Modular Design of Processing and Storage Facilities for Small Volumes of L & IL Radioactive Waste and Disused Sealed Radioactive Sources

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Waste Technology Section (WTS)
Division of Nuclear Fuel Cycle and Waste Technology
Radioactive waste in generated in Member States from:

- Nuclear power plants
- Nuclear Fuel cycle facilities
- Research reactors
- Nuclear applications, including DSRS
- Installations & equipment to be decommissioned
Waste management steps

- **Pre-Disposal**
  - Waste
    - Pre-Treatment
    - Treatment
    - Conditioning
    - Storage
    - Disposal

**Pre-Disposal**:
- Collection
- Characterization
- Segregation
- Chemical/physical adjustment
- Decontamination

**Treatment**:
- Volume reduction
- Radionuclide removal
- Change of composition

**Conditioning**:
- Immobilization
- Packaging
- Over-packing

**Storage**:
- Placement in licensed facility
- Monitoring
- Retrieval

**Disposal**:
- Placement in licensed facility
- No intention of retrieval
Existing reference designs to address the needs of developing MSs with low volumes of RW and DSRS

- Reference design for a centralized waste processing and storage facility (CWPSF)
  IAEA-TECDOC-776 (1994)

- Reference design for a centralized spent sealed sources facility (CSSSF)
  IAEA-TECDOC-806 (1995)
Reference design for a CWPSF (1/3)

• Targeted at MSs producing small but significant quantities liquid and solid wastes
• Design basis:
  • Aqueous waste: 100 m$^3$/y
  • Solid waste: 90 m$^3$/y
• Processing facility:
  • Chemical precipitation for aqueous waste
  • Low force in-drum compaction for solid waste
  • In-drum cementation in 200 L steel drums
• Storage facility:
  • 3000 drums total @300 drums/y
Reference design for a CWPSF (2/3)

- Two separate buildings (5 m high)
  - Process & support functions – 29 m x 28 m
  - Storage – 39 m x 26 m
- 3-Volume reference design package prepared by AEA Technology (UK)
  - Process flow diagram
  - Engineering line diagrams for ventilation
  - Building layouts and architectural drawings
  - Equipment, specifications with performance data, etc
  - Cost data
- The reference design package itself was not published
Reference design for a CWPSF (3/3)
Reference design for a CSSSF (1/2)

• Targeted at MSs with small amounts of DSRS and other solid waste from nuclear applications

• Design basis:
  • Sources with activity < 10 TBq (270 Ci) in their housing or suitable shielding
  • No handling of unshielded, high activity sources

• Conditioning:
  • In-drum cementation in 200 L steel drums

• Storage:
  • 110 drums total
Reference design for a CSSSF (2/2)

• Two buildings
  • Main building (conditioning & support functions) – 18 m x 14 m
  • Storage building – 7 m x 11 m

• 2-Volume reference design package prepared by AEA Technology (UK)
  • Layout and construction details
  • Safety assessment
  • Operating procedures
  • Quality assurance
  • Treatment of leaking or contaminated sources
  • Cost data

• The reference design package itself was not published
Present work on modular design

• Targeted at MSs with very small quantities of solid and liquid waste from nuclear applications and research

• Design basis (based on MSs input during TM in 2006):
  - ~10 m³/y aqueous waste
  - ~25 m³/y solid waste
  - ~1 m³/y wet solids
  - ~20 each of DSRS-SL and -LL

• Modular concept is chosen to provide maximum flexibility

• Processing:
  - A variety of modules depending on type and quantity of waste

• Storage:
  - A variety of modules depending on number of packages, duration and conditions of storage, etc

• Entire design package to be published
Processing
Key features of modular design

• Processing facility designs based on a set of modules for different functions
• Each module constructed independently
• Modules can be skid mounted
  — Simplifies installation and future re-location
  — Allows modules to be built and tested in factory
  — Only final connection of services (e.g. power, water) required by end-user
• Combination of modules to meet the required functions (waste streams, pre-disposal steps)
• Interfaces defined
• Advantages:
  — Flexibility in addressing RWM needs
  — Economical optimisation
IAEA Design Engineering Package for Processing Modules

- Waste streams
- Waste processing modules
- Waste management decision flowcharts
- Module specifications
- Process module integration guidance
- Example technical specifications for procurement
Waste streams considered

1. Low volume aqueous waste
2. High volume aqueous waste
3. Organic liquid
4. Compactable solid
5. Non-Compactable solid
6. Ion exchange resin
7. Sludge
8. DSRS-SL
9. DSRS-LL
10. Biological
11. SHARS
Process modules

