Mobile processing systems for radioactive waste and disused sealed radioactive sources

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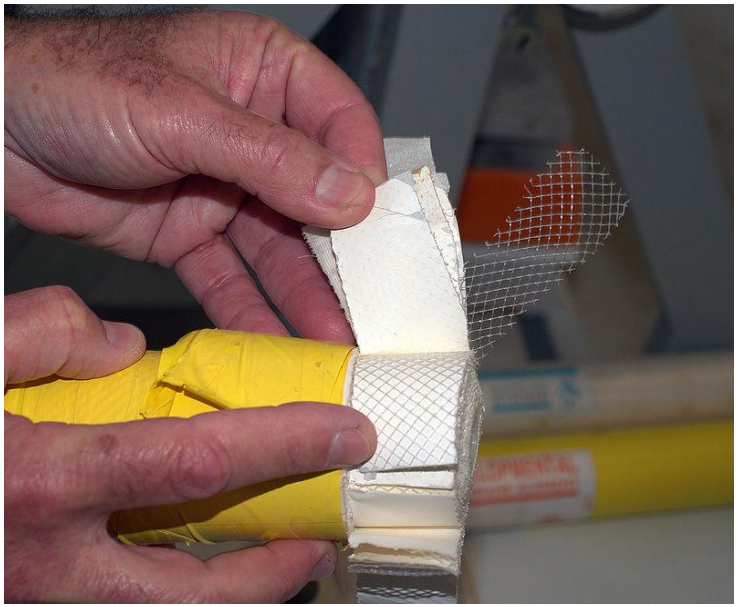
Overview

- Module B3 – Reverse osmosis
- Module B4 – Cross-flow filtration
- Module B5 – Filtration
- Module B6 – Solidification
- **Module D2 – Low force compaction**
- **Module D3 – Unshielded booth**
- **Module L4 – Hot cell**
- **Module E1 – Encapsulation**
- **Processing Module integration**

MODULE B3 - REVERSE OSMOSIS

- **Reverse osmosis** - water molecules are driven through a **spiral RO membrane** under pressure, leaving fine particulates, larger and small molecules and ions on the initial side.
- The **concentrated waste is directed back to the same carboy with** dissolved solid loadings typically 40–50 g/L.
- Removes 90–95% of **soluble components**, including radionuclides
- Reverse osmosis is an option when **surfactants, complexing agents and variety of radionuclides are present**
- The raw effluent must be **pre-filtered before treatment** with a spiral RO filter.
- The permeate may be **suitable for discharge** or require 'polishing' i.e. by ion exchange

REVERSE OSMOSIS MEMBRANE



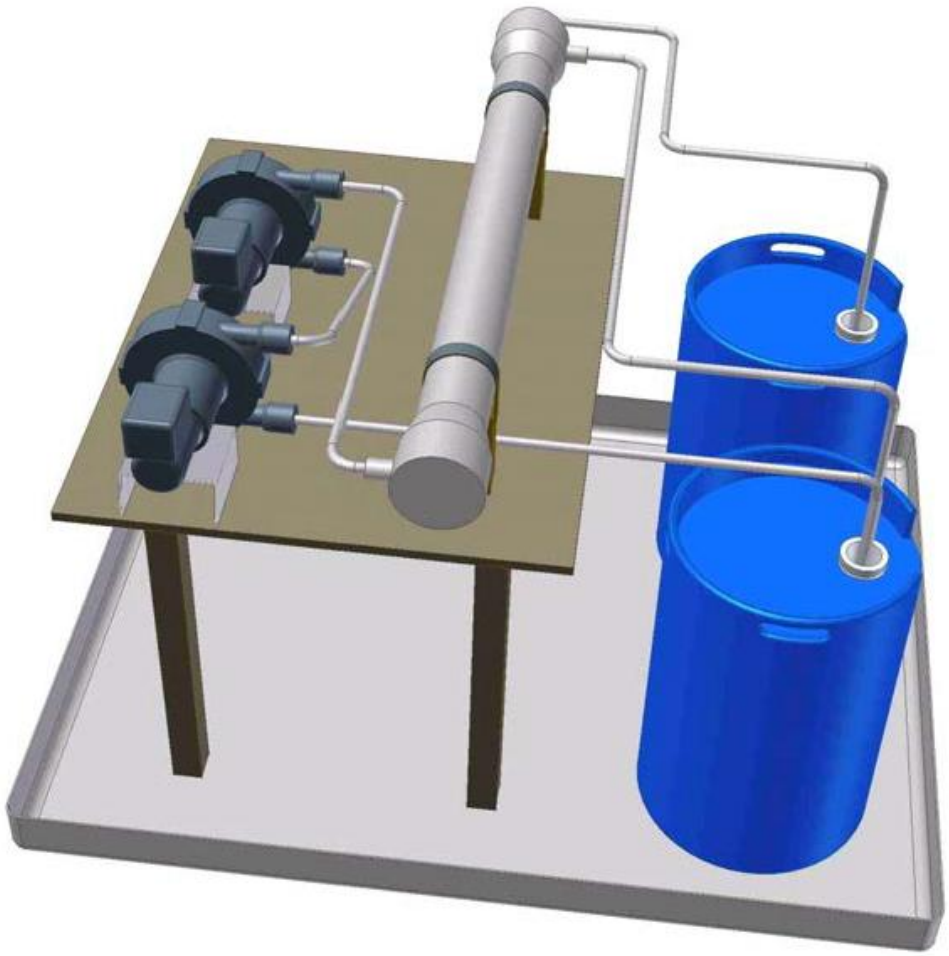
Membrane **allows only water to pass through**.

High pressure on the high concentration side of the membrane, usually **2–17 bar**

RO B3 - Waste feed characteristics

Total liquid **volume**	Typically **0.5–10 m³ per year**, for the ref case 5 m³ per year should be used.
Timing	Arrives periodically in **batches of ~50 L**.
Peak **treatment rates**	Up to **100 L/h**.
Feed **activity** content	**Low levels of activity**, single or multiple radionuclides.
Physical form	Aqueous liquid, no oils or other organic liquids present.
Solids content	Can contain small quantities of fine particulates (size less 0.1 µm).
Chemical content	No oxidizing agents, salt content <25 g/L.

RO B3 – Schematic view



Equipment:

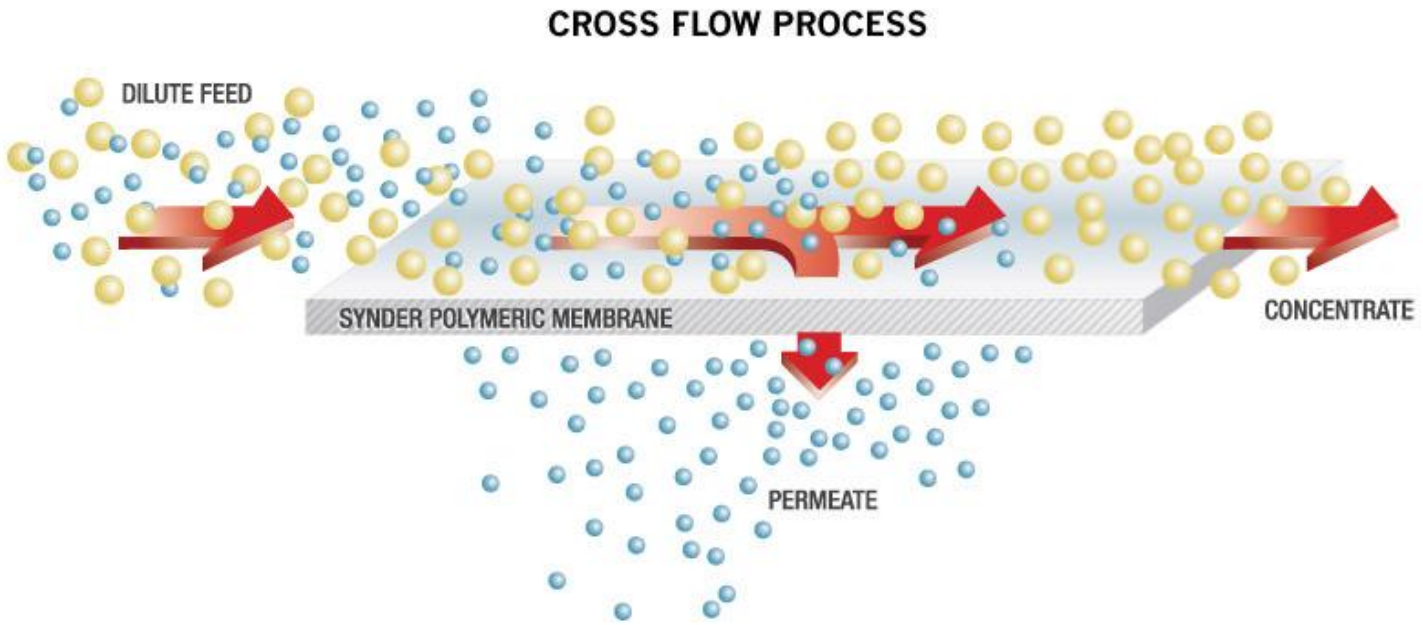
- **Feed container** for the aqueous waste
- **Feed pump**
- **High pressure pump**
- Stainless steel interconnecting **pipe**
- **Receipt container** for treated effluent
- **RO filter** in a stainless steel or plastic housing, equipped with **pressure monitoring instruments**
- The **RO membrane** is made from different **polymeric materials** depending on the required separation characteristics

