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MOBILE PROCESSING SYSTEMS FOR RADIOACTIVE WASTE MANAGEMENT

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The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world''.

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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 to 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.

Radioactive waste is generated from the operation of nuclear power plants, fuel cycle facilities and other nuclear applications. It consists of distinct 'waste types' with a variety of characteristics.

Mobile systems have recently been increasingly deployed for predisposal management of radioactive waste streams (e.g. pretreatment, treatment and conditioning). In addition, considerations of performance, cost and flexibility may render mobile systems attractive for future nuclear facilities.

This publication provides guidance for evaluating and implementing processing technologies in mobile radioactive waste processing applications. It is applicable to major, advanced and small to medium waste management programmes, and can be used for planning and developing waste programme strategies.

The IAEA has produced several publications which describe related technologies and their historical deployment in detail, including applicable waste streams, waste forms, equipment descriptions, and benefits and limitations. That information is generally not replicated in this publication unless it is required as a point of clarification or immediate reference.

The IAEA wishes to express its appreciation to all those individuals who took part in the preparation and publication of this report. At the IAEA, V. Tsyplenkov and Z. Drace of the Division of Nuclear Fuel Cycle and Waste Technology were responsible for the initial work. The IAEA officer responsible for further development of the work and finalization for publication was S.K. Samanta of the same division.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

Radioactive waste is generated during the operation of nuclear power plants, fuel cycle facilities and other nuclear applications. It comprises distinct liquid, solid, gaseous and multiphase waste streams, which have varying physical, chemical and radioactive characteristics. Waste management programmes typically address the management of these wastes from the point of generation through to disposal.

A number of processing technologies are available for pretreatment, treatment and conditioning of these waste streams. The related strategies, technologies and relevant safety issues are described in detail in IAEA publications, including Technical Documents, Technical Report Series, Nuclear Energy Series and IAEA Safety Standards [1–15]. Typically, the technologies are deployed either as permanently installed stationary systems in centralized or on-site waste processing facilities, or in a mobile configuration. Centralized stationary facilities provide a single processing location for multiple users within a State that requires transport of the waste to the facility. Conversely, on-site stationary or mobile systems may provide for the selection and application of the optimum technology for a specific waste stream by bringing the process to the point where the waste is generated. In addition, mobile systems could offer additional flexibility by sharing equipment among multiple generating sites for processing campaigns that vary in duration, from very short periods to several years.

The term ‘mobile processing system’ used in this publication refers to any radioactive waste processing system or component which is designed to be transportable and which is not considered permanently installed [16].

Mobile systems may offer some unique benefits. In some instances, the use of a mobile processing system may be a more desirable option compared with a fixed processing system — especially with regard to technology advancements. For example, deployment of a mobile system that can be readily upgraded or replaced at a comparatively low cost makes mobile technology appear more attractive than upgrades of fixed, permanent systems. Similarly, where there is a potential for frequent waste stream volume or characteristic changes, utilizing mobile processing technology in a modular form that supports efficient capacity upgrades or using it in a campaign based processing strategy could be more cost and performance effective.

Numerous sources were used to develop this publication, including IAEA publications and an international team of radioactive waste management experts. In addition, other recognized industry reports and standards were also consulted [16, 17]. Significant vendor information is also available from various sources and through Internet literature searches.

1.2. OBJECTIVE

The primary objective of this publication is to provide basic information on the utilization of mobile systems in different waste management predisposal steps (e.g. pretreatment, treatment and conditioning) and to introduce methodology for the assessment required to determine the viability of mobile waste processing technology for specific applications.

In addition, this publication provides information to assess accurately mobile systems that employ one or more technologies.

1.3. SCOPE

This publication addresses possible applications of mobile waste processing systems for operational radioactive waste from nuclear power plants, fuel cycle facilities and other radionuclide applications, including industry, research, education and medicine. It describes proven mobile processes that can be used at a nuclear facility, either individually, as components of a more complex configuration for new applications, upgrading, or replacing degraded or dated technology. The assessment methodology includes considerations related to mobile technology selection, application, limitations and benefits, and aids in determining the technical and economic viability of mobile system deployment in lieu of permanent, fixed systems.

This publication is primarily intended for waste management professionals responsible for selecting, designing and deploying waste processing systems. It can also assist regulators responsible for reviewing and licensing mobile waste processing systems and possible bilateral agreements related to sharing such systems.

1.4. STRUCTURE

Section 2 of this publication briefly describes the applicability of mobile waste processing systems, detailing their role, capability, benefits and limitations. It describes a two stage assessment process, which could be used firstly to verify that the processing technology could be applied in a mobile configuration, and secondly for detailed technical screening of the option to utilize a specific mobile technology.

Sections 3–7 provide illustrations and examples of mobile processing systems for pretreatment, treatment, conditioning, combined treatment and conditioning, and waste characterization. Cases on processing solid, liquid, gaseous and multiphase waste streams have been provided to give an idea of the actual application of mobile systems and key screening considerations for comparison with permanently installed (stationary) systems. It should be noted that the descriptions are based on a collection of the best available information to illustrate current practice. Section 8 concludes.

Annexes I and II provide examples of the information and parameters to be used for detailed technical screening and be included in mobile system technical specifications for procurement. The two systems illustrated in greater detail are mobile solid waste supercompaction, and mobile filtration and ion exchange.

1.5. KEY DEFINITIONS

The following is a list of some key definitions taken from the IAEA Safety Glossary [18]:

(a) **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 overpack.
(b) **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.
(c) **Predisposal**: Any waste management steps carried out prior to disposal, such as pretreatment, treatment, conditioning, storage and transport activities.
(d) **Pretreatment**: Any or all of the operations prior to waste treatment, such as collection, segregation, chemical adjustment and decontamination.
(e) **Processing**: Any operation that changes the characteristics of waste, including pretreatment, treatment and conditioning.
(f) **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.
(g) **Treatment**: Operations intended to benefit safety and/or economy by changing the characteristics of the waste. Three basic treatment objectives are:
    (i) Volume reduction;
    (ii) Removal of radionuclides from the waste;
    (iii) 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.
(h) **Volume reduction**: A treatment method that decreases the physical volume of a waste. Typical volume reduction methods are mechanical compaction, incineration and evaporation.
(i) **Waste characterization**: Determination of the physical, chemical and radiological properties of the waste to establish the need for further adjustment, treatment or conditioning, or its suitability for further handling, processing, storage or disposal.

(j) **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.

(k) **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.

2. ASSESSMENT OF THE APPLICABILITY OF MOBILE PROCESSING SYSTEMS

Section 2 provides background information and a method for evaluating specific applications to determine whether a mobile processing system is to be considered for deployment in lieu of a fixed system. It is important to note that the specific details related to each potential process technology and application can be quite different, and that this methodology has to be applied iteratively for initial and subsequent evaluations. It should also be noted that some of the factors included in the decision process are very subjective and cannot be quantitatively defined (e.g. complexity and local societal factors). One, or more, of these factors may affect the outcome of an applicability assessment. In addition, not all of the factors will be applicable to all evaluation cases.

A critical aspect of the decision process is the assessment of risks and how these are understood by the stakeholders. This understanding can be significantly different depending on the deployment mode of technologies (e.g. fixed installation or mobile) and the arrangement for waste management (self-operated or service contracts). For example, a comparison of the safety risks associated with transporting mobile processing equipment to multiple locations versus transporting the waste to a centralized processing facility needs to be made.

2.1. EXAMPLES AND KEY FEATURES OF MOBILE SYSTEMS IN RADIOACTIVE WASTE PROCESSING

Mobile processing systems play an important role in a variety of waste management applications, from processing unique or small quantities of waste to utilization in nuclear power plants and fuel cycle facilities on a large scale. They are being considered in designs of next generation advanced commercial power reactors.

This publication focuses on waste processing technologies that are proven in mobile applications. A list of these technologies is given in Table 1 for quick reference. However, the reader is encouraged to read related reference documents for additional details. The list is not exhaustive, and there could be other existing or emerging mobile processing technologies not addressed in this publication or in the references listed. The methodology for evaluation and selection presented here can, however, be applied to any mobile processing candidate.

2.1.1. Capabilities and benefits

The evaluation process includes considerations of the mobile system’s capabilities, benefits and potential limitations, for comparison with fixed systems. The following illustrates the most notable capabilities, benefits and limitations of mobile systems. The list is not inclusive and, furthermore, it should be noted that considerations of capabilities, benefits and limitations are case specific:

(a) **Technology**: The basic process employed in mobile applications is typically the same as the one used in a fixed or permanent configuration. For example, the process for mobile ion exchange mirrors the one used in permanent installations, regardless of system size or deployment strategy. The most obvious difference lies in the ability to use, replace or relocate mobile equipment with relative ease.

TABLE 1. SUMMARY OF EXAMPLES OF MOBILE PROCESSING TECHNOLOGIES IN USE

	Technology	Waste stream physical phase[a]	Member States with examples of known applications[b]
Pretreatment	Low force compaction	S	Russian Federation, UK, USA
	Mechanical decontamination	S	India, USA
	Chemical neutralization/precipitation	L	USA
Treatment	Soil washing	S	Russian Federation, USA
	Cable insulation separation	S	Germany, USA
	Radioactive oil decontamination	L	Canada, USA
	Filtration	L	Russian Federation, USA
	Filtration and ion exchange	L	India, Russian Federation, UK, USA
	Filtration, membrane and ion exchange	L	Russian Federation
	Selective ion exchange in a nuclide removal system	L	Finland
	Dewatering of spent ion exchange and filtration media	WS	UK, USA
	In-drum drying of liquid and wet solid waste	L, WS	USA
	Off-gas treatment	G	Russian Federation
Conditioning	Encapsulation of disused sealed sources in a metallic matrix	S	Russian Federation
	Solidification (cementation)	L	France, Germany, India, Italy, Russian Federation, Slovakia, UK, USA
	Encapsulation of spent ion exchange resins in polymer binders	WS	France
Combined: treatment and conditioning	Supercompaction	S	Brazil, Canada, Czech Republic, Germany, Italy, UK, USA
	Volume reduction and packaging of activated components	S	USA
	Dismantling and packaging high activity disused sources	S	South Africa, UK
	In situ vitrification of soil	S	Australia, USA
Characterization	Waste characterization systems	S, L	France, Italy, USA

[a] G — gas; L — liquid; S — solid; WS — wet solid.

[b] The list of known applications is not exhaustive — only some examples are presented here.

(b) **Performance**: In most applications, mobile technologies offer the same level of performance (e.g. volume reduction and decontamination factors) as that from a fixed installation of the same capacity. However, the flexibility associated with mobile systems often permits technology upgrades or configuration changes, which can result in performance improvements being more easily achieved. In many instances, mobile technology can also be easily deployed to support revisions to local, regional or national safety and pollution control standards.

(c) **Safety**: The applicable safety standards for mobile equipment vary according to application, and are typically linked to the requirements for surrounding structures, systems and components. In some instances, the safety requirements may be less restrictive (e.g. seismic classification) than those of fixed systems.

(d) **Cost**: In some cases, the cost of using a prefabricated and already licensed mobile system could be less than that associated with the design, regulatory safety evaluation, fabrication, construction and operation of a permanent (fixed) installation (e.g. use of a high capacity mobile supercompactor for periodic short campaigns versus use of a permanently installed supercompactor optimized and operated for annual throughput of generated waste). By introducing a mobile system, the cost of configuration management at permanent systems or structural interfaces could be reduced. In some instances, mobile equipment may be operated and maintained by the service provider, and additional cost benefits may come from the associated reduction in the number of qualified permanent staff members required for process operation. Finally, the ability to deploy mobile systems in multiple applications could reduce the investment, operational and disposition costs through cost sharing between users in either a procurement or lease arrangement.

(e) **Shared use**: Mobile equipment is inherently designed to facilitate movement to alternate locations on-site and off-site. This also enables more effective use of human resources and contributes to an effective sharing of expertise.

(f) **Emergency response**: Some mobile processing systems have the unique advantage of relatively rapid deployment in response to emergencies or as a timely upgrade or replacement for existing technologies.

(g) **Decommissioning and remediation use**: Mobile systems can be applied to decommissioning activities where some wastes would be amenable to treatment and conditioning at the decommissioning site instead of processing at the dedicated location. In most instances, remediation of contaminated soil or radioactive liquid spills can be resolved using mobile systems.

2.1.2. Limitations

There are several aspects to the deployment of mobile technology that may limit its potential:

(a) **Physical arrangement and size**: The physical arrangement and size of mobile units are restricted to support the method of assembly and conveyance (e.g. skid, container and trailer), as well as any containment to protect workers, the public and the local environment, as required by site specific and other local, national or international regulations. Therefore, the number of modules or system components to be transported and the feasibility of accommodating them at the site also need to be considered.

(b) **Transport**: The size and weight need to support transport using commercially available conveyance in accordance with applicable regulations, and may require special permits, approval or licensing.

(c) **Decontamination**: Transport of previously used, radioactively contaminated equipment across regional and international borders increases liability, and may necessitate internal or external equipment decontamination.

(d) **Floor loading**: The system and its operating platform (e.g. skid and trailer), including accumulated, treated or conditioned waste, cannot exceed floor loading limitations, and may require special compaction or other ground stability enhancement measures for outside applications.

(e) **Management of liquid and gaseous releases**: Mobile processing system deployment may require provisions for collecting or monitoring liquid and airborne effluents. This may result in an additional burden related to system design or interface with existing facilities, and, in some instances, may involve areas that are external to facility structures. Specific situations resulting from inadvertent leakage of liquid or gaseous wastes and exhaust from drying operations, among other things, may require unique or complex solutions to be incorporated into the system design and be readily adaptable to a variety of user facilities.

2.2. APPLICABILITY OF MOBILE SYSTEMS: METHODOLOGY FOR ASSESSMENT AND DECISION TO IMPLEMENT

With any deployment of technology in either a fixed or a mobile configuration, a wide variety of factors needs to be carefully considered. It is strongly recommended that the considerations addressed in the evaluation process used in this publication are thoroughly vetted by professionals prior to selecting a specific approach. It is also suggested that the user develops a thorough understanding of the resources required to address technical, regulatory, legal, business and labour issues related to other stakeholders, such as governmental and local agencies, as part of the technology evaluation and implementation process.

This section provides a methodology to assess the applicability of mobile waste processing systems, and outlines a decision process to select the most suitable. The logic diagram illustrates the two distinct steps of the iterative assessment (see Fig. 1). Step 1 includes [4]:

— Capturing realistic waste inventory data (e.g. volumes, rates to be processed and waste characteristics);
— Processing goals (e.g. treatment, immobilization, and packaging for storage and disposal);
— Identifying candidate processing technologies (which alone requires complex considerations).

This step also includes preliminary technical screening of candidate mobile systems to determine whether such a system is a viable option.

If the results of the preliminary evaluation in step 1 do not support the application of a mobile system, a permanent or fixed installation may warrant consideration. However, if the preliminary analysis demonstrates that the mobile system is suitable, the evaluation process continues to step 2, which includes detailed technical screening and then a thorough economic analysis to justify fully the implementation of a mobile system. Step 2 is to provide detailed evaluation of the economic aspects — including tentative bids from suppliers if a similar system is already in use, or a cost estimate on the basis of scheme design drawings. Mobilization, operating, maintenance, secondary waste management, demobilization and disposal costs are also to be addressed in such an evaluation. Using this approach, a technically and financially sound decision can be made.

The following further elaborates the major issues that are to be considered in each step of the decision logic, as illustrated in Fig. 1. It is important to note that the decision to implement may require multiple iterations in both steps, with timely involvement of management and eventual reconsideration of processing goals and options.

2.2.1. Preliminary assessment of viability of mobile system utilization (step 1)

The first task of preliminary assessment is to understand the waste stream, the generation rate and waste characteristics to narrow down processing goals and options. A detailed understanding of the radiological, physical, thermal, chemical and biological properties is essential to starting this analysis [19].

Establishing processing goals (e.g. treatment, immobilization, and packaging for storage and disposal) and, even more importantly, identifying candidate processing technologies have to satisfy local, national, international and site specific regulations and requirements. From this standpoint, a regulatory and safety framework, consisting of codes, requirements and guides, licensing application requirements, transport regulations, environmental impact, desired properties of final waste form and international conventions and agreements, needs to be satisfied before proceeding to any further analysis.

Identification of one or more candidate waste processing technologies means that several options may exist, but considerations are to be given firstly to optimal processing systems and configurations that will meet the goals and objectives. Comparison of proven and emerging technology are also to be considered as part of the assessment process. It is important to review results of this assessment with management and appropriate stakeholders before proceeding further to the preliminary screening of the candidate technologies.

Preliminary screening of candidate options typically has to take into consideration the following issues and parameters:

— Characteristics of incoming and source waste (i.e. volume, type, activity and form);
— Characteristics of secondary waste generated by the process (i.e. volume, type, activity and form);
— Characteristics of the final waste form (i.e. container type, activity and form);

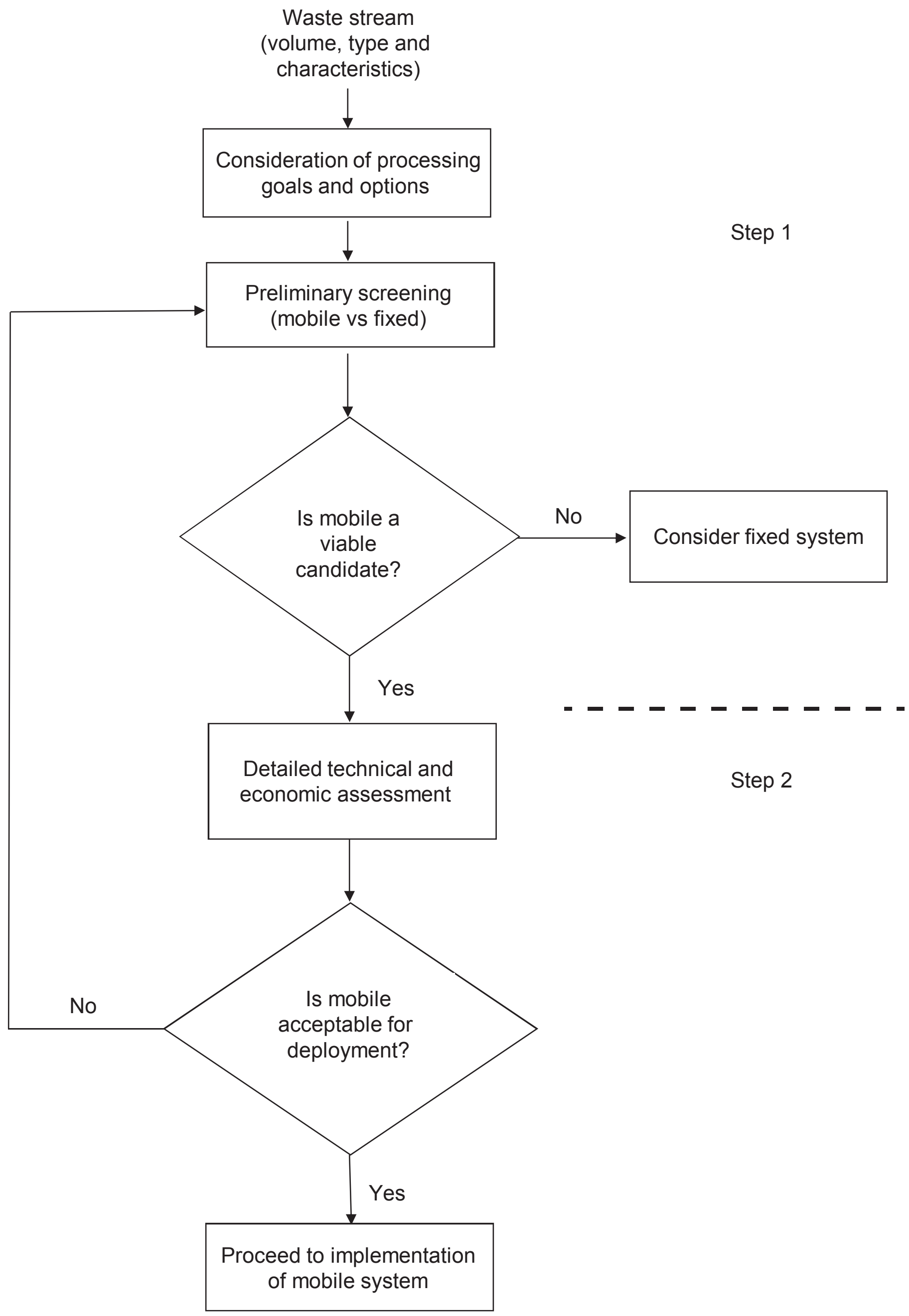


FIG. 1. Decision process for determining the applicability of mobile processing systems.

— Regulatory and legal considerations (national, local, international, licensing, operation, and waste movement and transport);
— Transport requirements (system operation, waste shipments and access roads);
— Mode of use: batch or continuous processing (system and secondary waste);
— Cost: contractual arrangements (leased/procured), periodic (monthly/annual/campaign/volume) installation, consumables, staff, equipment removal and disposal, shipping, and final waste disposition;
— System configuration (fixed, mobile or skid mounted);
— Footprint or physical size of the fixed or mobile system (maximum dimensions, media handling/replacement/repair space);
— Total weight (for floor loading and movement);
— Staffing (i.e. number, contracted staff, technical qualifications, operations, security and maintenance);
— Maximum or optimal throughput and capacity, and volume reduction;

— Space requirements (area for consumable storage, waste staging and storage);
— List of consumables required for processes (e.g. media, containers, parts and chemicals);
— General service requirements (air, water, steam, electricity and ventilation);
— Handling equipment required for placement, operation, and waste handling and packaging (i.e. cranes, forklifts and load capacity);
— General requirements for industrial and radiological safety (barriers, respiratory protection, personnel exposure monitoring, contamination controls and air monitoring).

It should be noted that some of the issues and parameters are already considered at the higher level (e.g. regulatory, transport and waste characteristics). For the purpose of this publication, screening features of candidate options are optimized to provide answers to the question whether a mobile system is a viable candidate worthwhile for further analysis.

The evaluation team are to assess and to weigh the importance of individual factors when considering the advantage of a mobile system compared with a fixed system. The relative importance (weight) of each factor is subject to each unique application and requires input and decision making by the collective evaluation team.

Sections 3–7 provide information on all key features for several proven mobile processing technologies for the various waste processing steps that could be used directly from this publication during preliminary screening. The information is considered current at the time of publication. However, as stated previously, the information is not all inclusive and is to be used solely as a starting point in a particular analysis.

2.2.2. Detailed assessment for mobile system implementation (step 2)

Step 2 involves a detailed technical screening of the option to utilize a specific mobile technology, followed by thorough economic analysis. The detailed technical screening will include the collection of data and analysis to better understand technical details and potential shortcomings from:

(a) Technology overview;
(b) System components;
(c) Hardware interfaces;
(d) Space and weight distribution;
(e) Physical controls;
(f) Waste and material movement.

The use of a formal economic analysis may include requests for proposals from several potential suppliers. It may also involve financial and legal representatives and the completion of a risk assessment with technical, environmental and financial factors influencing the conclusions. Care is to be taken to ensure that discussions with the parties concerned are technically accurate and in terms readily understood by everyone.

At the end of the economic analysis, all information is to be compiled and summarized. This is then used to determine the best approach, with support from internal and external stakeholders. The final step in the process is validation of the decision on the deployment acceptability of the mobile system. If the detailed evaluation does not fully justify deployment, the analysis is to be repeated — most often starting at the identification of alternative candidate options. An alternative to such an iterative loop could be a decision to consider a fixed installation.

Annexes I and II provide detailed technical information for two widely used mobile processing technologies. It should be noted that the information is not all inclusive and will be used solely as a starting point for developing a detailed screening that would include, among other considerations:

— Operation and maintenance requirements;
— Flammability;
— Hazardous gas generation;
— Additional shielding;
— Potential recriticality issues for secondary wastes.