1. Module A6 – Solidification
2. Module B1 – Chemical treatment
4. Module B3 – Reverse Osmosis
5. Module B4 – Cross-flow Filtration
6. Module B5 – Filtration
7. Module B6 – Solidification
8. Module D2 – Low-force Compaction
9. Module D3 – Unshielded booth
10. Module E1 – Encapsulation
11. Module L1 – Hot Cell (SHARS)
<table>
<thead>
<tr>
<th>Ref #</th>
<th>Waste stream</th>
<th>Liquid and Wet Solid Waste</th>
<th>Solid Waste</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Chemical Treatment</td>
<td>Ion Exch</td>
</tr>
<tr>
<td>A</td>
<td>Low Vol Aq Liq</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>High Vol Aq Liq</td>
<td>B1</td>
<td>B2</td>
</tr>
<tr>
<td>C</td>
<td>Organic Liq</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Compactable Solid</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>Non-Compactable Solid</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>Ion Exch Resins</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>Sludge</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>Disused Sealed Source - Short Lived</td>
<td></td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>Disused Sealed Source - Long Lived</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>Biological (Carcasses)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>High Activity Sealed Source</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Waste Management Decision Flowcharts

1. Radioactive waste management strategy
2. Radioactive waste categorization
3. Sources waste management
4. Solid waste management
5. Low volume liquid waste management
6. High volume liquid waste management
7. Organic liquid waste management
Example of flowchart questions

High Volume Liquid Waste Management

- Is there sufficient volume to process immediately?
- Is a liquid waste discharge route with defined CFA available?
- Can the liquid be decontaminated sufficiently by treatment to allow it to meet the discharge CFA?
- Does the liquid contain trace oils and solvents?
- Is the activity mainly insoluble?
- Does the liquid waste have a very complex chemical and radionuclide composition?
- Do the soluble radionuclides have insoluble hydroxides?
- Does the liquid waste have a high dissolved salt content?
- Does the liquid waste have a low pH?
Module specifications

• **General**
  — To define the functional requirements, key features, design life, etc

• **Basis of design**
  — To identify the key parameters and assumptions used in determining the design of the process module

• **Process Flow Diagram (PFD)**
  — To illustrate the process module

• **Equipment lists**
  — To identify the main equipment items, valves, piping and instrumentation

• **Equipment description**
  — To provide further details on the major equipment items
Module specifications (contd.)

• Photographs of similar process modules or module equipment or simple models
  — To illustrate a possible arrangement of the module

• Facility requirements
  — To identify the requirements that need to be taken into account in incorporating the process module into a facility

• Process description and operation
  — To provide further details on how the module will be operated including pre-requisites prior to start of operation

• Interface requirements
  — To define the need for services (power, water, air), lighting, drains, HVAC, communications
  — Integration with other process modules – downstream or upstream
An example of process module design

Chemical treatment
Chemical Treatment Module

Key functions:

• Treat aqueous waste in batches
• Produce a small volume of sludge containing the radionuclides
• Discharge of bulk volume of the aqueous waste either immediately, or after further "polishing"
Liquid Waste Characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total liquid vol.</td>
<td>0.5 – 10 m³ per year</td>
</tr>
<tr>
<td>Timing</td>
<td>Arrives periodically in batches of about 50 litres.</td>
</tr>
<tr>
<td>Peak treatment rates</td>
<td>100 litres for each batch</td>
</tr>
<tr>
<td>Feed activity</td>
<td>Low level</td>
</tr>
<tr>
<td>Physical form</td>
<td>Liquid, mainly aqueous but could have small quantities of oils or other immiscible species.</td>
</tr>
<tr>
<td>Solids content</td>
<td>Could contain particulates</td>
</tr>
<tr>
<td>Chemical content</td>
<td>No significant chemical content except potential for presence of small quantities of complexing agents.</td>
</tr>
</tbody>
</table>

Discharge requirements

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discharge activity</td>
<td>Decontamination factor between 10 and 100 assumed.</td>
</tr>
<tr>
<td>pH</td>
<td>pH 6-9 assumed</td>
</tr>
<tr>
<td>Other constituents</td>
<td>Sludge separated from aqueous stream.</td>
</tr>
</tbody>
</table>

Services Availability

<table>
<thead>
<tr>
<th>Services</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Services</td>
<td>The designs shall identify options for connections to existing services or the need for dedicated services.</td>
</tr>
<tr>
<td>Water</td>
<td>Required</td>
</tr>
<tr>
<td>Power</td>
<td>Required</td>
</tr>
<tr>
<td>Building heating</td>
<td>Required if temperatures likely to fall below 5°C.</td>
</tr>
<tr>
<td>HVAC</td>
<td>Not required</td>
</tr>
<tr>
<td>Chemical reagents</td>
<td>Required</td>
</tr>
<tr>
<td>Drainage</td>
<td>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 e.g. the module transfer pump.</td>
</tr>
</tbody>
</table>
Chemical Treatment Module – Model picture
Chemical Treatment – Large and Small facilities