RO B3 – Considerations

- 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 or cartridge filtering** is recommended
- Once wetted, the RO filter is ready to process aqueous waste and must remain **wet at all times**
- The RO membrane elements **will require replacement typically once per year** depending on usage, the volume of waste and the presence of abrasive solids

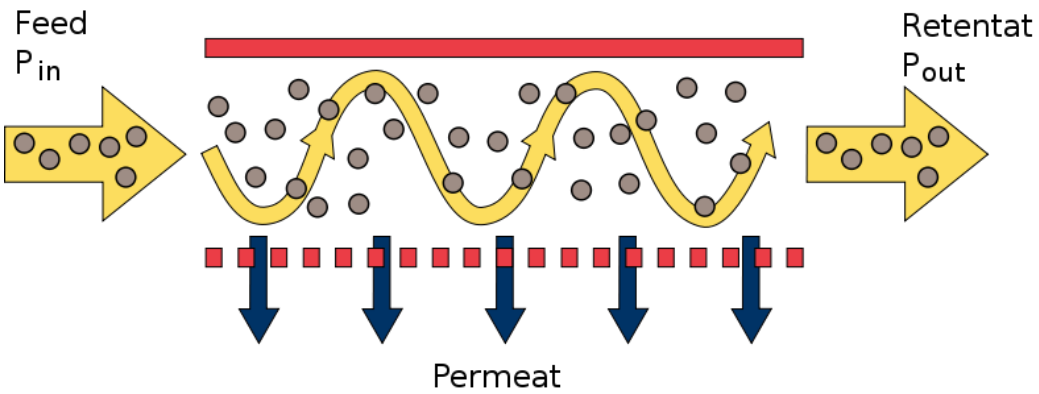
Module B4 – Cross-flow filtration

- In cross-flow filtration the **liquid waste is passed through the filter membrane under pressure (**typically **2–4 bar**)
- The cross-flow membrane **allows only water molecules** through
- Water molecules are driven through the cross-flow membrane **by the pressure gradient**



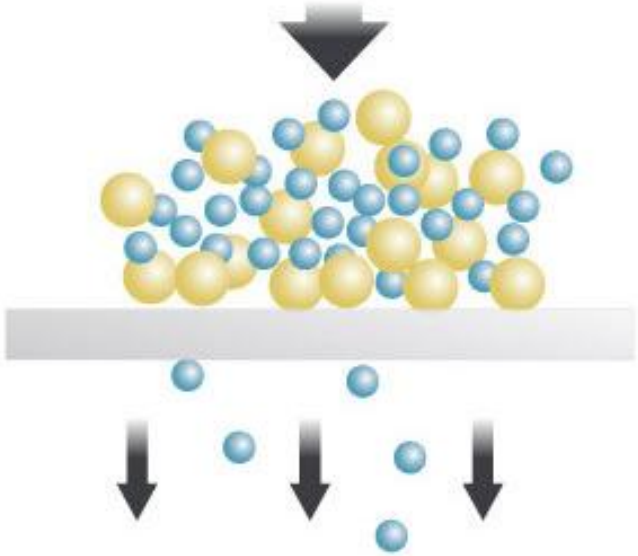
Module B4 – Cross-flow filtration

- Removes **insoluble radionuclide contaminants** from aqueous liquid waste.
- Pumps aqueous waste out of the carboy and passes it **through a cross-flow filter**.
- The **concentrate** is returned back **into the same carboy**
- The **treated liquid** which has been filtered (i.e. permeate) is directed **to another carboy**



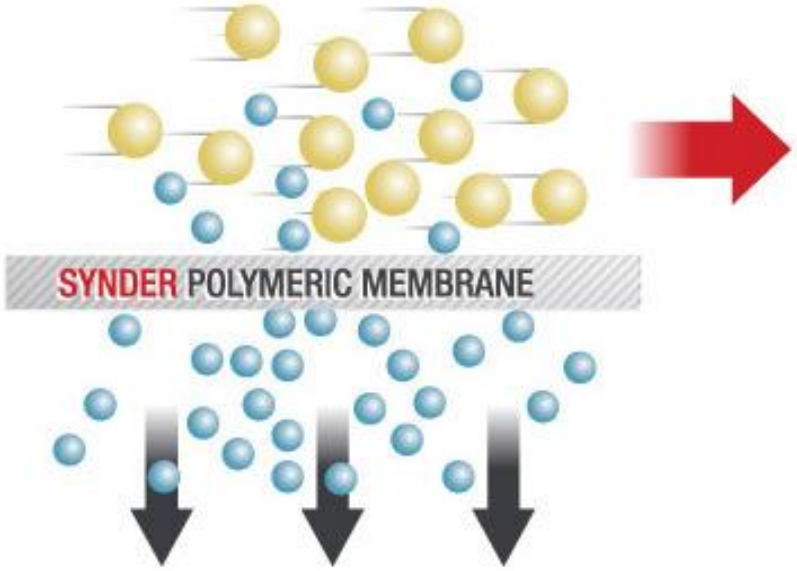
Cross Flow Filtration

CONVENTIONAL FILTRATION



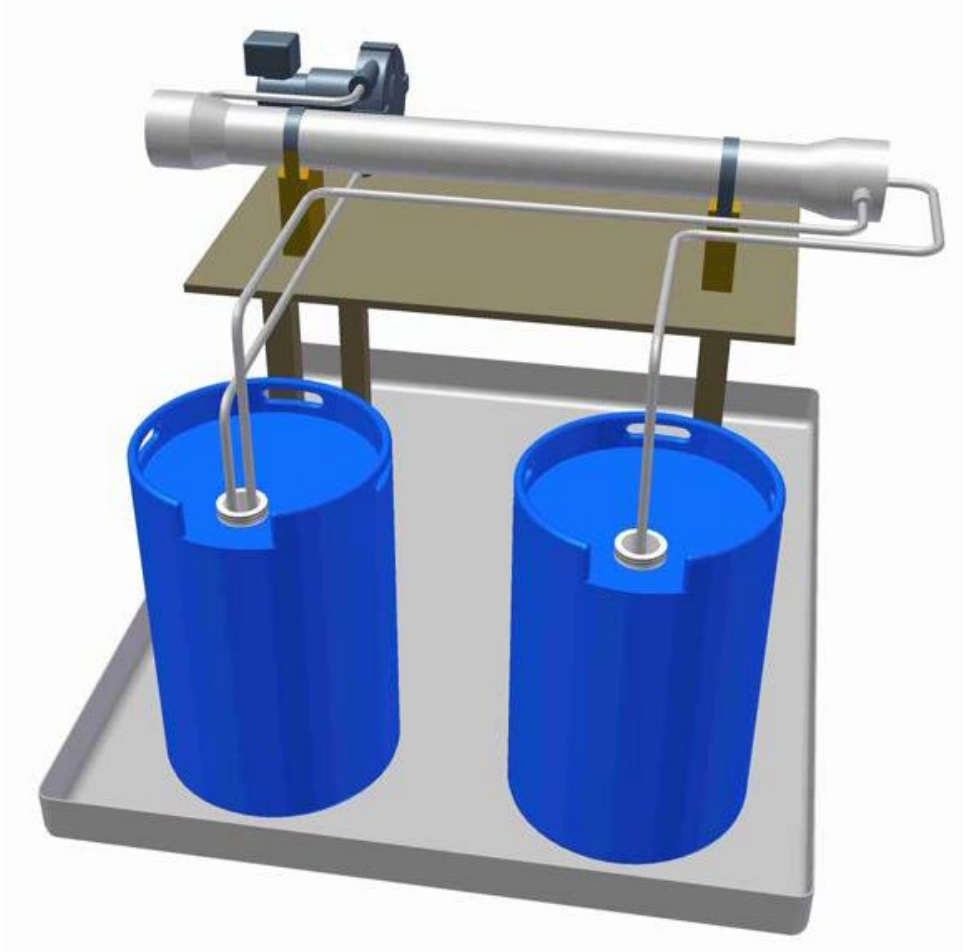
Perpendicular flow causes a quick build up of solids on the membrane surface, which reduces flux.

