Modular Design of Processing and Storage Facilities for Small Volumes of Low and Intermediate Level Radioactive Waste including Disused Sealed Sources - 12372

David R. Keene*, Susanta Kumar Samanta** and Zoran Drace**
* Nuvia Limited, UK
** Waste Technology Section, International Atomic Energy Agency, Vienna, Austria

ABSTRACT

There are a number of IAEA Member States generating relatively small quantities of radioactive waste and/or disused sealed sources in application of nuclear techniques in medicine, industry and research and in nuclear research centres having small research reactors. At present many of these Member States do not have facilities for processing and storing their radioactive wastes; notably in those countries with small quantities of generated radioactive wastes. In other Member States the existing waste processing and storage facilities (WPSF) are in need of varying degrees of upgrading in order to address new waste streams, incorporate new waste processing technologies, or expand interim storage capacities. The IAEA has developed a modular design approach for a WPSF that is based on a variety of modules for different waste stream treatment and conditioning processes. The modular WPSF design is elaborated in a substantial Design Engineering Package that will be published by IAEA as a technical report.

INTRODUCTION

There are a number of IAEA Member States generating relatively small quantities of radioactive waste and/or disused sealed sources in application of nuclear techniques in medicine, industry and research and in nuclear research centres having small research reactors. At present many of these Member States do not have facilities for processing and storing their radioactive wastes; notably in those countries with small quantities of generated radioactive wastes. In other Member States the existing waste processing and storage facilities (WPSF) are in need of varying degrees of upgrading in order to address new waste streams, incorporate new waste processing technologies, or expand interim storage capacities.

The IAEA supports these Member States to manage their radioactive wastes in a safe and cost-effective manner through the provision of guidance on the selection of technical options, formulation of design specifications and operational procedures for waste processing and storage facilities. Because of wide variation in the types and quantities of radioactive waste a single WPSF design is not adequate to meet the needs of these Member States.

The IAEA has therefore developed a modular design approach for a WPSF 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 then combined with other modules to meet the country specific needs. Similarly for storage, different storage module concepts are available ranging from simple storage cabinets up to a purpose designed storage building.

The modular WPSF design is elaborated in a substantial Design Engineering Package, prepared by engineering company Nuvia Ltd. (UK) and finalized by IAEA for publication as a technical report.

The Design Engineering Package provides:

- An overview of the technical and regulatory requirements for setting up WPSF.
- A description of typical wastes generated in these Member States.
- Identification of the preferred processing technologies for those wastes that have been developed into process and storage modules.
- Decision flowcharts that present a logical framework for consideration of key decisions/questions that need to be addressed in order to select the most appropriate option for processing or storage of waste.
- Design and specification information for each of the process or storage modules.
- Guidance on the integration of the modules to provide a complete waste management capability.
- Operating guidelines for a modular WPSF.

DESCRIPTION OF TYPICAL WASTES GENERATED

As noted above, this work addresses the needs of Member States that do not have nuclear power reactors or fuel cycle facilities, but generate relatively small quantities of low and intermediate level wastes and disused sealed sources. Previous work by the IAEA has reviewed typical wastes generated by these Member States and identified their principal characteristics [1]. Table I overleaf summarises the waste streams. Not all of these Member States will necessarily produce all of these waste streams.

Each waste stream is identified by a letter (A - Low Volume Aqueous Liquid; B - High Volume Aqueous Liquid etc.) and these letters are also used to identify the individual waste treatment process modules. The waste stream information provided in this table has been used as a basis for developing the designs and specifications of the waste treatment process modules in the Design Engineering Package.

The Design Engineering Package does not specifically address waste and disused sealed radiation sources with short-lived radionuclides that are suitable for decay storage and therefore these are not included in Table I. Such wastes shall be safely stored until clearance levels have been reached.

IDENTIFICATION OF PROCESSING TECHNOLOGIES FOR LIQUID WASTE, SOLID WASTE AND DISUSED SEALED RADIATION SOURCES

A wide range of waste treatment technologies are available for the treatment and conditioning of the types of radioactive wastes identified in Table I [1-7]. Some, such as evaporation, that may be used for treating radioactive wastes elsewhere in the world have been reviewed and assessed as being unsuitable for application in the Member States being considered here, generally because they are too costly and too complex to implement for the relatively small volumes of waste that are anticipated.

