rates measured on contact with the exterior surface of the building walls (or penetrations) can be greater than 0.025 mSv/h, but must be less than 3 mSv/h. In such cases, the signage requirements as specified in the relevant recognized standards should be applied.
(f) The dose rate at the fenced boundary of the storage site adjacent to the storage building must be less than 0.0005 mSv/h on a monthly averaged basis.
(g) An average dose rate measured at 1 m above the storage building roof after 15 years of service should not exceed 0.1 mSv/h.
(h) Operational controls have to be in place and to comply with the dose rates noted above. For example, self-shielding by storing packages with lower dose rates adjacent to or on top of each higher dose rate packages should be used to minimize the dose rate. Areas should be posted in regard to compliance with radiological protection requirements.
(i) Operational controls should be provided to ensure that exterior dose rate requirements for all accessible areas adjacent to building wall penetrations such as doors and ventilators are fulfilled.
(j) Building interior inspection and maintenance, procedures should be designed to minimize exposure and proximity of workers to the stored wastes.
(k) Hand and foot monitors and /or contamination meters should be provided at the building access point(s).

### 10.1.17. Industrial safety requirements

#### *10.1.17.1. Operational safety*

(a) The construction of the building's interior should be such as to minimize any unsafe interfaces between personnel and vehicular traffic.
(b) The distances from building columns and walls should be sufficient to allow safe movement of authorized vehicles and personnel within the storage building.
(c) All catch basins and sumps should be equipped with properly fitting covers and either protected by bollards or designed to withstand anticipated vehicular loads.
(d) During operations, all personnel should follow the client's radiation protection procedures and corporate safety rules.
(e) The storage building's surrounding site should be constructed to minimize, if not completely eliminate, any unsafe interfaces between vehicular and personnel traffic.
(f) Distances from building perimeter and fencing should be sufficient to allow safe passage of both authorized vehicles and personnel around the storage building compound.
(g) The storage building should be fitted with all safety and building signs for fire, emergency exit, building identification, etc.

#### *10.1.17.2. Construction safety*

The following general requirements are identified. Additional requirements may be added as appropriate for the Member State.

(a) During construction and operation, all personnel should wear hard hats, safety footwear and safety eyewear with side shields.
(b) All personnel working on elevated surfaces should wear proper fall arrest devices.

(c) Personnel operating man lift devices should be adequately qualified. All personnel travelling in man lift devices should be equipped with proper fall arrest devices.
(d) While working around any moving equipment, all personnel should wear reflective safety vests.
(e) While working in excavations over 1200 mm deep, all personnel should wear personal extraction devices.
(f) All construction work should be executed in accordance with the relevant Member State's occupational health and safety regulations for construction projects, the contractor's own health and safety manual, and the environmental management and environmental protection plans.

#### 10.1.18. Physical protection/security requirements

Access to areas in which waste is processed and stored should be controlled to ensure safety and the physical protection of materials. In meeting operational requirements to control access, a zoned approach, working inwards towards areas having more stringent controls, may be applied.

Security measures should prevent acquisition of radioactive wastes by those with malevolent intent by:

— Deterring unauthorized access to sources or source location;
— Detecting intrusion (e.g. motion sensors, CCTV, guards);
— Assessing intrusion (e.g. cameras, guards);
— Delaying perpetrators (e.g. cages, tie downs) until appropriate forces can respond;
— Providing response capabilities (e.g. security or law enforcement personnel);
— Security management over time (e.g. adequate resources, procedures).

A graded approach to security is proposed, with security levels (A, B or C) applied depending on the categorization of the hazard (1 through to 5) posed by the source or radioactive material (Table 10.1). Further guidance is provided in an Ref. [10.1].

#### 10.1.19. Maintenance and inspection requirements

(a) The design aim should be that all proposed corrective and planned maintenance activities should be within the skill base capabilities of the client's organization.
(b) However, where on-site maintenance is believed to be beyond the capabilities of the client's organization, this should be identified and justified as requiring specialist maintenance support.

#### 10.1.20. Reliability

(a) The storage building as well as the individual equipment items should be available to meet the storage operational requirements as per the design intent of 250 days operation per year.
(b) The equipment should be designed to ensure an operating capability to receive X $m^3$ per year of waste.
(c) This should be demonstrated during the first year of operation.
(d) The storage building and equipment should be designed to optimize system availability, to minimize the amount of maintenance required, and to ensure that any maintenance required can be easily, quickly and safely carried out at minimum cost.

#### 10.1.21. Standards

(a) The standards to be used will be those necessary to ensure the safe and efficient operation of a fit for purpose storage building over the 50 year service life.
(b) The design should comply with statutory regulations, current legislation and ensure safety of operation.
(c) Commercial standards may be used providing they do not compromise conventional and nuclear safety.

TABLE 10.1. GRADED APPROACH TO SECURITY DEPENDING ON THE CATEGORIZATION OF THE HAZARD

<table>
<tr><th>Category</th><th>Source</th><th>Security level</th><th>Security goal</th></tr>
<tr><td>1</td><td>Radioisotope thermoelectric generators (RTGs).<br>Irradiators.<br>Teletherapy sources.<br>Fixed multibeam teletherapy (gamma knife) sources.</td><td>A</td><td>Prevent unauthorized removal of a source.</td></tr>
<tr><td>2</td><td>Industrial gamma radiography sources.<br>High/medium dose rate brachytherapy sources.</td><td>B</td><td>Minimize the likelihood of unauthorized removal of a source.</td></tr>
<tr><td>3</td><td>Fixed industrial gauges that incorporate high activity sources.<br>Well logging gauges.</td><td>C</td><td>Reduce the likelihood of unauthorized removal of a source.</td></tr>
<tr><td>4</td><td>Low dose rate brachytherapy sources (except eye plaques and permanent implants).<br>Industrial gauges that do not incorporate high activity sources.<br>Bone densitometers.<br>Static eliminators.</td><td rowspan="2">Apply measures as described in the IAEA’s Basic Safety Standards</td><td></td></tr>
<tr><td>5</td><td>Low dose rate brachytherapy eye plaques and permanent implants.<br>X ray fluorescence (XRF) devices.<br>Electron capture devices.<br>Mossbauer spectrometry sources.<br>Positron emission tomography (PET) check sources.</td><td></td></tr>
</table>

#### 10.1.22. Management system

(a) The contractor should perform the works in accordance with the contract requirements in respect of quality management (further specific requirements may be developed over and above the basic statements here). Any reference stated herein to the contractor should be similarly applicable to any subcontractor or self-employed person employed, engaged or otherwise retained by the contractor.
(b) Where, and to the extent that, materials products and workmanship are not fully detailed or specified, they are to be of a standard appropriate to the works being supplied and suitable for the purposes stated in, or reasonably to be inferred from, the contract documents.
(c) The contractor should establish and maintain a quality management system (QMS) which should be applied in accordance with, for example, the ISO 9001 standard.
(d) Adherence to the QMS should ensure the provision that the work is executed and completed by the contractor in accordance with the contract and that appropriate evidence of such is provided to the client.
(e) In support of this, the contractor should submit to the client a quality programme detailing how the quality of the contract will be managed by the contractor during the contract.

#### 10.1.23. Training

(a) The contractor should provide recommendations for training courses for engineering and operations staff. Training courses should be structured and include simulation of the plant by either built-in, PC based or separately wired simulators. The training courses should include descriptions of the hardware and any software implementation, fault diagnosis and rectification. The course should include instruction on the methods of implementing changes to any equipment software and the precautions to be taken. The course should utilize the system operation and maintenance manual during the training of the step by step operations and this should assist verification of the manual for future use.

(b) A documentation package should include explicit and easy to understand information and step by step procedures.

#### 10.1.24. Warranty

(a) The warranty should commence from the satisfactory completion of inactive commissioning and the acceptance by the regulator that the storage facility is ready to receive waste drums/packages;

(b) The warranty period should be for 12 months after the commencement date.

## REFERENCE TO SECTION 10

[10.1] INTERNATIONAL ATOMIC ENERGY AGENCY, Security of Radioactive Sources, IAEA Nuclear Security Series No. 11, IAEA, Vienna (2009).

# 11. OPERATING GUIDELINES FOR A WASTE PROCESSING AND STORAGE FACILITY

This section presents further considerations in setting up a WPSF. These are ‘software’ issues rather than the equipment hardware issues that have been detailed with in most of this publication. The responsibilities of the operator are summarized, followed by the management system for fulfilling these responsibilities.