CROSS FLOW FILTRATION



Cross flow increases permeate passage through the membrane. This greatly improves membrane efficiency.

Module B4 – Cross-flow filtration



Equipment includes:

- **Feed container**
- Cross-flow **membrane**
- Feed **pump**
- **Pressure gauge**
- **Radiation monitor**
- **Container for treated liquid**
- **Tubing** /piping
- Collecting **tray for spillages**

Module B4 – 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

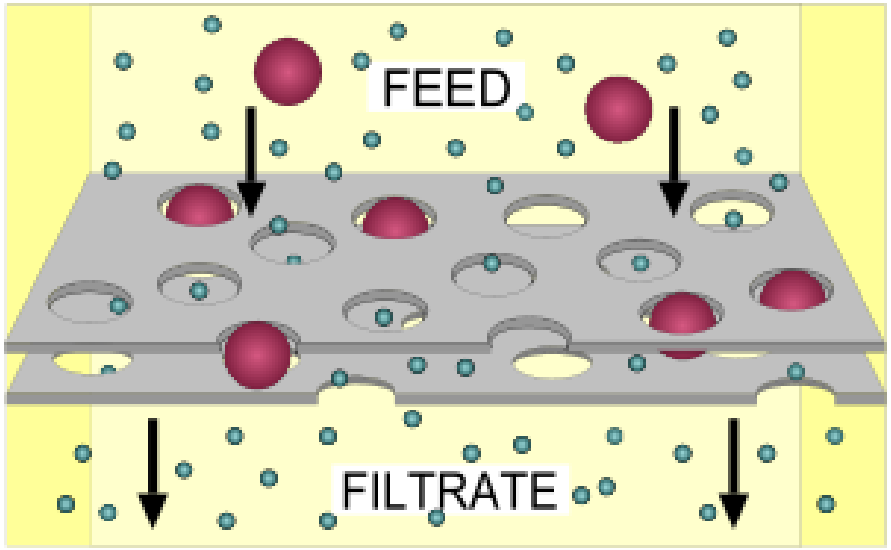
Module B4 – cross flow membrane

- The filter **membrane can be steel, ceramic or graphite**, depending on the required filtration characteristics (ceramic or graphite membranes are fragile)
- Sintered **stainless steel membranes are generally more robust** and so these types of membranes are the **preferred option**
- Membrane **pore size will depend on the nature and content of solids** in the aqueous waste and can only be **established through trials**
- **Smaller pore size** have **higher separation efficiency** but have **low flow-rate**
- The cross-flow filter **will require replacement** during the life of the plant (**typically after five years**) depending on usage, volume of waste treated, presence of abrasive solids and frequency of cleaning

MODULE B5 – Filtration

➢Aims at removing a significant proportion of the **insoluble** radionuclide contaminants from the bulk volume of the aqueous liquid waste. The filtration module is **suitable for the removal of fine particulates (1–100 µm)**. The filtered stream will usually **require further 'polishing'** i.e. by ion exchange

➢The filtration module **pumps aqueous waste** out of the carboy and circulates it **through a filter**. Solid **particles are retained within the filter** and the treated liquid which has been filtered (i.e. **permeate) is directed into a treated waste** carboy.



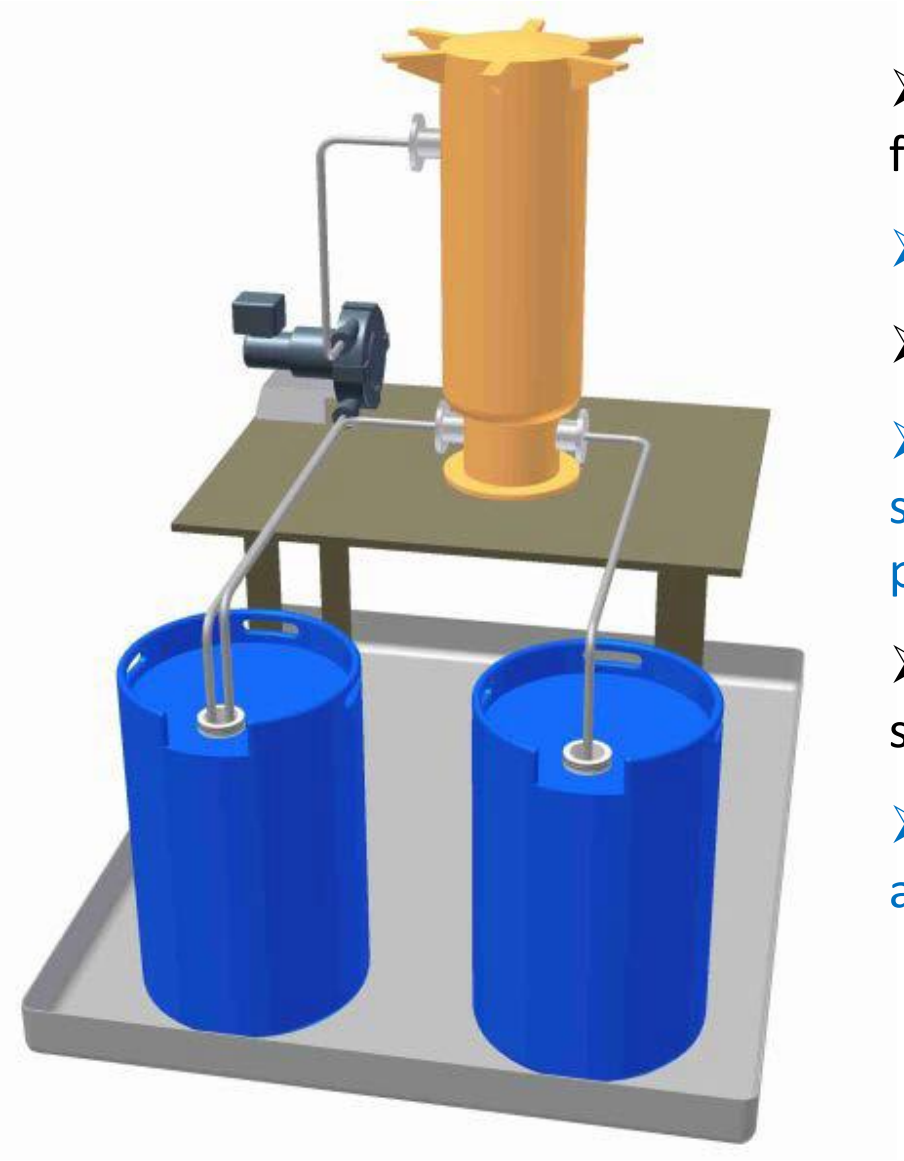
MODULE B5 – Filtration

- 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 to a carboy

- The filter unit and the pump are located within a **drip tray** that provides **containment** in the event **of leaks** or spillages

MODULE B5 – Filtration



- The process module comprises the following:
- A **feed container** for the aqueous waste
- A self-priming **feed pump** (i.e. peristaltic)
- A proprietary **cartridge or bag filter**, in a stainless steel or plastic housing, capable of processing 100 L/h
- A range of **pipe work**, size 15 mm NB in stainless steel or plastic
- A **container to receive** the aqueous waste after passing through the filter

MODULE B5 – Considerations

- **Waste receipt area** with a tray to collect any spillages
- **Manual trolley for moving** containers
- **Hand held radiation monitoring** equipment for monitoring radiation levels
- **Storage area** (on a tray) **for spent filters**.
- Storage in a **bunded area for filtered aqueous waste** (40–50 L carboys)
- **Radiochemical laboratory** for sampling and **analysis the solids content** in both the treated and untreated liquids.
- **Provision of water** for washdown of plant and equipment
- Barriers and/or controls must be in place **to manage the access to the area**
- The operator(s) must wear **appropriate PPE**

MODULE B5 – Considerations

- The filtrate **flow rate will decrease as the filter becomes blocked**
- The **pressure drop** across the filter will **indicate when it needs to be replaced**.
- The **activity** build-up **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 WAC**
- Sample the treated effluent container and **measure the activity to determine the level of decontamination** achieved

Waste streams and processing modules

		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

MODULE B6– SOLIDIFICATION

➢The solidification module will **mix aqueous waste with a pre-tested cement** mixture **in a 200 L steel drum** using a 'lost paddle' mixer.