100 m³/batch

100 L/batch
Other examples of processing modules

- Filtration
- Ion exchange
- Cross flow filtration
- Reverse Osmosis
- Solidification
- Unshielded booth
Process module integration

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

• Minimising 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 un-conditioned or incompletely treated waste because waste streams are processed from their raw form to final conditioned form in one campaign.
Examples of module integration

- Chemical treatment
- Filtration
- Ion exchange
- Solid waste sorting
- Encapsulation
Example of module integration

- Chemical treatment
- Cross-flow filtration
- Ion exchange
- Solidification of sludge and IX media
Storage
Waste package types

• The majority are based on 200-litre waste drums
• Typical dimensions: 610 mm (OD) x 880 mm (high).
• Drum weight typically between 50kg (in-drum compacted soft waste) and 400 kg for encapsulated and solidified wastes.
• In good condition, with a protective coating
• Low radiation dose rates to allow contact handling
• Drums are clean i.e. sealed and free of external contamination
• Drum handling by manual or electric lift trucks
Standard drums for storage

Typical mild steel drum with clamp lid.

Mild steel drum with bolted lid.

Stainless Steel Drum.
## Number of Waste Packages

<table>
<thead>
<tr>
<th>Waste Stream</th>
<th>Annual Quantity to be Processed</th>
<th>Estimated Annual Conditioned Waste Volume for Reference Design</th>
<th>Equivalent Number of 200-litre Drums per Annum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Volume Aqueous Liquid</td>
<td>Typically up to 0.5 m³, for the reference design, 0.1 m³ should be used</td>
<td>200-litres</td>
<td>1</td>
</tr>
<tr>
<td>High Volume Aqueous Liquid</td>
<td>Typically in the range 0.5 -10 m³, for the reference case 5 m³ should be used</td>
<td>10 m³ if directly solidified. If bulk volume is treated and discharged then 500 litres of conditioned residue.</td>
<td>3 to 50</td>
</tr>
<tr>
<td>Organic Liquid</td>
<td>Typically less than 0.3 m³, for the reference case 0.1 m³ should be used</td>
<td>1 m³ if directly solidified.</td>
<td>5</td>
</tr>
<tr>
<td>Compactable</td>
<td>Typically less than 20 m³, for the reference case 5 m³ should be used</td>
<td>1 m³ after compaction</td>
<td>5</td>
</tr>
<tr>
<td>Non-Compactable</td>
<td>Typically less than 5 m³, for the reference case 1 m³ should be used</td>
<td>1 m³ when encapsulated</td>
<td>5</td>
</tr>
<tr>
<td>Waste Stream</td>
<td>Annual Quantity to be Processed</td>
<td>Estimated Annual Conditioned Waste Volume for Reference Design</td>
<td>Equivalent Number of 200-litre Drums per Annum</td>
</tr>
<tr>
<td>--------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>Ion Exchange Resins</td>
<td>Typically less than 0.5 m³, for the reference case 0.1 m³ should be used</td>
<td>250-litres when encapsulated</td>
<td>1 to 2</td>
</tr>
<tr>
<td>Sludge</td>
<td>Typically less than 0.5 m³, for the reference case 0.1 m³ should be used</td>
<td>200-litres when encapsulated</td>
<td>1</td>
</tr>
<tr>
<td>Disused Sealed Source - Short Lived Isotope (&lt;30 Years)</td>
<td>Large variation of number of sources, for the reference case 20 should be used</td>
<td>Depends on physical size of source in shielded container. Assumed 1 to 4 m³ when encapsulated</td>
<td>5 to 20</td>
</tr>
<tr>
<td>Disused Sealed Source - Long Lived Isotope</td>
<td>Large variation of number of sources, for the reference case 20 should be used</td>
<td>Depends on physical size of source in shielded container. Assumed 1 to 4 m³ when encapsulated</td>
<td>5 to 20</td>
</tr>
<tr>
<td>Biological (Carcasses)</td>
<td>Typically up to 0.5 m³, for the reference case 0.1 m³ should be used</td>
<td>Assumed 400-litres when encapsulated</td>
<td>2</td>
</tr>
<tr>
<td>Waste and Disused Sources Suitable for Decay Storage</td>
<td>Typically less than 0.5 m³ of solid and liquid waste and less than 10 disused sources, for the reference case 0.2 m³ of solid and liquid waste and 5 disused sources should be used</td>
<td>Interim decay storage</td>
<td>1 for solid waste 1 for liquid waste 1 for sealed sources</td>
</tr>
</tbody>
</table>
Key functions of store

— To provide safe and secure storage of conditioned radioactive waste packages pending disposal to a suitable repository. Safety includes the operators who will access the store for operational duties and the public.