2.2.3. An example of the two step decision process

The proposed methodology for implementing a mobile system (e.g. approach, assessment of relevant considerations and technoeconomic analysis) is a two step decision process (see Fig. 1). One simple example is the treatment of operational solid waste from five nuclear power plant sites with 1500 MW(e) installed with multiple reactor units and dispersed within a perimeter of 300 km. The average mix of solid waste generation is 70% combustible (out of which 85% is also compactible) and the remaining 30% non-processable.

2.2.3.1. Step 1: Consideration of processing goals and options

For the treatment of defined waste streams, incineration and compaction are the most obvious treatment options to consider, in accordance to proven international experience and best practices. After preliminary review of regulatory and safety requirements, it is found that both candidate options could be further analysed, since both could meet the requirements. However, both candidate options have advantages and disadvantages, so it is worthwhile consulting management and other stakeholders to obtain feedback if it is required to continue with preliminary technical screening of both options or if one option only is to be short listed after identifying its obvious advantages. In this example, the management standpoint is to consider both options for preliminary screening.

2.2.3.2. Step 1: Preliminary screening including analysis of mobile versus fixed

Qualitative comparison of issues and parameters indicates, for example, that regulatory approval for incineration would be much more difficult (e.g. cost and time for licensing) in comparison to permitting a supercompactor. Secondary waste generation, especially gaseous releases, are more difficult to control and require a complex system for an incinerator. The waste form emerging from the supercompactor is final and does not require further immobilization, except eventual embedding (grouting) in the disposable container. The waste form from an incinerator (unless high temperature, plasma process based) would usually require further immobilization.

However, the volume reduction factor that could be achieved for the final waste form from an incineration is still much higher than after supercompaction. Many supercompactors are available commercially as modular installations working in campaigns at the waste generation spot or permanently installed at a centralized location. Not many incinerators are ‘transportable’. Therefore, a modular system would require some novel approaches to design, operation and definitely licensing. Hence, it could be eliminated as an option from further analysis. However, centralized waste incineration is quite a common practice for such volumes of waste, since it offers the best results relative to volume reduction.

Transporting waste from generating sites would require compliance with stringent transport regulations and could be a significant addition to the costs and risks to manage, The transfer of waste from generating units within particular sites on non-public roads, however, is more cost effective and freer of such risks. Staffing an incinerator would usually require licensed operators working in 24/7 shifts, whereas a supercompactor can be leased and entirely run by external operators.

The cost comparison (based on budgetary estimates) indicates that the difference between options considered is not substantial: it is of the order of a percentage instead of the order of magnitude in the unit cost ($\$/m^3$). The preliminary analysis takes into account capital, operation and maintenance, and permitting and miscellaneous costs from cradle to grave (e.g. the complete life cycle of the waste stream, including storage and disposal). Although, this cost comparison still demonstrates the relative advantage of a permanently installed central incinerator, it appears that either a mobile supercompactor operating in campaigns at dispersed sites or a permanently installed supercompactor at a centralized location are justifiable from the cost comparison point of view.

Such preliminary considerations imply that a decision needs to be made on softer issues (other factors) rather than conditional on a unit cost. Based on this qualitative preliminary screening, the evaluation team can conclude that a mobile supercompactor is a viable option that is worthwhile taking to step 2 for a detailed technical and economic assessment, which is required prior to taking the decision to implement.

It should be noted that such a qualitative analysis would probably lead to a different conclusion if the input parameters were different. For example, if the number of nuclear power plant sites were only one or two, if the volume were much smaller or if sites were very close to one another.

2.2.3.3. Step 2: Detailed technical and economic assessment

A detailed technical assessment requires a return to considered assumptions related to waste generation (i.e. volumes, rate, operating regime and required capacities) as well as to regulatory and safety aspects to confirm whether all the requirements for the licensing application were able to be met. The next step is to review design parameters, limits, constraints, reliability and availability, maintainability, constructability, working environment limits and national standards (e.g. technology overview). An analysis of system components will follow to better understand equipment requirements for implementing process flowsheets. An understanding of space requirements, weight distribution, interfaces, tie-ins, adjacencies with existing configurations, services required, as well as physical controls of the system (e.g. barriers, access, ingress and egress), is also an essential part of the technical analysis. Finally, the movement of waste and materials needs to be taken into account to complete the analysis. This list is neither sequential nor inclusive. The information that is required is case specific.

Annex I lists the most important parameters and considerations for mobile supercompactors used in this example. However, more detailed information can be obtained from vendors for a defined capacity and operating regime, which will include a process flow chart and other data useful for assessment.

Results of the analysis for this example indicate that a mobile supercompactor is a feasible option from a technical standpoint. However, treatment of waste could be conducted using mobile compactors of different capacities (throughput) that are tied up to their modes of operation (single or multiple shifts, and shorter or longer duration campaigns). An optimum solution is to be found based on economic analysis that would consist of detailed engineering cost estimates of various compactors and operating costs of compaction for various operating scenarios. This needs to be followed by an impact analysis of this technology on the waste life cycle cost. It should be noted that such complex economic analysis is mandatory for any solution which looks technically feasible, prior to its implementation.

When the analysis clearly indicates that the cost for using a mobile system is affordable and beneficial, implementation could start immediately. However, if it is found that the mobile system does not meet business targets (e.g. for the unit cost) or that it just satisfies boundary limits, without sufficient contingency margins on life cycle cost, a return to the preliminary screening step is necessary to reconsider assumptions made on the viability of the mobile system. It is to be expected that similar detailed analysis would then be performed for a permanently installed system — in this example, defined as either centralized incineration or centralized supercompaction. Such analysis would allow the comparison required for selecting the most suitable solution for implementation.

It should be noted that, depending on the particular case, the iterative analysis may have to be repeated a number of times before a final decision on implementation can be reached. Since the final decision on implementation of the most suitable solution not only depends on cost effectiveness but also on a range of other considerations related to the management of uncertainties and risks, a mobile system can still emerge to be the option of choice.

This discussion shows that even for the simple case considered in this example (treatment of operational solid waste from five nuclear power plant sites with 1500 MW(e) installed with multiple reactor units and dispersed within a perimeter of 300 km), the final decision to use a mobile, or alternative, system is not straightforward, and can be reached only after thorough and complex case specific analysis.

3. WASTE PRETREATMENT SYSTEMS

3.1. SOLID WASTE

3.1.1. Low force compaction

3.1.1.1. Typical system description

Low force compaction systems are typically self-contained units that employ hydraulic ram compaction technology, with a provision for collecting liquids that may be generated during the compaction cycle

FIG. 2. A low force compactor.

(see Fig. 2). The effluent — a mixture of gases, air and particulates — requires filtration and routing to a monitored and authorized release point. Low force compaction can be either a pretreatment system before high force compaction or an independent treatment system. The pressing force is usually 100–500 kN.

This technology can effectively reduce a standard 200 L drum to a disc or puck, or can be used to compact low density waste to smaller volumes within a drum, in preparation for subsequent supercompaction or disposition. The final product will vary with the compacting force and the original drum density, but typical volume reduction factors fall between 3 and 6, depending on whether the unit is used for in-drum or drum compaction. This technology is adapted in many cases as a mobile system catering to multiple facilities.

3.1.1.2. Description of individual components and elements

(a) **Compactor body**: This is essentially the heart of the system, with the hydraulic ram usually placed vertical and the compaction chamber with containment for effectively scavenging the gas and particulates generated during compaction. The drum for compaction, either in-drum or otherwise, is fed into the chamber, either by lifting the chamber or opening an access door.

(b) **Hydraulic power pack**: This is the hydraulic oil pressurizing system, with a high pressure pump and interconnecting pipes to the compactor. The power pack also houses the pressure regulators, flow control devices and safety relief valves.

(c) **Air, gas and particulate handling system**: The off-gas particulate handling system is to ensure that the gases released to the environment are free of radioactive particulates. This usually consists of a prefilter and a high efficiency particulate air (HEPA) filter configured in series and, in some cases, a mist eliminator in front of a suitably sized exhaust blower.

(d) **Liquid handling system**: The compaction process may generate liquids that originate from the material being compacted. In order to ensure the safe management of liquids, a drain or collection system is provided. This liquid is typically collected and transferred to waste treatment systems in batches.

(e) **Electrical power distribution and control panel**: Electrical power is required for the hydraulic pump and the blower for the exhaust system. The control panel contains controls and control logic electronics. Remote operation requires a control pendant and an associated power or control cable.

(f) **Secondary waste collection tanks**: In some cases, waste collection tanks are provided with the compactor. The treatment of the waste is typically the responsibility of the host site.

3.1.1.3. System specific benefits

— Relatively high volume reduction ratios;
— Small physical envelope dimensions;
— Up to 500 kN of compressive force;
— Special designs to match various drum dimensions;
— Option of in-drum compaction;
— Easily maintained and decontaminated;
— Well proven equipment.

3.1.1.4. System specific limitations

— The volume reduction ratio achieved can be influenced considerably by the nature of the waste;
— Not suitable for high density wastes (e.g. metals, concrete and wood);
— Secondary waste treatment is generally not included with the compactor system.

3.1.1.5. Key screening considerations

Table 2 identifies key screening considerations for low force compaction systems.

3.1.2. Mechanical decontamination

3.1.2.1. Typical system description

Mobile decontamination systems can be configured with a variety of decontamination options. Mobile mechanical decontamination technologies include carbon dioxide (dry ice) blasting, ice blasting, grit or sand blasting, plastic or glass bead blasting, aqua blasters (combination of high pressure water and abrasive blast media) and water jetting (high temperature water jets at a high pressure, together with vacuum cleaning, very high pressure and ultra-high pressure cleaners).

One example of a mechanical decontamination system employs a small, trolley mounted, high temperature water jet system used for the mechanical cleaning of plant floors, walls and components in special hoods, among other things (see Fig. 3). The principle involves effective cleaning by a combination of the mechanical impact of the water jet enhanced by steam. The residual water/steam mixture is collected by a powerful vacuum system, leaving the floor and component nearly dry. In this design, the mobile unit also treats the collected liquid and solid waste material. Variations in design can include condensers and cyclone separators in the off-gas system and filters, and ion exchanges for the liquid waste. Brush cleaning options are also available for floor cleaning applications.

TABLE 2. KEY SCREENING CONSIDERATIONS FOR LOW FORCE COMPACTION SYSTEMS

Consideration	Description
Characteristics of incoming and source waste (volume, type, activity, form)	Form or characteristics of waste streams most often associated with mobile low force compaction are: — Waste typically prepackaged in plastic bags, drums or boxes (skips); — Loosely packaged and low density waste typically associated with radioactive facility operation (e.g. paper, plastic, cloth); — Low activity waste that is managed as part of a relatively low cost disposal strategy (wastes for which higher force compaction or other more costly and higher volume reduction systems are not justified). Low force compaction can also be used as a pretreatment step to supercompaction if additional volume reduction is desired.
Characteristics of secondary waste generated by process (volume, type, activity, form)	Other than the resultant puck or drum with compressed material, secondary waste generated as a result of low force compaction is typically small in volume or non-existent. Small amounts of liquid, as well as filter media loaded with particulates, can be generated during operations. Contamination levels are typical of the waste being compacted, but are not typically concentrated as part of the process.
Characteristics of final waste form (container type, activity, form)	The final waste form is typically a low density, compressed waste form, which may be contained in a bag, drum or box. Some systems use simple forms of anti-springback devices (e.g. bands or inserts), which are compressed with the waste form to maximize volume reduction. Volume reduction factors depend on the type of waste, but are typically in the range of 3–6.
Regulatory and legal considerations (national, local, international, licensing, operation, waste movement and transport)	The system does not require a complex regulatory or legal process for deployment.
Transport requirements (system operation, waste shipments, access roads)	The unit can be transported by simple conveyance and, unlike radioactive material or waste, requires no special transport means for the equipment and the resulting waste forms.
Mode of use: batch or continuous processing (system, secondary waste)	Typical system operations are of the batch type. The frequency is typically based on the waste generation rate and the capacity for waste storage.
Cost: contractual arrangements (leased/procured); periodic (monthly/annual/campaign/volume) installation; consumables; staff; equipment removal and disposal; shipping; final waste disposition	Low force compaction systems can be leased or procured (typical). They are typically low in cost and are adapted directly from non-radioactive waste management applications. They do not require substantial monetary investment, nor are they costly to operate and to maintain.
System configuration (mobile or skid mounted)	The configuration of low force compaction systems can be either skid mounted for in-plant use or installed in a small mobile platform such as an ISO container.
Footprint or physical size of the mobile system (maximum dimensions, media handling/replacement/repair space)	Low force compaction systems require minimal space and can be typically placed in areas as small as 15 m^2.
Total weight (for floor loading and movement)	The unit weight is typically in the range of 1–5 t.
Staffing (number, contracted staff, qualifications, operations, security, maintenance)	This typically requires a single operator. Some sites require two-person teams as an industrial safety measure (high pressure hydraulic, compressive ram). Training is typically required only for system control and industrial safety operation. Some maintenance operations may require a skilled hydraulic system technician.

TABLE 2. KEY SCREENING CONSIDERATIONS FOR LOW FORCE COMPACTION SYSTEMS (cont.)

Consideration	Description
Maximum or optimal throughput capacity, decontamination factor and volume reduction	Typical capacity or throughput of a low force compactor is specified in 'minutes per compression cycle'. That cycle time is determined by the volume of solid waste in the container and the cycle termination pressure set by the manufacturer. A typical full compression-to-release cycle for a low force drum or box compactor is 1–5 min. Similar to the compression cycle time, the number of compression cycles per container is dependent on the waste type and density, and compactor pressure settings.
Space requirements (area for consumable storage, waste staging and storage)	— For self-contained systems: space for a 3 m × 6 m trailer. — For skid systems: typically 3.7 m × 2.3 m × 1.3 m. — Space requirements for consumables are negligible: for pre and postprocessing of waste containers, typically 15–30 m^2.
List of consumables required for process (media, containers, parts, chemicals)	— Consumables required for low force compaction are typically limited to drums, anti-springback devices, particulate filters and other containers used in the process; — Hydraulic fluid is changed periodically, but is not typically contaminated by the compaction process unless spilled or leaked from the system.
General service requirements (air, water, steam, electricity, ventilation)	— Electrical: 440/220 V AC. — Ventilation: 0.5–5 m^3/min; negative pressure at the compaction face.
Handling equipment required for placement, operation, and waste handling and packaging (cranes, forklifts, load capacity)	— Preprocessed bags of waste are manually handled and loaded into the compactor. — Compacted drums or boxes typically require standard industrial lifting/transport vehicles such as forklifts, push carts or simple lifts.
General requirements for industrial and radiological safety (barriers, respiratory protection, personnel exposure monitoring, contamination controls, air monitoring)	— Typically requires anti-contamination clothing, dosimetry and industrial safety protection (e.g. eye protection, safety shoes). — Respiratory protection may be required for compacting high contamination wastes and decontamination of the internal compaction chamber or ram. — Localized ventilation and air sampling are typically installed at the host site to minimize the potential for any release of airborne activity.

FIG. 3. Trolley mounted floor decontamination system (courtesy of BARC).

3.1.2.2. Description of individual components and elements

The components vary dramatically depending on the technology. However, in the system described above, the major components are:

— Spray vacuum hood;
— Water heating and pumping unit (high temperature/high pressure module);
— Off-gas module, consisting of the vacuum blower;
— Water purification and recirculation units, consisting of the cyclone separator module;
— Filter module;
— Ion exchange module.

All the modules are assembled on a mobile trolley (approximately 1.5 m × 1 m × 1.5 m), with each module configured for easy operation and maintenance access. The control and power unit for the system is also located on the trolley and is easily accessible. The mobile unit is designed to move in corridors and maintenance galleries. As the hood progresses forward during the cleaning process, the trailing (cleaned) space is left dry and decontaminated, allowing the operator and hoses to move without spread of contamination (see Fig. 4).

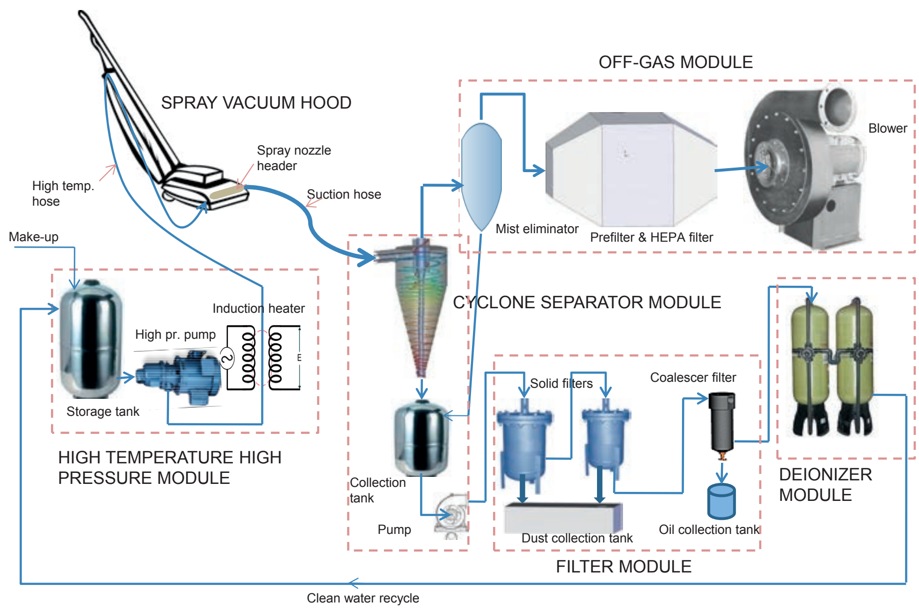


FIG. 4. Schematic of a mobile surface decontamination system (courtesy of BARC).

The major components of the system include:

(a) **Spray vacuum hood**: This consists of a hand held hood in which a series of spray jets are arranged for spraying high temperature and high pressure water. Small wheels fitted at the bottom of the hood (ground clearance of 2–3 mm) allow movement. The hoses for water and the vacuum are attached to the hood (typical radius coverage of 5–10 m). This allows the hood to be used in the contaminated area, with the mobile unit located in a remote, clean location. Longer hoses are possible, if required.

(b) **Water receiving tank, pump and heating system**: The module for heating and pumping water fits on the mobile trolley. Water is received and stored in a 100 L tank. The water is heated using an in-line heater. The water release rate is controlled by valves, allowing cleaning with lower quantities of water.

(c) **Cyclone, demister, prefilter, HEPA filter and vacuum blower**: The cleanup subsystem consists of the gaseous and liquid treatment elements. At the cyclone separator, the liquid is drawn to the bottom and the gaseous/vapour components are drawn through the top by the vacuum blower. The off-gas cleaner consists of a demister and a prefilter or HEPA filter. The condensed water in the demister is routed to the liquid cleanup system.

(d) **Cartridge solid filters, a coalescence filter, cation–anion exchange columns, recirculation pumps**: The liquid cleanup system consists of cartridge filters for the solid particles, a coalescence filter for separating oily substances and a deionizer module for removing dissolved salts. The clean water is recirculated. Recycling the treated water reduces the volume of secondary liquid wastes. Water from the site supply will be required to replace system losses during the cleaning process.

(e) **Electrical power supply, control and instrumentation system**: Electrical power is required from the host site. The power and control systems, including valving, are provided in the trolley with easy access for maintenance.

3.1.2.3. System specific benefits

— Recycle and reuse of tools and equipment;
— Unrestricted release of clean materials that meet release criteria;
— Combined pressure vacuum cleaning limits the spread of contamination;
— Reduction in disposed waste volumes, thereby reducing disposal costs.

3.1.2.4. System specific limitations

— Size of materials to be decontaminated is limited by hood and chamber size;
— Some States or nuclear facilities may not have any criteria for unrestricted release of materials.

3.1.2.5. Key screening considerations

Table 3 identifies key screening considerations for mechanical decontamination systems.

TABLE 3. KEY SCREENING CONSIDERATIONS FOR DECONTAMINATION SYSTEMS

Consideration	Description
Characteristics of incoming and source waste (volume, type, activity, form)	— Plant floor areas contaminated during operations or maintenance activities; — Components (metal, plastic, composites) with smooth or irregular surfaces; — Volume varies depending on the waste generating process; — Activity levels are typically low to medium in loose or partly trapped conditions.
Characteristics of secondary waste generated by process (volume, type, activity, form)	— Volumes of secondary wastes are low compared with mopping and wet cleaning. — Resultant wastes are solid or liquid (e.g. water used in the system, backwash water, prefilter/HEPA filters). — Some types of solid media can be reused several times (e.g. cartridge filter candles and elements, ion exchange media). — Depleted solid media require collection and conditioning. — Liquid waste generated requires treatment for release or reuse using aqueous treatment technologies.
Characteristics of final waste form (container type, activity, form)	— Solid in-drum, box or other container; — Spent filtration and ion exchange media may need conditioning to meet acceptance criteria for disposal.
Regulatory and legal considerations (national, local, international, licensing, operation, waste movement and transport)	Generally, regulatory issues are not very difficult, as the systems are used under controlled conditions. Local, regional and national regulations apply to activity management, shipping radioactive systems, and releasing materials and treated liquid wastes: — May require transfer of contaminated material from point of generation or collection to the decontamination system; — May require conveyance on open roadways during shipment to new site.

TABLE 3. KEY SCREENING CONSIDERATIONS FOR DECONTAMINATION SYSTEMS (cont.)

Consideration	Description
Transport requirements (system operation, waste shipments, access roads)	— System requires road access for truck or container for delivery and removal; — Waste movement with the help of small casks or shields in drums or containers; — For surface decontamination, the mobile system moves to the area to be cleaned either by tugging or manually pushing the trolley.
Mode of use: batch or continuous processing (system, secondary waste)	— Typically batch process but can be operated continuously; — Typically limited by operator fatigue.
Cost: contractual arrangements (leased/procured); periodic (monthly/annual/campaign/volume) installation; consumables; staff; equipment removal and disposal; shipping; final waste disposition	Costs vary according to process type. A surface cleaning system using the spray technique would typically cost ~US $200 000. Lease and procurement are both common strategies
System configuration (mobile or skid mounted)	— Leased options are typically containerized. — Procured systems are smaller units.
Footprint or physical size of the mobile system (maximum dimensions, media handling/replacement/repair space)	— Small in-plant units: 1 m × 1.5 m × 1.5 m with 1 m × 1 m floor area required for the hose reel unit. — Containerized units could be as large as 3 m × 15 m × 3 m.
Total weight (for floor loading and movement)	The typical weight of in-plant surface cleaning system is ~1000 kg, but the actual weight varies according to design.
Staffing (number, contracted staff, technical qualifications, operations, security, maintenance)	— Typically requires a single, trained operator assisted by one unskilled helper. — Maintenance staff may be required for hookup, removal and periodic corrective maintenance.
Maximum or optimal throughput, capacity, decontamination factor and volume reduction	Mobile surface cleaning system for in-plant application can typically cover an 800–1000 m^2 area in an eight hour shift, depending on contamination type and level.
Space requirements (area for consumable storage, waste staging and storage)	Storage space is typically 3 m × 3 m × 4 m.
List consumables required for process (media, containers, parts, chemicals)	— Prefilter/HEPA filter elements; — Ion exchange columns; — Water; — Air and water filters; — Spray nozzles; — Blast tips; — Additives specific to cleaning.
General service requirements (air, water, steam, electricity, ventilation)	— Electrical: requirements vary according to equipment; typically 440/220 V AC. — Liquid systems: drain system or other authorized, monitored release pathways. — Air: compressed air cylinder attached to mobile system or hose to plant service air.
Handling equipment required for placement, operation, and waste handling and packaging (cranes, forklifts, load capacity)	Handling systems such as hoists and forklifts required for mobilization and demobilization (loading).
General requirements for industrial and radiological safety (barriers, respiratory protection, personnel exposure monitoring, contamination controls, air monitoring)	Radiological control points for radiation and contamination are required, including space for donning and removing protective clothing. Personnel contamination monitoring is required following work.

Note: HEPA — high efficiency particulate air.