➢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 to **reduce the risk of the spread of contamination**.

➢Solidification could be **applied to the bulk aqueous waste** volume **or to the concentrated waste arising from**

✓Precipitated **sludge from chemical treatment**

✓**Spent ion exchange resins** from ion exchange treatment

✓Concentrate from **reverse osmosis or cross-flow filtration**

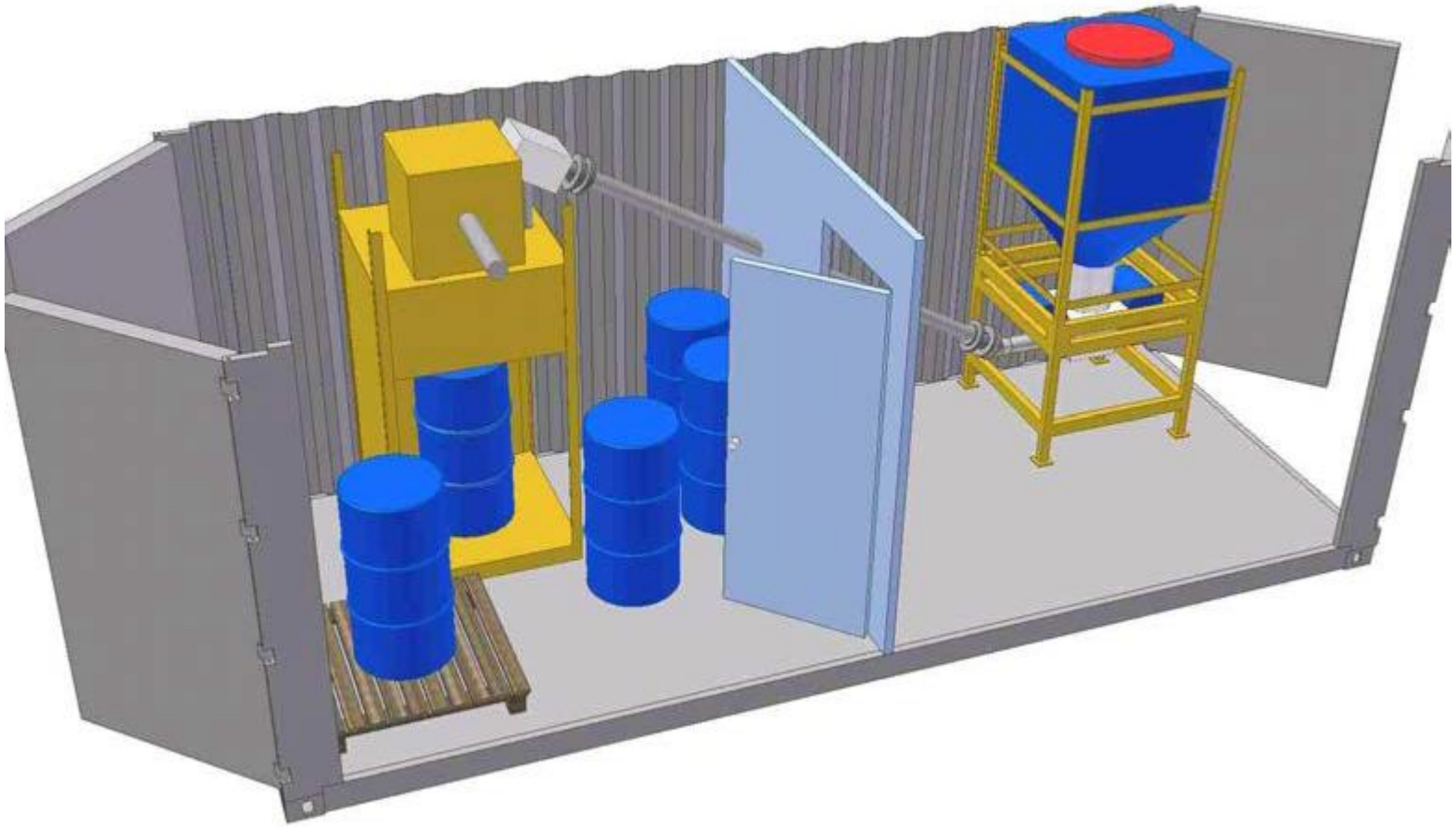
B6 Lost paddle mixer

The paddle is fabricated from mild steel and the drum has locating points welded at the top and bottom to support the paddle in the centre of the drum

MODULE B6–SOLIDIFICATION

The solidification equipment can be **built into a single module to provide containment**.

It will include a **cement powder feed system**, **ventilation** system, a **control station**, etc.



MODULE B6–SOLIDIFICATION

Solidification module at Novi Han repository site, Bulgaria
Source: ww.dprao.bg

MODULE B6 – Facility considerations

- The solidification module **B6 can share equipment with the encapsulation module E1**
- **Laboratory is** required for sampling and analysis of the liquid waste to ensure the **correct waste-cement formulation** is used
- The provision of water for the wash-down of plant and equipment
- **Manual trolley for moving carboys** and empty drums
- **Fork lift** for moving **loaded drums**
- A **curing area** where drums that have been solidified can stand and cure for **typically 24 h**
- **Storage area** for drums, adequate for up to five days of operation

MODULE D2–LOW FORCE COMPACTION

- Reduces the volume of **dry, compactable waste** such as paper and plastic by compressing the waste **in a 200 L drum** so the compressed waste is ready for long term storage at an appropriate storage facility

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

MODULE D2–LOW FORCE COMPACTION

A low force compactor has the **following features**:

- Compaction force can range from **a few tonnes to 40 t**

- **Higher compaction forces** allow the compaction of **empty tins, cartridge filters and plastic** components. The lower force compactor unit will be easier to accommodate inside the unshielded booth (Module D3)

- The low force compaction module **can receive dry, lightweight, pre-sorted waste** in a variety of containers, **typically 200 L steel drums**

- The in-drum low force compactors are **commercially available** and can be purchased direct from the manufacturer

MODULE D2–LOW FORCE COMPACTION

Waste container for compactable waste
200 L steel drums with lids

- Adequate **storage space** will be required for non-compacted and compacted waste
- The compactor shall **operate in conjunction with an unshielded booth** (Module D3) where the waste can be sorted/segregated and placed into 200 L drums
- Ideally, the **compactor would be located within the unshielded booth**
- Filling of the drum may involve **several cycles of filling, compaction and then further filling** to make use of the space created by compaction