## 11.1. OPERATOR’S RESPONSIBILITIES

It should be the responsibility of the operator:

- To ensure that the generation of radioactive waste is kept to the minimum practicable;
- To establish and implement a suitable waste management programme with an appropriate management system to ensure compliance with conditions of authorization;
- To ensure that radioactive waste is managed by providing appropriate collection, segregation, characterization, classification, treatment, conditioning, storage and disposal arrangements, including timely transfer between waste management steps;
- To ensure that equipment and facilities are available to carry out the activities for radioactive waste management safely;
- To ensure that suitable staff are adequately trained and have operational procedures available to perform their duties safely;
- To maintain an awareness of practices in waste management and to ensure the feedback of relevant operating experience;
- To conduct safety assessment, commensurate with the complexity of the facility and its potential impact on human health and the environment;
- To establish and keep records of information on the generation, processing, storage and disposal of radioactive waste, including the maintenance of an up to date inventory of stored radioactive waste;
- To ensure the monitoring, recording and reporting to the regulatory body of discharges in sufficient detail and accuracy to demonstrate compliance with any discharge authorization;
- To report promptly to the regulatory body any discharges or releases exceeding the authorized amounts;
- To provide an inventory of radioactive waste held, discharges made and radioactive material removed from regulated facilities and activities to the regulatory body at such intervals, in such a form and containing such details as the regulatory body may require;
- To assess the integrity of the waste control measures and facilities to ensure that they are fault tolerant;
- To establish contingency plans and emergency procedures;
- To notify the regulatory body of events and accidents;
- To provide any other information on radioactive waste as required by the regulatory body.

## 11.2. MANAGEMENT SYSTEM

The fulfilment of these responsibilities is achieved through the management system together with selection and provision of appropriate equipment for processing and storage of radioactive wastes. As the equipment has been the topic of much of this publication, attention in this section is given to the management system. This is necessarily an overview and further guidance is given in several IAEA publications [11.1, 11.2].

The particular aspects of the management system covered here are:

- Management and staffing;
- Procedural control of operations.

### 11.2.1. Management and staffing

The precise definition of the management structure of any particular WPSF will be dictated by local circumstances, but some general principles apply and these should be addressed whenever a management structure for a facility is being set up:

— One person should be appointed as the head of the facility in which is vested complete responsibility and accountability for the operation and safety of the facility. The facility should be managed and operated by suitably qualified and experienced personnel.
— Sufficient numbers of staff should be appointed to cover the range of tasks identified. Tasks will include general management, safety (including regulatory compliance), quality, operations and administration.
— In a small facility, it will probably be prudent and effective to combine tasks within a small group of job holders.
— It is essential to ensure that the tasks of safety and quality are independent of operational responsibilities and that the person(s) appointed to manage those tasks has(have) a direct reporting line to the head of the facility.
— Persons appointed to key tasks should be suitably qualified and experienced. If either qualifications or experience are lacking then opportunity to remedy the deficiency must be made available prior to taking up the post.
— The management structure needs to endure even when the facility is quiescent. This is likely to be part of regulatory requirements in any case, but in their absence the continuation of the management structure, with its defined accountabilities and responsibilities, will demonstrate a prudent approach to the management of radioactive materials.

Typically, the facility will require the following managers and staff.

#### *11.2.1.1. The manager (the head of the facility)*

The manager is the person responsible and accountable for the operation and safety of the facility and for quality policy concerning the facility, its processes and its systems of management. The manager should define an operating management structure with commitment to a quality policy with defined, appropriate responsibilities, accountabilities and reporting levels to assist him with his task, and should appoint suitably qualified and experienced persons to key posts.

#### *11.2.1.2. Radiation protection supervisor*

The radiation protection supervisor should be experienced in radiological protection procedures and regulations. The duties and responsibilities of the radiation protection supervisor will include:

— Establishment of the necessary monitoring regime;
— Receiving and assessing the results from the dosimetry service;
— Maintenance of the dosimetry records for the appropriate period of time;
— Taking necessary action on the basis of the radiation records and dosimetry.

#### *11.2.1.3. Quality manager*

The quality manager should be an experienced radiochemist or a radiophysicist trained to university degree level with experience in radioactive waste management. The duties and responsibilities of the quality manager will include:

— Implementation, management and maintenance of the defined quality system;
— Audit, internal and external, of the workings of the quality system;
— Ensuring that non-compliances and corrective actions are followed-up promptly and to their proper and logical conclusion.

*11.2.1.4. Operations manager*

The duties and responsibilities of the operations manager will include:

- Receiving, storing and conditioning all radioactive waste in accordance with quality arrangements;
- Sentencing of radioactive waste;
- Maintenance of records of receipt, storage and conditioning of radioactive waste for the appropriate period of time;
- Management of the operational staff.

In addition, the facility will need:

- A supervisor with practical experience with the handling of radioactive material and quality control to supervise day to day operations;
- Trained operators with experience in process equipment, instrumentation and electrical equipment and mechanical handling operations.

As noted above, in a small facility it will probably be prudent and effective to combine tasks within a small group of job holders with each person carrying out one or more roles.

### 11.2.2. Procedural control of operations

Typical operational activities associated with waste processing and storage are the routine operations of receipt, processing, emplacement, storage and retrieval of waste packages and their preparation for disposal. Supporting activities include: radiation protection; monitoring and surveillance; testing and examination of waste packages; inspection of the components of the storage facility; maintenance and repair; labelling of waste packages and record keeping.

Processing and storage facilities should be operated in accordance with written protocols for the handling, treatment and storage of contaminated solid and liquid radioactive waste. These protocols should be such as to ensure compliance with the operational limits and conditions approved for the storage facility by the regulatory body. Operational protocols are also established so as to minimize the final conditioned volume that goes for storage and eventual disposal. Operational protocols include:

- Operational limits and conditions;
- Operating procedures;
- Maintenance, testing and inspection;
- Training;
- Information and records;
- Radiation protection;
- Security.

Each of these is discussed below.

*11.2.2.1. Operational limits and conditions*

Processing and storage facilities should be operated in accordance with a set of operational limits and conditions that are derived from the safety assessment of the facility to identify the safe boundaries of operation. Operational limits and conditions set out specifications relating to waste packages, safety systems and procedures, radiological criteria and requirements for personnel. Operational limits and conditions for processing and storage facilities should be developed by the operator and should be subject to approval by the regulatory body. An IAEA publication provides guidance for the development and implementation of operational limits and conditions for nuclear power plants [11.3]; much of this guidance is applicable to processing and storage facilities for radioactive waste.

Operational limits and conditions for the processing and storage of waste should include, as appropriate:

- — Specifications for waste packages (waste form, radionuclide content and container characteristics) consistent with the waste acceptance criteria for the storage facility;
- — Concentration limits for liquid waste, e.g. to prevent the precipitation of solids;
- — Requirements for safety systems, e.g. requirements for ventilation, heat removal, tank agitation and radiation monitoring, including requirements for the availability of these features in normal and abnormal conditions;
- — Periodic testing of equipment, especially backup systems that need to be available in emergency conditions;
- — Maximum radiation dose rates, especially on container surfaces;
- — Maximum levels of surface contamination for containers;
- — Requirements for training and qualification of personnel and minimum staffing levels;
- — Limits on the cumulative radionuclide inventory.

The initial operational limits and conditions should normally be developed in cooperation with the facility designers well before the commencement of operation to ensure that adequate time is available for their assessment by the regulatory body.

The operational limits include the waste acceptance criteria (WAC) for the processing or storage facility that define the criteria for the acceptance of low and intermediate level waste into the facility for processing or storage. WAC should be consistent with the national waste management strategy, regulatory framework and the basis of design.

The criteria should include both radiological and non-radiological acceptance criteria, including physical form and packaging. Exclusion criteria should also be noted. The criteria should be to make the acceptance of routine low and intermediate level waste as straightforward as practical describing:

- — The method that waste generators should take to make arrangements for the acceptance of low and intermediate level waste;
- — The approaches that will be taken to address the handling of non-compliant low and intermediate level waste receipts;
- — The requirement for periodic assessment of waste generators’ compliance with the acceptance criteria contained herein.

The criteria should provide a process for managing the offering of non-routine wastes for acceptance consideration.

*11.2.2.2. Operating procedures*

Procedures should be developed for managing and operating the processing and/or storage facility under normal conditions, in incidents and under postulated accident conditions. Procedures should address such issues as those identified for the safety assessment in Section 2 and should be prepared so that the designated responsible person can understand and perform each action in the proper sequence.

*11.2.2.3. Maintenance, testing and inspection*

Before the start of operations, the operator should prepare a programme of periodic maintenance, testing and inspection of systems that are essential to safe operation. The need for maintenance, testing and inspection should be addressed from the design stage. Testing and inspection should establish and verify correct function, performance and conditions against acceptance criteria. Maintenance is conducted to protect the long term viability of operating systems and radioactive waste handling and transportation equipment. Preventive and predictive maintenance strategies are used which optimize system and equipment performance and reliability.

Systems and components that should be considered for periodic maintenance, testing and inspection may include:

— Waste containment systems, including tanks and other containers;
— Waste handling systems, including pumps and valves;
— Heating and/or cooling systems;
— Radiation monitoring systems;
— Calibration of instruments;
— Ventilation systems;
— Normal and standby systems for electrical power supply;
— Utilities and auxiliary systems such as systems for water, gas and compressed air;
— The system for physical protection;
— Building structures and radiation shielding;
— Fire protection systems.

*11.2.2.4. Training*

On the job field training is an effective method of providing structured task instructions. Written risk based procedures are invaluable resources when identifying the basis for the design of such training for operating and maintenance staff.

The elements of an effective on the job training should include:

— Understanding of task (step by step) performance expectations;
— Demonstrated performance of the task;
— Observation and acceptance of proper task execution.

*11.2.2.5. Information and records*

A system for tracking waste packages should be developed and maintained. For large processing and storage facilities, a computerized system for tracking waste packages should be considered. Where practicable, a detailed storage plan showing the configuration of the emplaced waste packages, including the zoning for the level of hazards, should be prepared and maintained.