3.2. LIQUID WASTE

3.2.1. Chemical neutralization and precipitation

3.2.1.1. Typical system description

Chemical composition changes are affected by pH adjustment, addition of flocculants, precipitants or other supplementary treatments. Their use as a solo treatment or in combination with other processing media is a proven method for waste treatment. The addition of chemicals can be manual or automated using dosing feed systems in a batch, in-line or automatic mode. Figure 5 is a simplified schematic for an automated, continuous feed arrangement. Figure 6 shows a photograph of a supplier’s control unit.

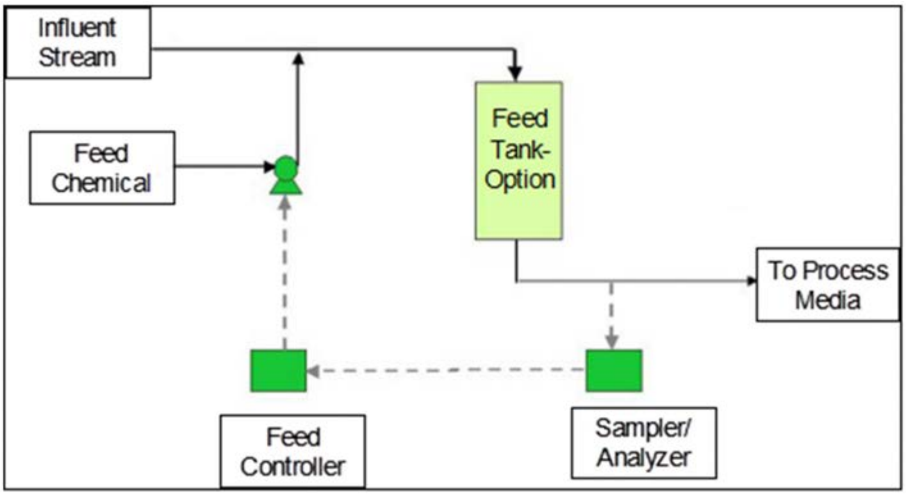


FIG. 5. Typical continuous chemical injection system schematic.

FIG. 6. Continuous chemical injection system control panel (courtesy of EnergySolutions).

3.2.1.2. Description of individual components and elements

The equipment requirements for chemical pretreatment are minimal and do not significantly impact the service or space requirements for mobile processing facilities. A 110/220 V AC metering pump is usually used to inject the chemicals directly from the supplier container to the system piping. Supplemental treatment equipment is typically installed to feed directly a mixing tank in-line or upstream of the media. These options ensure liquids are stabilized and that there is sufficient reaction time for precipitation prior to reaching the downstream media. The equipment includes the use of:

— Automated or manual chemical injection or metering pumps;
— Electric potential differential probes;
— pH and conductivity probes;
— Streaming current detectors;
— Small chemical addition tanks with blending capabilities.

3.2.1.3. System specific benefits

— Improved activity removal with minimal secondary waste volume increase;
— Low cost;
— Small system size;
— Portability;
— Flexibility: numerous chemical types targeting a wide variety of impurities.

3.2.1.4. System specific limitations

— Requires accurate influent stream characterization;
— Not applicable to all waste streams or characteristics;
— Chemicals may require special handling and controls;
— May require installation of an in-line mixer, such as mechanical swirl vanes.

3.2.1.5. Key screening considerations

Table 4 identifies key screening considerations for chemical neutralization and precipitation systems.

TABLE 4. KEY SCREENING CONSIDERATIONS FOR CHEMICAL NEUTRALIZATION AND PRECIPITATION SYSTEMS

Consideration	Description
Characteristics of incoming and source waste (volume, type, activity, form)	This technology is applicable to liquid waste and waste slurries. Volume will vary according to application, and it can be used for low to medium level waste.
Characteristics of secondary waste generated by process (volume, type, activity, form)	— The process is used to remove activity or chemical impurities. Secondary wastes can be in the form of precipitated sludge (solids), processing media used to capture the modified impurities such as filter media for insoluble activity or ion exchange resin for soluble impurities. — Secondary waste volume is dependent on the impurity concentration, the incoming liquid volume and the removal method employed.
Characteristics of final waste form (container type, activity, form)	The secondary waste will typically require conditioning (e.g. dewatering, cementation, thermal treatment) to remove moisture or to create a solid monolith, and can be packaged in 200 L drums, or other approved waste containers.

TABLE 4. KEY SCREENING CONSIDERATIONS FOR CHEMICAL NEUTRALIZATION AND PRECIPITATION SYSTEMS (cont.)

Consideration	Description
Regulatory and legal considerations (national, local, international, international, licensing, operation, waste movement and transport)	Local, regional, national or international regulations related to handling, storage, transport and disposition of the chemicals are to be consulted.
Transport requirements (system operation, waste shipments, access roads)	No special considerations other than those addressed above.
Whether the system is to be used for batch or continuous processing (system, secondary waste)	The system can be used in either mode, depending on the application. Typically, manual bulk additions are performed on a batch basis. Manual or automated metering systems are used to support continuous processes.
Cost: contractual arrangements (leased/procured); periodic (monthly/annual/campaign/volume) installation; consumables; staff; equipment removal and disposal; shipping; final waste disposition	The cost varies by type of chemical and consumption. Automated, continuous systems are typically more costly than manual. An automated system designed for continuous processing usually costs <US $10 000.
System configuration (mobile or skid mounted)	The system can be configured either way. The system penetrations may include taps into processing feed tanks or processing lines.
Footprint or physical size of the mobile system (maximum dimensions, media handling/replacement/repair space)	— Manual system: 4 m^2. — Fully automated system: 9 m^2.
Total weight (for floor loading and movement)	<100 kg.
Staffing (number, contracted staff, qualifications, operations, security, maintenance)	— Some chemistry knowledge is required. — Batch operations require one person to add chemicals. — Continuous operation requires one person to add chemicals to maintain chemical feed on a periodic basis (<15 min per process batch). — The bulk chemicals are delivered to the facility and the process equipment.
Maximum or optimal throughput capacity, decontamination factor and volume reduction	— Varies by system design; — Bulk up to 40 m^3 (mixing is limiting factor); — Continuous, typically at 115 L/min or less.
Space requirements (area for consumable storage, waste staging and storage)	Varies by consumption rate, typically <10 m^3.
List consumables required for process (media, containers, parts, chemicals)	Specific chemicals (e.g. caustic, acid, flocculants) based on influent characteristics and target activity or chemical species.
General service requirements (air, water, steam, electricity, ventilation)	— Typically 110/220 V AC; — Demineralized water.
Handling equipment required for placement, operation, and waste handling and packaging (cranes, forklifts, load capacity)	— Forklift or hand truck may be required for bulk chemical movement. — Some chemicals are provided in hand carried volumes (e.g. 20 kg/19 L plastic containers).

TABLE 4. KEY SCREENING CONSIDERATIONS FOR CHEMICAL NEUTRALIZATION AND PRECIPITATION SYSTEMS (cont.)

Consideration	Description
General requirements for industrial and radiological safety (barriers, respiratory protection, personnel exposure monitoring, contamination controls, air monitoring)	Some supplemental treatments employ the use of hazardous chemicals. Those options are to be carefully evaluated for their impact on adjacent work area equipment and personnel access. Special radiological controls are not normally required.

4. WASTE TREATMENT SYSTEMS

4.1. SOLID WASTE

4.1.1. Soil washing

4.1.1.1. Typical system description

Soil washing processes typically consist of several unit operations connected in an integrated process to separate soil components from contaminating materials, and separate contaminants from each other. Much of the system is based on commonly available mineral treatment technologies widely used in the mining industry, and has well known scale-up parameters. Figure 7 illustrates the major components for a system available from one supplier.

FIG. 7. Soil washing system (courtesy of EnergySolutions).

The soil washing system can be designed to accommodate a wide variety of soil types, including those with a moderately high clay content. Most soil washing systems separate contaminated soils primarily by physical particle size, although they can be modified to separate according to other physical parameters, such as density, flotation characteristics, or chemical, magnetic and electrical properties. Contaminated soils containing excessive amounts of clay material (more than approximately 40–50%) are usually too difficult to separate. The minimum particle size cut is around 200 mesh size (0.075 mm).

The rocks and cobbles that are separated are pressure washed, with the water recycled for use in the pressure washer or used as make-up water in the soil washing system. Any water used to decontaminate equipment is handled in the same way.

Soils removed from rocks and cobbles are sent through the soil washing system. The clean solid fractions are recombined into a clean soil and returned to the site. The small volume of contaminated solids is packaged for disposal or further treatment, as required. The only water discharged from the system results from emptying the equipment at demobilization, which is treated and released.

The configuration of mobile soil washing systems is skid mounted and loaded onto trailers for transport to and from the site. The main soil processing equipment for a typical mobile 20 t/h soil washing system may be mounted on three flatbed trailers, with support equipment transported by five additional trailers.

4.1.1.2. Description of individual components and elements

- Conveyors and hoppers;
- Tanks, pumps and piping;
- Drive systems;
- Hydraulic systems;
- Heavy equipment;
- Secondary containment.

4.1.1.3. System specific benefits

- On-site remediation.
- Segregation of mixed waste into its radioactive and hazardous components allows for the safe disposal of each at an appropriate disposal site.
- Full scale operations: continuous type, managed on a shift basis.
- High processing rates are feasible.
- Secondary waste is minimized by the design of the soil washing system.

4.1.1.4. System specific limitations

- Size and complexity to mobilize and to demobilize;
- Initial negative environmental impact;
- Typically high in cost;
- Soil washing is performed under a complex regulatory framework.

4.1.1.5. Key screening considerations

Table 5 identifies key screening considerations for soil washing systems.

TABLE 5. KEY SCREENING CONSIDERATIONS FOR SOIL WASHING SYSTEMS

Consideration	Description
Characteristics of incoming and source waste (volume, type, activity, form)	The form or characteristics of waste streams most often associated with mobile soil washing systems are typically large land areas with extensive radium contaminated soils, and soils containing Th and U. However, other radioactive and non-radioactive contaminants (As, Cd, Pb, PCBs) may also be potentially treated by the soil washing process.

TABLE 5. KEY SCREENING CONSIDERATIONS FOR SOIL WASHING SYSTEMS (cont.)

Consideration	Description
Characteristics of secondary waste generated by process (volume, type, activity, form)	— Effluents from the soil washing system may include rocks, cobbles, gravel, dewatered sands, contaminated fines and wash/rinse solutions (water). — The predominant secondary waste stream is wash water and process sludge, which is generated as part of the separation process and typically consists of water, reagents and additives, such as acids, bases, surface active agents (surfactants), solvents and chelating or sequestering agents, to enhance the solubility or separation of the contaminants. — Wash water will also contain a mixture of contaminated fine particles or dissolved contaminants. — Process sludge is the sludge resulting from the removal of dissolved contaminants or the contaminated fine particles in the spent wash water.
Characteristics of final waste form (container type, activity, form)	Most of the inlet soil is discharged with the contaminant levels reduced below regulatory limits, while the extracted contaminants are concentrated in the remaining soil for disposal. The final waste form for the concentrated material will consist of contaminated soil that can either be disposed on-site (in a contained manner, e.g. shallow landfill burial) or packaged in suitable containers for off-site radioactive disposal. Final waste form characteristics are dependent upon the feed soil characteristics and soil washing system performance.
Regulatory and legal considerations (national, local, international, licensing, operation, waste movement and transport)	Soil washing is typically performed under a complex regulatory framework, as it pertains to environmental impact laws, regulations and policies associated with land and waste water management.
Transport requirements (system operation, waste shipments, access roads)	— Most pilot scale mobile systems are transported on two to four trailers; a typical 20 t/h system may require eight to ten trailers. — The volume of equipment necessary is dependent on the size of the project. — The equipment can be transported by road or rail (assuming site access). — Requires roadway access for on-site staging, set-up and final waste removal.
Mode of use: batch or continuous processing (system, secondary waste)	— Pilot scale systems can provide batch or continuous processing. — Full scale operations are continuous and managed on a shift basis.
Cost: contractual arrangements (leased/procured); periodic (monthly/annual/campaign/volume) installation; consumables; staff; equipment removal and disposal; shipping; final waste disposition	— Soil washing systems are typically expensive and require substantial monetary investment to build, store, mobilize and maintain. — Typical contractual arrangements include a mobilization and demobilization fee with a lump sum rate based on adjusted dry weight of soil in tonnes per hour. — Operating labour and consumables (e.g. reagents) are typically included in the lump sum rate. — Costs may include laboratory testing, pilot testing, equipment selection, design reviews, procurement, fabrication, site set-up and system startup. — Operating costs may include soil collection, processing, respreading of the soil, electric power, heavy equipment, air, support tanks, resin columns, sampling, laboratory analyses and disposal of primary and secondary waste.
System configuration (mobile or skid mounted)	— Usually skid mounted and loaded onto trailers for transport to and from the site. — The main soil processing equipment for a typical mobile 20 t/h soil washing system may be mounted on three flatbed trailers, with support equipment transported by five additional trailers.
Footprint or physical size of the mobile system (maximum dimensions, media handling/replacement/repair space)	A lay down area of 37 m × 46 m is required for a typical 20 t/h system; 15 m × 21 m is required for a 4 t/h pilot scale system.

TABLE 5. KEY SCREENING CONSIDERATIONS FOR SOIL WASHING SYSTEMS (cont.)

Consideration	Description
Total weight (for floor loading and movement)	— Total weight and area loading (floor loading) can vary dramatically, depending on capacity and equipment configuration. — Suitable foundations for placing soil washing equipment vary widely, depending on physical site constraints. — It can range from a simple foundation consisting of synthetic liner, sand or gravel, to an asphalt or a concrete slab to support and accommodate the equipment. — The area around the soil washing equipment is usually graded so that the water drains away from the work area adjacent to the treatment area.
Staffing (number, contracted staff, technical qualifications, operations, security, maintenance)	— Full time, 24 h/d operation is possible. — ~10% downtime is to be allowed for equipment maintenance. — A typical field deployment team consists of 10–20 people.
Maximum or optimal throughput, capacity, decontamination factor and volume reduction	— Feed rates are ~1–2 t/h for small pilot scale systems, up to 50 t/h for larger scale systems. — A 20 t/h system may process an average of >900 t of soil per week (based on 6 d, 9 h/d, with high clay content soil). — Typical project volumes run in the thousands of tonnes to hundreds of thousands of tonnes. — Higher processing rates are feasible, depending on the particular soil and contaminant characteristics or system throughput.
Space requirements (area for consumable storage, waste staging and storage)	Reagents and additives used in the treatment plant require storage in tanks, drums or other containers made of suitable material.
List consumables required for process (media, containers, parts, chemicals)	— A wide range of reagents and additives, such as acids, bases, surface active agents (surfactants), solvents, and chelating or sequestering agents. — Chemicals may include flocculants, dispersing agents, acidic or caustic extractants, and pH adjustment chemicals. — Ion exchange media may be required to assist in the cleanup and release of wash water.
General service requirements (air, water, steam, electricity, ventilation)	— Water; — Diesel fuel to power equipment; — 110 and 220 V AC electricity for lighting, radiation monitoring equipment, repair equipment and security equipment.
Handling equipment required for placement, operation, and waste handling and packaging (cranes, forklifts, load capacity)	Typically crane and forklift.
General requirements for industrial and radiological safety (barriers, respiratory protection, personnel exposure monitoring, contamination controls, air monitoring)	— Standard radioactive safety operations are required, including the application of localized engineering controls (e.g. negative ventilation) to minimize airborne and waste and wash water contamination as a result of the process. — A geomembrane type liner is often used under the stockpiles of soils to prevent the release of contaminated leachate to the environment. — An ultraviolet resistant (e.g. stabilized polyethylene) cover is often used to prevent precipitation from entering a soil stockpile and to minimize possible volatile emissions and dust from escaping. — Additional dust control measures such as wetting the stockpile surfaces are often employed to suppress dust. — Berm/bunds or other suitable diversion measures (e.g. drainage swale) are often constructed around the stockpiles to prevent runon and runoff. — General personnel protection requirements for operation include protective clothing, dosimetry and industrial safety protection (eye protection, safety shoes). — Respiratory protection is not typically required, except on the rare occasion for system decontamination of the internal components.

Note: PCB — polychlorinated biphenyl.

4.1.2. Cable insulation separation

4.1.2.1. Typical system description

This system is used following pretreatment of the copper wires and cables, including cleaning, sorting and removal of outer insulation. Separation of cable insulation from the internal copper wire takes place in the shredding facility using mechanical processes (see Fig. 8). A significant advantage of this process is that the contamination is separated from the internal wire because the contamination is typically limited to the cable insulation. In this process, the cable shredding facility is loaded with the material using a conveyor belt. It is then prepared in the preshredder for granulation. The shredding takes place in the cutting mill. Because of the aggressive mechanical action in the cutting mill, the majority of the contamination is removed from the insulation. Sorting copper and insulation fractions takes place by air and vibratory mechanical separation, and the resultant dust is collected and separated.

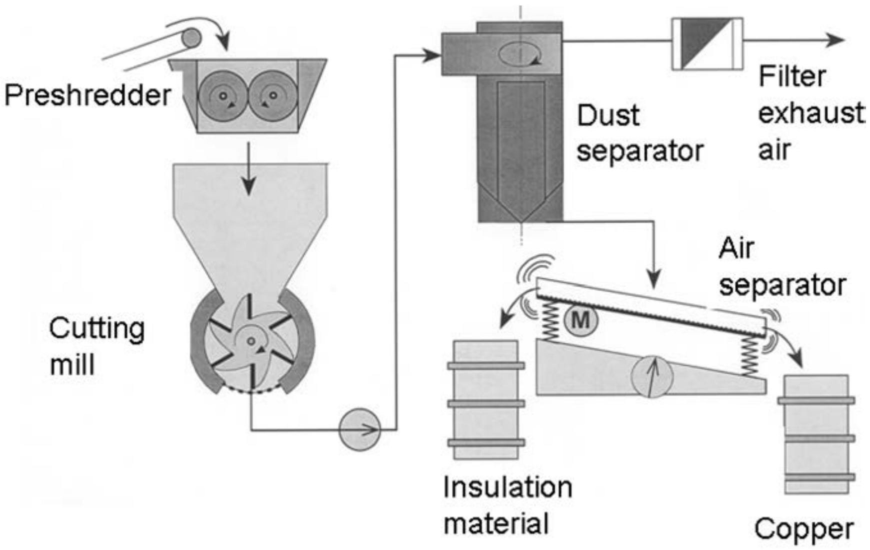


FIG. 8. Process flow diagram of the cable insulation separation system (courtesy of GNS Gesellschaft für Nuklear-Service mbH).

4.1.2.2. Description of individual components and elements

The system comprises the following major components:

— Pretreatment (cleaning, sorting, removal of outer insulation);
— Preshredder;
— Cutting mill (grinder);
— Dust separator;
— Air separator (to remove copper from insulation by airflow);
— Ventilation system with gaseous effluent treatment (air filter);
— Collection of copper and insulation material.

4.1.2.3. System specific benefits

— Copper that may be suitable for free release;
— Some insulation material that may be suitable for free release;
— Good volume reduction of radioactive waste;
— Low overall costs: minimization of disposal costs; copper resale; mobile system campaign costs are more economical than for a fixed system.

4.1.2.4. System specific limitations

— Can treat cables up to 120 mm in diameter;
— Pretreatment necessary;
— Suitable only for copper cable.

4.1.2.5. Key screening considerations

Table 6 identifies key screening considerations for cable insulation separation systems.

TABLE 6. KEY SCREENING CONSIDERATIONS FOR CABLE INSULATION SEPARATION SYSTEMS

Consideration	Description
Characteristics of incoming and source waste (volume, type, activity, form)	— Prepared and sized Cu cables (including the individual strands of Cu wire and associated insulation material); — Maximum cable diameter is 120 mm; typically in the range of 40–60 mm.
Characteristics of secondary waste generated by process (volume, type, activity, form)	Cu in granules (10% volume), insulation in granules (50% volume), dust (40% volume).
Characteristics of final waste form (container type, activity, form)	— Cu: may be suitable for free release. — Insulation: part may be suitable for free release and part will require disposal as radioactive waste (can be used as void filler). — Dust: radioactive waste disposal.
Regulatory and legal considerations (national, local, international, licensing, operation, waste movement and transport)	Treatment of contaminated cable at an existing nuclear facility would require confirmation that operation of the process can be performed within the existing safety basis of the facility and local, regional and national regulations.
Transport requirements (system operation, waste shipments, access roads)	— Transport in two ISO containers; — Crane required at the receiving site to locate the system.
Mode of use: batch or continuous processing (system, secondary waste)	System can be operated both in batch or continuous operation.
Cost: contractual arrangements (leased/procured); periodic (monthly/annual/campaign/volume) installation; consumables; staff; equipment removal and disposal; shipping; final waste disposition	Cost effective for 10–11 t of cables in a single campaign when compared with direct disposal as radioactive waste.
System configuration (mobile or skid mounted)	Transportable system: two ISO containers, assembled one on top of the other.
Footprint or physical size of the mobile system (maximum dimensions, media handling/replacement/repair space)	Floor area: 10 m × 5 m × 6 m high (under crane).
Total weight (for floor loading and movement)	Up to 16 t.
Staffing (number, contracted staff, technical qualifications, operations, security, maintenance)	Minimum work crew: — One equipment operator (training, skill and experience required); — Two unskilled workers for pretreatment.

TABLE 6. KEY SCREENING CONSIDERATIONS FOR CABLE INSULATION SEPARATION SYSTEMS (cont.)

Consideration	Description
Maximum or optimal throughput and capacity, and volume reduction	— 200–400 kg/h of primary waste; — Volume reduction factors of 20–25.
Space requirements (area for consumable storage, waste staging and storage)	— No special requirements; — Waste storage space varies by waste volume processed.
List consumables required for process (media, containers, parts, chemicals)	HEPA filters.
General service requirements (air, water, steam, electricity, ventilation)	— Power: 400 V AC, 50 Hz; ~100 kW. — Ventilation system for system exhaust air.
Handling equipment required for placement, operation, and waste handling and packaging (cranes, forklifts, load capacity)	One crane (10 t) for placement and one forklift for waste handling.
General requirements for industrial and radiological safety (barriers, respiratory protection, personnel exposure monitoring, contamination controls, air monitoring)	— Noise hazards; — Contamination controls; — Tripping hazards; — Forklift operation; — Lifting and cutting cable.

Note: HEPA — high efficiency particulate air.

4.2. LIQUID AND WET SOLID WASTE

4.2.1. Radioactive oil decontamination

Some reactor systems use oils as lubricants and as hydraulic fluids for mechanical system drives. During the course of operation, oil leakage may become radioactively contaminated. For example, in Canada deuterium–uranium (CANDU) reactors, this waste stream can be significant, since hydraulically operated on-line fuelling machines can produce several hundred litres of waste oil per year. More modern plants have avoided the problem by utilizing pneumatic systems for their fuelling machines.

The high thermal energy content of oils makes incineration an attractive method to treat, and dispose of, waste oils. However, this is not always possible. An alternative process has been developed in Canada to remove a wide cross-section of radioactive contaminants from waste oil [20].

4.2.1.1. Typical system description

Two different processes have been developed, depending on whether beta/gamma activity or tritium needs to be removed from the oil. The beta/gamma removal process is illustrated in Fig. 9.