MODULE D2– LOW FORCE COMPACTION

40t in-drum compactor at Novi Han repository site, Bulgaria
Source: www.dprao.bg

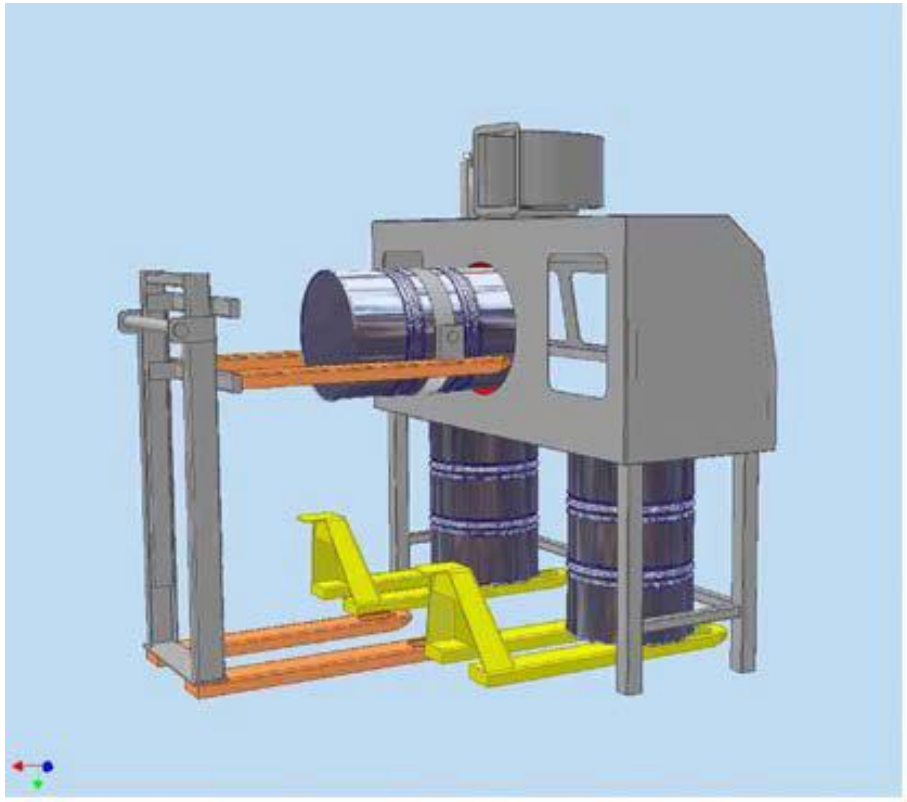
MODULE D2 - Considerations

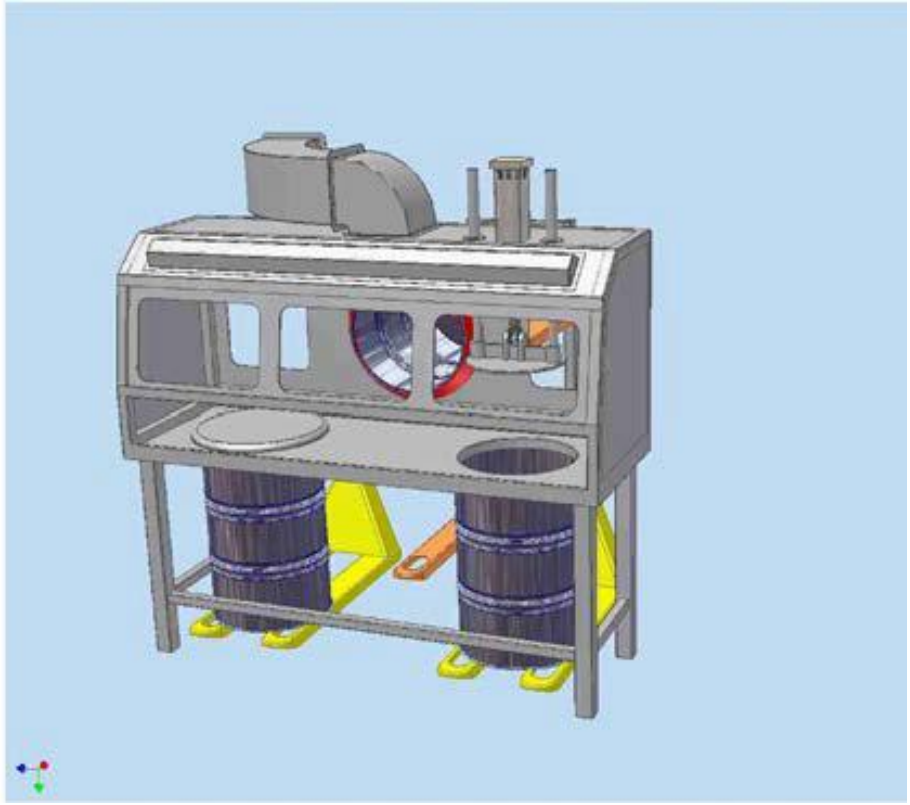
- Waste **has to be sorted** (e.g. in the unshielded booth) to remove non-compactable waste before compaction
- **Pre-sorting** and compaction of waste is **labour intensive**
- There is **risk of airborne contamination** during the compaction, therefore the module requires **ventilation system**
- Operators **have to take swab samples** from the drum after the waste has been compacted to make sure there is **no surface contamination**

MODULE D3–UNSHIELDED BOOTH

- The unshielded booth is **primarily used for 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**
- The booth is a **cabinet fabricated in stainless steel or reinforced plastic**, it has windows and a sash opening for the operator to reach in and handle/sort the solid waste
- The booth has **a horizontal drum loading port** at the rear.
- Typically, it should be possible to **sort and segregate approximately 1 m^3** of compactable waste **each day** or about **five days of operation per year**
- The booth is served by an extract **ventilation system** that provides a degree of contamination control during operation

MODULE D3–UNSHIELDED BOOTH





Model pictures of Module D3–Unshielded booth with in-drum compactor

MODULE D3–UNSHIELDED BOOTH

The unshielded booth includes a cabinet, constructed in stainless steel, painted mild steel or glass reinforced plastic, with the following specifications:

- **Windows** to view the sorting table
- **Openings for operator to put hands** into the cabinet to sort waste
- Ventilation system equipped with HEPA filters and air velocity >0.5 m/s
- **Sorting table** inside the cabinet, in stainless steel, at a comfortable height to work at and with **smooth surfaces for ease of cleaning**
- Inlet **port for unsorted waste**, positioned so that waste can easily be placed onto the sorting table
- **Port to drum, containing sorted compactable waste**, with seal and removable lid to provide airtight connection when not in use
- **Port to drum containing sorted non-compactable waste** with seal and removable lid to provide airtight connection when not in use

MODULE D3 - Disadvantages

- **Labour intensive**
- May **require some pre-sorting** at source, i.e. separate collection **containers for sharp objects**
- There is risk of **airborne contamination**
- **Dose rate** in the area will need to be **monitored** to ensure that dose rates remain acceptable
- **Wet compactable waste** is not suitable for compaction and may require **further treatment to remove moisture** prior to compaction
- **High activity** disused sealed sources are dealt with separately (in Module L4 **- hot cell**)

MODULE L4– HOT CELL

- The handling of **high activity disused sealed sources** requires the use of a **hot cell** equipped with remote handling

- Examples of equipment containing **high activity** sealed radioactive sources include industrial **γ-irradiators, teletherapy equipment**, industrial **radiography equipment**, etc.

- The **hot cell wall acts as a biological shield**, protects operators from ionizing radiation and prevents the spread of contamination

- It is typically **designed to handle** radiation levels up to the equivalent of **1000 Ci (37 TBq) ^{60}Co source at a time**

MODULE L4 - Waste feed 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	While most sources are of relatively low activity, there are **some of high or very high activity**
Physical form	Radioactive material permanently **sealed in a capsule**
Solids content	Source is in **solid form**
Chemical content	**No** significant **chemical** content