Information on the waste and the various stages of the conditioning process should be collected and stored. The location of the drums in the interim storage facility should be recorded.

Before detailed planning is possible it is necessary to have all relevant facts about the waste:

— Waste package unique identification number.
— Position of waste package in the storage facility.
— Description of waste package contents:
  • Physical characteristics;
  • Chemical characteristics;
  • Biological characteristics;
  • Radioactivity content.
— Originator of waste (i.e. the user that generated the waste), name and address.
— Results and date of the last waste package inspection.
— Measured dose rate (usually at 1 m distance and on contact).

The information on the waste package shall be obtained where possible from the generator of the waste package.

*11.2.2.6. Radiation protection*

The objectives of the radiation protection programme are to ensure that the radiation doses to workers and to members of the public arising from the normal operation and the possible abnormal operation of the storage facility do not exceed regulatory limits and that radiation protection is optimized. Releases of radioactive material to the environment should also be controlled in accordance with the requirements of the regulatory body.

Management systems should be established which control activities having an impact on:

- — Radioactive contamination;
- — Contamination monitoring practices;
- — Release of radioactive liquids and gases to the environment;
- — Radiation dose received by individuals;
- — Access control to those areas of the licensed facilities considered to be high radiation areas.

More detailed guidance on radiation protection is given in other IAEA publications [11.4, 11.5].

*11.2.2.7. Security*

Access to areas in which waste is processed and stored should be controlled to ensure safety and the physical protection of materials. In meeting operational requirements to control access, a zoned approach, working inwards towards areas having more stringent controls, may be adopted.

Information on security measures and approaches to security has been provided in Section 10.1.18 along with reference to a relevant IAEA publication for more details on this subject.

## REFERENCES TO SECTION 11

[11.1] INTERNATIONAL ATOMIC ENERGY AGENCY, The Management System for the Processing, Handling and Storage of Radioactive Waste, IAEA Safety Standards Series No. GS-G-3.3, IAEA, Vienna (2008).

[11.2] INTERNATIONAL ATOMIC ENERGY AGENCY, Application of the Management System for Facilities and Activities, IAEA Safety Standards Series No. GS-G-3.1, IAEA, Vienna (2006).

[11.3] INTERNATIONAL ATOMIC ENERGY AGENCY, Operational Limits and Conditions and Operating Procedures for Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-2.2, IAEA, Vienna (2000).

[11.4] INTERNATIONAL ATOMIC ENERGY AGENCY, Optimization of Radiation Protection in the Control of Occupational Exposure, Safety Reports Series No. 21, IAEA, Vienna (2002).

[11.5] INTERNATIONAL ATOMIC ENERGY AGENCY, Occupational Radiation Protection, IAEA Safety Standards Series No. RS-G-1.1, IAEA, Vienna (1999).

# 12. PLANNING AND PREPARATION FOR SETTING UP A WASTE PROCESSING AND STORAGE FACILITY

Establishment of facilities for the management of radioactive waste has to take place within the framework of national policy and strategy, legislation and regulatory control. Careful planning and preparation are necessary for successful implementation of the waste management programme. The following is an overview of some of the major aspects that need to be taken into account in the planning and preparation for setting up WPSFs.

## 12.1. NATIONAL POLICY AND STRATEGY

A national policy for radioactive waste management is a fundamental cornerstone of a radioactive waste management system [12.1]. It sets out the goals or requirements to ensure the safe and efficient management of radioactive waste in the country. The policy should include safety and security objectives, arrangements for providing resources for radioactive waste management, identification of the main approaches for the management of radioactive waste categories, policy on export/import of radioactive waste, and provisions for public information and participation. In addition, the policy should define the roles and responsibilities of the organizations involved in its implementation. Policy is mainly established by the national government and may become codified in the national legislative system.

The radioactive waste management strategy sets out the means for achieving the goals and requirements set out in the national policy. Formulation of strategy requires an understanding of the current and future waste arisings, their characteristics and classification. The steps in formulating and implementing the strategy include selecting the technological procedures, allocating the responsibility for implementing the identified procedures, establishing supervisory mechanisms and developing implementation plans. A key element in the strategy is the extent to which national or regional waste management facilities are developed rather than managing the waste at a number of locations, where it arises. There may be significant safety benefits to be obtained from the use of specialized national or regional waste management facilities. However, the decision should be made with account taken of, among other things, the quantities and types of waste generated and the expertise available and its distribution in the region or State. In the siting of a nationally or regionally designated facility or facilities for radioactive waste management, it may be appropriate to take advantage of facilities where larger amounts of radioactive waste are managed, such as national laboratories at which the necessary expertise is available. Strategy is normally established by the relevant waste owner or operator, either a governmental agency or a private entity.

## 12.2. LEGAL AND REGULATORY FRAMEWORK

A comprehensive legal and regulatory framework is essential for achieving and maintaining a high level of safety in the management of nuclear facilities and activities [12.2]. For radioactive waste management, the regulatory body is likely to be required to supplement the primary national regulations for licensing of nuclear facilities with more detailed coverage of the waste management sequence of operations to include waste generation, transport, buffer or decay storage, treatment, immobilization and long term or interim storage pending disposal. The regulatory body may control the design and operation of all waste management and storage facilities through direct detailed directives or through requirements for comprehensive safety analysis reports.

## 12.3. PLANNING AND SELECTION OF PROCESSING OPTIONS

A coherent and well thought out waste management plan is essential before beginning to construct facilities for radioactive waste management. Effective planning must be based on a good inventory of the types and volumes of wastes presently being generated as well as good projections of future waste production.

At its simplest, a long term plan for radioactive waste management should specify:

— What facilities are to be provided for the treatment, conditioning and disposal of wastes;
— Where and when those facilities are to be built;
— The capacity of the planned facilities.

Ideally, the end point should be the disposal of the conditioned waste in a disposal facility isolated from the human environment. However, the planning of such facilities can take many years, and frequently it is necessary to consider interim storage of the waste pending final disposal.

Many different options will be available and these will require evaluation based on a number of often conflicting criteria in order to determine the optimum overall plan. The criteria could include political considerations, cost, environmental impact, technical reliability and flexibility to deal with an uncertain future.

The flow charts discussed in Sections 4 and 9 provide guidance on the selection of options for both processing and storage. In some instances, e.g. non-compactable solid waste, a single recommendation is made for the treatment process. For others, e.g. high volume aqueous wastes, some further assessment is needed to select the preferred treatment process(es).

However, a plan for radioactive waste management is not an end in itself; it represents merely the first step. It must be implemented, its progress monitored and it must be regularly reviewed to identify the need for change. Among the aspects which require particular attention are the following:

— Adequate regulations;
— Effective enforcement;
— Coordination with, and cooperation from, waste producers;
— Professional management of facilities;
— Proper training of staff.

## 12.4. DESIGN AND CONSTRUCTION OF FACILITIES

This publication provides guidance not only on the selection of processing and storage modules, but also on the design requirements and specification of those processing and storage modules. After identifying the design requirements for the processing and/or storage modules, it is then necessary to determine whether it is feasible to adapt an existing facility or to site and construct a new facility. Several factors, as discussed in Section 9.6.2, will have to be taken into consideration in deciding the location of the new facility.

Planning permission from appropriate government agencies may be required to construct the facility or convert the existing building as planned. Assessments and on-site investigations will need to be undertaken to support an application for planning permission.

Regulatory approval will be required for permission to site a processing or storage facility for radioactive waste. Again, assessments and on-site investigations will need to be undertaken to demonstrate the security and safety of the facility with respect to the protection of human health and the environment.

## 12.5. AUTHORIZATION AND LICENSING

An important factor which contributes to the safe management of radioactive waste is the authorization and licensing of waste management activities and facilities by the regulatory body. Authorization is the granting by a regulatory body of a written permission for an operator to perform a specified activity or a set of activities dealing with the siting, design, construction, commissioning, operation, decommissioning or closure of a facility. A licence is the principal document produced by the regulatory body that relates the legal framework of the regulatory system (i.e. laws and regulations) to the responsibilities of the operator of a facility at each stage of the authorization process.

The regulatory body has responsibility for authorization, regulatory review and assessment, inspection and enforcement, and for establishing safety principles, criteria, regulations and guides. In order to discharge the responsibility for authorization, the regulatory body establishes a process for dealing with applications for granting an authorization. According to the IAEA safety standards, the prime responsibility for the safety of a waste processing and storage facility rests with the operator. To obtain an authorization for a facility, the operator should submit adequate information including a detailed demonstration of safety to the regulatory body for its review and assessment in accordance with clearly defined procedures. Approval of an application by the regulatory body is formalized by granting an authorization to the operator in accordance with the laws and regulations of the Member State concerned. Once it has been issued, the terms of the authorization, including any conditions attached thereto, are binding on the operator unless and until amended, suspended or revoked by the regulatory body.

The authorization process for a predisposal waste management facility, the safety requirements and the supporting documentation for an authorization application should be in accordance with the relevant national legislation. Although the details in the national legislation may differ, they should be in line with good international practice as outlined in IAEA and other international standards.