The process is based on extensive research and development, which established that radioactive species are incorporated into the additives in the lubricating oil mixture as organic complexes. The process utilizes catalytic thermal oxidation to decompose these additives and causes them to become particulates in the oil, which can be removed by mechanical means. The process is batch based since the kinetics of oxidation are quite slow (hours). The waste oil is recirculated through a strainer, a particulate filter and an in-line heater that feeds a vacuum degasser which removes suspended and dissolved water. The recirculation is continued until the oil reaches the required temperature of 180–200°C. Oxygen gas is then bubbled through the oil, and an initiator (cumene hydroperoxide) and a catalyst (copper naphthenate) are added to start the oxidation process. The oil is then stirred for 3–6 h and recirculated through the centrifuge to remove the sludge. Periodic sampling results are used to determine when the

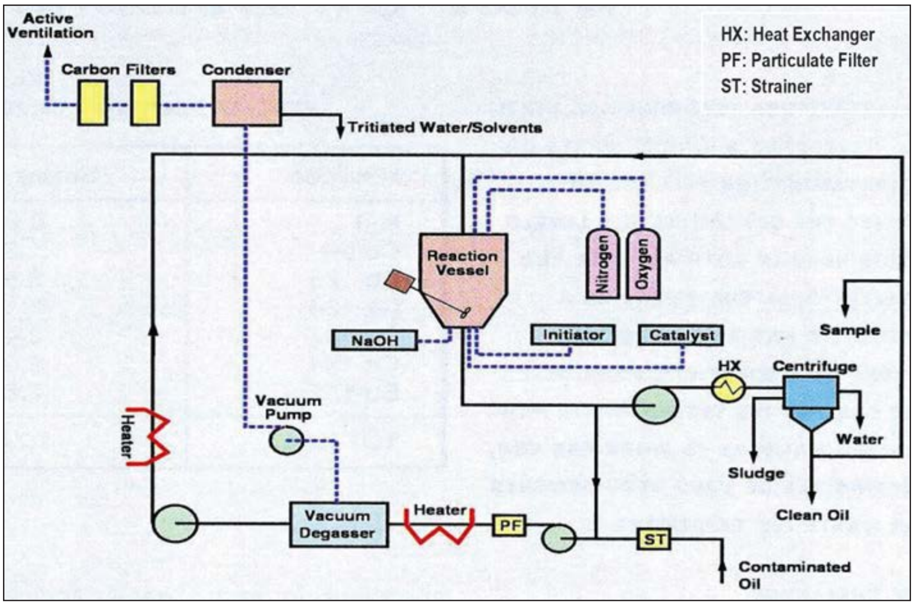


FIG. 9. Waste oil decontamination process simplified flow diagram.

target decontamination factor has been achieved. The resulting oil is free of contamination. This process is also able to remove conventional contaminants such as cadmium and lead.

If the contaminant in the oil is predominantly tritium as tritiated water, then the thermal oxidation process can be bypassed and only the vacuum degassing unit operation is required. However, when there is significant tritiated water in the oil, non-volatile organics associated with the additives in the oil incorporate tritium, and vacuum degassing by itself may not reduce tritium concentration in the oil to acceptable release levels. For this waste stream, it is necessary to provide an activated alumina column to remove polar non-volatile tritiated species. Figure 10 shows a pilot scale version of the vacuum degassing unit and the activated alumina column.

FIG. 10. Oil decontamination system: the vacuum degassing unit and the activated alumina column (courtesy of Kinectrics).

4.2.1.2. *Description of individual components and elements*

The system consists of:

- A mixing tank;
- In-line heaters;
- A vacuum degasser;
- A centrifuge;
- A condenser and desiccant based drier system to remove tritiated contaminated gases.

4.2.1.3. *System specific benefits*

- Provides an alternative to incineration;
- End product can be recycled;
- Ideal for small volumes of problematic oils (e.g. those also contaminated with polychlorinated biphenyls);
- Simple unit operations;
- Easy to operate.

4.2.1.4. *System specific limitations*

- Kinetics of oxidation are relatively slow;
- Secondary waste sludge needs to be conditioned prior to disposal.

4.2.1.5. *Key screening considerations*

Table 7 identifies key screening considerations for radioactive oil decontamination systems.

TABLE 7. KEY SCREENING CONSIDERATIONS FOR RADIOACTIVE OIL DECONTAMINATION SYSTEMS

Consideration	Description
Characteristics of incoming and source waste (volume, type, activity, form)	— Lubricating oil mixed with suspended and dissolved water containing mixed fission and activation products from normal power plant operations. — CANDU associated waste oils also contain MBq/L levels of ^{3}H as tritiated water and organically bound ^{3}H.
Characteristics of secondary waste generated by process (volume, type, activity, form)	— Waste sludge and tritiated water from the off-gas system; — A volume reduction factor of 100 is achievable; — The secondary waste sludge generation rate is proportional to the processing duration.
Characteristics of final waste form (container type, activity, form)	Small volume of radioactive oily particulate that can be packaged and disposed of in an HIC.
Regulatory and legal considerations (national, local, international, licensing, operation, waste movement and transport)	— Large scale processing would require regulatory approval at the processing site. — Regulatory approval for air emissions may also be required because volatile hydrocarbons formed in hot oil could be emitted from the off-gas system.
Transport requirements (system operation, waste shipments, access roads)	Skid mounted and assembled at the processing site.

TABLE 7. KEY SCREENING CONSIDERATIONS FOR RADIOACTIVE OIL DECONTAMINATION SYSTEMS (cont.)

Consideration	Description
Mode of use: batch or continuous processing (system, secondary waste)	Batch use.
Cost: contractual arrangements (leased/procured); periodic (monthly/annual/campaign/volume) installation; consumables; staff; equipment removal and disposal; shipping; final waste disposition	— A mobile system built according to nuclear design standards costs <US $50 000, depending on size. — Procurement may not be cost effective (the equipment would be idle between waste campaigns). — Two days are required to assemble the equipment and perform operability checks prior to a processing campaign.
System configuration (mobile or skid mounted)	Typically skid mounted, but a mobile system can also be utilized depending on the volume of oil to be processed.
Footprint or physical size of the mobile system (maximum dimensions, media handling/replacement/repair space)	12 m ISO container on a trailer is the maximum size required.
Total weight (for floor loading and movement)	Not normally an issue unless the oil contains high levels of radioactivity, and shielding needs to be utilized.
Staffing (number, contracted staff, technical qualifications, operations, security, maintenance)	Two people with chemical technician qualifications.
Maximum or optimal throughput, capacity, decontamination factor and volume reduction	— It is dependent on the degree of contamination in the oil and the degree of cleanliness required. — A decontamination factor of 100 is achievable for beta and gamma activity. — A lower decontamination factor can be expected for ^{3}H contamination. — A volume reduction of 100 is achievable, but depends on the duration of processing.
Space requirements (area for consumable storage, waste staging and storage)	5 m^2 for consumables.
List consumables required for process (media, containers, parts, chemicals)	— Homogenous catalyst: copper naphthenate. — Initiator: cumene hydroperoxide. — O_2 gas. — Clean drums for decontaminated oils. — Storage drums for sludge waste.
General service requirements (air, water, steam, electricity, ventilation)	— Electrical: 600 V for oil heating and centrifuge; 110/220 V electrical supply for other electrical loads (pumps, lighting, fans, mixers). — Ventilation to active ventilation, assuming there are radioactive volatile contaminants in the oil ($^{14}CO_2$, tritiated water vapour). — Fire suppression system. — Service water for cooling the oil prior to sludge removal by centrifuging.
Handling equipment required for placement, operation, and waste handling and packaging (cranes, forklifts, load capacity)	Drum handling.

TABLE 7. KEY SCREENING CONSIDERATIONS FOR RADIOACTIVE OIL DECONTAMINATION SYSTEMS (cont.)

Consideration	Description
General requirements for industrial and radiological safety (barriers, respiratory protection, personnel exposure monitoring, contamination controls, air monitoring)	— Portable shielding for reaction vessel and centrifuge is necessary if oil has a high activity. — The oxidative process operates at 180–200°C, and the heater and reaction vessel needs to be insulated. — The entire system, including feed tank and drums, and product tank and drums, is to be surrounded by a berm/bund with a volume twice that of the liquid inventory in the system. — Spill control and cleanup equipment are required. — Provisions need to be made for air scrubbing of volatile organics (carbon filtration) and condensing any water vapour that is produced during the oxidation; — Personnel protective equipment is necessary for handling radioactive liquids. — If handling tritiated oils, a ^{3}H cartridge respirator is to be worn. — If the oil contains a significant amount of ^{3}H, then a ^{3}H air monitor is to be installed in the ventilation system downstream of the carbon filter to assess the environmental releases and the performance of the condenser and filters.

Note: CANDU — Canada deuterium–uranium; HIC — high integrity container.

4.2.2. Filtration

4.2.2.1. Typical system description

Filtration systems for aqueous wastes are used to remove insoluble impurities to produce the desired effluent for disposition or for further processing. A typical mobile filtration system is illustrated in Fig. 11. It consists of a vessel containing a pleated or wound cartridge, or bag elements, a motive force pump, and valves and interconnecting hoses. Some applications may employ media such as carbon, sand, diatomaceous earth or other application specific materials. Filtration systems are often coupled with supplemental treatment technologies, such as chemical pretreatment, evaporation, crystallization, ion exchange or membrane technologies, to further improve the effluent quality.

FIG. 11. A mobile aqueous filtration air operated diaphragm pump (left, courtesy of Verder GPM) and a filter vessel and cartridge filter (right, courtesy of Tri Nuclear Corp.).

4.2.2.2. Description of individual components and elements

— Filter housing(s);
— Differential pressure indicator;
— Filter handling tools (removal and replacement);
— Filter elements;
— Pumps or other liquid motive force equipment;
— Hoses or piping;
— Inlet and outlet valves;
— Power or air supply for electric or air driven pumps;
— Transfer shields (for high activity applications).

4.2.2.3. System specific benefits

— Can be very effective using simple designs;
— Little space required;
— Simple technology reduces level of knowledge required to operate;
— Inexpensive.

4.2.2.4. System specific limitations

— Not typically effective for soluble species (some exceptions for ion exchange material impregnated filter elements);
— Poor waste packaging efficiency for pleated and string wound cartridges (volume increase following packaging);
— Filtration media other than cartridges or bags may require additional equipment, such as sluice equipment, and technical expertise to replace media.

4.2.2.5. Key screening considerations

Table 8 identifies key screening considerations for aqueous waste filtration systems.

TABLE 8. KEY SCREENING CONSIDERATIONS FOR AQUEOUS WASTE FILTRATION SYSTEMS

Consideration	Description
Characteristics of incoming and source waste (volume, type, activity, form)	— Volumes vary according to application; — Typically liquid, with undissolved chemical or radioactive impurities; — Concentrations can range from very low to 10–15% by weight (sludge, slurry); — Activity levels can range from very low to medium.
Characteristics of secondary waste generated by process (volume, type, activity, form)	— Cartridge and bag elements are solid and can be packaged in their removed condition following drainage of residual liquid. — Flowable media (carbon, sand, diatomaceous earth) will be in its original form, with a higher density and activity, and may require additional drying, encapsulation, cementation or drainage verification.
Characteristics of final waste form (container type, activity, form)	Can be packaged in a variety of waste containers, including 200 L drums, high density polyethylene containers, boxes or other containers that are approved for the waste chemical, physical and activity characteristics.

TABLE 8. KEY SCREENING CONSIDERATIONS FOR AQUEOUS WASTE FILTRATION SYSTEMS (cont.)

Consideration	Description
Regulatory and legal considerations (national, local, international, licensing, operation, waste movement and transport)	— Needs to meet local, regional, national and standards for system design, packaging, staging, storing, transport and disposal. — Higher activity waste will require additional precautions to control dispersion and worker and public exposure.
Transport requirements (system operation, waste shipments, access roads)	— System is typically very easy to move, either as an integrated wheel mounted unit or with lifting equipment. — Shipment for new systems can be via common commercial carrier. — There are no special transport requirements.
Mode of use: batch or continuous processing (system, secondary waste)	— System can be used for either. — Infrequent batch processing may result in deterioration of the media over time. — Recommended that the media manufacturer be consulted for recommendations regarding replacement frequencies in either continuous or batch operation.
Cost: contractual arrangements (leased/procured); periodic (monthly/annual/campaign/volume) installation; consumables; staff; equipment removal and disposal; shipping; final waste disposition	Systems are typically inexpensive (<US $10 000 for a single vessel and pump configuration), and procurement is typically the most cost effective option. However, for one time or very infrequent use, campaign leasing is to be considered
System configuration (mobile or skid mounted)	Either can be specified.
Footprint or physical size of the mobile system (maximum dimensions, media handling/replacement/repair space)	A single vessel, single pump configuration requires $<4\ m^2$ for the skid and access for replacement. Optimally, $10\ m^2$ is more typical.
Total weight (for floor loading and movement)	<770 kg with shielding (related to filters up to 0.20 Sv/h).
Staffing (number, contracted staff, technical qualifications, operations, security, maintenance)	One operator on an as required basis to start and to stop the system and to evaluate differential pressure (frequency varies by host site requirements or expected rate of increase).
Maximum or optimal throughput, capacity, decontamination factor and volume reduction	Varies by application; typically in the range of 1 L/min to >2000 L/min flow rate.
Space requirements (area for consumable storage, waste staging and storage)	— Space required for media varies by type. — Cartridge elements are typically 0.01–0.1 m^3 each.
List consumables required for process (media, containers, parts, chemicals)	— Filter media; — Diaphragm for air driven parts.
General service requirements (air, water, steam, electricity, ventilation)	— Water-free air for air driven pump option; — 220 V AC service for typical electric pump operation; — Clean flush water may be required for vessel flush following spent element removal.
Handling equipment required for placement, operation, and waste handling and packaging (cranes, forklifts, load capacity)	— Wheeled module, forklift or hand truck, depending on size; — Small capacity crane may be required for difficult to access locations.

TABLE 8. KEY SCREENING CONSIDERATIONS FOR AQUEOUS WASTE FILTRATION SYSTEMS (cont.)

Consideration	Description
General requirements for industrial and radiological safety (barriers, respiratory protection, personnel exposure monitoring, contamination controls, air monitoring)	— Radiological barriers required for controlling access to equipment during and following use; — Contamination control area required for spent media replacement; — Personnel protective clothing required for change, typically of the waterproof variety; — Airborne controls are typically not required.

4.2.3. Filtration and ion exchange

4.2.3.1. Typical system description

A mobile filtration and ion exchange treatment system developed and employed by Bhabha Atomic Research Centre (BARC), India, for treatment of alkaline intermediate level waste stream is discussed here (see Fig. 12). The process involves passing the aqueous waste through a disposable filter cartridge to remove suspended solids after in-line pH adjustment and then through a series of three ion exchange columns for removal of the predominant radionuclides [21–24]. The first two ion exchange columns are filled with resorcinol formaldehyde polycondensate resin (RFPR) specific to ^{137}Cs and the third with iminodiacetic acid (IDA) resin specific to ^{90}Sr. The effluent is passed through a resin trap, monitored and sent for further treatment, as required, followed by discharge. After loading, the activity is eluted in a small volume of dilute nitric acid, and the resin is regenerated with sodium hydroxide for further use. In this way, the same resin filling can be used in multiple loading–elution–regeneration cycles before it is degraded and requires replacement with a fresh charge. The eluted activity is stored for further conditioning or recovery of ^{137}Cs, as required. The ion exchange treatment system is installed on a 10 m trailer ready to be connected on-site and operated. Control room and chemical preparation set-ups have to be installed adjacent to the mobile system on-site. The system is equipped with a radiation monitoring system and instrumentation for remote operation. Engagement and removal operations of ion exchange columns are remotely controlled.

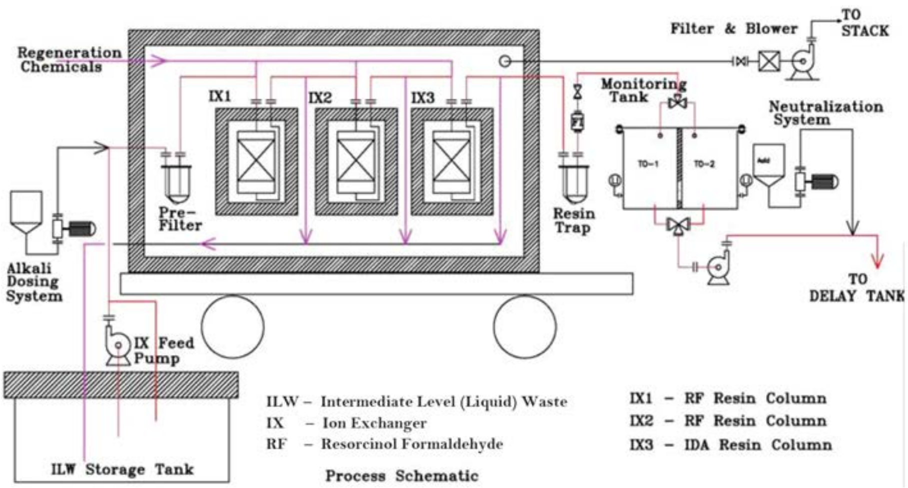


FIG. 12. Mobile filtration and ion exchange treatment system (adapted from an image from BARC).

4.2.3.2. Description of individual components and elements

(a) **Shielded processing unit**: Radionuclide specific resins (RFPR for ^{137}Cs and IDA resin for ^{90}Sr) are filled in 100 L columns designed for remote replacement. They are connected in series with valves and piping suitable for reversal of flow. The columns are locally shielded, and all radioactive components are installed in a shielded enclosure to protect operating personnel from radiation.

(b) **Controls**: The system is operated remotely from a control room to be installed on-site, adjacent to the mobile trailer. Automatic safety interlocks and high level annunciations are provided for safe operation. Contact operations are required only for maintenance, if required. Radiation and system check surveillance by the crew is necessary once per shift. A control console for remote movement of ion exchange columns is incorporated on the trailer outside the shield at the radiation shielding window station.
(c) **Mechanical handling**: Mechanical handling is involved in the removal or replacement of the ion exchange columns, filter cartridges and chemicals. A 5 t capacity mobile crane and a 2 t capacity forklift are employed for this purpose.
(d) **Gaseous effluent routing, monitoring and treatment**: The shielded enclosure is maintained at a negative pressure with up to ten air changes per hour, and the air is exhausted through prefilters and HEPA filters before release. Liquid effluents are monitored by sampling and routed for further treatment (chemical precipitation, if required by the waste characteristics), dilution and discharge.

4.2.3.3. System specific benefits

— Simple to install, connect and operate;
— No specific limits on volumes of waste treated;
— High performance with regard to decontamination factors, volume reduction and effluent release (specific radionuclides are separated in a series of ion exchange columns);
— Low volumes of secondary waste with simple disposal options;
— Radioactive processing zone exhausted through the HEPA filter module;
— Low cost;
— Low maintenance;
— Low personnel exposures;
— Easy to decontaminate and remove from site.

4.2.3.4. System specific limitations

— The mobile system is designed for resins that are selective for specific radionuclides. The system needs to be redesigned, depending on the input waste characteristics.
— The mobile system is designed to operate in a temperature range of 10–40°C. For operation and transportation in lower temperature regions, a remodelling of the system is necessary.
— Shielding is limited by the capacity of the trailer and optimized for the type of wastes to be processed. During elution cycles, a special work permit is required to control personnel movement in the case of higher active waste.

4.2.3.5. Key screening considerations

Table 9 identifies key screening considerations for a filtration and ion exchange system.

TABLE 9. KEY SCREENING CONSIDERATIONS FOR A FILTRATION AND ION EXCHANGE SYSTEM

Consideration	Description
Characteristics of incoming and source waste (volume, type, activity, form)	— Aqueous waste, small to very high volumes; — Resin to be selected for input waste; — Typically activity up to 1.85 MBq/mL with high proportion of ^{137}Cs; — Liquid waste transferable by pumps to the mobile unit.

TABLE 9. KEY SCREENING CONSIDERATIONS FOR A FILTRATION AND ION EXCHANGE SYSTEM (cont.)

Consideration	Description
Characteristics of secondary waste generated by process (volume, type, activity, form)	— Ion exchange columns, filter cartridges, cleanup solutions; — Low level secondary waste requiring further chemical treatment; — Solids disposable in trenches in the near surface disposal facility; — Effluents to be monitored before sending for further treatment and discharge.
Characteristics of final waste form (container type, activity, form)	— Concentrated liquid waste to be stored or conditioned further; — Specific activity up to 12 times that of input waste.
Regulatory and legal considerations (national, local, international, licensing, operation, waste movement and transport)	— National regulatory considerations; — Licensing: moderate difficulty level.
Transport requirements (system operation, waste shipments, access roads)	— No waste movement from the site; — Drive-in type trailer; — Truck for movement of tanks and control room chemicals.
Mode of use: batch or continuous processing (system, secondary waste)	— Continuous processing until resin replacement; — Secondary liquid waste to be collected in tanks prior to treatment and discharge.
Cost: contractual arrangements (leased/procured); periodic (monthly/annual/campaign/volume) installation; consumables; staff; equipment removal and disposal; shipping; final waste disposition	— Low cost compared with fixed installation; — Periodic campaigns; — Leased or procured; — Easy to install; — Ion exchange resins and filter cartridges readily available; — Trained and qualified staff required; — Specialized skills or knowledge are generally not required; — Easy to clean, dismantle and remove; — Transportable on trailers and trucks.
System configuration (mobile or skid mounted)	— Mobile configuration is described here. — Skid mounted configuration is also possible.
Footprint or physical size of the mobile system (maximum dimensions, media handling/replacement/repair space)	— Typically 10 m long trailer mounted system with a height of 5 m. — The system in use is permanently mounted on a trailer. — Can be designed for skid mounting.
Total weight (for floor loading and movement)	— Weight of system depends on activity levels handled and the shielding required for safe operation. — Weight: ~30 t.
Staffing (number, contracted staff, technical qualifications, operations, security, maintenance)	— Easy to operate, qualified staff required; — Three people in a shift; — Operation and maintenance staff and health physicist.
Maximum or optimal throughput, capacity, decontamination factor and volume reduction	— Optimal throughput: 400–500 L/h. — Decontamination factors >10 000 for ^{137}Cs. — Volume reduction factors: 10–12 (as a ratio of volume of original waste processed and volume of eluted solution). — Disposal of resin column typically after 10–12 cycles of operation.
Space requirements (area for consumable storage, waste staging and storage)	~25 m^2 area with 5 m height for control room, chemical preparation and storage of consumables.

TABLE 9. KEY SCREENING CONSIDERATIONS FOR A FILTRATION AND ION EXCHANGE SYSTEM (cont.)

Consideration	Description
List consumables required for process (media, containers, parts, chemicals)	— Ion exchange resins; — Filter cartridges; — Chemicals for pH adjustment, elution and regeneration; — Spares such as gaskets, O-rings and flexible hoses.
General service requirements (air, water, steam, electricity, ventilation)	— Electrical: 5 kW for fans, lighting, control and safety monitoring. — Ventilation requirement dependent on host site requirements: system and transfer lines to be maintained at 25–30°C. — Compressed air for operation of pumps and valves: 300 m^3/h at 0.6 MPa.
Handling equipment required for placement, operation, and waste handling and packaging (cranes, forklifts, load capacity)	Local handling equipment required are cranes for removal of shielded ion exchange columns (5 t) and forklifts for movement of chemicals.
General requirements for industrial and radiological safety (barriers, respiratory protection, personnel exposure monitoring, contamination controls, air monitoring)	— Barriers during elution of loaded ion exchange columns. — Personnel monitoring: thermoluminescent dosimeter. — Periodic health physics monitoring may be required. — Area gamma monitors and continuous air monitors. — Contamination controls based on host site requirements.

4.2.4. Filtration, membrane and ion exchange

4.2.4.1. Typical system description

The mobile modular system Aqua-Express was designed by MosNPO Radon, the Russian Federation, for the treatment of liquid low and intermediate level radioactive waste (LILW). The system is intended for application in small to medium research centres and other organizations where the generation of low and intermediate level wastewater is rather low (up to 500 m^3/a) [25, 26]. Treatment is achieved through a technological chain including filtration, sorption and ultrafiltration processes, and is designed to release non-radioactive salts together with the cleaned water. The system consists of three autonomous wastewater purifying modules and a sampling system (see Fig. 13). The system can be transported by road, rail or air, and it can be installed in a standard ISO transport container.

4.2.4.2. Description of individual components and elements

The present process scheme is shown in Fig. 14 [26], and includes a filter container, a filtration module and an ultrafiltration module.

The process diagram for the system can be divided into the following elements, which correspond to different stages of water purification: a filter container with a ferrocyanide sorbent, flowable media filters and an ultrafiltration module. Typically, the facility would also include additional water purifying modules. However, the basic system is suitable for the purification of low level radioactive and low salinity liquid waste (salinity below 3 g/L). The principles of the Aqua-Express purification process are described below.