MODULE L4 – hot cell facility

Source: www.dprao.bg

MODULE L4 - hot cell facility

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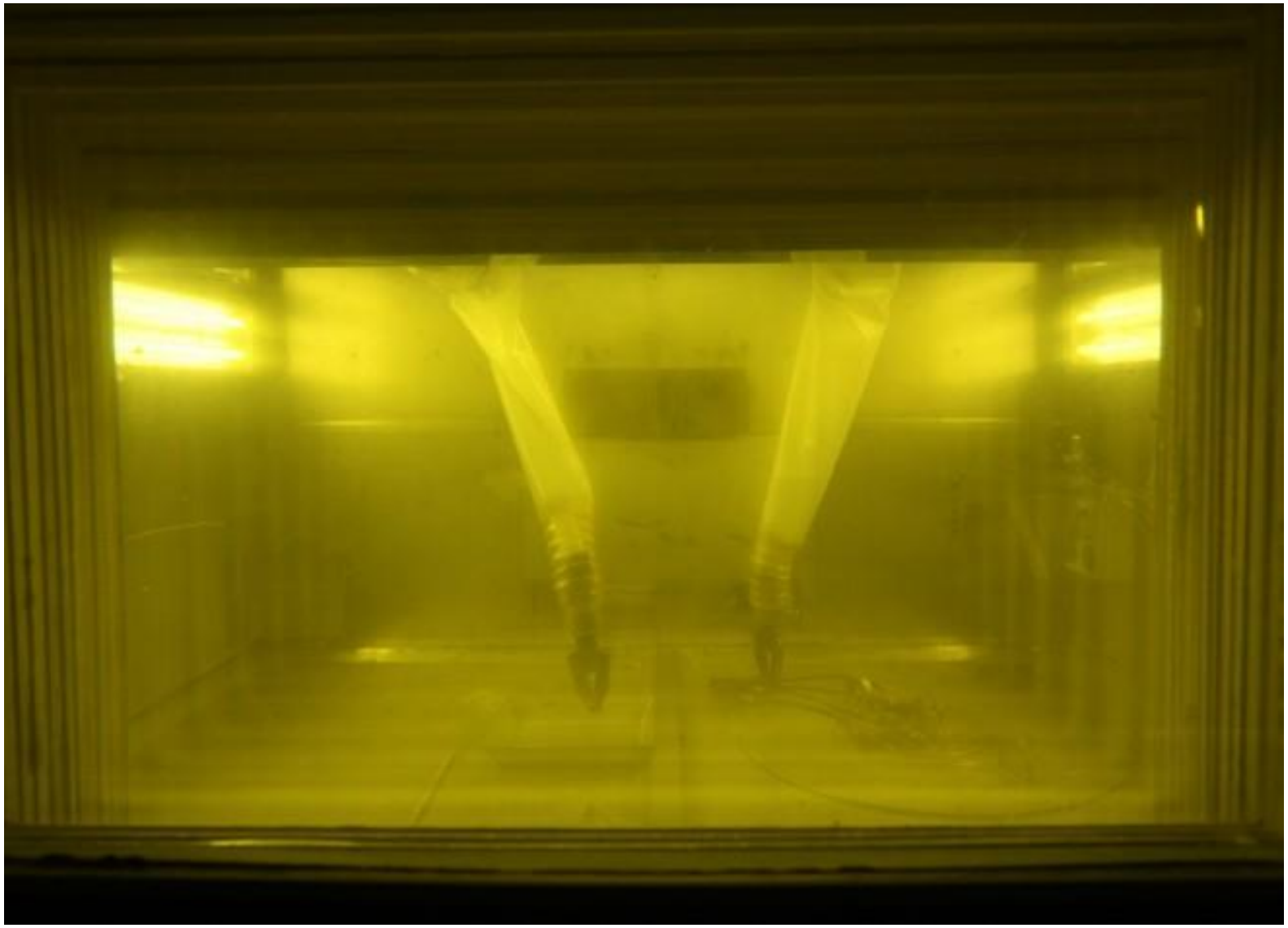
MODULE L4 - hot cell facility



Source: www.dprao.bg

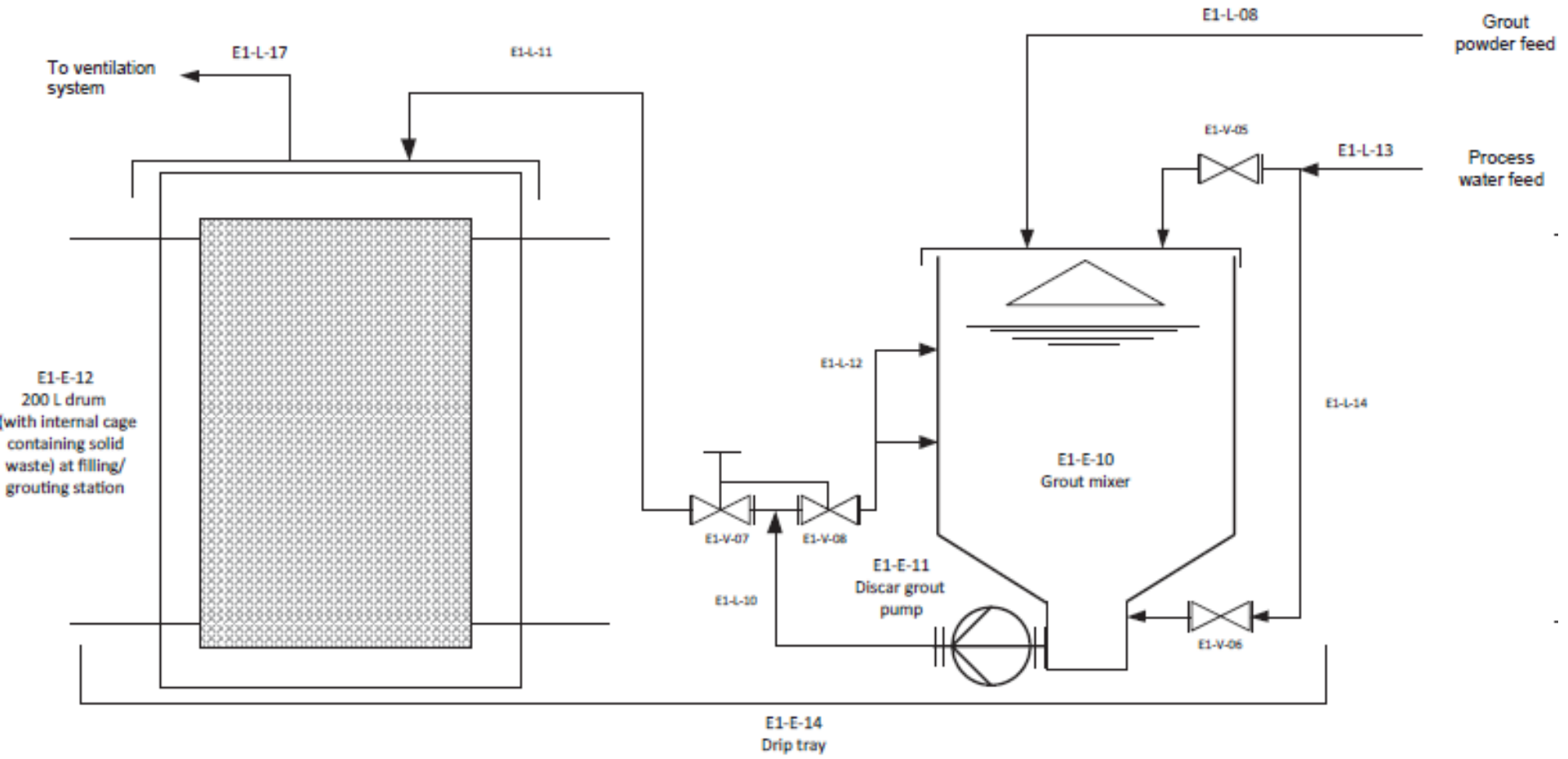
MODULE E1–ENCAPSULATION

- Aim- **immobilisation of solid waste** and its radioactive contamination **by cementation** to prevent dispersion
- The module can be used for the encapsulation of **non-compactable wastes and disused sealed sources**
- The wastes is placed **in 200L drums** and the **cement** grout **added**
- The module will be capable of p**reparing up to five batches of grout per day**, sufficient to encapsulate five 200 L drums per day

MODULE E1–ENCAPSULATION

Typical **grout batch mixer**, able to **mix a single batch** of grout and then **pump it into a 200 L drum** to encapsulate the waste

Encapsulation – schematic view



Encapsulation – Facility considerations

- The storage of **untreated** and **treated** waste should be **in separate areas**. The containers should be **uniquely marked** for easy identification
- 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**
- A **forklift** will be required **for moving grouted containers**, e.g. using a drum grab
- Provision of **water supply** for washdown of plant and equipment

PROCESSING MODULE INTEGRATION

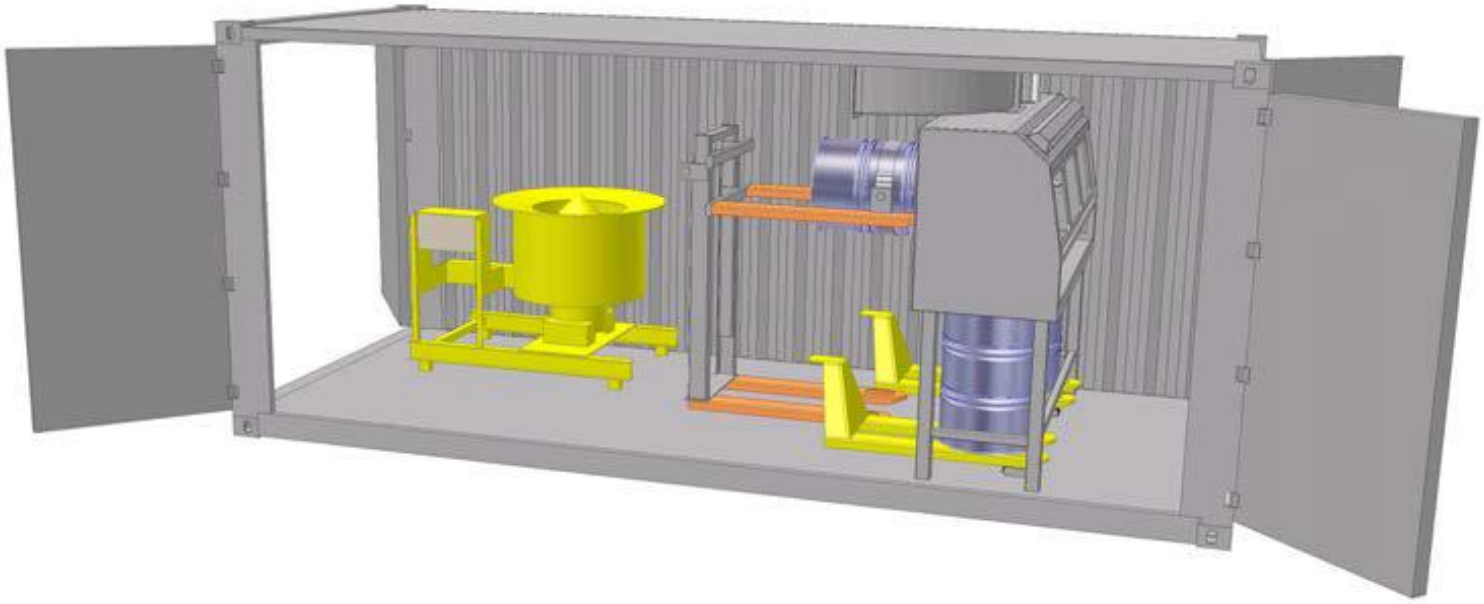
The process modules will **rarely be used in isolation**, instead **two or more process modules** will be needed to manage a waste stream.