Typically, the application for an authorization should comprise:

- A demonstration of the required level of safety of the facility;
- A demonstration of the protection of the environment both in the short and long term perspective;
- An assurance that the generation of secondary radioactive waste in the facility is kept to the minimum practicable;
- A demonstration that account is taken of interdependencies among all steps in radioactive waste management;
- An assurance that any processing of radioactive waste will be compatible with the anticipated type and duration of the storage and the need for retrievability of the radioactive waste from storage;
- The cost estimates of the waste management facilities and the liability of the operator with regard to the management of radioactive waste in the long term;
- An assurance that account is taken of anticipated waste arisings, accountability of waste, disposal options and safety considerations;
- An assurance of acceptance/tolerance of the facility by the public;
- An assurance of adequate physical security.

An IAEA publication provides guidance on the detailed contents of documents which should be submitted to the regulatory body in support of the application for authorization of waste processing and storage facilities and the ways of obtaining the required information [12.3].

## 12.6. SAFETY

The overall role of the regulatory body in relation to the safety of radioactive waste management is to establish safety standards and ensure compliance with these standards. The requirements for waste safety can be fulfilled in a number of ways. It is appropriate for the regulatory body to provide national guidance on how these can be met. There are a number of IAEA Safety Standards that should be referred to on relevant issues of interest in the areas of waste processing and storage [12.4–12.8].

The regulatory body should require the user or the operator to submit safety documentation in support of an application for a licence or other type of authorization involving the management of radioactive waste. The safety documentation should include a safety assessment report commensurate with the complexity of the facility.

The safety documentation to be developed in support of a licence application should, as a minimum, address the following:

- The expected volumes and characteristics of the waste to be processed and/or stored and the relevant acceptance criteria;
- A description of handling, processing and storage activities;
- A description of the facility and its components, equipment and systems;
- Site characterization;
- The organizational control of the operations;
- Procedures and operations manuals for activities with significant safety implications;

— Safety assessment;
— Monitoring programmes;
— The training programme for staff;
— The safeguards aspects, where applicable;
— The arrangements for physical protection of radioactive material;
— The emergency preparedness and response plan;
— The management system;
— Decommissioning;
— Acceptance criteria for waste packages.

The safety assessment of the WPSF will be necessary in building the safety case for the facility to demonstrate compliance with the regulatory requirements of the individual Member State. The key steps in this methodology are typically:

— The identification of exposure to both operators and the public arising from normal operations;
— The identification of potential hazards arising from accident considerations;
— An assessment of the frequency of the accidents taking place;
— A calculation of the consequences should the accidents occur;
— A combination of the assessed frequencies and consequences of the accidents to produce a risk;
— A summation of the risk from all accident scenarios;
— A comparison of this total risk with regulatory or other criteria;
— A reassessment of the design of the plant if the calculated total risk exceeds the regulatory criteria.

## REFERENCES TO SECTION 12


[12.1] INTERNATIONAL ATOMIC ENERGY AGENCY, Policies and Strategies for Radioactive Waste Management, IAEA Nuclear Energy Series No. NW-G-1.1, IAEA, Vienna (2009).

[12.2] INTERNATIONAL ATOMIC ENERGY AGENCY, Legal and Governmental Infrastructure for Nuclear, Radiation, Radioactive Waste and Transport Safety, IAEA Safety Standards Series No. GS-R-1, IAEA, Vienna (2000).

[12.3] INTERNATIONAL ATOMIC ENERGY AGENCY, License Applications for Low and Intermediate Level Waste Predisposal Facilities: A Manual for Operators, IAEA-TECDOC-1619 (2009).

[12.4] INTERNATIONAL ATOMIC ENERGY AGENCY, Storage of Radioactive Waste, IAEA Safety Standards Series No. WS-G-6.1, IAEA, Vienna (2006).

[12.5] INTERNATIONAL ATOMIC ENERGY AGENCY, Predisposal Management of Radioactive Waste, IAEA Safety Standards Series No. GSR Part 5, IAEA, Vienna (2009).

[12.6] INTERNATIONAL ATOMIC ENERGY AGENCY, Classification of Radioactive Waste, IAEA Safety Standards Series No. GSG-1, IAEA, Vienna (2009).

[12.7] INTERNATIONAL ATOMIC ENERGY AGENCY, Management of Waste from the Use of Radioactive Material in Medicine, Industry, Agriculture, Research and Education, IAEA Safety Standards Series No. WS-G-2.7, IAEA, Vienna (2005).

[12.8] INTERNATIONAL ATOMIC ENERGY AGENCY, Predisposal Management of Low and Intermediate Level Radioactive Waste, IAEA Safety Standards Series No. WS-G-2.5, IAEA, Vienna (2003).

# 13. CONCLUSIONS

This publication presents a modular approach to the design of waste processing and storage facilities to address the needs of Member States that do not have nuclear power reactors or fuel cycle facilities, but generate small quantities of low and intermediate level radioactive waste and disused sealed sources from applications of nuclear techniques. This approach is a cost effective and flexible solution that allows easy adjustment to changing needs in terms of the capacity and variety of waste streams. An engineering design package has been developed and presented in this publication to provide specific guidance on the modular approach that might be best suited to address the predisposal management needs for such situations. The publication includes a section on operating guidelines and an overview of the major requirements for setting up a waste processing and storage facility.

The processing design package contains a set of 11 predesigned modules for different treatment and conditioning methods for low volumes of liquid and solid waste, as well as disused sealed sources. The pre-designed modules are intended to be skid mounted and could be built and tested in a factory, requiring only final connection of services (e.g. power and water) by the end-user. The package includes guidance on selection of appropriate technical options for waste processing. Design and specification information is provided for each processing module, including the basis of design, PFD, equipment list and description, process description and operation, and interface and integration requirements. In most cases, a combination rather than a single module will be required for the processing of a waste stream. To illustrate how modules can be integrated, some typical combinations have been included. Guidance on how to specify the requirements for procurement of individual modules is included in the annexes along with a sample procurement specification for a processing module.

The processing of waste usually results in a package that is suitable for storage and/or disposal. The design package for storage includes a variety of concepts, starting from a simple storage cabinet to standard ISO shipping container to a purpose built storage building. Depending on the volume of waste to be stored, the most appropriate concept can be selected and guidance is provided for this purpose based on decision flow charts. Design and specification information have been presented for the purpose built storage building, including storage and building functional requirements, operational requirements, mechanical and electrical requirements, as well as requirements for environment control, ventilation, safety, security, maintenance and inspection, etc. This information is provided in descriptions that are presented in such a way that they can be adapted into procurement specifications for detailed design and construction of a storage facility.

In summary, the key feature of this publication is the provision of practical guidance to enable users to determine their waste processing and storage requirements, specify those requirements to allow the procurement of the appropriate processing and storage modules and to install and eventually operate those modules. Though based on the assumption of low throughput requirement of the processing modules, higher processing capacity can be achieved to some extent by increasing the frequency or duration of module operation. Similarly, storage modules can be added or expanded to increase capacity. It is expected that this modular design package will allow end-users to select and combine various waste processing and storage modules together in order to address current needs in a real time and cost effective manner with a possibility to adjust easily to future expansion.

## Annex I

## GUIDANCE ON PREPARING TECHNICAL SPECIFICATIONS FOR PROCUREMENT

The information required to prepare technical procurement specifications is largely available within the main body of this publication for both processing and storage modules. This annex provides guidance on the format and headline topics of a specification for processing modules. A sample technical specification for one process module to illustrate the topics that need to be covered within a technical specification and how this information can be obtained is presented in Annex II. It should be noted that the specifications are going to be similar, whether it is for a single process module or for a complete WPSF that contains several process modules. The aim of the specification is to provide a clear definition of:

- The scope of work required, i.e. what the contractor must do and equally what he or she does not do (that somebody else will do);
- The technical requirements, i.e. what the design, equipment or facility must be able to do;
- How the work must be done, e.g. the quality assurance standards, the standards for drawings and documentation, the requirement for review, acceptance or approval of work before proceeding to the next stage;
- How the contractor must demonstrate that he or she has met the technical requirements, e.g. inspection, testing and commissioning of equipment as well as delivery of documentation;
- Any information the contractor needs to do the work or at least to tender for the work.