The source liquid radioactive waste from a storage tank is pumped through the filter container, which has a ferrocyanide sorbent and flowable media filters. The ferrocyanide sorbent is synthetic (e.g. nickel ferrocyanide or copper ferrocyanide deposited on silica gel) and selectively extracts caesium ions, including ^{134}Cs and ^{137}Cs, from the liquid waste. In many radioactive waste streams, caesium isotopes are the primary gamma emitters, so their extraction from the solution in the first purification stage promotes reduction in area radiation levels in the processing facility. Decontamination factors for caesium isotopes at this stage can be as high as 10 000.

FIG. 13. The Aqua-Express facility (courtesy of MosNPO Radon).

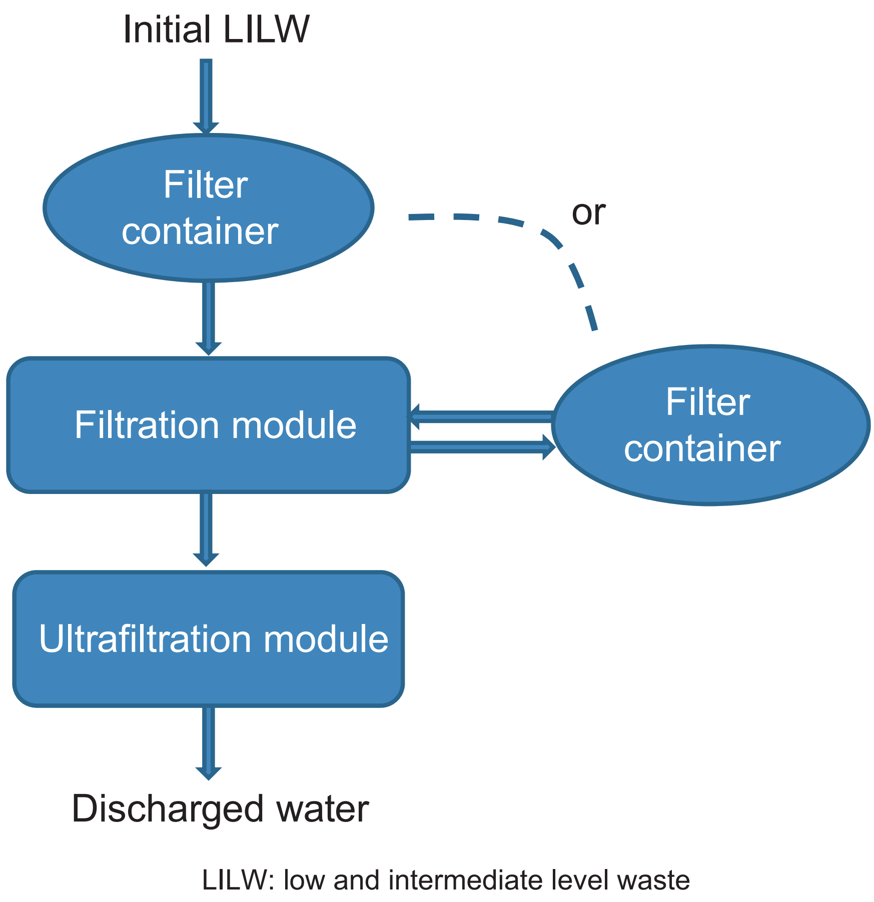


FIG. 14. Process scheme of the Aqua-Express facility.

The composition of the sorbents used in the flowable media filters depends on the composition of the liquid radioactive waste and is determined based on preliminary chemical and radiochemical analyses. This is the most important radionuclide removal step in the purification process. Therefore, the sorbent selection is to be performed by experts in the field of radioactive water treatment.

Subsequent to the radionuclide removal treatment by sorbents, the liquid waste is routed to the ultrafiltration module feed tank. It is circulated in the 'tank ultrafiltration apparatus' by a pump at a pressure of 0.2–0.3 MPa. The size of the membrane pores does not exceed 50–100 nm. Following this stage, the water is completely purified and free of suspended solids, colloids and polymeric molecules. The ultrafiltration technology purifies the water by removing radionuclides, which are integrated with submicron size suspension particles, as well as products resulting from the abrasion of the sorbents. The latter is especially important when natural sorbents (e.g. clinoptilolite, chabazite and bentonite) and activated charcoals are used. Decontamination factors at the last stage can vary from 1 to 10, depending on the ratio of submicron size suspensions in the liquid waste stream and the extent of their carry over through the flowable media filters.

When treating liquid radioactive waste containing high concentrations of oil products or suspended solids, it is recommended that a flowable media filter be used prior to sorbent and ultrafiltration treatment. The materials to consider include layered stringy synthetic and hydrophobic material, sand or crushed claydite, and activated charcoal or crushed anthracite. In this scenario, the filter container is connected to the filtration module between the first and the second filters (see Fig. 14).

During operation of the filter container and flowable media filters, it is recommended that gases which accumulate in the upper part of filters be withdrawn on a periodic basis, and that reverse water flow (backwash) be used to loosen the filter loading.

4.2.4.3. System specific benefits

— Simple to install, connect and operate;
— No specific limits on volumes of waste treated;
— High performance with regard to decontamination factors and effluent release (specific radionuclides are separated in a series of ion exchange columns and by ultrafiltration);
— Good overall volume reduction, including radioactive secondary waste;
— Low cost;
— Low maintenance;
— Low personnel dose rates;
— Easy to decontaminate and remove from site.

4.2.4.4. System specific limitations

— The mobile modular installation is presently designed to operate in a temperature range of 10–40°C. For transportation and operation in lower temperature regions, modification of the system is necessary.
— The system uses various sorbents for various radionuclides. In each separate case, it is required to select specific sorbents.
— The system (except for the filter container) has no biological shielding. Therefore, it is possible to process only low level liquid waste. If the liquid contains only caesium isotopes, the filter container requires replacement after loading 7.4 GBq of caesium.
— The mobile modular installation has no system for conditioning secondary radioactive waste. Therefore, spent sorbents and membranes have to be packaged and transported to other installations for conditioning.
— If reverse osmosis is used (in this or in similar applications) instead of ultrafiltration, the following system limitations apply: careful influent characterization and control; may require influent chemical pretreatment; complex technology requires operator training and knowledge of process; requires technical support with chemistry and reverse osmosis membrane expertise; the unit may be large in size; higher initial cost than most alternate processing options.

4.2.4.5. Key screening considerations

Table 10 identifies key screening considerations for systems using filtration, membrane and ion exchange (Aqua-Express).

TABLE 10. KEY SCREENING CONSIDERATIONS FOR SYSTEMS USING FILTRATION, MEMBRANE AND ION EXCHANGE

Consideration	Description
Characteristics of incoming and source waste (volume, type, activity, form)	— Up to 500 m^3/a, liquid LILW. — Total gamma activity: up to 1×10^6 Bq/L; main contaminants: ^{134}Cs and ^{137}Cs, ^{110m}Ag, ^{140}Ba, corrosion products. — Total beta activity: mostly ^{90}Sr (100–1000 Bq/L). — Total alpha activity: (100–300 Bq/L). — pH1–10. — Moderate salinity of waste (1–10 g/L), can be a little higher in special cases. — If reverse osmosis is used, a relatively high quality feed is required.
Characteristics of secondary waste generated by process (volume, type, activity, form)	For treatment of 500 m^3 liquid waste, the following secondary waste is generated: — Five filter containers (0.2 m^3): total activity up to 8×10^8 Bq. — 15 standard metallic drums with granulated sorbents or sand (total volume <0.6 m^3): specific activity up to 3×10^6 Bq/L. — One spiral ultrafiltration element (0.1 m^3): activity is not significant. — Membranes, if reverse osmosis is used.
Characteristics of final waste form (container type, activity, form)	— Filter container (cemented standard metallic drum); — May be conditioned by cementation: before or after transport (total volume <0.6 m^3).
Regulatory and legal considerations (national, local, international, licensing, operation, waste movement and transport)	— Local, regional and national regulations (Russian Federation: Norms of Radiation Safety NRB-99).
Transport requirements (system operation, waste shipments, access roads)	— Small trucks; — Other variants: transport container or packing boxes and lifting mechanisms are required.
Mode of use: batch or continuous processing (system, secondary waste)	— The system can be used for continuous processing of up to 100 m^3 of liquid waste. — Media life determines process run length.
Cost: contractual arrangements (leased/procured); periodic (monthly/annual/campaign/volume) installation; consumables; staff; equipment removal and disposal; shipping; final waste disposition	— Capital installation cost: ~US $80 000; — Specific cost of treating 1 m^3 liquid radioactive waste can be up to US $500 (typically US $100–200); — Cost of final waste disposal varies in different States, and may be >US $10 000 for 1 m^3. — If reverse osmosis is used, system costs increase.
System configuration (mobile or skid mounted)	— Usually skid mounted; — Mobile configuration possible by installing on a small truck.
Footprint or physical size of the mobile system (maximum dimensions, media handling/replacement/repair space)	— <10 m^2 for ultrafiltration, typically more than twice that for reverse osmosis.
Total weight (for floor loading and movement)	— <1500 kg for ultrafiltration.

TABLE 10. KEY SCREENING CONSIDERATIONS FOR SYSTEMS USING FILTRATION, MEMBRANE AND ION EXCHANGE (cont.)

Consideration	Description
Staffing (number, contracted staff, technical qualifications, operations, security, maintenance)	— Operation: one to two people (at least one chemistry expert). — For maintenance: two technicians (mechanic and electrician).
Maximum or optimal throughput and capacity, and volume reduction	— 0.5 m^3/h (optimal 0.3 m^3/h); — Volume reduction: not less than 100 times. For reverse osmosis: — Capacity depends on application, can be as low as 1 L/min and >200 L/min; — Limited by number of stages, operating pressure, influent characteristics and effluent target; — Typical decontamination factors of 1000–10 000 are common.
Space requirements (area for consumable storage, waste staging and storage)	<20 m^2.
List consumables required for process (media, containers, parts, chemicals)	Per 500 m^3 of liquid waste: — 16 standard metallic drums; — Five filter containers; — 10 kg EDTA or equivalent (oxalic acid); — 50 kg NaOH; — 40 L, 12N HNO_3; — 10 kg citric acid.
General service requirements (air, water, steam, electricity, ventilation)	— Power: 220 V AC, 50 Hz, 3 kW. — Water: <0.2 m^3 for 500 m^3 of cleaned liquid radioactive waste. With reverse osmosis: — Power: 220 V, three phase, 50 A, 60 Hz. — Water: demineralized, 110 L/h, two lines, 1.0 and 0.5 MPa. — Air: 100 m^3/h, 0.4 MPa. — HVAC: vents to be connected to plant HVAC.
Handling equipment required for placement, operation, and waste handling and packaging (cranes, forklifts, load capacity)	— Forklift or crane if system is transported in a container or in boxes (weight of each module <800 kg). — For operation: filter containers and disposable sorbent drums (weight <400 kg). — Reverse osmosis system: requires crane with <25 t capacity.
General requirements for industrial and radiological safety (barriers, respiratory protection, personnel exposure monitoring, contamination controls, air monitoring)	— No special safety requirements; — Radiation monitoring around installation in selected points; — Contamination and radiological controls as required by host site.

Note: LILW — low and intermediate level waste; EDTA — ethylene diamine tetraacetic acid; HVAC — heatings ventilation and air conditioning.

4.2.5. Selective ion exchange in a nuclide removal system

4.2.5.1. Typical system description

A mobile nuclide removal system (NURES) is constructed and operated by Fortum Nuclear Services, Finland. It can be tailored to different requirements, either as a fixed or mobile system. Because of its flexibility, the mobile units can differ from case to case (see Fig. 15).

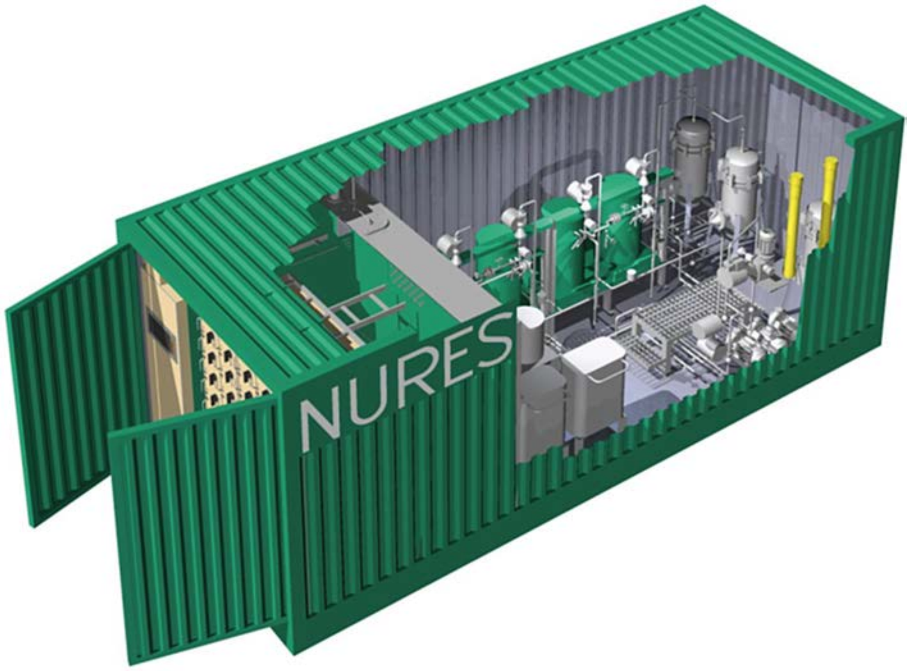
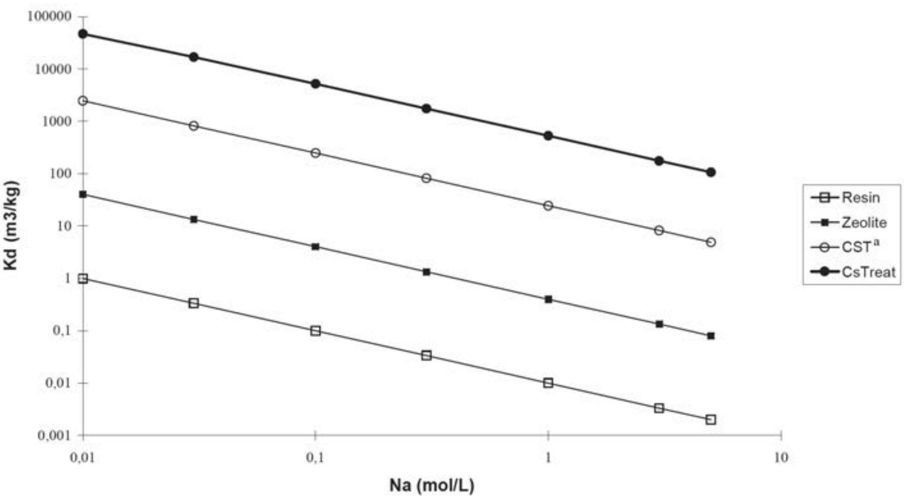


FIG. 15. Typical layout of the mobile NURES in a standard 6 m container (courtesy of Fortum Nuclear Services).

NURES can be used for the treatment of different liquids, including liquids with high salt concentrations. The system has been used for liquids with total salt concentrations up to 300 g/L, and has been tested up to 400 g/L. The first step in the process is an efficient filtering unit, which removes suspended radioactive particles. The next step removes target radionuclides as ionic radioactivity by highly selective ion exchange materials.

Three highly selective inorganic ion exchange materials have been used [27]. CsTreat was designed to have the highest possible selectivity for caesium, $k_{Cs/Na}$ = 1 500 000 and $k_{Cs/K}$ = 50 000, and very good ion exchange capacity, 0.35 meq/g. Figure 16 compares the K_d values for CsTreat to other typical media.



a Crystalline silicotitanate.

FIG. 16. Comparison of CsTreat K_d values (image from Ref. [27]).

In a mobile system, the typical use of CsTreat is in granular form in column operation. Column sizes from less than 1 L to 250 L have been used in fixed systems and 12 L columns in mobile systems. SrTreat was developed for removing strontium and CoTreat for removing cobalt and other corrosion products. Highly selective SrTreat was developed for removing strontium from alkaline solutions. It has a high selectivity factor with respect to sodium ($k_{Sr/Na}$ = 200 000), but it is sensitive to calcium and pH.

SrTreat has been successfully used for treatment of reprocessing liquids and liquids from nuclear icebreakers, and has been tested for liquid wastes in the United States Department of Energy Hanford and Savannah River Site tank farms.

Removing cobalt has always been one of the most significant challenges at a nuclear power plant. In response to this, 100% inorganic CoTreat was developed. CoTreat has efficiently removed cobalt and other corrosion products from nuclear power plant floor drainwater in laboratory tests, achieving decontamination factors as high as 1000 and processing capacities in excess of 50 m^3/kg, including high conductivity waters. Originally, CoTreat was developed to remove ionic cobalt. However, it was noticed that several other corrosion products could be removed at the same time.

New material for antimony removal is currently in the demonstration phase. Antimony causes about half of the radiation exposure during outages at the Loviisa nuclear power plant, in Finland. Early test results indicate that this media may reduce antimony and dose rates.

4.2.5.2. Description of individual components and elements

The filtering phase includes at least two phases of mechanical particle filtering. Prior to filtering, it may be beneficial to use an active charcoal bed for removal of organics (i.e. mostly oils). The filter sizes can be selected based on the feed stream, but 1 μm and 0.45 μm filters are generally used. The use of a 0.1 μm second stage filter will produce even better clarification.

In a mobile system, selective ion exchange material is used in particle form. The size of an individual column is typically 12 L, but several columns can be installed in parallel to increase the capacity of the system.

4.2.5.3. System specific benefits

— NURES has a flexible configuration and can be tailored for many different applications.
— The system can be a fully automatic and independent system at the site where no treatment system is installed, or it can be installed as a module into a larger treatment unit.
— It is very simple to install and to operate.
— The system can be small because of high selectivity of the ion exchange material.
— Very high decontamination factors make it possible to release purified liquid.
— High selectivity and capacity for target nuclides yield high volume reduction factors.
— It is very easy to maintain.
— It is easy to decontaminate and to demobilize.

4.2.5.4. System specific limitations

— Inorganic materials in a granular form allow only moderate flow rates. Typically, one 12 L column gives a processing flow rate from 120 to 240 L/h. Parallel use of columns or use of powdered material in cartridges can increase the capacity.
— The incoming liquid may contain radionuclides that limit the release of liquid after removal of caesium, strontium, cobalt or other corrosion products. In these cases, other phases have to be added to the system or the liquid has to be recycled instead of released.

4.2.5.5. Key screening considerations

Table 11 identifies key screening considerations for selective ion exchange in NURES.

TABLE 11. KEY SCREENING CONSIDERATIONS FOR SELECTIVE ION EXCHANGE IN NURES

Consideration	Description
Characteristics of incoming and source waste (volume, type, activity, form)	— Low and intermediate level liquid waste with salt concentrations up to 400 g/L; — pH in Cs removal 1–13 for high salt liquids and 2–12 for low salt liquids; for Sr, pH>9 (in some cases >7); for Co and corrosion products, pH6–8.
Characteristics of secondary waste generated by process (volume, type, activity, form)	— Filter and ion exchange media; — Volume dependent on the incoming liquid characteristics.
Characteristics of final waste form (container type, activity, form)	— Specific activity can be thousands of times higher than in incoming liquid. — Ion exchange columns: 100% inorganic. — Ion exchange material is normally in granular form, grain size 0.30–0.85 mm (other sizes available). — Dewatered columns can be disposed of in concrete containers or media removed from columns and conditioned for disposal.
Regulatory and legal considerations (national, local, international, licensing, operation, waste movement and transport)	— Local, regional or national requirements may apply. — No specific difficulties in licensing.
Transport requirements (system operation, waste shipments, access roads)	— Mobile system can be easily transported by a truck. — During operation, spent materials are transported by a forklift truck, push cart or lift.
Mode of use: batch or continuous processing (system, secondary waste)	— Either batch or continuous; — The mobile NURES system can include a fully automatic control system that supports full time operation with automated shutdown for activity breakthrough, overpressure or failure.
Cost: contractual arrangements (leased/procured); periodic (monthly/annual/campaign/volume) nstallation; consumables; staff; equipment removal and disposal; shipping; final waste disposition	— Low cost compared with a fixed system or to alternative solutions, such as solidification of liquid; — Operated typically in periodic campaigns; — System can be leased or procured, columns and cartridges are available with reasonable delivery time; — Training is given for operation personnel; — System can be transported with normal trucks or lorries; — System is easily installed, cleaned and removed; — Columns and cartridges disposed of in containers provided by the host site.
System configuration (mobile or skid mounted)	Either mobile or skid mounted.
Footprint or physical size of the mobile system (maximum dimensions, media handling/replacement/repair space)	Typically 15 m^2, but depends on the requirements of each case.
Total weight (for floor loading and movement)	Typically 20–30 t: shielding will add weight.
Staffing (number, contracted staff, technical qualifications, operations, security, maintenance)	— Operator required: frequency of oversight based on host site requirements. — Columns and cartridges changed as required, one qualified operator required, and one additional person for change of columns and cartridges.
Maximum or optimal throughput, capacity, decontamination factor and volume reduction	— Flow rate: 10–20 bed volumes per hour. — Decontamination factors typically >>1000 for Cs and Sr, 10–1000 for Co and corrosion products. — Capacity: thousands of m^3 with 1 kg of ion exchange material. — Volume reduction factor: as a ratio of generated liquid and the ion exchange material can be tens of thousands; >1000 relative to final disposed form.

TABLE 11. KEY SCREENING CONSIDERATIONS FOR SELECTIVE ION EXCHANGE IN NURES (cont.)

Consideration	Description
Space requirements (area for consumable storage, waste staging and storage)	Storage room required for final waste containers and for their handling usually 10–15 m^2.
List consumables required for process (media, containers, parts, chemicals)	— Ion exchange columns for removal of ionic radionuclides. — Filter media based on the specifications of the feed stream. — Typically 1 m^3 concrete container can hold 7–12 spent columns. — One container required for collection of columns and carbon, one for spent cartridges. — Type based on host site requirements.
General service requirements (air, water, steam, electricity, ventilation)	— Power; — Influent and effluent liquid connections; — Sample waste disposition.
Handling equipment required for placement, operation, and waste handling and packaging (cranes, forklifts, load capacity)	— Mechanical handling is required for removal of spent filter cartridges and ion exchange columns. — A shielded transport cask may be required for columns. — A forklift truck, a push cart or a simple lift is required for transportation of spent material.
General requirements for industrial and radiological safety (barriers, respiratory protection, personnel exposure monitoring, contamination controls, air monitoring)	— Personnel protective clothing; — Radiological barriers and berms/bunds based on host site requirements.

Note: NURES — nuclide removal system.

4.2.6. Dewatering of spent ion exchange and filtration media

4.2.6.1. Typical system description

The self-engaging dewatering system (SEDS) is designed to slurry spent resin and other waste media of a similar consistency into waste containers and to remove slurry water from them following media transfer. This is typically used for waste streams that have high radiation fields and therefore is to be operated remotely. The waste containers — also known as high integrity containers (HICs) — have integral filters to separate solid material from water. Once the SEDS components and dewatering container are properly positioned, the fillhead assembly is connected to the waste inlet hose and the waste outlet hose for slurry water return to the facility. After the dewatering container's lid is removed, the fillhead assembly is positioned over the container's opening. The fillhead assembly is virtually self-aligning with the container opening, requiring minimal manual adjustment by the operator.

Once in position, the fillhead is sealed to the container and all electrical and dewatering connections are made to the container in one motion. The waste resin or other media that is in the water slurry is then transferred through the fillhead assembly into the HIC. During transfer of the media slurry, the dewatering pump is energized to return the filtered water back to the facility's waste system. At a predetermined set point, the level detection system will close the inlet waste valve to prevent overfilling the container. The dewatering pump will continue to run to reduce the level of slurry water in the container. This cycle is repeated until the correct volume of waste is in the container and the slurry water is removed to meet applicable shipping and disposal site criteria. Figure 17 shows a typical unit installed on an HIC.

FIG. 17. The SEDS (courtesy of EnergySolutions).