Through the consideration of the different waste types and the expected volumes of waste, eleven preferred processing technologies have been identified and have been developed into simple treatment process modules for the treatment and conditioning of the range of waste streams identified in Table I.

Table I Waste Stream Descriptions

Matrix Cross Ref.	Waste Stream	Annual Quantity to be Processed	Waste Origin and Waste Type
A	**Low Volume Aqueous Liquid**	Typically up to $0.5 m^3$	Laboratories, Hospitals etc.
B	**High Volume Aqueous Liquid**	Typically in the range 0.5 -$10m^3$	Laboratories, Hot cells, Research reactor spent fuel storage pool, Decontamination, Sump and rinsing collection etc.
C	**Organic Liquid**	Typically less than $0.3m^3$	Scintillation solutions, Oil (from pumps etc), Extraction solvent etc.
D	**Compactable Solid**	Typically less than $20m^3$	Paper, Cardboard, Plastics, Rubber, Gloves etc.
E	**Non-Compactable Solid**	Typically less than $5m^3$	Glassware, metallic items, scrap etc. Disused sealed sources are included is a separate waste stream
F	**Ion Exchange Resins**	Typically less than $0.5m^3$	Research reactor tank and spent fuel storage pool, as secondary waste from treatment by ion exchange etc.
G	**Sludge**	Typically less than $0.5m^3$	Secondary waste from evaporation and chemical treatment etc.
H	**Disused Sealed Source - Short Lived Isotope (half- life ≤30 y)**	Large variation of number of sources, for the reference case 20 should be used	Medical, industrial and research applications etc.
J	**Disused Sealed Source - Long Lived Isotope (half-life > 30 y)**	Large variation of number of sources, for the reference case 20 should be used	Medical, industrial and research applications etc.
K	**Biological (Carcasses)**	Typically up to $0.5m^3$	Medical applications and research. Type: Animal carcasses, tissues and body fluids
L	**High Activity Disused Sealed Source**	Typically 1 or 2 sources per year	Medical, industrial and research applications etc.

The waste stream and process matrix in Table II identifies the waste processing technologies or “process modules” that are most appropriate for use by these Member States and the matrix correlates those processes with the waste streams identified in Table I.

Table II Waste Stream and Process Matrix

		Liquid and West Solid Waste						Solid Waste			
Cross Ref.	**Waste Stream**	Chemical Treatment	Ion Exchange	Reverse Osmosis	Cross-flow Filtration	Filtration	Solidification	Encapsulation	Low Force Compaction	Unshielded Booth	Mobile Hot Cell
A	Low Volume Aqueous Liquid						A6				
B	High Volume Aqueous Liquid	B1	B2	B3	B4	B5	B6				
C	Organic Liquid				B4	B5	A6				
D	Compactable Solid								D2	D3	
E	Non-Compactable Solid							E1		D3	
F	Ion Exchange Resins						A6				
G	Sludge						A6				
H	Disused Sealed Source - Short Lived Isotope (half- life ≤30 y)							E1		D3	
J	Disused Sealed Source - Long Lived Isotope (half-life > 30 y)							E1		D3	
K	Biological (Carcasses)							E1			
L	High Activity Disused Sealed Source										F1

It should be noted that each waste stream has the letter designator in the left hand column that was used in the waste stream descriptions table in the previous section. Similarly, each process module is identified with both the waste stream letter designator and a process numeric designator (e.g. process module A6 is waste stream A, process module 6, which designates the “Solidification” processing technology).

From the Waste Stream and Process Matrix, the individual process modules have been summarised in the table below, identifying the principle 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 spent sealed sources and animal carcasses. Therefore, it is not necessary to have a different process module for each waste stream. Table III summarises which waste streams each process module may be suitable for:

Table III Summary of Process Modules and their Application to Waste Streams

No.	Process Module	Waste Stream
A6	**Solidification** - Cementation of limited quantities of liquid waste within small containers (typically < 20 litres).	Sludge (small volumes) Low Volume Aqueous Liquid Ion Exchange Media (small volumes) **Also:** Organic Liquid
B1	**Chemical Treatment -** Batch treatment (typically < 500 litres) of aqueous liquid to adjust pH or decontaminate by precipitation of radionuclides.	High Volume Aqueous Liquid
B2	**Ion Exchange -** Batch treatment (typically < 500 litres) of aqueous liquid to decontaminate by removal of soluble radionuclides by ion exchange.	High Volume Aqueous Liquid
B3	**Reverse Osmosis -** Batch treatment (typically < 500 litres) of aqueous liquid to decontaminate by removal of soluble and insoluble radionuclides by reverse osmosis.	High Volume Aqueous Liquid
B4	**Membrane Filtration -** Batch treatment (typically < 500 litres) of aqueous liquid to decontaminate by removal of soluble and insoluble radionuclides by membrane filtration.	High Volume Aqueous Liquid **Also:** Organic Liquid
B5	**Filtration -** Batch treatment (typically < 500 litres) of aqueous liquid to decontaminate by removal of solids by cartridge filtration.	High Volume Aqueous Liquid **Also:** Organic Liquid
B6	**Solidification –** In-drum cementation of liquid or sludge waste to produce a solid waste product.	High Volume Aqueous Liquid **Also:** Sludge (large volumes) Ion Exchange Media (large volumes)
D2	**Low-Force Compaction -** In drum compaction of "soft" compactable waste to reduce waste volume.	Compressible/Compactable Solid
D3	**Unshielded Booth -** Enclosure for manual sorting and segregating solid waste prior to further processing or conditioning.	Compressible/Compactable Solid **Also:** Non-Compactable Solid Disused Sealed Source (low dose rates)
E1	**Encapsulation –** Encapsulation of waste within a cement grout.	Non-Compactable Solid **Also:** Disused Sealed Source
F1	**Mobile Hot Cell -** Special shielded cell for the dismantling and repackaging of high activity sealed sources.	High Activity Disused Sealed Sources

DESIGN AND SPECIFICATION INFORMATION FOR PROCESS MODULES

A key part of the Design Engineering Package is the provision of design and specification information for each of the process modules identified in Table III. This information is provided in two parts:

- Separate specification sheets that are divided into General Module Specifications and Interface Specifications.
- More detailed Module Specifications.

The aim of these specifications is to enable the user to determine their requirements, specify those requirements to allow the procurement of the appropriate process modules, to install those process modules and to eventually operate those process modules. The content of each of the different specifications is outlined below.

General Module Specifications

General Module Specifications are presented for each of the waste process modules. These provide a functional specification of the module with a short description of the process(es), advantages, disadvantages, order of magnitude costs, design life, commissioning requirements etc. Much of the information presented in the more detailed Module Specifications is developed from these General Module Specifications. However, the General Module Specifications do contain additional supplementary information including:

- Order of magnitude equipment costs.
- Advantages and disadvantages of the process.
- Identification of potential suppliers.

Interface Specifications

There is an Interface Specification for each module. This identifies the requirements such as services (power, water, air), lighting, drains, HVAC, communications. Again, this information supplements the information presented in the detailed Module Specifications.

Detailed Module Specifications

Design and specification information for each of the process modules is presented within the detailed module specifications. The information is provided in the following sections:

- A basis of design identifying the key parameters and assumptions used in determining the design of the process module.
- A schematic Process Flow Diagram to illustrate the process module where appropriate (see Figure 1).
- 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 process modules or module equipment (where available) or simple models (see Figure 2) to illustrate a possible arrangement of the module.