For example, to manage **solid radioactive waste** it might require:

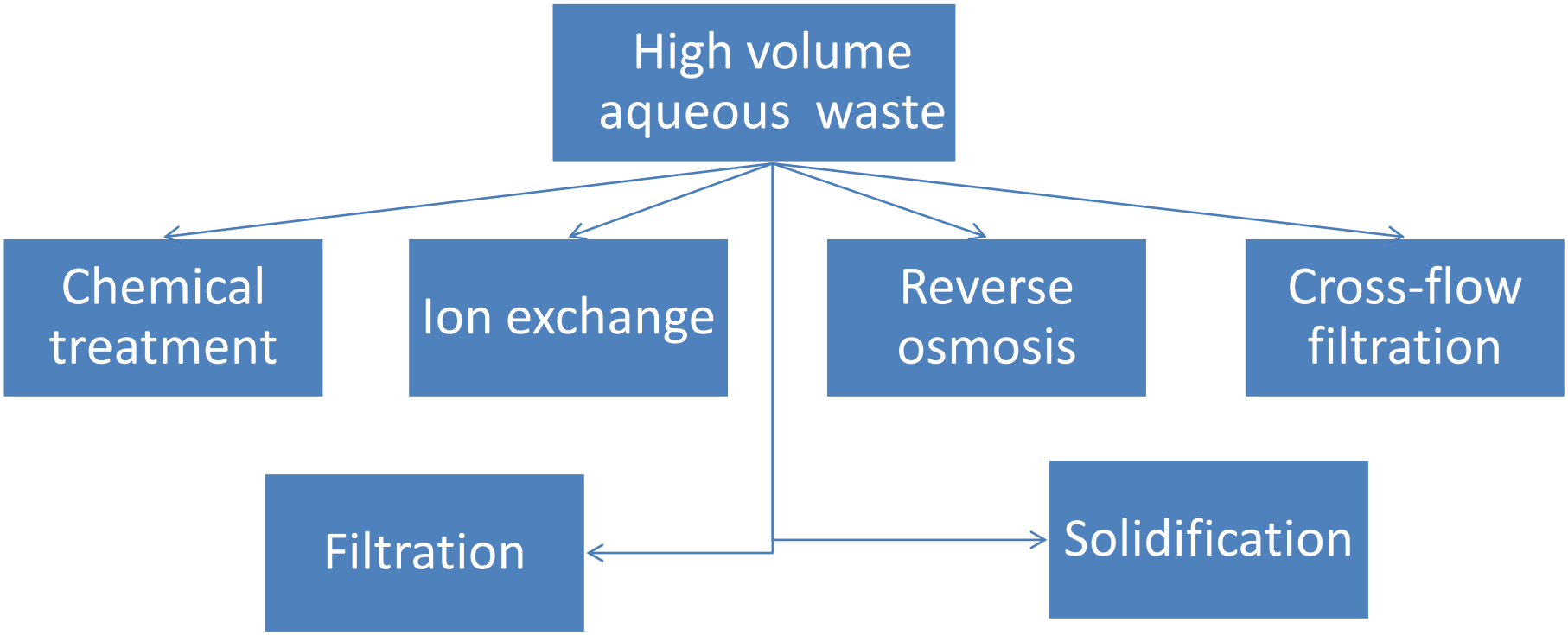
1. **Unshielded booth** to receive, **sort** and segregate the waste into **compactable, non-compactable waste and disused sealed sources**
2. **Low force compaction** to compact the compactable waste into 200 L drums
3. **Solidification module** to encapsulate **non-compactable** waste into 200 L drums.

SOLID WASTE PROCESSING MODULES

- The unshielded booth has **access** to **bring in waste drums**, rotating them horizontally
- From the front side of the booth operator can access the waste drum, remove the lid and **then pull the contents of the drum on to the sorting table** of the booth and **place the waste into the appropriate waste drum**- compactable or non-compactable