4.2.6.2. Description of individual components and elements

The slurry water acts as a transportation medium when transferring both resin and filtration media into dewatering containers. Removal of the slurry water from the resin and filtration media in containers reduces the volume of waste, as well as ensuring that transportation and disposal site criteria are achieved. Major components of the SEDS include a dewatering pump skid, fillhead assembly, control console, waste control valve and dewatering container (see Fig. 18).

FIG. 18. Major components of the SEDS (from left to right: control console, pump skid and fillhead assembly; courtesy of EnergySolutions).

4.2.6.3. System specific benefits

- — Easy installation and removal system;
- — Increased volume of waste in container;
- — Improved level detection system;
- — Improved camera and light assembly;
- — Mechanical level indicator;
- — Infrared temperature measurement.

4.2.6.4. System specific limitations

- — Physical design and dimensions of dewatering system need to be compatible with the container being dewatered;
- — Typically not applicable for fine particle slurries (e.g. sludge).

4.2.6.5. Key screening considerations

Table 12 identifies key screening considerations for dewatering systems.

TABLE 12. KEY SCREENING CONSIDERATIONS FOR SYSTEMS FOR DEWATERING OF SPENT ION EXCHANGE AND FILTRATION MEDIA

Consideration	Description
Characteristics of incoming and source waste (volume, type, activity, form)	Volume dependent on waste container, slurries of water and resins or activated carbon, activity dependent on disposal criteria and limitations.
Characteristics of secondary waste generated by process (volume, type, activity, form)	None.
Characteristics of final waste form (container type, activity, form)	Dewatered resin suitable for final packaging and licensed radioactive waste disposal.
Regulatory and legal considerations (national, local, international, licensing, operation, waste movement and transport)	The system does not require a complex regulatory or legal process for deployment.
Transport requirements (system operation, waste shipments, access roads)	Small crates or ISO containers.
Mode of use: batch or continuous processing (system, secondary waste)	Batches of waste are deposited into containers for dewatering. If dewatering leaves additional void space in containers, additional waste can be added.
Cost: contractual arrangements (leased/procured); periodic (monthly/annual/campaign/volume) installation; consumables; staff; equipment removal and disposal; shipping; final waste disposition	Equipment can be procured or leased as a service. Mobilization, installation and training are typically one time costs.
System configuration (mobile or skid mounted)	— Fillhead and stand are mobile; — Individual skid mounting for dewatering pump skid, control panel, service air/water; — Waste control valve installed on either system components or plant waste line.

TABLE 12. KEY SCREENING CONSIDERATIONS FOR SYSTEMS FOR DEWATERING OF SPENT ION EXCHANGE AND FILTRATION MEDIA (cont.)

Consideration	Description
Footprint or physical size of the mobile system (maximum dimensions, media handling/replacement/repair space)	— Fillhead and stand ~1 m in diameter, weighing ~270 kg with fillhead; — Dewatering pump skid about 0.6 m × 1 m, depending on plant requirements; — Control panel and service air/water (can be customized and separated) ~0.6 m × 1.5 m.
Total weight (for floor loading and movement)	Fillhead and stand 270 kg, pump skid 120 kg, control panel with service air/water 145 kg, hoses and cables 130 kg (varies).
Staffing (number, contracted staff, technical qualifications, operations, security, maintenance)	One to two trained operators required.
Maximum or optimal throughput, capacity, decontamination factor and volume reduction	Not applicable.
Space requirements (area for consumable storage, waste staging and storage)	Minimal.
List consumables required for process (media, containers, parts, chemicals)	Media for liquid processing, waste container and internals, SEDS compatible fillplates.
General service requirements (air, water, steam, electricity, ventilation)	— Air: 34 m^3/h, 0.62 MPa. — Water: 75 L/min, 0.55 MPa. — Electrical: 110 V AC, 20 A. — Design pressure: 1.0 MPa. — Vent: connection available to plant off-gas or portable HEPA.
Handling equipment required for placement, operation, and waste handling and packaging (cranes, forklifts, load capacity)	Fillhead includes lifting sling for placement over waste container. Initial installation requires forklift or crane for placement of skids.
General requirements for industrial and radiological safety (barriers, respiratory protection, personnel exposure monitoring, contamination controls, air monitoring)	Equipment is remotely operated and does not require special radiation safety equipment.

Note: SEDS — self-engaging dewatering system; HEPA — high efficiency particulate air.

4.2.7. In-drum drying of liquid and wet solid waste

4.2.7.1. Typical system description

In-drum thermal drying is used for drying contaminated wet solids (e.g. sludges, resins and filter elements), liquid concentrates and decontamination solutions to a solid cake. A typical system from one supplier is shown in Fig. 19.

Figure 20 shows the process schematic. The waste dried in 200 L United States Department of Transportation model DOT 17C drums can be safely stored, handled and transported. The system processes contaminated liquids directly from holding tanks or drums. Condensed distillate is sampled and released or returned for processing as radioactive waste, as required. The drum fillhead is placed on top of the 200 L drum. For automatic filling, a level sensor controls the liquid level in the drum. A thermocouple measures the temperature of the steam and air

FIG. 19. In-drum drying unit (courtesy of Diversified Technologies Services).

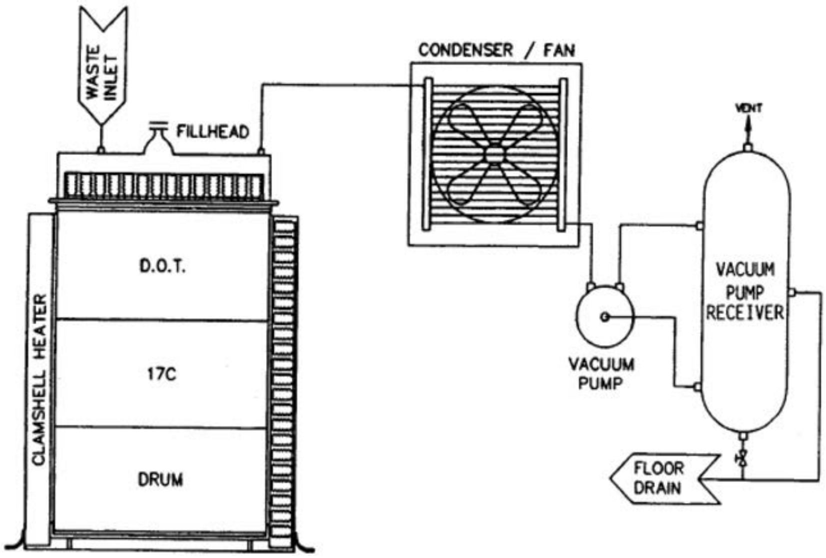


FIG. 20. In-drum drying unit schematic (courtesy of Diversified Technologies Services).

leaving the drum, and a vacuum breaker valve controls the vacuum in the drum. An optional fixed-head drum is available for high dose applications. The thermal energy source is electric heat. The two hinged half-shells of the clamshell heater surround the drum, providing the heat for evaporation. The clamshell heater can be operated at any temperature between 120°C and 230°C. As the temperature of the drum contents rises above 70°C, the boiling point of water at 0.5 m vacuum, liquids flash off as steam. Once full of dried solids, the drum is heated at the full operating temperature to ensure that no liquids remain inside.

4.2.7.2. Description of individual components and elements

The system has two main components — a control unit and drum modules:

— These components can be skid mounted or permanently installed.
— Drum modules can be placed in a shielded area away from the control skid.

4.2.7.3. System specific benefits

— Easy to install and to maintain;
— Automated controls;
— Minimal operator oversight;
— Flexible capacity;
— System capacity can be increased in 7.5–11.5 L/h increments by connecting more modules to the control skid;
— Waste volume reduction of 85–95%;
— Liquid activity capture of 100%.

4.2.7.4. System specific limitations

— Actual processing rate varies with the number of modules used and the level of already dried solids in the drum.

4.2.7.5. Key screening considerations

Table 13 identifies key screening considerations for in-drum drying systems.

TABLE 13. KEY SCREENING CONSIDERATIONS FOR SYSTEMS FOR IN-DRUM DRYING OF LIQUID AND WET SOLID WASTE

Consideration	Description
Characteristics of incoming and source waste (volume, type, activity, form)	Sludge, resins, filter elements, liquid concentrates and decontamination solutions.
Characteristics of secondary waste generated by process (volume, type, activity, form)	100% water recovery.
Characteristics of final waste form (container type, activity, form)	Solid cake.
Regulatory and legal considerations (national, local, licensing, operation, and waste movement and transport)	— Need to control concentration of activity to comply with waste classification goals; — Resultant waste form compatibility with requirements; — Shielding for radiation protection; — Capture and control of airborne effluents.
Transport requirements (system operation, waste shipments, access roads)	— Move drums of raw waste to unit; — Movement of final form waste from unit: concentrated solids may require hoist, drum transporter or forklift.
Mode of use: batch or continuous processing (system, secondary waste)	Operation frequency is dependent on source waste. It can be operated continuously or in periodic campaigns.
Cost: contractual arrangements (leased/procured); periodic (monthly/annual/campaign/volume) installation; consumables; staff; equipment removal and disposal; shipping; final waste disposition	— Low cost compared with a fixed system or to alternative solutions, such as solidification of liquid; — System can be leased or procured; — Training is given for operation personnel, or operated by the supplier technicians; — System can be transported with normal trucks or lorries; — System is easily installed and removed; — System components that are exposed to radioactive contaminants cannot be easily decontaminated for unconditional release.

TABLE 13. KEY SCREENING CONSIDERATIONS FOR SYSTEMS FOR IN-DRUM DRYING OF LIQUID AND WET SOLID WASTE (cont.)

Consideration	Description
System configuration (mobile or skid mounted)	Can be mobile or skid mounted.
Footprint or physical size of the mobile system (maximum dimensions, media handling/replacement/repair space)	~3 m × 3 m (two drum system).
Total weight (for floor loading and movement)	~635 kg, not including waste drums.
Staffing (number, contracted staff, technical qualifications, operations, security, maintenance)	— One operator to start and to stop the system (can be contracted or provided by the facility); — Minimal qualifications (very basic equipment operation); — Labour to move raw and processed waste drums; — Task times dependent on usage (batch, continuous, frequency, volume); — Maintenance typically performed by supplier; — No testing requirements; — No security requirements in most applications.
Maximum or optimal throughput, capacity, decontamination factor and volume reduction	— 7.5–11.5 L/h with incremental increases by adding more drum units; — Volume reduction of 2:1 for bead/powder resin, 5:1 for sludges and 100:1 for liquids; — Decontamination factor of 1000 for processed liquids (except volatiles).
Space requirements (area for consumable storage, waste staging and storage)	Varies by process rate, but typically requires storage for 200 L DOT 17C raw waste drums and processed waste drums.
List consumables required for process (media, containers, parts, chemicals)	200 L DOT 17C drums for raw waste.
General service requirements (air, water, steam, electricity, ventilation)	— Power: 230 V for unit. — May require ventilation based on host site requirements.
Handling equipment required for placement, operation, and waste handling and packaging (cranes, forklifts, load capacity)	Forklift, pallet mover or hoist.
General requirements for industrial and radiological safety (barriers, respiratory protection, personnel exposure monitoring, contamination controls, air monitoring)	— Radiation monitoring for drums during drying process is recommended. — Routing effluent from air exhaust to facility ventilation systems for monitoring is recommended. — General safety precautions related to using high temperature equipment.

4.3. GASEOUS WASTE

4.3.1. Off-gas treatment

4.3.1.1. Typical system description

The mobile off-gas treatment system is an autonomous unit intended for treatment of off-gases resulting from thermal processing of radioactive waste (e.g. incinerator and salt melter) or from decontamination of surfaces by mechanical methods. The treatment removes aerosols and particulates from the off-gas before release to the environment. The system shown in Fig. 21 is mounted inside a standard transport container.

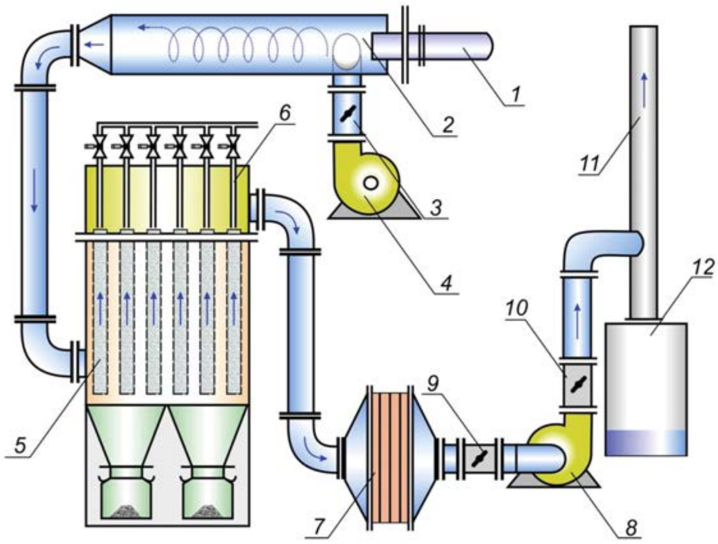
FIG. 21. Mobile off-gas treatment system (courtesy of MosNPO Radon).

4.3.1.2. Description of individual components and elements

The system consists of:

— An air mixer;
— Several fans;
— A cartridge filter;
— A fine particulate HEPA filter;
— A collector for condensate;
— A stack for discharge of the cleaned gas;
— A stack monitoring system.

If it is necessary to decrease the temperature of off-gases containing radioactive aerosols, they are directed to the air mixer, in which they are mixed with air from the supply fan (see Fig. 22). Gases then pass through the perforated tube cartridge filter elements, which are manufactured using a basalt based fabric. During treatment of the gases, the surfaces of the filtering elements can be regenerated using a serial pulse of compressed air from the compressor into an internal cavity of the filter cartridges. The removed aerosol particles are then collected in two cylindrical vessels at the bottom part of the cartridge filter. The final treatment of the gases occurs by filtering, using a small mesh filter (e.g. HEPA filter). The cleaned gases are discharged to the environment through the removable pipe, which has a collector for condensed water.



(1) gas input; (2) air mixer; (3, 9, 10) dampers; (4, 8) fans; (5) perforated tube elements; (6) cartridge filter regeneration system; (7) HEPA filter; (11) stack; (12) condensed water collector.

FIG. 22. Schematic view of the mobile off-gas treatment system (courtesy of MosNPO Radon).

4.3.1.3. System specific benefits

- High processing rates;
- Low costs of processing;
- Low secondary waste volumes to be treated or conditioned;
- Simplicity of system service;
- Gas cleaning at elevated temperatures;
- Low maintenance;
- Low personnel exposures;
- Easy to decontaminate and to demobilize.

4.3.1.4. System specific limitations

- The temperature of the gas is not to be above 1000°C.
- The gas to be cleaned is not to contain chemically aggressive, flammable and explosive impurities.
- The off-gas treatment system has no biological protection, so the maximum specific activity of the gas is not to exceed 1×10^5 Bq/m^3.
- The off-gas treatment system can clean gas from aerosols only.
- The off-gas treatment system has no secondary radioactive waste conditioning capability. Spent filtration materials and dust require packaging and transport to a separate location for conditioning.

4.3.1.5. Key screening considerations

Table 14 identifies key screening considerations for off-gas treatment systems.

TABLE 14. KEY SCREENING CONSIDERATIONS FOR OFF-GAS TREATMENT SYSTEMS

Consideration	Description
Characteristics of incoming and source waste (volume, type, activity, form)	Gases from thermal waste processing facilities (incinerator, salt melter) or decontamination facilities using mechanical decontamination; <200 000 m^3/a; specific activity <1 × 10^5 Bq/m^3.
Characteristics of secondary waste generated by process (volume, type, activity, form)	Per 200 000 m^3 of cleaned gases: — Radioactive desalinated water: <0.05 m^3, activity concentration <1 × 10^2 Bq/L. — Basalt based fabric material: <0.2 m^3, total activity <1 × 10^8 Bq. — Dust from aerosol particles: <20 kg, specific activity <1 × 10^8 Bq/kg.
Characteristics of final waste form (container type, activity, form)	Per 200 000 m^3 of cleaned gases: — Fewer than two 200 L drums with 0.05 m^3 radioactive desalinated water, 20 kg radioactive dust from aerosol particles and 0.2 m^3 radioactive fabric material (total activity <2 × 10^9 Bq); — Secondary waste conditioned by cementation after transport (total volume <0.4 m^3).
Regulatory and legal considerations (national, local, international, licensing, operation, waste movement and transport)	Need to meet local, regional and national regulations.
Transport requirements (system operation, waste shipments, access roads)	Forklift or crane and a truck.
Mode of use: batch or continuous processing (system, secondary waste)	The system can be used for continuous processing of up to 200 000 m^3 gases. Processing can continue following a filter change.
Cost: contractual arrangements (leased/procured); periodic (monthly/annual/campaign/volume) installation; consumables; staff; equipment removal and disposal; shipping; final waste disposition	— Capital cost of installation is ~US $70 000. — Treatment cost is very low and varies by feed characteristics. — Cost of final waste disposal varies by State.
System configuration (mobile or skid mounted)	Skid mounted inside ISO container.
Footprint or physical size of the mobile system (maximum dimensions, media handling/replacement/repair space)	6 m × 2.4 m × 2.7 m (height).
Total weight (for floor loading and movement)	<4200 kg.
Staffing (number, contracted staff, technical qualifications, operations, security, maintenance)	— At work: one person (physics technologist, no need for higher education). — At repair: two people (mechanic and electric, no need for higher education).
Maximum or optimal throughput and capacity, and volume reduction	— 450 m^3/h (900 m^3/h with cooling air); — Volume reduction factor ~500 000.
Space requirements (area for consumable storage, waste staging and storage)	<20 m^2.
List consumables required for process (media, containers, parts, chemicals)	— 200 L drums; — 12 m^2 basalt based fabric material; — One HEPA filter (with capacity not less than 500 m^3/h).

TABLE 14. KEY SCREENING CONSIDERATIONS FOR OFF-GAS TREATMENT SYSTEMS (cont.)

Consideration	Description
General service requirements (air, water, steam, electricity, ventilation)	Power: 380 V AC, 50 Hz, 20 kW.
Handling equipment required for placement, operation, and waste handling and packaging (cranes, forklifts, load capacity)	Crane required.
General requirements for industrial and radiological safety (barriers, respiratory protection, personnel exposure monitoring, contamination controls, air monitoring)	— Operator; — Health physics monitoring around the facility, especially near the two cylinder vessels at the bottom part of the cartridge filter.

Note: HEPA — high efficiency particulate air.

5. WASTE CONDITIONING SYSTEMS

5.1. DISUSED SEALED SOURCES

5.1.1. Encapsulation of disused sealed sources in a metallic matrix

5.1.1.1. Typical system description

The Moskit system is intended for encapsulation of disused sealed sources into metal matrices that will be placed in containers for long term storage, or in well type underground repositories [28–31]. Metal matrices are used to provide both heat conductivity and biological shielding. The system configurations shown in Figs 23 and 24 are designed for the following operations:

— Pumping and collecting water or other liquids that may be present in the storage container;
— Drying the internals of the container or the well, if required;
— Melting the material matrix and maintaining the required temperature;
— Pouring the melted material into a container or spent radioactive source repository;
— Purification of off-gas created during drying, melting or pouring.

The minimal required diameter to feed encapsulated spent radioactive sources in the metal matrix using Moskit technology is 30 mm for containers or the well type repository.

5.1.1.2. Description of individual components and elements

The Moskit system consists of the following units:

(a) The adaptor unit provides a hermetically sealed connection between a container or repository and other functional units of the module (gas purifying unit, air heater and heated metal conductor). The unit has a side flange for connection with the gas purifying unit and an upper flange for connection with other functional units. The adaptor unit is to be placed on the top of the container or well repository.
(b) The gas purifying unit cleans and discharges the off-gas that forms in a container or repository during drying, melting and pouring. It consists of a fine air filter and a radial air exhauster with a tailpipe of 2 m in length. The gas purifying unit is connected to the adaptor unit with a rubber hose. The gas purifying unit can process up to 1000 m^3/h and has a rarefaction of less than 500 Pa.

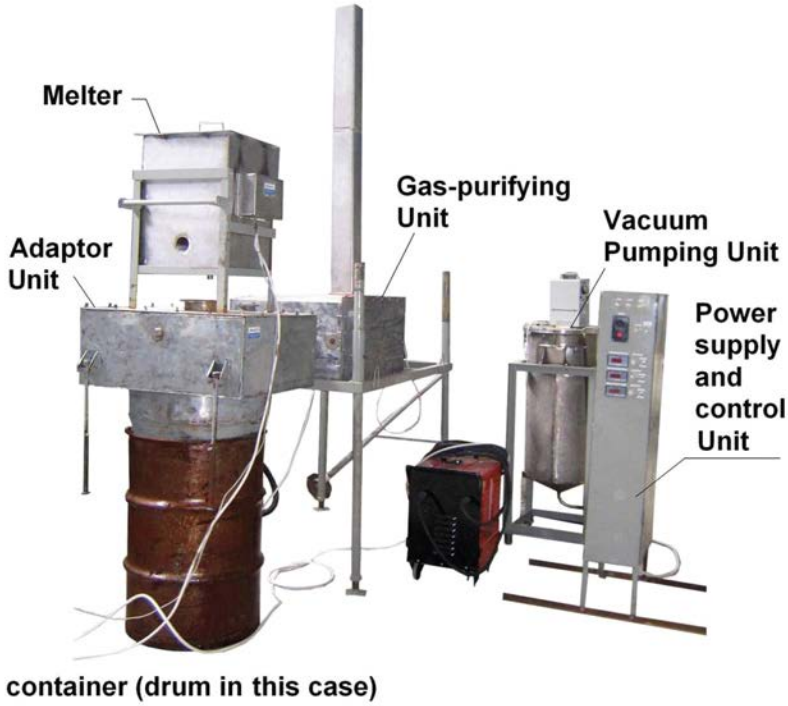


FIG. 23. General view of the Moskit system (courtesy of MosNPO Radon).

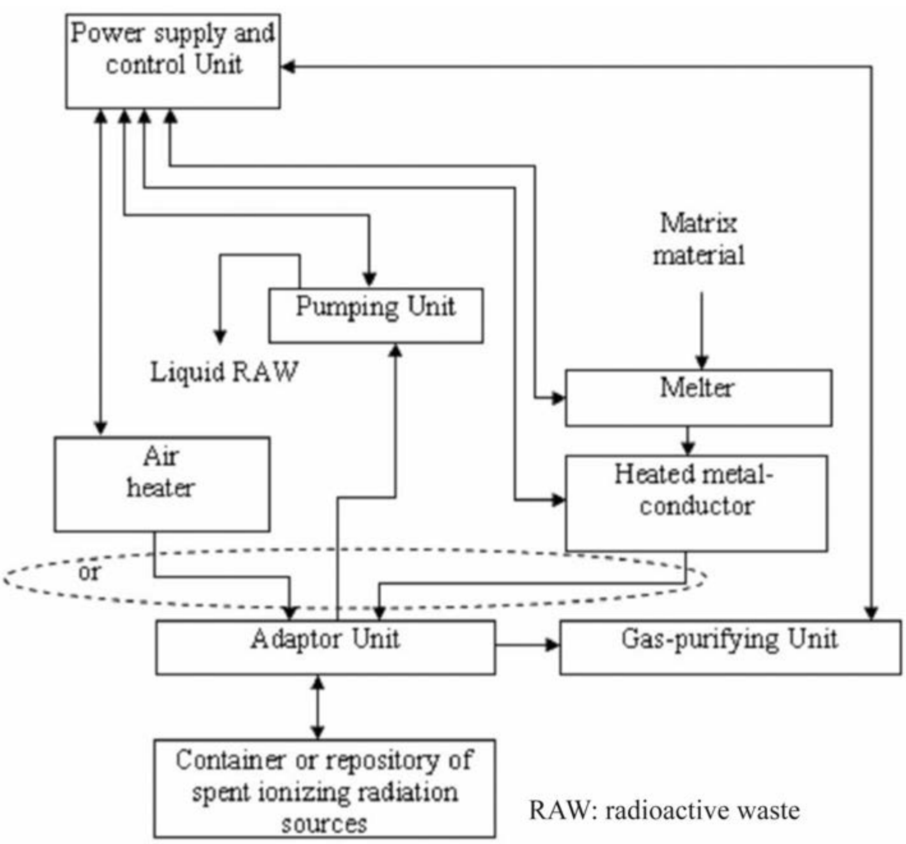


FIG. 24. Process scheme of the Moskit system.