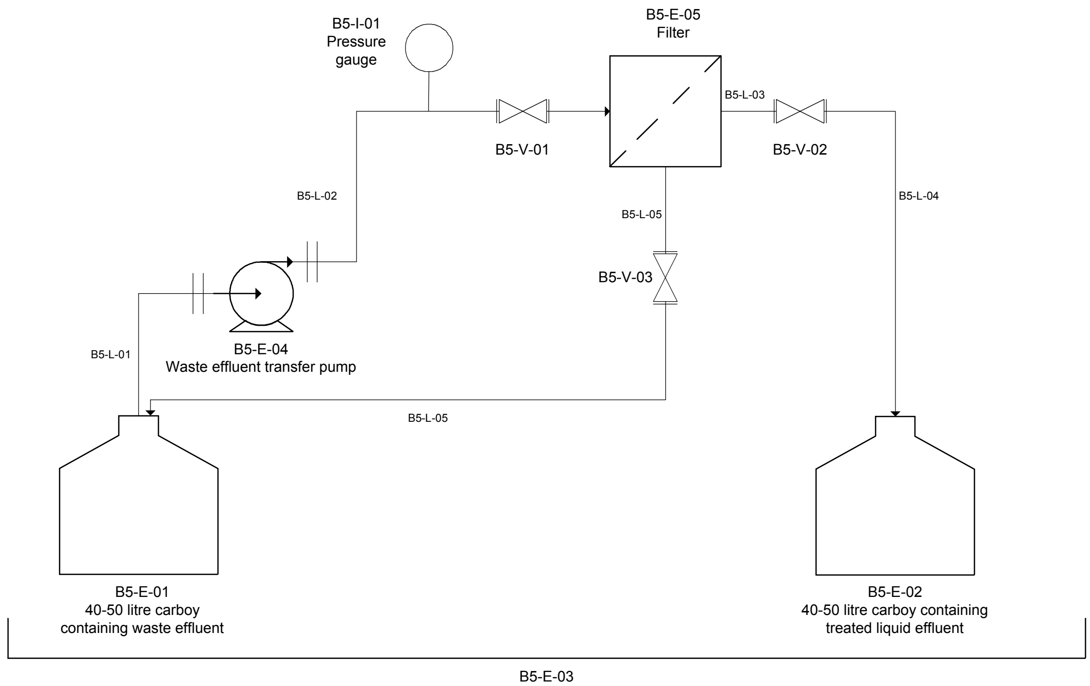

Figure 1 Example of Process Module Flow Diagram (Module B5 - Simple Filtration)

Figure 2 Example of Model of a Process Module (Module B5 - Simple Filtration)

- 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 pre-requisites prior to start of operation.

FLOWCHARTS FOR SELECTION OF APPROPRIATE PROCESSING MODULES

In order to provide guidance in determining which is the most appropriate waste processing technology to apply to a particular waste stream a series of waste management decision charts have been developed. The flowcharts present a logical framework for consideration of key decisions/questions that need to be addressed in order to select the most appropriate option for processing of waste. Each flowchart is accompanied by text that expands upon the individual decisions to be made in progressing down through the flowchart.

There are seven flowcharts that provide guidance on:

- Radioactive Waste Management Strategy.
- Radioactive Waste Categorization.
- Radioactive Sources Waste Management - This flowchart considers the management of spent radiation sources depending upon their half-life.
- Solid Waste Management - This flowchart considers the sorting and segregation of solid waste into a number of discrete categories depending upon the waste characteristics so that it can then be treated appropriately by in-drum compaction or by encapsulation.
- Low Volume Liquid Waste Management - This flowchart recommends the use of solidification for low volumes of aqueous waste including small quantities of aqueous sludges and ion exchange materials.
- High Volume Liquid Waste Management - This flowchart considers the characteristics of the aqueous waste, particularly the nature of the radioactive contamination in order to select the most appropriate processing technology.
- Organic Liquid Waste Management - This flowchart considers the nature of the radioactive contamination of the low volume aqueous waste and, unless significant decontamination can be achieved by filtration then recommends the use of solidification.

The flowcharts are, to a large extent, self explanatory. The reader is guided through the flowcharts depending on their answers to questions at decision points. Although the answers are simple “Yes” or No”, a great deal of effort may be required to gather information, analyse and review it and then make the “Yes/No” decision. Guidance is provided within the Design Engineering Package on using the flowcharts and making the decisions at each stage. Additional guidance is available from the IAEA and other IAEA publications.

TECHNICAL PROCUREMENT SPECIFICATIONS FOR DESIGN AND CONSTRUCTION SERVICES

A technical specification for one process module is provided to illustrate the topics that need to be covered within a technical specification and how this information can be obtained. The information to prepare such a specification is largely available within the process module specifications in the Design Engineering Package.

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 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 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.

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 the 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, health physics staff, laboratory for analysis, monitoring equipment, and consumables such as waste containers and filters.