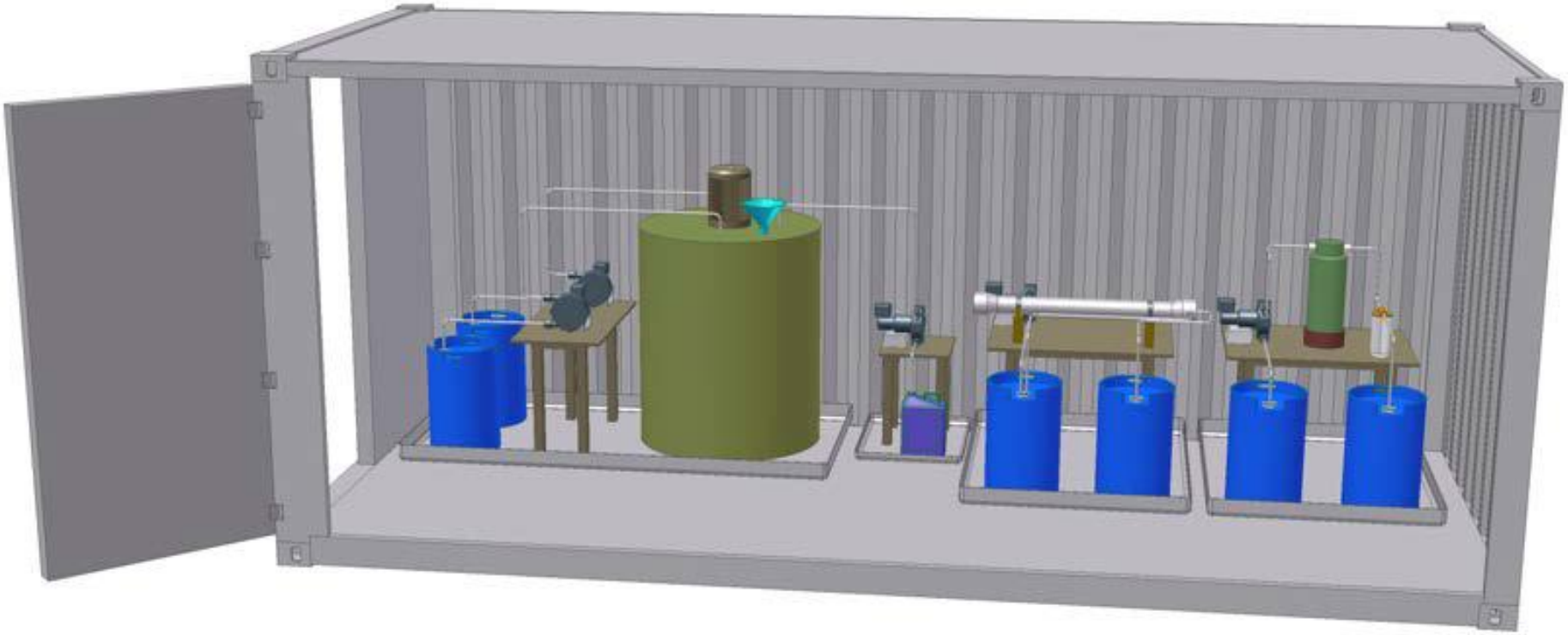


PROCESSING MODULE INTEGRATION



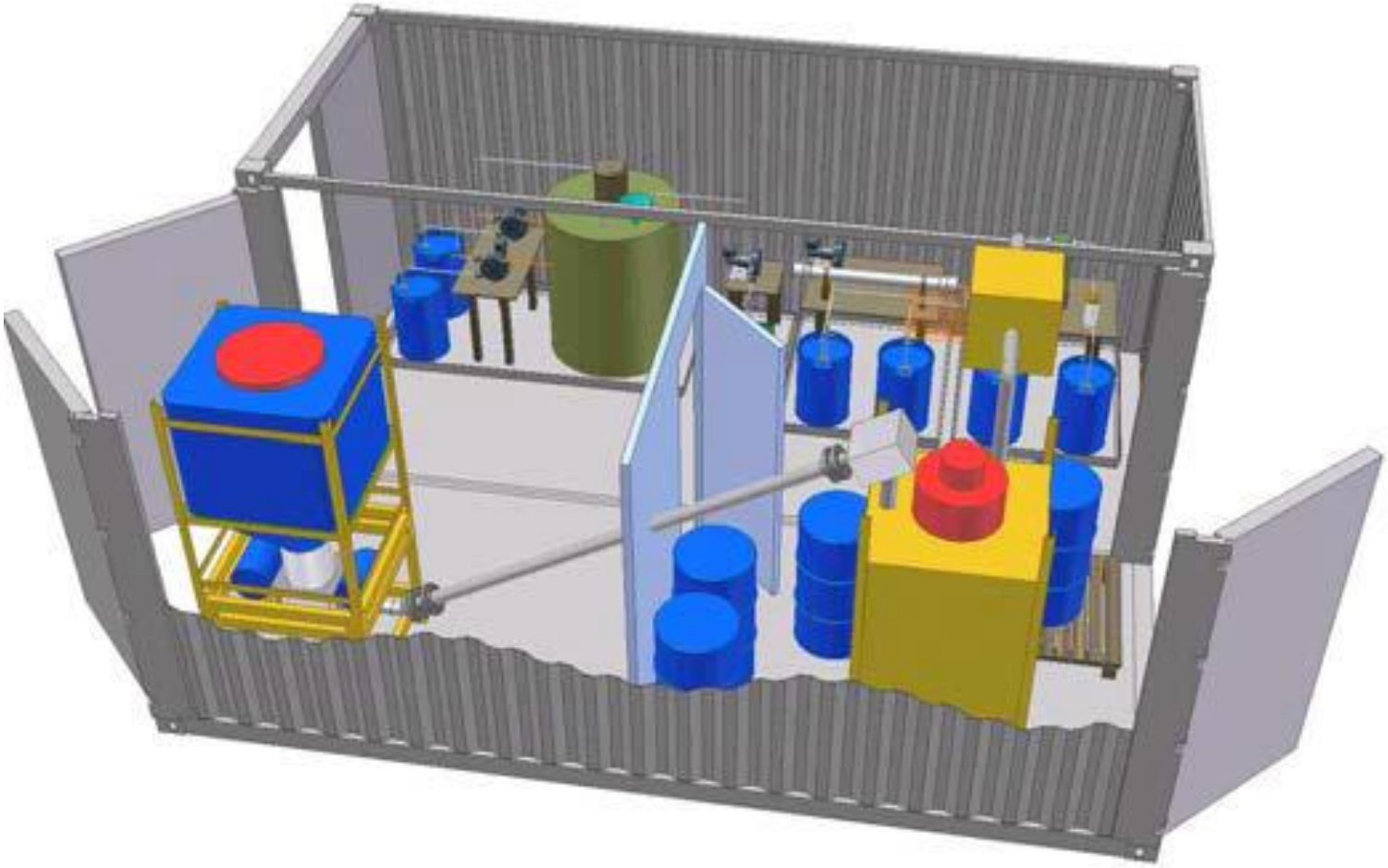
➢**High volume aqueous waste** requires two or more of the following process modules to be integrated: **Chemical treatment, Ion exchange, Reverse osmosis, Cross-flow filtration, Filtration and Solidification**

HIGH VOLUME AQUEOUS WASTE



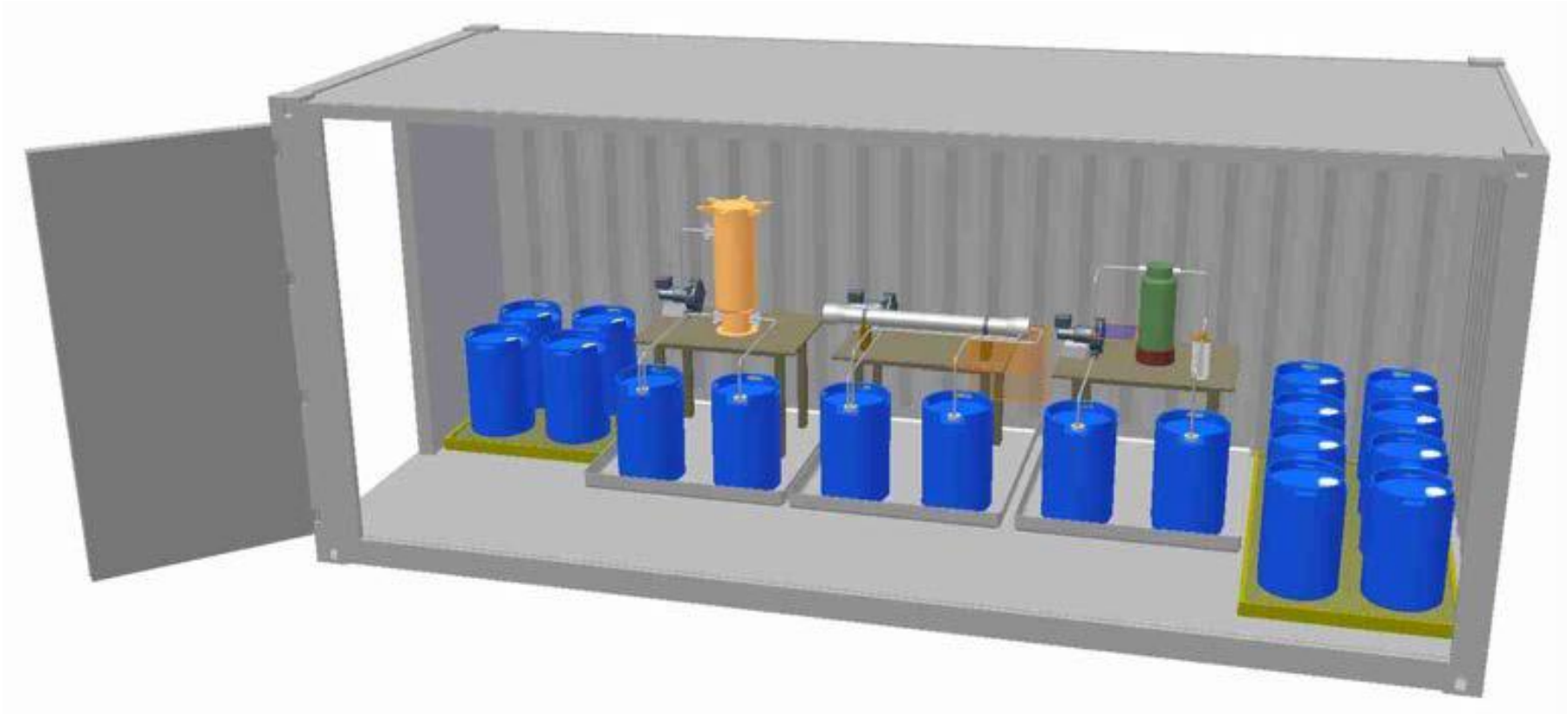
Housing of modules for Chemical treatment, Cross-flow filtration and Ion exchange **within ISO freight container**

HIGH VOLUME AQUEOUS WASTE



Integration of modules for **chemical treatment**, followed by **cross-flow filtration**, **ion exchange** and **solidification** of the precipitated sludge from chemical treatment and spent ion exchanger **within two ISO freight containers**

HIGH VOLUME AQUEOUS WASTE



Same modules - filtration followed by ion exchange **in an ISO freight** container with **storage areas** for waste containers

IAEA
International Atomic Energy Agency

Thank you!
Questions?