(c) The pumping unit removes freestanding water and other liquids that may be present in the container or repository. It consists of a hermetically sealed cylinder tank with a vacuum pump. When the pump is operating under vacuum, liquid from a container or repository is pumped through the hose into the tank. It is equipped with an automatic level control system to prevent overfilling.

(d) The air heater heats and dries the air entering the container or repository. It is equipped with a flange, which is hermetically sealed to the adaptor unit. The air heater outlet is connected to a hose, which conducts heated air into the bottom of the container or repository. The gas purifying unit provides air circulation through the air heater.

(e) The melter is for melting matrix materials, heating and required temperature maintenance. It consists of a stainless steel smelting chamber heated with electric heaters. The bottom of the smelting chamber is equipped with a discharge unit, for discharging matrix materials. The discharge unit is also heated with the smelting unit electric heaters. The smelting chamber inlet lid is closed to decrease heat loss and to prevent vapour emission from the matrix material.

(f) The heated metal conductor is designed to discharge the melted matrix material down to a depth of 7 m. The metal hose is heated, which prevents the melt from untimely crystallization inside the hose. The metal hose consists of a flexible stainless steel hose placed into a thermal insulating shell made of a glass fabric. The metal hose is heated by the electric current. The metal hose is routed to the repository or container through the adaptor unit. The heated metal conductor is not required to discharge the melted matrix materials when using containers in lieu of the well repository.

(g) The power supply and control unit provides power to the module units, monitors equipment and controls pumping, drying and pouring. The unit comprises of a power supply and control cabin, a step down transformer (380/60 V) and interface cables. The front of the power supply and control unit is equipped with instrumentation and actuators. Power connectors and control equipment are located in the rear of the cabinet.

5.1.1.3. System specific benefits

- Easy installation on-site.
- Low processing cost.
- Heated metal conductor to prevent blockage in the hose.
- Low secondary waste volumes (water, filtration materials) to be treated or conditioned.
- Simplicity of system service.
- Low maintenance: one or two operators, the heated metal conductor is the only part of the installation that requires deactivation.
- Easy to demobilize.

5.1.1.4. System specific limitations

- The melter is restricted to 5 L of metal (lead or lead alloy).
- The temperature of the melted metal is not to exceed 450°C.
- The vertical distance for discharging is not to exceed 5 m.
- The thickness of a layer of spent radioactive sources is not to exceed 0.2 m.

5.1.1.5. Key screening considerations

Table 15 identifies key screening considerations for systems intended for the encapsulation of disused sealed sources.

TABLE 15. KEY SCREENING CONSIDERATIONS FOR SYSTEMS INTENDED FOR THE ENCAPSULATION OF DISUSED SEALED SOURCES

Consideration	Description
Characteristics of incoming and source waste (volume, type, activity, form)	— Sealed radioactive sources, in well type (borehole) underground repositories up to 6.6×10^6 GBq in ^{226}Ra equivalent; — Sealed radioactive sources in containers for long term storage up to 370 GBq in ^{226}Ra equivalent.
Characteristics of secondary waste generated by process (volume, type, activity, form)	For well type (borehole) underground repositories: — Radioactive water (up to 0.1 m^3; specific activity $<1 \times 10^6$ Bq/L); — Off-gas filter (radioactive <0.2 m^3, combustible). No secondary waste for containers for long term storage.
Characteristics of final waste form (container type, activity, form)	— Metal matrix directly in well type (borehole) undersurface repositories; — Containers specified by host site (e.g. 200 L drum).
Regulatory and legal considerations (national, local, international, licensing, operation, waste movement and transport)	Local, regional, national and international regulations may apply for off-gas discharge, collected liquid treatment, waste transport and waste storage or disposition.
Transport requirements (system operation, waste shipments, access roads)	— Transport container or packing boxes for system transport; — Lifting mechanisms are not necessary.
Mode of use: batch or continuous processing (system, secondary waste)	Batch processing.
Cost: contractual arrangements (leased/procured); periodic (monthly/annual/campaign/volume) installation; consumables; staff; equipment removal and disposal; shipping; final waste disposition	— Capital cost of installation is ~US $50 000. — Specific cost of treating one well type (borehole) underground repository or one container for long term storage can be up to US $50 000.
System configuration (mobile or skid mounted)	Skid mounted.
Footprint or physical size of the mobile system (maximum dimensions, media handling/replacement/repair space)	<3 m^2.
Total weight (for floor loading and movement)	<900 kg.
Staffing (number, contracted staff, technical qualifications, operations, security, maintenance)	— Operation: one physics technologist, higher education; one unskilled labourer. — Maintenance: one mechanic; one electrician.
Maximum or optimal throughput and capacity, and volume reduction	One filled well type (borehole) undersurface repositories or one container for long term storage per two day period.
Space requirements (area for consumable storage, waste staging and storage)	<10 m^2.
List consumables required for process (media, containers, parts, chemicals)	For one filled well type (borehole) undersurface repository or one container for long term storage: — 500–1000 kg Pb; — 500–1000 kg low melted alloy.

TABLE 15. KEY SCREENING CONSIDERATIONS FOR SYSTEMS INTENDED FOR THE ENCAPSULATION OF DISUSED SEALED SOURCES (cont.)

Consideration	Description
General service requirements (air, water, steam, electricity, ventilation)	Power: 380 V AC, 50 Hz, 20 kW.
Handling equipment required for placement, operation, and waste handling and packaging (cranes, forklifts, load capacity)	Not required.
General requirements for industrial and radiological safety (barriers, respiratory protection, personnel exposure monitoring, contamination controls, air monitoring)	— No special safety requirements; — Radiation monitoring and controls in accordance with host site requirements; — Typically minimal radiation surveys, area controls and barriers, and off-gas monitoring.

5.2. LIQUID AND WET SOLID WASTE

5.2.1. Solidification (cementation)

5.2.1.1. Typical system description

A typical solidification system consists of a cementation unit with a programmed cement and waste feeding system and shielded mixing machine with preset quantities of waste. The mixed product is collected in waste containers. The system is designed to operate from the mobile unit control panel, with safety interlocks. The waste is transferred with a pumping system from the host site's storage tank to the unit. The air effluents are captured and are to be routed to a monitored and authorized release point. Two examples are discussed below for aqueous liquid waste. The numbered drums in Fig. 25 represent the sequence of operation, where the empty container is placed on the conveyor (1), then filled with waste and cement (2) and then moved aside for curing (3) [32].

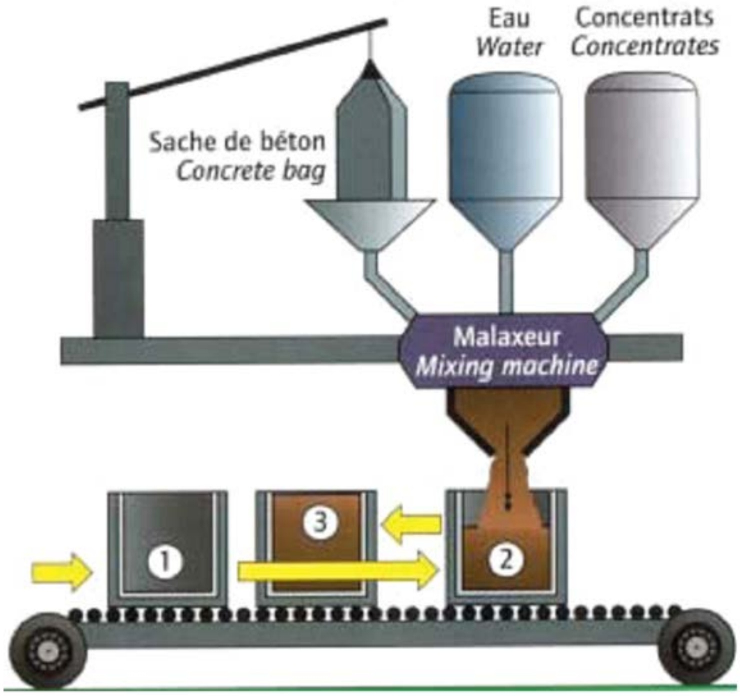


FIG. 25. Mobile cementation system (courtesy of SOCODEI).

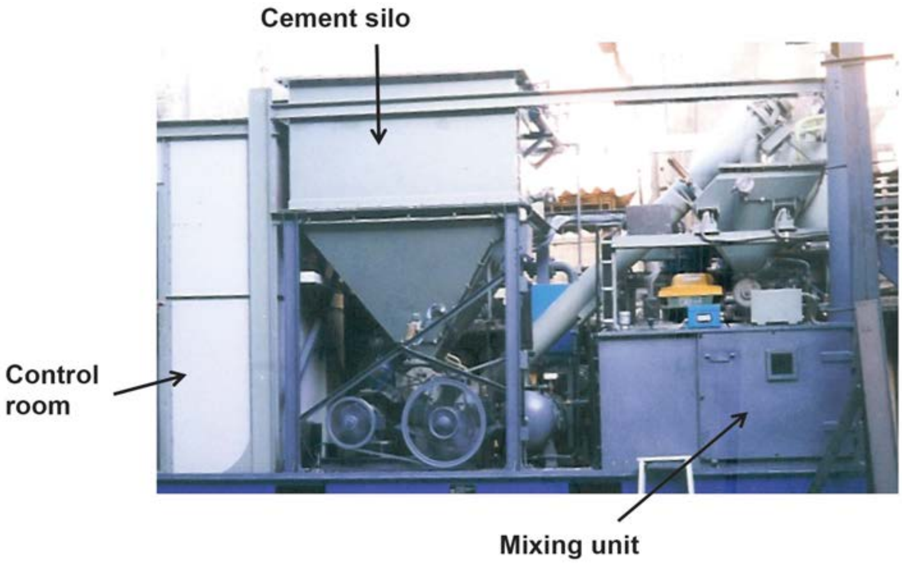


FIG. 26. Mobile cementation unit for aqueous liquid waste (courtesy of BARC).

The Indian cementation unit shown in Fig. 26 is fully enclosed in a 2.5 m × 6 m × 3 m freight container, which is trailer mounted. It is used to immobilize radioactive low level liquid waste. The waste is mixed with cement to form a slurry, which can be cast in a container (batch mode) or pumped to waste disposal trenches (continuous mode of operation). The production capacity of the system is 500 L/h of slurry in the batch mode and 1000 L/h for continuous operation.

Dry ordinary Portland cement is conveyed by a vacuum transfer system into the cement storage silo of the mobile unit. The cement is conveyed via a screw to the feed hopper. Waste, stored in the unit's hold up tank, is pumped to a mixing vessel. Simultaneously, a metered quantity of cement is fed by the rotary valve of the feed hopper. The slurry created is pumped to waste storage containers and disposal trenches. A shielded enclosure built from 25 mm thick carbon steel plates accommodates all the equipment in contact with radioactive material and is kept under a negative pressure of 25 mm of water gauge. The unit is operated from a control cabin through a personal computer, programmable logical controller (PLC) or push buttons. Provision is made for cleaning and decontamination of the system with water.

5.2.1.2. Description of individual components and elements

- Mechanical handling for waste and cement (pumping, conveyor, drum/special container);
- Mixing device;
- Gaseous effluent routing, filtration and monitoring;
- Instrumentation and controls.

5.2.1.3. System specific benefits

- Simple to operate and to maintain;
- Gravity or vacuum transfer system for cement handling avoids dust problems;
- Moderate capacity;
- Good product quality based on a laboratory scale assessment of the required waste to cement ratio, consistent with the storage or disposal acceptance criteria in the jurisdiction where the waste will be handled;
- Design variation possible to take care of chemical precipitation sludge;
- Operation from a control panel;
- Can be used for embedding of solid waste;
- Designs available with a fully containerized system.

5.2.1.4. System specific limitations

- — It is designed for a temperature range of 10–45°C and is not suitable for low ambient temperatures.
- — Small volumes of secondary waste generated need to be treated separately.
- — The processing chamber needs to be vented using the dedicated exhaust system during the process to guarantee that the mist laden with powder is managed safely.
- — It is essential that the waste composition be properly characterized and a laboratory scale assessment conducted to ensure that the solidified waste product has the desired characteristics. For example, organics can inhibit cement curing and need to be removed prior to cement addition to the waste using filtration through hydrophobic media or activated carbon. Certain inorganic minerals such as sulphates and boron containing materials also affect the strength of the final cement product.

5.2.1.5. Key screening considerations

Table 16 identifies key screening considerations for cementation systems.

TABLE 16. KEY SCREENING CONSIDERATIONS FOR SOLIDIFICATION (CEMENTATION) SYSTEMS

Description	Details of system from France	Details of system from India
Characteristics of incoming and source waste (volume, type, activity, form)	— Liquid waste evaporation concentrates usually stored in tank; — B up to 30 000 ppm; — Na up to 120 000 ppm; — P up to 20 000 ppm; — Activity: depending on shielding and disposal requirements.	— Liquid waste, usually stored in tank; — Up to 2% (w/v) of suspended solids; — Activity: low level aqueous waste depending on shielding and disposal requirements.
Characteristics of secondary waste generated by process (volume, type, activity, form)	Cleaning solutions are also conditioned by the system. Rinse water used to clean system between waste batches can be used in a subsequent batch, if required.	
Characteristics of final waste form (container type, activity, form)	Block of cement solidified waste, characteristics depending on final disposal requirements (drums or bulk).	
Regulatory and legal considerations (national, local, international, licensing, operation, waste movement and transport)	Except for final package agreement, the systems do not require complex regulatory or legal processes for deployment.	
Transport requirements (system operation, waste shipments, access roads)	— Trailer mounted transport container; — One ISO container workshop; — Solidified waste containers to be transported to disposal.	— Trailer mounted transport container; — Solidified waste containers to be transported to disposal.
Mode of use: batch or continuous processing (system, secondary waste)	Batch of incoming waste.	
Cost: contractual arrangements (leased/procured); periodic (monthly/annual/campaign/volume) installation; consumables; staff; equipment removal and disposal; shipping; final waste disposition	— Moderate cost, periodic operation (typical cost of the Indian unit will be ~US $400 000). — Consumables: cement, water for cleanup, spares. — Trained staff. — Easy to remove after disconnection of waste lines.	
System configuration (mobile or skid mounted)	Skid mounted components to be assembled on-site.	Mobile.

TABLE 16. KEY SCREENING CONSIDERATIONS FOR SOLIDIFICATION (CEMENTATION) SYSTEMS (cont.)

Description	Details of system from France	Details of system from India
Footprint or physical size of the mobile system (maximum dimensions, media handling/replacement/repair space)	— Space for a 4 m × 9 m × 5 m unit; — Road for drive-in; — Free access around the mobile unit of at least 2 m width.	— Space for 6 m ISO container and trailer; — Road for drive-in; — Free access around the mobile unit of at least 2 m width; — Cordoning off the product movement area to restrain other than the trained operators.
Total weight (for floor loading and movement)	Weight ~15 t.	
Staffing (number, contracted staff, technical qualifications, operations, security, maintenance)	— Installation, operation, demobilization: four trained operators, including one for the crane and forklift. — Radiation protection person, as required by host site.	— Two qualified operators per shift; — Radiation protection person, as required by host site.
Maximum or optimal throughput and capacity, and volume reduction	~1 m^3 per shift.	0.5–1 m^3 per shift.
Space requirements (area for consumable storage, waste staging and storage)	100 m^2, including machine (36 m^2) in controlled area.	Cement storage space required is the minimum for a week's operation.
List consumables required for process (media, containers, parts, chemicals)	— Predosed packages of lime; — Cement; — Aggregates.	— Filter for exhaust system; — Containers/drums for collection of mixed product; — Cement.
General service requirements (air, water, steam, electricity, ventilation)	— Compressed air. — Demineralized water. — Power: 25 kW. — Ventilation.	— Compressed air; — Water; — Power: 25 kW.
Handling equipment required for placement, operation, and waste handling and packaging (cranes, forklifts, load capacity)	— Placement: crane and forklift (10 t). — Operation: forklift (consumable, final packages).	
General requirements for industrial and radiological safety (barriers, respiratory protection, personnel exposure monitoring, contamination controls, air monitoring)	— No particular requirements, except personnel exposure monitoring; — Area gamma monitors, portable radiation monitoring equipment; — Barriers required in the area of waste transfer and product movement to prevent unauthorized movements.	

5.2.2. Encapsulation of spent ion exchange resins in polymeric binders

5.2.2.1. Typical system description

This technology involves pumping waste from the host site storage tank to the unit. The ion exchanger media is dewatered and incorporated in the polymer bicomponent matrix in shielded 200 L drums. The water returns to the host site. The air effluents are captured and are to be routed to a monitored and authorized release point.

A typical system consists of an encapsulating unit carried on a road trailer, a double tank unit for the process reactants (epoxy resin and hardener), a control station integrated in an ISO container and a workshop truck containing tools and spare parts (see Figs 27 and 28) [33].

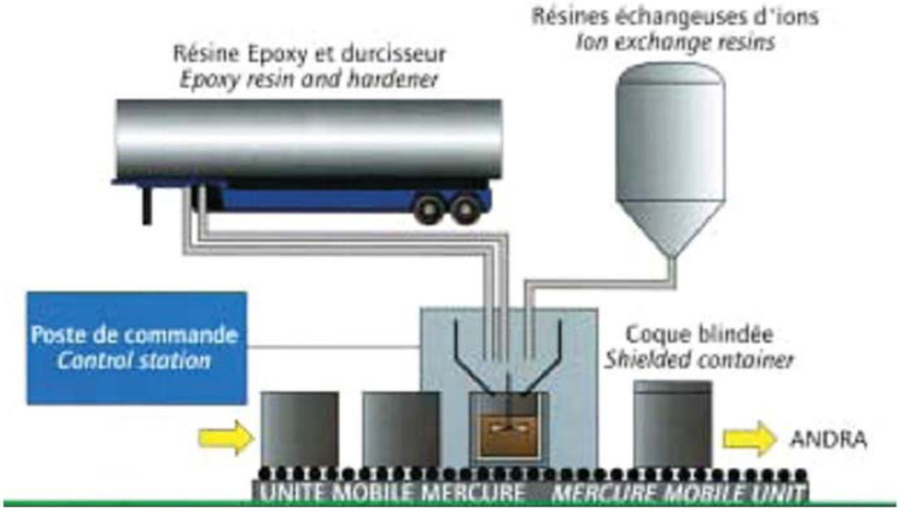


FIG. 27. Schematic of mobile system for encapsulation of ion exchange resins in polymers (courtesy of SOCODEI).

FIG. 28. Mobile system for encapsulation of ion exchange resins in polymers (courtesy of SOCODEI).

5.2.2.2. Description of individual components and elements

— Controls;
— Mechanical handling;
— Weighing system;
— Gaseous effluent routing and monitoring.

5.2.2.3. *System specific benefits*

- — Much more cost effective than a fixed system at each plant;
- — Dedicated permanent qualified crews;
- — Short campaigns (two months each) and long time between them (e.g. may be more than three years);
- — Special designs to match varying size of auxiliary buildings of nuclear facilities;
- — Only one design to operate and to maintain;
- — Generic procedures for embedding and for waste radiological characterization (results can be easier to compare and to control);
- — Generic documentation (safety, operating system and training).

5.2.2.4. *System specific limitations*

- — Campaign needs to be planned over a long range (about two years), considering the different requirements of plants without previous experience;
- — Requires more than two crews of seven people to provide continuous service.

5.2.2.5. *Key screening considerations*

Table 17 identifies key screening considerations for a system for encapsulation of spent ion exchange resins in polymeric binders.

TABLE 17. KEY SCREENING CONSIDERATIONS FOR A SYSTEM FOR ENCAPSULATION OF SPENT ION EXCHANGE RESINS IN POLYMERIC BINDERS

Consideration	Description
Characteristics of incoming and source waste (volume, type, activity, form)	— Ion exchange resins from liquid treatment systems (e.g. primary cooling purification, spent fuel storage basin purification systems, liquid waste treatment plants). — Ion exchange media stored in water in a site tank. — Polystyrene, phenolic, acrylic or formophenolic resin networks; resin beads or grains 0.3–1.2 mm in diameter; cation or anion resins. — Chemical constituents may include: borates, Ca, Co, Cr, Fe, Li, Na and Ni. — Acceptable radionuclides (e.g. ^{110m}Ag, ^{57}Co, ^{58}Co, ^{60}Co, ^{134}Cs, ^{137}Cs, ^{54}Mn). — Radiological criteria: total activity of beta and gamma emitters $<$13 500 GBq/m^3.
Characteristics of secondary waste generated by process (volume, type, activity, form)	— Aqueous effluents: water for storage of ion exchanger returned to the host site. — Technological solid waste: polyethylene drums (200 L, about two drums to 40 m^3 resins). — Personnel protection equipment.
Characteristics of final waste form (container type, activity, form)	— Usually a shielded cylindrical metal container; — Depends on final disposal requirements.
Regulatory and legal considerations (national, local, international, licensing, operation, waste movement and transport)	If connected to host site piping lines, it will be subject to plant requirements governed by local, regional or national regulators.
Transport requirements (system operation, waste shipments, access roads)	— Two special transport containers that comply with appropriate regulation for dangerous goods transport; — Two standard, non-regulated transports.

TABLE 17. KEY SCREENING CONSIDERATIONS FOR A SYSTEM FOR ENCAPSULATION OF SPENT ION EXCHANGE RESINS IN POLYMERIC BINDERS (cont.)

Consideration	Description
Mode of use: batch or continuous processing (system, secondary waste)	Batch, campaign basis: typically 0.3 m^3 of waste per batch, but depends on size of final package.
Cost: contractual arrangements (leased/procured); periodic (monthly/annual/campaign/volume) installation; consumables; staff; equipment removal and disposal; shipping; final waste disposition	— Equipment can be procured or leased as a service; — Mobilization, installation and training are typically one time costs.
System configuration (mobile or skid mounted)	— One encapsulating, self-propelled unit carried on a road trailer; — One double tank unit for the process reactants (epoxy resin and hardener); — One control station integrated in a 6.5 m ISO container; — One workshop truck containing tools and spare parts.
Footprint or physical size of the mobile system (maximum dimensions, media handling/replacement/repair space)	— Mobile unit: ~7 m × 2.5 m × 4 m. — Polymer storage tank: 13 m × 2.5 m diameter.
Total weight (for floor loading and movement)	37 t (mobile unit).
Staffing (number, contracted staff, technical qualifications, operations, security, maintenance)	Installation, operation: team of seven operators with high skill levels.
Maximum or optimal throughput and capacity, and volume reduction	— ~1 m^3 of resin per 8 h shift; — Volume reduction factor is ~1.
Space requirements (area for consumable storage, waste staging and storage)	— The encapsulation unit is typically installed in a radiologically or security controlled area. The location varies by site configuration and applicable regulatory based security requirements and radiological controls. — Other units (tank, control station, workshop) in an area near to the encapsulation unit.
List consumables required for process (media, containers, parts, chemicals)	— Polymer components; — Waste containers.
General service requirements (air, water, steam, electricity, ventilation)	— Air; — Demineralized water; — Electricity; — Ventilation.
Handling equipment required for placement, operation, and waste handling and packaging (cranes, forklifts, load capacity)	Packaging: crane or forklift.
General requirements for industrial and radiological safety (barriers, respiratory protection, personnel exposure monitoring, contamination controls, air monitoring)	— Personnel exposure monitoring; — Contamination controls.