TYPES AND QUANTITIES OF CONDITIONED WASTE PACKAGES FOR STORAGE

The second part of the Design Engineering Package document is concerned with the interim storage of conditioned waste packages pending disposal. The packaged waste arises from the processing and conditioning of the different waste types identified in Table I. It is expected that wastes requiring storage will be packaged as follows:

- General solid and liquid wastes conditioned into 200-litre drums
- Disused sealed sources in their shielded transport and storage containers and overpacked into 200 litre drums

In principle 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 relatively small numbers of radiation sources. In this case the disused sealed sources may be sealed in smaller packages (e.g. cans) and stored within cabinets.

The types and quantities of conditioned waste packages for storage are described below by reference to:

- the number of waste packages;
- the Waste Package Characteristics i.e. size and weight of packages and their radiological characteristics.

Number of Packages

Not all of the waste streams identified in Table I will be generated by all Members States and not necessarily at the indicated rates of generation. Typical packaged waste volumes could vary from 1 or 2 drums per year up approximately 30-40 drums produced each year. In addition Member States may have quantities of historical or legacy waste to be conditioned, packaged and stored. Member States also need to consider expected future use of nuclear materials and the impact that will have on future waste generation and subsequent waste storage requirements.

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 storage needs are to be provided from the start, or whether it can be expanded over a period of time.

Waste Package Characteristics

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

Size/weight of packages **-** The majority of packages are based upon the 200-litre drum. Typical dimensions are 610 mm (OD) and 880 mm (high). 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 shielded containers that have been overpacked into 200 litre drum could weigh 500 kg.

Radiological characteristics **-** As the wastes have originated from the waste processing facility/modules it can be assumed that:

- 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 store to allow store operations and ensure operator dose rates are ALARA.
- the drums are clean i.e. they are sealed and free of external contamination when received.

STORAGE MODULES FOR CONDITIONED WASTE AND DISUSED SEALED RADIATION SOURCES

Brief Description of the Storage Modules

A wide variety of storage concepts are available and these were reviewed in the Design Engineering Package and a number were recommended for application in the WPSF. Each of the storage options are outlined below:

Storage cabinet – Security cabinets and safes are ideal for 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 materials are being used such as a hospital or research facility. Cabinets are lockable and therefore provide a degree of security. Although not suitable for storage of waste in 200 litre drums, they are suitable for storage of small waste packages and spent radiation sources.

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 litre drums). A number of proprietary designs are available.

Dedicated storage 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.

ISO freight container - 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.

Purpose built storage 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 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 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 ground storage facility - In ground concrete bunkers or trenches have been widely used for storage of 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.

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.

FLOWCHARTS FOR SELECTION OF APPROPRIATE STORAGE MODULES

The storage decision flowcharts in the Design Engineering Package provide further guidance on the selection of the most appropriate storage option(s). The flowcharts present a logical framework for consideration of key decisions/questions that need to be addressed in order to select the most appropriate option for storage of waste. Each flowchart is accompanied by text that expands upon the individual decisions to be made in progressing down through the flowchart.

The flowcharts provide guidance on:

- Storage strategy
- Store type selection
- Ventilation Requirements
- Shielding requirements
- Mechanical handling requirements
- Implementation of storage facility project

The flowcharts are, to a large extent, self explanatory. The reader is guided through the flowcharts depending on their answers to questions at decision points. Although the answers are simple “Yes” or No”, a great deal of effort may be required to gather information, analyse and review it and then make the “Yes/No” decision. Guidance is provided within the Design Engineering Package on using the flowcharts and making the decisions at each stage. Additional guidance is available from the IAEA and from other IAEA publications.

DESIGN AND SPECIFICATION INFORMATION FOR STORAGE MODULES

A key part of the Design Engineering Package is the provision of design and specification information for each of the storage modules identified above. This information is provided in descriptions of each of the storage modules 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. For each waste storage type the descriptions provide guidance on a range of topics that will need to be considered and specified in the storage module procurement specification.

SUMMARY

The Design Engineering Package enables users to select the optimum waste processing and storage modules to meet their needs, and to specify the requirements for procurement of individual modules and their integration into a waste processing and storage facility.

The Design Engineering Package is planned for publication by the IAEA in 2012 and is presented as:

- A Design Engineering Package Summary document.
- A supporting CD that contains:
    - Process module general specifications.
    - Process module interface specifications.
    - Design Engineering Package for process modules.
    - Sample technical specifications for design and construction of modular processing facility.
    - Design Engineering Package for storage modules.

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