A summary of the typical headings and content of a technical specification is provided below.

| Section and description | Content |
|---|---|
| **1. INTRODUCTION**<br>Brief description of the project to set the scene. | This will need to be written specifically for the project. |
| **2. SCOPE AND INTERFACES**<br>Detailed and careful definition of the extent of supply. This should include a detailed description of the items or services the contractor is required to provide, including hardware, software, reports, etc.<br>Definition of boundaries, battery limits, termination points and interfaces with a schedule of owners/responsibilities.<br>Exclusions specifically identified for additional clarity. | The overall scope of work could cover design, build, test, deliver to site, install and commission.<br>The extent of supply could be just a single module, or several modules or a complete WPSF, including a building and a waste storage facility.<br>The module interface specification identifies the interface requirements such as services (power, water, air), lighting, drains, HVAC, communications for each module. |
| **3. DEFINITIONS**<br>Definition of any terms which are not in common use. | This will need to be written specifically for the project. |

| Section and description | Content |
|---|---|
| **4. TECHNICAL REQUIREMENTS**<br>These will vary depending on the scope of work of the contractors, e.g. if the contractor is to design and build, if the technical requirements will focus on functions, concepts and interfaces, if the contractor is to manufacture whether they will focus on manufacturing standards and drawings. This section will include, as appropriate:<br>— Specification of the design code, e.g. any country specific standards, international standards, US standards, UK standards, etc., any mandatory and regulatory standards, specifications, performance parameters, functional requirements.<br>— Description of task, modification, machine, system requirements.<br>— Description of the operating and design conditions, e.g. temperatures, pressures, radiation, etc.<br>— Design life, reliability, availability, maintainability, etc.<br>— Painting, special finishes, assembly requirements, cleanliness, etc. | The following information can be obtained from the descriptions included in the main body of the document:<br>**Basis of design:** This is important information that needs to be provided to the contractor. It will need to be expanded to fully describe each waste stream. It describes the waste to be treated, what the performance requirements are and what services are required and need to be provided to operate the particular process modules.<br>**Process flow diagram:** A PFD is provided to illustrate the equipment.<br>**Equipment lists:** A summary list of equipment, providing sizes, throughputs and materials of construction.<br>**Equipment description:** A picture of a typical module, together with a description of the equipment within the module (types of equipment, materials of construction, size, throughput). |
| **5. MANAGEMENT SYSTEM**<br>Definition of the quality management standard to be applied. | This will need to be written specifically for the project. |
| **6. DOCUMENT, CALCULATION AND DRAWING APPROVAL**<br>Definition of the approval regime for the contractor's documents, calculations and drawings. | This will need to be written specifically for the project. |
| **7. INSPECTION AND TESTING**<br>Detailing the inspection and test requirements during manufacture, assembly and installation.<br>Acceptance standards or criteria/approval of deliverables.<br>Specification of any 'notification points' at which the client is to be advised of impending inspection and tests and 'hold' points beyond which manufacture or construction should not proceed without the client's approval.<br>Definition of works testing requirements–performance tests.<br>Provision of test equipment and facilities. | This will need to be written specifically for the project.<br>A typical example is included in the sample specifications in Annex II. |
| **8. PACKAGING AND DELIVERY**<br>Specification that the contractor is responsible for packaging to protect items during transport and site storage.<br>Definition of any special packaging requirements.<br>Definition of who is responsible for transport, delivery and site off-loading, including craneage and supervision. | This will need to be written specifically for the project.<br>A typical example is included in the sample specifications in Annex II. |
| **9. SITE INSTALLATION REQUIREMENTS**<br>Definition of the installation requirements. | This will need to be written specifically for the project.<br>A typical example is included in the sample specifications in Annex II. |
| **10. SITE COMMISSIONING, TESTING AND HANDOVER REQUIREMENTS**<br>Definition of the commissioning requirements, including any tests and criteria for handover, including completed documentation. | This will need to be written specifically for the project.<br>A typical example is included in the sample specifications in Annex II. |

| Section and description | Content |
|---|---|
| **11. OUTPUT DOCUMENTATION**<br>Identification of what is to be submitted and for what purpose (i.e. information or approval) using document submission schedule, if desired.<br>List of specific requirements for as-built or marked up (red line) drawings/documents, handover documentation, operating and maintenance manuals, certificate of conformity, electromagnetic compatibility (EMC) file, technical file, health and safety file, etc., to satisfy essential health and safety requirements.<br>Documentation for hardware, e.g. drawings, design calculations, certification authority approvals, design descriptions, operating instructions, maintenance instructions, test and commissioning requirements, warranties.<br>Documentation for software, e.g. design specification, validation, source code listings, principle of operation, flow diagrams, debugging procedures, input instructions, output formats, quality assurance procedures, maintenance procedures, user manuals, installation instructions.<br>Style of documentation and content if specifically required. | Documentation requirements are indicated in the individual module functional specifications:<br>Typically, a technical file, as required by the relevant national directives will be required, including:<br>— As-built drawings;<br>— Quality records;<br>— Safety report;<br>— Commissioning report;<br>— Operating instructions;<br>— Maintenance instructions;<br>— Maintenance schedule;<br>— Operating and maintenance manuals;<br>— Preparations for equipment storage and recommissioning instructions;<br>— Spares list. |
| **12. SAFETY, HEALTH AND ENVIRONMENT**<br>Definition of any client or site related safety, health and environment controls or risks. | This will need to be written specifically for the project. |
| **13. SITE CONDITIONS**<br>Description of any client requirements for safety, health and environment and any contractor obligations.<br>A statement to define the specific radiological and/or environmental conditions for site working.<br>Services and facilities supplied by the client.<br>Interaction with other contractors.<br>Specific site conditions and contractor access constraints (refer to contract terms for general site working terms and conditions). | This will need to be written specifically for the project.<br>If the specification is for a single process module to go into an existing facility, then this section will be able to refer to existing documentation for working in that facility. |
| **14. INPUT DATA**<br>List drawings, reports and other data provided to the tenderer. | This will need to be written specifically for the project.<br>A typical example is included in the sample specifications in Annex II. |
| **15. WARRANTY** | The start date and period of warranty will need to be defined. |
| **16. TENDER RETURN ASSESSMENT CRITERIA** | This might include price, programme, experience of supplying similar equipment, compliance with the specification. |

The above specification information largely covers the provision of the process modules themselves. There is still a considerable amount of preparation needed to accommodate and operate the process module(s) and information and guidance is provided within this design engineering package on this. For example:

— A facility will be needed to house the process module(s). This could be an existing building, a new building or even an ISO freight container. The latter will require a hard-standing.
— Services will need to be provided, such as electrical power and water and possibly a drain for treated effluent.
— Other requirements include trained operators, radiation protection staff, laboratory for analysis, monitoring equipment, and consumables such as waste containers, filter media, etc.

## Annex II

## SAMPLE TECHNICAL SPECIFICATIONS FOR PROCUREMENT OF PROCESSING MODULES

*Note on the use of 'shall' in this sample specification.*

It is the normal practice of the IAEA to restrict the use of the word 'shall' to 'normative' IAEA publications, such as those in the IAEA Safety Standards Series, in order to make statements about defined requirements, responsibilities and obligations, rather than in advisory publications such as this technical report. However, the use of 'shall' is also normal terminology in procurement contracts in that it defines what the contractor is legally required to do or provide under the contract, and it is so used in this annex. However, this use must *not* be interpreted as comprising a requirement that the IAEA is stipulating.

### II–1. INTRODUCTION

A brief description of the project is to be given here to set the scene. This will need to be written specifically for the project.

### II–2. SCOPE AND INTERFACES

A detailed and careful definition of the extent of supply is to be given here. This is to include a detailed description of the items or services the contractor is required to provide, including hardware, software, reports, etc.

Also to be included are definitions of boundaries, battery limits, termination points and interfaces with the owners, as well as responsibilities. Exclusions may be specifically identified for additional clarity.

The overall scope of work could cover design, construction, test, delivery to the site, installation and commissioning. The extent of supply could be a single module, several modules or a complete waste processing and storage facility (WPSF), including a building and a waste store. The module interface specification identifies the interface requirements, such as services (power, water, air), lighting, drains, HVAC (heating, ventilation and air conditioning) and communications for each module.

The sections below provide some sample text.

#### II–2.1. Scope

*Example.*

This specification details the requirements for the design, manufacture, works testing, packaging and delivery to site of process modules for the waste treatment plant. In summary, the process modules are:

— One module for chemical treatment;
— One module for filtration;
— One module for ion exchange;
— One module for cementation;
— Modules for interim storage of liquid waste containers, solidified waste drums;
— Modules for storage of treatment chemicals, cement powders and consumables.

The contractor shall:

— Detail the mechanical and electrical, control and instrumentation (EC&I) design;
— Detail the civil design and/or interfaces;
— Produce the design drawings;

— Procure all necessary material and proprietary items;
— Procure and install the instrumentation;
— Manufacture and/or assemble the equipment;
— Provide full inspection of the works and allow client inspection;
— Demonstrate fulfillment of the functional and performance requirements through testing at the contractor's works;
— Provide all necessary works 'as built' documentation;
— Dismantle, package and deliver the equipment to the client;
— Install and commission at the client's site;
— Provide design manuals;
— Provide spares and consumables for one year of operation;
— Provide risk based operating and maintenance instructions;
— Provide training of technical, operating and maintenance staff.

All of these shall be in accordance with this specification and the main contract requirements. The design and supply of all equipment shall meet the full requirements of the relevant current statutory acts and regulations of the country. All of the equipment shall be CE marked (if supplied within the European Union) and a declaration of conformity supplied.

If the client does not intend to carry out any further design work, the contractor is responsible for the completion of the design and space layout to meet the specification. The client will maintain responsibility for the process design provided to date.

Off-loading and installation of the completed package at the client is included as part of this contract. The contractor is expected to take account in their design of the requirements and restrictions in installing the equipment in the specified position in the building.

The contractor shall ensure that all work is carried out in accordance with this specification and all statutory regulations, in particular the current country regulations. In addition, the contractor shall comply fully with the manufacturer's requirements for all proprietary equipment that has been incorporated within the final design.