— To provide 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 repository

— To provide security to prevent inadvertent or malicious entry to the store
Available options for storage

- Shielded cabinet
- Concrete container
- ISO Freight container
- Dedicated room
- Below ground vault
- Purpose built industrial building
- Existing building
Some examples of store design options

**Shielded cabinet**

- Ideal for storage of small waste packages in small quantities
- Can be located within an existing facility
- Can be locked to provide security
Concrete container

- Widely used as transport, storage and disposal containers.
- Particularly suitable for higher dose rate waste packages as the box provides shielding.
- Most, if not all designs have a removable lid for loading waste packages.
- Requires a crane and grab for handling waste packages and removal of the lid.
- Adds complexity and cost to drum handling.
ISO freight container

• Widely available throughout the world
• Container Safety Convention certification.
• In wind and water tight condition.
• Fitted with a steel floor (or steel cladding of the existing wooden floor, sealed to the walls) to provide a decontaminable surface.
• Finished with a good paint finish outside and inside.
• Fitted with lock boxes on the doors to improve security.
Purpose designed storage building (1)
In situ reinforced concrete framed building with walls and flat roof
also made of concrete  *(Warm, arid climate)*
Purpose designed storage building (2)
In situ reinforced concrete framed building with concrete walls and pitched roof to improve water run-off (*Warm, humid climate*).
Purpose designed storage building (3)
Steel framed, metal clad and thermally insulated building with pitched roof (*Cold climate*).
Selection of Technical Options for Storage

Decision Flowcharts:

• Storage Strategy
• Store type selection
• Ventilation requirements
• Shielding requirements
• Mechanical handling requirements
• Implementation of storage facility project
Store type selection

- Is the total waste inventory and classification known for storage in a new facility?
- Are high activity radiation sources to be stored?
- Are the waste packages small and few in number?
- Is the total anticipated inventory of waste packages < 20 drums?
- Is the typical annual volume of waste received > 50 drums/year?
- Is anticipated period of storage > 10 years?
- Are the waste packages to be retrieved and/or inspected periodically?
Ventilation Requirements

• Do local environmental conditions involve extended periods of high relative humidity?
• Can waste be packaged within stainless steel drums?
• Are volatile nuclides or hazardous gases likely to be released?
• Is ventilation required to reduce the exposure?
• Can the necessary ventilation be achieved by natural means?
Shielding requirements

• Are waste package surface dose rates acceptable for contact handling?
• Are dose rates from operating the store within regulatory requirements?
• Are dose rates from operating the store ALARA?
Mechanical Handling Requirements

• Can the waste package be safely handled manually?
• Does the size and quantity of waste packages require powered handling facilities?
• Is electrical power available to support powered handling equipment?
Store specifications

- Overall Functional Requirement
- Scope
- Location of the Storage Building
- Wastes Description
  - Size/weight of packages
  - Radiological characteristics
  - Number of Packages
  - Period of Storage
- Operational Requirements (Normal and Abnormal Conditions)
- Information and Records
Store specifications (contd.)

• Building Functional Requirements
  – Overall construction
  – Ground Conditions
  – Building Base Slab/Floor
  – Building Structure
  – Finishes
  – Shielding
  – Access
  – Modular construction
  – Waste Drum/Package Stacking
  – Fire protection
Some shielding options
Store specifications (contd.)

- Mechanical Handling Requirements
- Mechanical Equipment Requirements
- Electrical Equipment Requirements
- Environmental Control
- Environmental Conditions
- Seismicity
- HVAC Requirements
- Radiation Safety Requirements
- Industrial Safety Requirements
- Physical Protection / Security Requirements
- Maintenance and Inspection Requirements
- Reliability
- Standards
- Quality Assurance
- Training
Training courses & workshops on Modular WPSF

- Moldova, March 2009
- Armenia, July 2009
- Columbia, Jan 2010
- South Africa, August 2010
Integrated modular WPSF package for MSs with low volumes of RW and DSRS

- **Enable Operator to**
  - select technical options for processing and storage - available
  - prepare technical specifications for procurement - available
  - develop safety case and safety assessment - future work with WES
  - develop operating procedures - future work in WTS
  - prepare a licensing application for design, construction and operation - existing document to be integrated

- **Enable Regulator to**
  - define the requirements for operating license - future work with WES
  - scrutinize and evaluate licensing application prior to granting of license - future work with WES
Thank you for your attention