Nothing in this specification shall relieve the contractor of the responsibilities for performing, in addition to the requirements of this specification, such analyses, tests, inspections and other activities which are considered necessary to ensure that the detail design, materials, manufacture and workmanship are satisfactory for the services intended or may be required by good practice. Unless stated otherwise, all activities covered by this specification shall be in accordance with the latest edition of the relevant country standards.

Where specifications, codes and standards are referred to, it is the contractor's responsibility to obtain such documents and become familiarized with the requirements thereof. Where a conflict occurs between the requirements of any of the conditions or documents forming part of the contract, the matter shall be referred to the client for a decision.

This specification shall be read in conjunction with the details, terms and conditions contained in the main contract documents.

### II–2.2. Extent of supply

*Example.*

The extent of supply is the chemical treatment process module (Module B1) for processing volumes of aqueous waste. The chemical treatment process module includes all of the equipment shown in the process flow diagram (PFD) referenced in Section 5.2.3 of this publication, including:

— Valves;
— Pipe work and fittings up to the identified termination points;
— Chemical treatment tank and agitator;
— Support steelwork/frame(s) and drip trays;
— Control and electrical cabinet;
— Cable trays for cables/wiring;

— Dosing chemical tank;
— Waste effluent containers (two for testing purposes);
— Treated effluent containers (two for testing purposes);
— Sample container (20 in total for operations);
— Chemical dosing pump;
— Waste transfer pump;
— Treated effluent transfer pump;
— Funnel for dosing solid chemicals.

All of these shall be in accordance with this specification and the requirements of the main contract.

**II–2.3. Terminations and interfaces**

*Example.*

The chemical treatment process module is effectively separated from other possible treatment process modules by the use of waste containers to feed aqueous waste to the process and to collect treated aqueous waste from the process. However, the chemical treatment process module will interact with the following services that will be supplied and installed by others:

— Power supply (400 V AC, 50 Hz, pH3 and neutral) to the control panel/isolator on the process module. All on-module power supplies shall be derived from this one connection via a small distribution panel.
— Services. Process water supply: Routing of services from the interface point to equipment within the scope of this specification shall be carried out by the contractor. The contractor shall ensure that any such routing is neatly and securely run and does not hinder access, cleaning or plant operations. This routing shall be formally submitted to the client and accepted prior to its implementation.

The chemical treatment process module shall be free standing on a concrete floor and will eventually be placed on a suitable flat surface with adequate load bearing capability.

*Or:*

The chemical treatment process module shall be fixed to the freight container floor that will be used to house the process module. The contractor shall design suitable features for fixing the modules and provide all fixing bolts. The contractor shall provide civil engineering and fixing requirements to the client.

The termination points should be located as indicated on the supplied drawings. The layout of equipment shall take account of access requirements for operation and maintenance. Space envelopes are as indicated on the supplied drawings.

## II–3. DEFINITIONS

Define any terms which are not in common use. These terms will need to be written specifically for the project.

## II–4. TECHNICAL REQUIREMENTS

The technical requirements will vary depending on the scope of the work of the contractors. For example, if the contractor is to design and build, the technical requirements will focus on functions, concepts and interfaces. If the contractor is to manufacture, the focus will be on manufacturing standards and drawings. This section will include, as appropriate:

— Specification of the design code, e.g. any country specific or international standards, any mandatory and regulatory standards, specifications, performance parameters, and functional requirements.
— Description of task, modification, machine and system requirements.
— Operating and design conditions, e.g. temperatures, pressures, radiation.
— Design life, reliability, availability, maintainability, etc.
— Painting, special finishes, assembly requirements, cleanliness, etc.

### II–4.1. Process module description and technical requirements

This section describes the main components of the equipment and any relevant requirements and standards. These can be taken from the design and specification information presented in the main body of the document, where the following information is available:

— Basis of design: This is important information that needs to be provided to the contractor. It will need to be expanded upon to fully describe each waste stream. It describes the waste to be treated, what the performance requirements are, and what services are required and need to be provided to operate the particular process modules.
— Process flow diagram: A PFD is provided to illustrate the equipment.
— Equipment lists: A summary list of equipment is drawn up, providing sizes, throughputs and materials of construction.
— Equipment description: A picture is included of a typical module, together with a description of the equipment within the module (types of equipment, materials of construction, size, throughput, etc.).
— Specific sections in the document (described below) are identified that can be used to describe the Module B1–Chemical treatment. If other modules are also required, each can be described by obtaining the relevant information from the document and inserting it into a section for each module.

#### *II–4.1.1. Process description*

A description of how the process module is intended to operate should be available.
This will include operating parameters such as:

— Normal, off-normal;
— Design limits for equipment.

This information can be taken from the process descriptions in Section 5.2.1 of this publication.

#### *II–4.1.2. Basis of design*

This can be taken from Section 5.2.2 of this publication.

#### *II–4.1.3. Process flow diagram*

This can be taken from Section 5.2.3 of this publication.

#### *II–4.1.4. Equipment lists*

The equipment can be identified from the PFD. The list of equipment, as presented in Section 5.2.4 of this publication, should be inserted here.

*II–4.1.5. Equipment description*

A description of the equipment, including text and illustrations, can be taken from Section 5.2.5 of this publication.

*II–4.1.6. Process description and operation*

This can be taken from Section 5.2.8 of this publication.

*II–4.1.7. Mechanical module frames*

*Example.*

A support frame shall be designed to support all of the equipment identified in the PFD, supporting services and other input documentation. The securing and location of components on the frame shall permit quick and easy removal and replacement, minimizing the need to align and adjust components; i.e. modular design principles shall apply to all maintainable items. Consideration shall be given to the provision of anti-vibration mounts for all equipment with the potential to generate vibration.

All support frames shall have an integral stainless steel drip tray, sized to collect any leakages/spills from all mounted equipment and waste containers. The capacity of the drip tray shall be 110% of the largest vessel, or 25% of the total inventory of all equipment and waste containers on the process module, whichever is greater. The drip tray shall have falls of no less than 1:50 to collect the fluids and have corner radii to facilitate decontamination. There should be at least 50 mm of clearance between the drip tray and the support frame, and between the underside of the drip tray and the ground, to afford access for cleaning and swab monitoring.

Where lubrication oils/greases are required, it shall be ensured that this material cannot enter the process stream, either due to leaking into a process flow, or by leaks entering a tank directly or as a result of the washing/flushing of equipment.

Plant supports, mounting plates and the like that would not in normal circumstances come into contact with the process liquor, shall be manufactured in stainless steel (type 304 or 316). Lifting lugs for delivery, installation and maintenance purposes shall be incorporated within the design. Where they are welded, they shall be subjected to non-destructive examination, as for load bearing welds, and provided with certification.

The process module shall be fixed to the freight container floor, but can be freestanding on a concrete floor if located within a building. The contractor shall design suitable features for fixing the modules and provide all fixing bolts. The contractor shall provide civil engineering and fixing requirements to the client, if any.

### II–4.2. Operational life

*Example.*

The equipment shall be designed to achieve an intended operational life of 25 years. The contractor shall demonstrate that the predicted safe working life (design life) exceeds this by at least 10%.

### II–4.3. Reliability

*Example.*

The process module as well as the individual equipment items shall be available for performing the process to meet the operational requirements as per the design intent of 250 days per year. The equipment shall be designed to ensure an operating capability to process X $m^3$/year. This shall be demonstrated during the first year of operation.

### II–4.4. Layout

Statement of any special requirements for the layout of plant and equipment: Example for similar process modules.

It shall be the contractor's responsibility to design a suitable layout for all the equipment supplied. This shall meet good professional standards and take the following into consideration:

- — The modules shall be installed and operated within ISO freight containers/existing building (give details of existing building).
- — There shall be the flexibility to remove the process modules from the ISO freight containers in the future so that they can be relocated elsewhere.
- — The layout shall generally be in accordance with the pictures included with this specification.
- — The size of each process module should be restricted to allow it to be fitted into ISO freight containers or into the existing building (give details of any access restrictions).
- — The equipment and pipe work layout shall allow access to all components, and in particular valves and instruments, for commissioning, testing, maintenance and replacement. This shall ensure that sufficient space exists for the removal and replacement of these items. Where possible, access shall be provided to at least two sides of a piece of equipment.
- — The layout shall, at a minimum, meet relevant national and international standards with regard to dimensions for access. Note that this alone may not provide sufficient space to meet commissioning, maintenance and replacement requirements, which shall also be met.
- — Pipe work shall be run neatly, be of a minimum length and have a minimum of bends while still allowing dismantling for maintenance. In general, where a clash occurs, service (air/water) lines should be re-routed around active process lines (rather than the reverse).
- — Pipe work shall run in parallel and in 'isometric' layouts (i.e. north–south, east–west and up–down, not diagonally) where possible.
- — Where appropriate, pipe work shall be self-draining and have a fall to drain not less than 1:50 (1° slope).
- — Line and pump layouts shall minimize the suction pressure losses on pumps.
- — The layout of valves, and other equipment, shall minimize the occurrence and effect of 'water hammer'.
- — All pipe work, valves and equipment shall be suitably labelled.
- — Storage space should be available for equipment spares.
- — Storage space should be available for up to X waste containers awaiting processing and Y waste containers that have been processed.
- — The storage area should be available for waste identified as being unsuitable for processing.
- — There shall be a means to isolate electrical equipment on the module prior to maintenance.
- — There shall be an 'emergency stop' button to stop all equipment on the skid.
- — Storage of inactive materials and tools shall be separated from active equipment.

The layout should address the following:

- — Maintenance of lighting;
- — Maintenance of ventilation system from the outside;
- — Floor grading;
- — Reparability of the floor and easy decontamination;
- — Access of the forklift (movement, turning, etc.);
- — Inspections;
- — Fire detection equipment;
- — Portable fire suppression equipment;
- — Radiation detectors, alarms, hand and foot monitors.

### II–4.5. Labelling

*Example.*

All valves, pumps, instruments and other equipment shall be clearly marked with labels. All labels shall be two colour plastic (or similar material, subject to the client's acceptance) and shall have black letters inscribed on a white background. They shall be mechanically fixed using non-corrosive fixing screws. Adhesive labels shall not be used on these items.

All lines shall be marked with permanent adhesive tapes at appropriate intervals to enable easy identification and tracing of lines. The label shall indicate, in addition to other information, the fluid contained within the lines and the direction(s) of flow. The text on labels shall be a minimum of 3 mm in height and easily readable when the equipment is installed. Where labels are applied to stainless steel, the adhesives shall not contain chlorine. The labelling shall be in accordance with relevant codes and standards (to be specified).

### II–4.6. Spares

*Example.*

The contractor shall submit a list of recommended spares for approval. The list shall include separate entries for quantities of commissioning and operational spares. The list shall incorporate the component manufacturer's name and address, contact, telephone number, delivery and unit cost. Contractors shall indicate the components that are held as stock items in their works and recommendations for a parts management system to minimize the spares holding.

The contractor shall state the period of time for which the spares shall be readily available, and this period shall be subject to agreement. The contractor shall be responsible for notifying of any likelihood of equipment spares becoming scarce during the equipment's life.

### II–4.7. Operating environment

The operating environment will need to be written specifically for the project.

*Example.*

Equipment shall be designed and supplied to operate in external ambient conditions at the client's site, e.g. equipment should have humidity ingress protection and sealing; marine coastal climates will need additional corrosion protection. All process and instrumentation equipment and components shall be suitable for operation in the range of +25°C to −10°C *(insert suitable range for the site).*

### II–4.8. Standards

*Example.*

The standards to be used shall be those necessary to ensure the safe and efficient operation of a fit for purpose plant over the X (*insert suitable value here*) years of the plant's life. The design shall comply with statutory regulations and current legislation, and shall ensure safety of operation. Commercial standards may be used, provided they do not compromise conventional and nuclear safety.

Furthermore, at a minimum, any applicable standards should be adhered to where relevant, along with legislative requirements. It is the contractor's responsibility to select the appropriate codes, specifications and standards applicable to the scope of work. Where a conflict occurs between the requirements of any of the conditions or documents forming part of the contract, the matter shall be referred to the client for resolution. If clients do not know the relevant standards for the equipment, they can ask the supplier to propose these standards.

## II–5. MANAGEMENT SYSTEM

This will need to be written specifically for the project.

*Example.*

The contractor and sub-suppliers shall be certified to ISO 9001:2000 or ISO 9002:1994 by an accredited authority, and evidence of such certification must be available. Within two weeks of the award of the purchase order, the contractor shall issue a quality plan (inspection and test plan) for the system for comment. The plan should be completed by the client to indicate review, witness and hold points. Further detailed requirements could be added, as described below.

### II–5.1. Units of measurement

*Example.*

All measurements shown on documents and drawings shall be in metric units, in accordance with the International System of Units (SI).

### II–5.2. Welding

*Example.*

Approval testing of welding procedures shall be conducted, recorded and reported in accordance with appropriate standards. All welding shall be performed in accordance with a welding procedure which conforms to appropriate standards. Welders shall be suitably qualified to appropriate standards and all welding procedure specifications (WPSs)/weld procedure quality records (WPQRs) shall be submitted for review prior to construction. Welding inspectors shall be in possession of current nationally recognized qualification appropriate to visual and surface crack detection methods.

### II–5.3. CAD software

*Example.*

Where the design utilizes computer aided design (CAD) software, the supplier shall provide a copy of the most recent verification document of the software used. In addition, the contractor shall provide verification results supported by certification showing compliance with the software design procedures.

## II–6. DOCUMENT, CALCULATION AND DRAWING APPROVAL

Define approval regime for contractor's documents, calculations and drawings. This will need to be written specifically for the project.

## II–7. INSPECTION AND TESTING

- Detail the inspection and test requirements during manufacture, assembly and installation.
- Specify acceptance standards or criteria/approval of deliverables.
- Specify any 'notification points' at which the client is to be advised of impending inspection and tests and 'hold' points beyond which manufacture or construction shall not proceed without the client's approval.
- Specify works testing requirements performance tests.
- Provide test equipment and facilities. This will need to be written specifically for the project.

*Example.*

The equipment design shall be modular to facilitate shipping, transportation and ease of site assembly. The modules, control systems and other ancillary equipment shall be fully assembled, tested and commissioned off-site, before transportation to the site for installation and inactive commissioning. Test requirements shall be fully developed and described in detailed contractor procedures to be approved by the client. Works testing shall include full operation/simulation of equipment function and characterization of system performance. The client shall be offered the opportunity to witness all off-site testing. All test results and certificates shall be included in technical manuals.

### II–7.1. Inspection and testing

*Example.*

The contractor shall inspect and test the skids to demonstrate compliance with the contract and this specification. Acceptance standards for inspection and testing shall be in accordance with national standards, wherever appropriate; otherwise, the client will specify the required standard.

The client reserves the right to carry out inspections, but this does not absolve contractors of the responsibility of carrying out their own in accordance with their quality plan.

The contractor shall provide all equipment and facilities for inspection and testing carried out prior to delivery. The contractor shall be responsible for CE (or equivalent as appropriate) marking the skids and providing a certificate of incorporation (into the overall process scheme). Certification shall confirm that the skids meet electromagnetic compatibility (EMC), low voltage and machinery directives.

The client should provide the contractor with EMC and low voltage directive details (from the ECI contractor) to allow the contractor to apply the CE (or equivalent as appropriate) mark to the skids.

### II–7.2. Factory acceptance tests

*Example.*

The contractor shall ensure independent witnessing of the capability to effectively process X (*insert appropriate value here*) $m^3$/day. All mechanical and electrical equipment shall be tested for function and performance at the contractor's premises prior to delivery, as far as practicable. The factory acceptance tests shall test, as far as practicable, all mechanical and electrical equipment for function and performance prior to delivery. The factory acceptance tests shall also provide operator familiarization and demonstrate that the equipment can be easily and safely maintained. Any special tools required for the maintenance of equipment shall be provided under the same contract terms. All testing shall be carried out in accordance with procedures written by the contractor and approved by the client. The procedures shall detail any special equipment that the contractor will need to manufacture, purchase or hire to complete the functional testing. The contractor shall include the specialized equipment in the tender return.

The factory acceptance tests shall provide inactive functional commissioning, operator familiarization and maintenance demonstration trials. All operations are to be done with reference to and in accordance with the contractor's operation and maintenance documents. The demonstration shall prove the ease of maintenance in removal and reassembly of the equipment.

After functional testing, the equipment shall be visually examined for signs of physical damage and excessive wear, and a report should be submitted to the client who will instruct any rectification work to be undertaken in accordance with the contract conditions. The contractor shall be responsible for standard electrical testing on all electrical equipment, which shall include continuity, insulation and earth bonding. In general, electrical components will be fully proven both on a 'stand alone' basis before connection and in functional tests with the mechanical components it may control or monitor.

Where appropriate, and particularly for electrical tests, the tests shall be in accordance with the relevant standard. Where specific standards are not applicable, the test procedures shall be agreed with the client.

The client should be allowed to witness works testing. The contractor shall provide all other material, equipment, services and personnel to allow the trials to be carried out. The contractor shall propose a cost effective methodology to enable this to be achieved.

On completion of the demonstration and acceptance by the client, the contractor shall present the client with the quality records for review. On successful completion of this review, the equipment together with the quality records will constitute formal handover. The contractor can submit the handover acceptance documentation for the consideration of the client in accordance with the contract conditions.

## II–8. PACKAGING AND DELIVERY

The contractor is responsible for packaging to protect items during transport and site storage. This should be specified. Any special packaging requirements should be defined, as should who is responsible for transport, delivery and site off-loading, including cranage and supervision. This will need to be written specifically for the project.

*Example.*

The equipment shall be packaged and prepared for shipping by the contractor to a procedure approved by the client. The packaging shall be suitable for outside storage of X (*insert appropriate value here*) months (if the module will not be installed immediately).

Equipment that cannot be easily packaged may be shipped secured to pallets, but delicate items, sealing surfaces or similar items shall be protected with a 'hard' covering. The following information shall be included on all layers of packaging:

— Equipment name or drawing number;
— Client's purchase order number;
— Contractor's name;
— Gross weight and approximate position of centre of gravity (for lifting purposes);
— Contractor's delivery note number;
— Special off-loading instructions, if appropriate.

The contractor is responsible for the equipment until handover on the client's site. The contractor is required to give the client two weeks notice of the intention to deliver the equipment, together with the off-loading facilities that will be required. Requirements for off-loading, slinging, handling and putting down shall be provided to the client. The client shall be advised of any special considerations that are applicable to off-loading, such as length, height and weight, and any special storage requirements — for example, for electronic equipment, control panels, etc. — so that appropriate precautions may be taken. The use of such off-loading instructions must be indicated on the outer packaging.

Lifting points, if appropriate, shall be readily accessible and clearly identified. Proof load certificate(s) shall accompany the equipment, together with guidance on any handling limitations. If lifting beams or load spreaders are required, they shall also accompany the equipment, together with instructions regarding their use.

The maximum allowable headroom on site is X (*insert appropriate value here*) metres. Width restriction is X (*insert appropriate value here*) metres. Length restriction is X (*insert appropriate value here*) metres. There is also a weight restriction of X (*insert appropriate value here*) tonnes. Unloading at site will be carried out by the client/contractor (as appropriate).

## II–9. SITE INSTALLATION REQUIREMENTS

The installation requirements should be defined. They will need to be written specifically for the project.

*Example.*

The methods of construction and the identification marks used shall be detailed in an installation method statement (IMS) supplied with the equipment for use at the site. Unless advised to the contrary, the contractor shall be responsible for all necessary plant and equipment required for completing the installation works.

All plant and equipment used must be in compliance with the relevant dated certification, which shall be maintained and kept up to date throughout the period of the contract. The contractor shall be responsible for the provision of all handling equipment, and any necessary documentation required for use in the erection of equipment. This includes, but is not limited to, crane berthing studies, health and safety documentation, risk assessments, etc. Or, if the equipment is going to be installed by another contractor for the client, the contractor shall provide a written outline proposal for installation of the equipment in the scope of supply. This shall include safety functional tests and functional test requirements, and shall form the basis of the installation procedures to be prepared by and carried out by the client or installation contractor.

If required, the contractor will be asked to provide specialist technical advice and/or assist in this process and in resolving problems. The contractor should quote separate rates for providing this service during the installation and commissioning period.

## II–10. SITE COMMISSIONING, TESTING AND HANDOVER REQUIREMENTS

The commissioning requirements should be defined, including any tests and criteria for handover and training and completed documentation. These will need to be written specifically for the project.

*Example.*

Site acceptance tests will typically repeat factory acceptance test results. At the site, the contractor shall provide on the job field training to operating staff.

### II–10.1. Training

*Example.*

The contractor shall provide training courses for engineering and operations staff. Training courses shall be structured and include simulation of the plant by either built-in, PC based or separately wired simulators. The training courses shall include descriptions of the hardware and software implementation, fault diagnosis and rectification. The course shall include instruction on the methods of implementing changes to the equipment software and the precautions to be taken. The course shall utilize the system operations manual during the training of the step by step operations, which shall assist verification of the manual for future use. A documentation package shall include explicit and easy to understand information and step by step procedures.

## II–11. OUTPUT DOCUMENTATION

Material to be submitted must be identified and the purpose described (i.e. information or approval) using the document submission schedule if desired. The specific requirements are to be listed for the following: as-built or marked up (red line) drawings/documents, handover documentation, operating and maintenance manuals, certificate of conformity, electromagnetic compatibility (EMC) file, technical file, health and safety file, etc., to satisfy essential health and safety requirements, and other documentation. Examples are documentation for hardware, drawings, design calculations, certification authority approvals, design descriptions, operating instructions, maintenance instructions, test and commissioning requirements, and warranties.

Documentation for software includes design specification, validation, source code listings, principles of operation, flow diagrams, debugging procedures, input instructions, output formats, quality assurance procedures, maintenance procedures, user manuals and installation instructions.

Specify the style of documentation and content, if specifically required.

*Example.*

Documentation requirements are indicated in the individual general module functional specifications. Typically, a technical file will be required (as per the EU Directives or equivalent as appropriate), including:

- — Quality records;
- — As-built drawings;
- — Operation and maintenance manuals;
- — Safety report;
- — Commissioning report;
- — Operating instructions;
- — Maintenance instructions;
- — Maintenance schedule;
- — Preparations for equipment storage and re-commissioning instructions;
- — Spares list.

An example of the text to expand upon the first three items is given below.

### II–11.1. Quality records

*Example.*

Three hard copies of the following documentation are to be provided by the contractor:

- — Material certificates;
- — Performance and results of each hydrostatic and pneumatic pressure test, if appropriate;
- — Performance and results of each proof load test, if appropriate;
- — Performance and results of each functional test;
- — Report on each non-destructive examination, if appropriate;
- — A list of all concessions approved by the client;
- — EC Declaration of Conformity (or equivalent) and quality documentation for proprietary components;
- — Contractor's quality plans approved by the client;
- — Contractor's procedures approved by the client;
- — Contractor's certificate of conformity for the supply.

### II–11.2. Design drawings

*Example.*

Manufacturing drawings and design documents shall be prepared, checked and approved by the contractor and submitted to the client for approval. The drawings shall contain all information necessary to manufacture the items and construct the assemblies. Drawings shall be produced with a computer aided design system (CAD). The contractor shall liaise with the client to ensure that the CAD system is suitable.

Drawings produced specifically for the contract shall be the sole property of the client. They shall be produced using the standard ISO A series of drawing sheets, electronic copies of the client's templates will be supplied to the contractor. Upon request, the client will issue the contractor with a batch of drawing numbers for the contract. All drawings are to be reviewed and updated to the satisfaction of the client to an 'as built' condition after inactive commissioning. Three sets of 'as built' record drawings in hard copy format along with an electronic set shall be supplied on completion of the contract.

Vendor drawings shall be included in the operating and maintenance manuals. These vender drawings shall be to the vendors own standard and will not be required to be produced in accordance with the requirements of the drawing standard.

### II–11.3. Operating and maintenance manuals

*Example.*

The operating and maintenance manuals shall contain comprehensive information to allow the installed system to be maintained and operated by the client's personnel. They shall include manufacturer's handbooks, drawings, configuration details, software design documentation, and maintenance and operational procedures. The contractor shall ensure that the final documents are developed during the project. The format of the information shall be agreed with the client. The contractor shall include the following:

- Full step by step instructions to operate and maintain the equipment;
- Emergency shutdown instructions;
- Recommendations for routine maintenance and any safety precautions necessary;
- Details of any special equipment or special tools required for maintenance;
- List of recommended spare parts for one year and five years of operation;
- Identification of components that need replacement sooner than one year because of their limited life, non-reusable nature or susceptibility to breakage;
- An estimate of repair time for likely and unavoidable failures;
- The approximate delivery time for the procurement of long lead spare parts;
- Technical manuals and data sheets of proprietary equipment purchased for the contract shall be included as appendices;
- A maintenance instruction for replacing each major plant item on the skid to include access requirements removal of other items required to gain access.

Draft copies shall be available for formal review and acceptance as part of customer acceptance testing.

## II–12. SAFETY, HEALTH AND ENVIRONMENT

Any client or site related safety, health and environment controls or risks shall be defined. This will need to be written specifically for the project.

## II–13. SITE CONDITIONS

A description of any client requirements for safety, health and environment and any contractor obligations is to be provided. A statement to define the specific radiological and/or environmental conditions for site working is needed. Services and facilities supplied by the client. Interaction with other contractors. Specific site conditions and contractor access constraints (refer to contract terms for general site working terms and conditions). These will need to be written specifically for the project.

If the specification is for single process modules to go into an existing facility, then this section will be able to refer to existing documentation for working in that facility.

## II–14. INPUT DATA

A list of drawings, reports and other data provided to the tenderer is to be provided. This will need to be written specifically for the project. Information to be included could include the following:

— If relevant, drawings of existing area/building where the module will be located, to illustrate the space envelope available and the access route for installation, including any constraints, e.g. height of doorways, floor loading restrictions, safe working loads of existing lifting equipment that the contractor can use;
— Information from the design engineering package, e.g. the process flow diagram, equipment and instrumentation schedules.

If preliminary drawings are being provided to assist the contractor in understanding requirements the following could be added: The contractor shall be responsible for finalizing the design of these components to meet the requirements of this specification.

## II–15. WARRANTY

*Example.*

The warranty shall commence from the satisfactory completion of inactive commissioning and acceptance by the regulator that the plant is ready to receive active waste. The warranty period shall be for 12 months after the commencement date.

## II–16. TENDER RETURN ASSESSMENT CRITERIA

This might include price, programme, experience of supplying similar equipment, compliance with this specification.

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**Consultants Meetings**

Vienna, Austria: 30 October–3 November 2006, 22–26 January 2007, 25–28 March 2008, 10–14 November 2008

**Technical Meetings**

Vienna, Austria: 30 October–1 November 2006, 10–13 November 2008

# Structure of the IAEA Nuclear Energy Series

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*Key*

| | |
|---|---|
| **BP:** | Basic Principles |
| **O:** | Objectives |
| **G:** | Guides |
| **T:** | Technical Reports |
| **Nos 1-6:** | Topic designations |
| **#:** | Guide or Report number (1, 2, 3, 4, etc.) |

*Examples*

| | |
|---|---|
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