6. COMBINED WASTE TREATMENT AND CONDITIONING SYSTEMS

6.1. SOLID WASTE

6.1.1. Supercompaction

6.1.1.1. Typical system description

Hydraulic compaction systems for solid waste collected in drums or special containers of capacities greater than 500 t are generally called supercompactors. Typically, a supercompactor consists of a vertical compaction unit with associated controls, feed and removal systems for waste drums, and compacted discs called pucks. Mobile supercompactors are available in skid or trailer mounted configurations. Figure 29 shows a skid mounted unit, and Fig. 30 shows a trailer mounted version. Drums to be compacted are fed on conveyors and placed on the platform of the compactor, below the ram. The system also consists of a directional ventilation and gas filtration system for the compaction chamber, to control the release of radioactive particulates. Water may also be compressed out of the raw waste drum during compaction and requires collection or transfer for treatment. The mobile system also requires storage areas for secondary containments, liquid waste collection tanks and space for filters.

FIG. 29. Skid mounted supercompactor (courtesy of GNS Gesellschaft für Nuklear-Service mbH).

FIG. 30. Mobile supercompactor (courtesy of Nucleco).

6.1.1.2. Description of individual components and elements

Typical components of a mobile supercompactor are:

— A trailer mounted hydraulic ram and structural supports;
— A hydraulic power pack;
— A control system for the hydraulics;
— Material handling systems for drum feeds and puck handling, including hoists;
— A ventilation system for the radioactive zone;
— An air-conditioning system for the control room;
— Waste collection containments (moat and berm/bund) for capturing small volumes of liquid. Liquid can be removed by a wet vacuum or a small pump for disposition in a radioactive liquid processing system.

6.1.1.3. System specific benefits

— High volume reduction ratios;
— Significant compaction forces;
— Special designs to match varying container dimensions;
— Good maintainability;
— Well proven equipment.

6.1.1.4. System specific limitations

— The volume reduction ratio achieved can be influenced by the nature of the waste.

6.1.1.5. Key screening considerations

Table 18 identifies key screening considerations for supercompactors.

TABLE 18. KEY SCREENING CONSIDERATIONS FOR SUPERCOMPACTORS

Consideration	Description
Characteristics of incoming and source waste (volume, type, activity, form)	Form or characteristics of waste streams most often associated with mobile supercompaction are: — Typically prepackaged in 200 L drums with dose rates up to 15 mSv/h (with remote handling tools and shielding); — Low density wastes typically associated with radioactive facility operations (e.g. paper, plastic, cloth) as well as other higher density waste forms (e.g. metals, debris); — Low force (drum) compaction can also be used as a pretreatment step; — Compaction of asbestos and other higher activity waste is feasible.
Characteristics of secondary waste generated by process (volume, type, activity, form)	— Liquids or sludge removed from the compaction process; — Dust generated during operations; — Activity levels are typical of the waste being compacted and can be concentrated in and around the compaction chamber as part of the process; — Because of the extreme forces involved with the supercompaction process, discharge of liquids and air during the compaction can, and should, be expected.
Characteristics of final waste form (container type, activity, form)	— Final waste form is typically a compressed solid form (crushed drum). — Volume reduction factors depend on the waste type and can be in the range of 3–8. — Compacted drums (also known as pucks) are typically repackaged in overpack drums or boxes following compaction.
Regulatory and legal considerations (national, local, international, licensing, operation, waste movement and transport)	Supercompaction is not typically a complex regulatory or legal process to deploy. Local, regional and national regulations may apply for transport, operation, effluent monitoring and waste disposal.
Transport requirements (system operation, waste shipments, access roads)	Supercompaction systems are typically transported by tractor and trailer by road, or by barge. They are typically overweight and oversized, and require special permits or escorts during transport.
Mode of use: batch or continuous processing (system, secondary waste)	Batch on a required basis.
Cost: contractual arrangements (leased/procured); periodic (monthly/annual/campaign/volume) installation; consumables; staff; equipment removal and disposal; shipping; final waste disposition	Supercompaction systems are typically expensive and have been specifically adopted for radioactive waste management applications. They require substantial monetary investment to procure, lease and maintain.
System configuration (mobile or skid mounted)	— The supercompaction systems are typically trailer mounted inside a one and two trailer configurations. — Set-up times are typically 1–2 weeks.
Footprint or physical size of the mobile system (maximum dimensions, media handling/replacement/repair space)	Supercompaction systems require significant working space (e.g. 20 m × 16 m) and a working perimeter of an additional 5 m.
Total weight (for floor loading and movement)	— Typically 30–50 t; — Requires a substantial concrete pad for operation.
Staffing (number, contracted staff, technical qualifications, operations, security, maintenance)	— Staffing of a supercompaction system is typically limited to a material handling operator, who loads and unloads the system, and a lead system operator who operates the equipment. — System control and industrial safety operations: training is required. — Maintenance: hydraulic and other mechanical skills.

TABLE 18. KEY SCREENING CONSIDERATIONS FOR SUPERCOMPACTORS (cont.)

Consideration	Description
Maximum or optimal throughput and capacity, and volume reduction	— Typical capacity or throughput for supercompaction is measured in several minutes per compaction cycle, with a typical throughput rate of 10–15 drums per hour. — Compaction forces are in the range of ~750–2200 t compression force.
Space requirements (area for consumable storage, waste staging and storage)	— Space requirements for consumables are minimal. — Waste staging in terms of pre and postprocessing waste containers are typically 15–30 m^2.
List consumables required for process (media, containers, parts, chemicals)	— Drums or other containers; — Hydraulic fluid is changed periodically.
General service requirements (air, water, steam, electricity, ventilation)	— Electrical: 480 V AC, three phase, ~300 A service; 110/120 V AC, single phase, 20 A. — Ventilation: HEPA ventilation to maintain a negative pressure inside the compaction room.
Is handling equipment required for placement, operation, and waste handling and packaging (cranes, forklifts, load capacity)	— Drum hoist or conveyor apparatus; — Forklift truck.
General requirements for industrial and radiological safety (barriers, respiratory protection, personnel exposure monitoring, contamination controls, air monitoring)	— General personnel protection requirements (industrial and radiological) are determined by the host site and may include clothing, barriers, and personnel and area radiation monitoring. — Respiratory protection is not typically required. — Integrated ventilation and air sampling are typically incorporated into the design of the system.

Note: HEPA — high efficiency particulate air.

6.1.2. Volume reduction and packaging of activated components

6.1.2.1. Typical system description

A typical activated component volume reduction and packaging system consists of several remotely operated compactors, shears, waste containers, and transfer casks and shields. The primary application is the volume reduction of reactor components of General Electric boiling water reactors (BWRs), which consist of control rod blades (CRBs), local power range monitors (LPRMs), filters and miscellaneous materials. The components used at a typical project include, but are not limited to:

- — An advanced crusher shear (ACS);
- — A stellite bearing punch;
- — A CRB crimper;
- — An LPRM cutter;
- — Packaging equipment.

Various system components can also be used at pressurized water reactor plants, government research facilities, university reactors and other types of commercial nuclear stations.

6.1.2.2. Description of individual components and elements

(a) Advanced crusher shear

An ACS is a remotely operated device for crushing and shearing irradiated hardware from nuclear facilities. A system is shown in Fig. 31, suspended adjacent to a spent fuel pool (SFP) in preparation for use.

The shear blades are designed with multiple cutting surfaces. Should the cutting surfaces become dull, the blades can be reversed to expose a new cutting edge. An electric/hydraulic power unit drives the shear, utilizing demineralized water as the hydraulic fluid. The use of demineralized water in lieu of petroleum fluids prevents contamination of the SFP should a leak develop.

The ACS is designed with a remotely removable vacuum and filter system. The system maintains a flow of water across the working face of the shear. Any fine material produced by the shearing of irradiated components will be entrained in the water flow and deposited in the stainless steel filters. Pieces too heavy to be entrained fall directly into the process container. Upon completion of a job, or depletion of a filter, the filters are easily removed and disposed of in the waste container with the irradiated hardware. The filters will typically process up to 100 CRBs before replacement is necessary.

The ACS is assembled from two basic components, each of which is constructed from stainless steel. The shear assembly is bolted onto the shear stand, which contains the transfer container and the vacuum system, and placed into the SFP as an assembled unit.

The irradiated components are fed vertically into the top of the ACS. The unit crushes and then shears the component to the desired length. The processed hardware falls directly into the process container.

Very little boron is released to the SFP while processing CRBs. The CRBs are first crimped to retain boron tubes and the subsequent shearing action tends to fold the metal tubes over the B_4C material during each cut. Particulate material released is captured in the utility provided underwater vacuum system.

The ACS will process a wide variety of reactor hardware, such as CRBs, LPRMs, flow channels, poison curtains and other miscellaneous hardware.

FIG. 31. An ACS at the pool side (courtesy of EnergySolutions).

(b) Stellite bearing punch

A stellite bearing punch (see Fig. 32) is a water driven hydraulic cutting device that removes the stellite bearing and pin as a one piece coupon prior to processing the remaining portion of the CRB. A rigid support assembly and redundant safety cable are used to suspend the punch from the pool curb during operation.

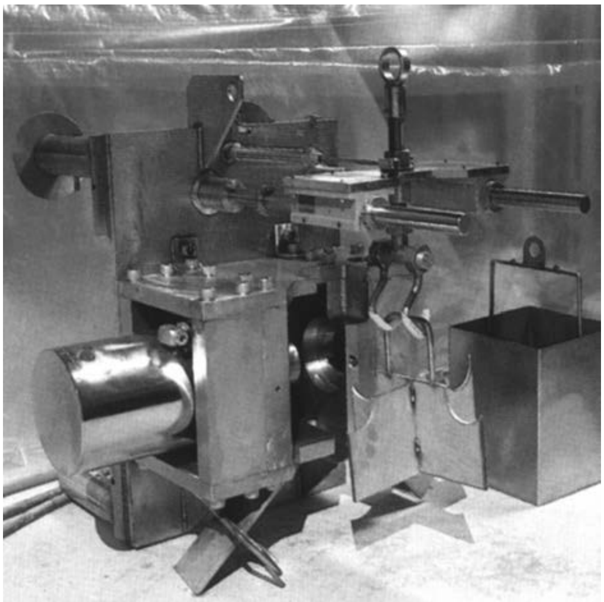


FIG. 32. A stellite bearing punch (courtesy of EnergySolutions).

A 76.2 mm (3 inch) diameter cutting die is attached to a hydraulic cylinder. The cylinder is driven by an air powered, self-contained hydraulic power pack located on the refuelling floor. The power pack uses demineralized water as the hydraulic fluid and is capable of developing up to 36 t of force at the cutting surfaces.

Decontamination efforts for the stellite bearing punch are minimized due to the electropolished surfaces. In addition, the cutting die may be removed and placed in a hardware liner to comply with ALARA (as low as reasonably achievable) and transport requirements.

(c) Control rod blade crimper

A CRB crimper, hydraulically operated by demineralized water, is used to crimp the CRB tube sheet prior to processing (see Fig. 33). Each fin of the CRB blade is crimped into multiple places to ensure the B_4C tubes stay intact during processing. The crimping process is typically performed during the stellite bearing punching process. The crimper system is packaged with the stellite bearing punch.

(d) Local power range monitor cutter

An LPRM cutter is a hydraulically operated cutting head used to segment LPRMs and dry tubes into lengths acceptable for packaging (see Fig. 34). The LPRM cutter uses demineralized water as the hydraulic medium.

The cutter is remotely operated and uses a fixed anvil and moveable blade to segment tubing sections. During operation, the LPRM cutter is suspended from the SFP curb using a curb hanger bracket. Stainless steel extension poles are used to connect the cutter to the curb hanger bracket.

A self-contained, air driven hydraulic power pack provides the required pressure to the cutting head. The power pack is supplied with hydraulic hoses and connections for demineralized water and service air.

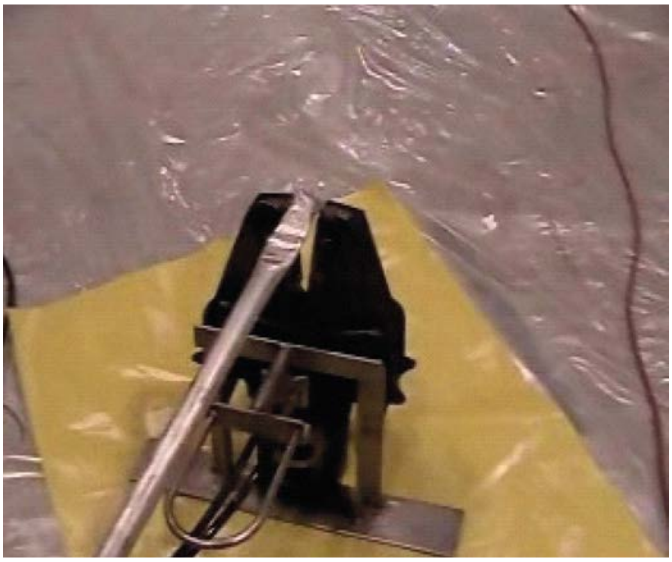


FIG. 33. A CRB crimper (courtesy of EnergySolutions).

FIG. 34. An LPRM cutter (courtesy of EnergySolutions).

(e) Packaging equipment

Tools for handling and packaging irradiated hardware include:

— Air operated grapples;
— Manually and air operated extension tools;
— Remotely operated wrenches;
— Underwater lights and camera systems.

The tools are designed to support packaging the volume reduced material with minimum personnel exposure. The waste products are placed into one of several types of waste containers staged in transport shields or casks (flasks). The tools and one specific example of a waste container are shown in Fig. 35.

6.1.2.3. System specific benefits

— The system is reliable.
— Consistent volume reduction values are obtained.

FIG. 35. Remote underwater handling tools (left) and an irradiated hardware container (right) (courtesy of EnergySolutions).

- — The system meets or exceeds requirements for: heavy loads (American National Standards Institute and NUREG 0612 compliant); foreign material exclusion (controls material in the SFP); and pool chemistry (the system operates with demineralized water).
- — There is a reduction in disposal and storage costs for resultant waste.
- — Remote operation is possible.
- — Shielding use is incorporated into the design where practical.
- — Cutting surfaces are changed due to wear and exposure rates after each campaign.

6.1.2.4. System specific limitations

- — The ACS was designed specifically to volume reduce CRBs from General Electric BWR plants. As a result, items wider than 25 cm in diameter cannot be processed using the system.
- — The system is limited to a material thickness of 12.5 mm.

6.1.2.5. Key screening considerations

Table 19 identifies key screening considerations for systems for volume reduction and packaging of activated components.

TABLE 19. KEY SCREENING CONSIDERATIONS FOR SYSTEMS FOR VOLUME REDUCTION AND PACKAGING OF ACTIVATED COMPONENTS

Consideration	Description
Characteristics of incoming and source waste (volume, type, activity, form)	—Types or characteristics of waste streams most often associated with irradiated fuel pool hardware processing are typically very high in radioactive dose and stored under water in the SFP at nuclear reactor facilities. — Physical description of the types of waste forms include: CRBs, in-core instrumentation, filters, dry tubes, jet pump beams, filters, stellite bearings and other miscellaneous hardware, as well as radioactive sources.
Characteristics of secondary waste generated by process (volume, type, activity, form)	Secondary waste forms generated as a result of process are typically limited to filters. The volume and activity vary greatly based on the amount of hardware processed and the quality of the SFP water. Other secondary wastes are relative to radiation protection measures (protective clothing, decontamination supplies).
Characteristics of final waste form (container type, activity, form)	— Final waste form is typically a medium density compressed or shredded metal or segmented metal. — Volume reduction factors depend on the waste type and can easily be in the range of 3–5.

TABLE 19. KEY SCREENING CONSIDERATIONS FOR SYSTEMS FOR VOLUME REDUCTION AND PACKAGING OF ACTIVATED COMPONENTS (cont.)

Consideration	Description
Regulatory and legal considerations (national, local, international, licensing, operation, waste movement and transport)	— Transport requirements for contaminated equipment; — Waste characterization and classification requirements.
Transport requirements (system operation, waste shipments, access roads)	Transported in self-contained SCO or Type 7A container that is ~3 m × 1 m × 1 m.
Mode of use: batch or continuous processing (system, secondary waste)	Typically campaign (batch).
Cost: contractual arrangements (leased/procured); periodic (monthly/annual/campaign/volume) installation; consumables; staff; equipment removal and disposal; shipping; final waste disposition	Mobile underwater segmenting and processing equipment is typically expensive and has been specifically adapted for underwater, high dose fuel pool work. They require substantial monetary investment to build and to maintain, and are therefore typically leased for a specific campaign. Furthermore, this equipment needs to be accompanied by other high activity shipping containers or casks that are also capable of submerged operations (including loading and unloading). The purchase of this type of equipment is also possible, however, rare.
System configuration (mobile or skid mounted)	— Mobile or skid mounted; — Set up as close to, or in, the SFP or receiving area; — Set-up times in the range of 1–2 weeks are to be expected.
Footprint or physical size of the mobile system (maximum dimensions, media handling/replacement/repair space)	— The in-pool footprint for specific components ranges from 1 m or less of curb length (suspended tools) to a 3 m × 3 m footprint on the floor of the pool. — Control skids require an additional 4 m × 4 m area adjacent to the pool. — Stellite bearing punch: 0.3 m × 0.66 m × 0.3 m. — LPRM cutter: 0.3 m × 0.3 m × 1.8 m.
Total weight (for floor loading and movement)	— ACS in-pool system: 4100 kg. — Stellite bearing punch: 340 kg. — LPRM cutter: 295 kg.
Staffing (number, contracted staff, technical qualifications, operations, security, maintenance)	— Staffing of the underwater irradiated fuel pool hardware system is typically limited to a highly trained and specialized material handling operator, who loads and unloads irradiated components, and a lead system operator, who operates the equipment. — Other than system control and industrial safety operations, special training in high dose rate work is typically required. — With regard to maintenance, hydraulic and other mechanical skills are necessary to maintain system operations.
Maximum or optimal throughput and capacity, and volume reduction	— Processing rates vary, depending on the specific hardware component and operational constraints. — ACS can process components up to 254 mm in diameter or 228 mm square, of virtually any length. — ACS power unit develops 100 t of force on both the crusher anvil and the shear blade. — Volume reduction factors depend on the waste type and can easily be in the range of 3–5.
Space requirements (area for consumable storage, waste staging and storage)	Space requirements for consumables are minimal. Waste staging in terms of pre and postprocessing waste containers are typically 15–30 m^2.
List consumables required for process (media, containers, parts, chemicals)	Cartridge filter media for particulate capture system.

TABLE 19. KEY SCREENING CONSIDERATIONS FOR SYSTEMS FOR VOLUME REDUCTION AND PACKAGING OF ACTIVATED COMPONENTS (cont.)

Consideration	Description
General service requirements (air, water, steam, electricity, ventilation)	— Electrical: 480 V AC, three phase, 50 A; 120 V AC, 20 A, single phase (system can be modified for 380 V AC, 50 Hz service). — Service air: 0.7 MPa minimum. — Water: demineralized water, <400 L. — Ventilation: none additional to plant systems is required.
Handling equipment required for placement, operation, and waste handling and packaging (cranes, forklifts, load capacity)	Equipment is loaded and placed in the fuel pool by a facility overhead crane (not part of the mobile system equipment). Waste items are loaded into and removed from the equipment by means of an overhead hoist and crane apparatus. Forklift trucks are often used to transport incoming drums to and over packed drums from the system.
General requirements for industrial and radiological safety (barriers, respiratory protection, personnel exposure monitoring, contamination controls, air monitoring)	— General personnel protection requirements for operation include standard radiation worker dress, dosimetry and industrial safety protection (e.g. eye protection, safety shoes). — Respiratory protection is not typically required, except in the rare occasion for decontamination of the equipment.

Note: SFP — spent fuel pool; CRB — control rod blades; LPRM — local power range monitor; ACS — advanced crusher shear.

6.1.3. In situ vitrification of soil

6.1.3.1. Typical system description

In situ vitrification (ISV) is a commercially available mobile thermal treatment process that involves electric melting of contaminated soils, sludges, or other materials, waste and debris for the purposes of permanently destroying, removing or immobilizing hazardous and radioactive contaminants [34, 35]. The process is widely applicable to all soil types and all classes of contaminants, including organics, heavy metals and radionuclides. The ISV process is a batch process that involves forming a pool of molten soil under the surface of a treatment zone between an array of electrodes (see Figs 36 and 37).

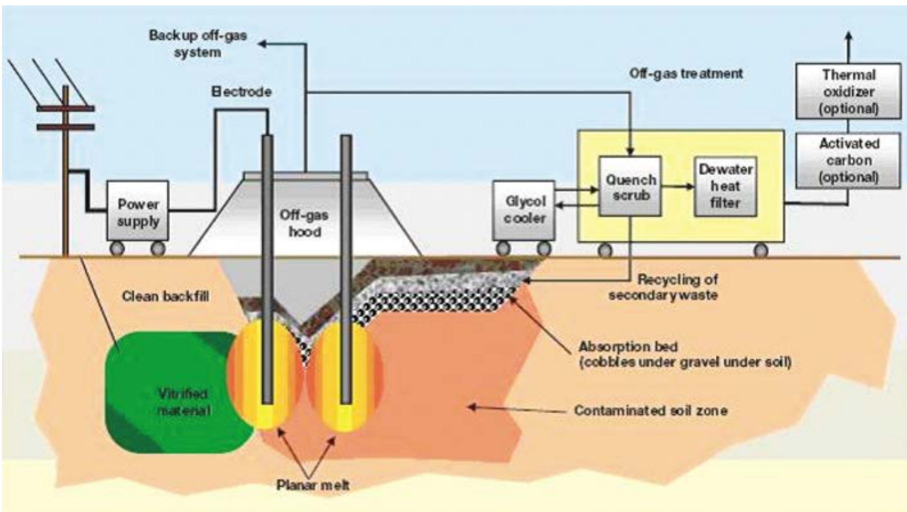


FIG. 36. Process scheme of an ISV process.

FIG. 37. Sample photograph of vitrified monolith resulting from use of ISV process (image from Ref. [34]).

The molten soil serves as the heating element of the process wherein electrical energy is converted to heat via joule heating as it passes through the molten soil. The ISV melt temperatures typically range between 1500°C and 2000°C. Continued pumping of energy results in the melt pool growing deeper and wider until the desired volume has been treated. When electrical power is shut off, the molten mass solidifies into a vitreous monolith, with unequalled physical, chemical and weathering properties compared with alternative solidification and stabilization technologies. Individual melts up to 7 m deep and 15 m in diameter are formed during commercial operations. Large volumes of contaminated material requiring more than one batch melt are treated by making a series of adjacent melts, resulting in the formation of one massive continuous monolith. The process is operated on an around the clock basis and can achieve treatment rates of up to 150 t/d.

6.1.3.2. Description of individual components and elements

The ISV treatment system consists of an electrical power transformer, an off-gas collection hood, an off-gas treatment system and a process control system. All equipment is trailer mounted, with the exception of the off-gas hood, which is transported to the site and then assembled. The off-gas hood is used to collect emissions escaping from the treatment zone and to support the graphite electrodes used in the melting process. The hood is a dome shaped structure that completely covers the area to be treated. A low vacuum is maintained in the off-gas hood to contain off-gases, which are then piped to the off-gas treatment system. The off-gas treatment system consists of a quencher, scrubber, demister, heater, particulate filter, activated carbon adsorber, blower and optional thermal oxidation unit. Off-gas is processed by the quencher to lower its temperature and by the scrubber to remove acid gases and large particulates. It is then dewatered and reheated to prevent wetting of the particulate filters. Next, it is filtered to remove fine particulates and then polished to remove trace organics using either an activated carbon adsorber or a thermal oxidation unit. An electrical power transformer provides two phase alternating current at the appropriate voltage and amperage to the electrodes. The entire ISV system is monitored from a process control room where electrode power consumption, off-gas temperature, hood vacuum and other system parameters are tracked and monitored.

There is information about modification of this method based on conventional ISV and using essentially the same power system and off-gas controls. ‘Planar’ melting uses starter paths injected through a series of closely spaced holes bored or driven alongside the zone to be treated — in planes on either side of the waste or above and below the waste — and the two melts are allowed to converge. Since planar melting is typically completed below the surface, this approach enables deeper zones to be treated without higher power requirements. In fact, the unmelted soil above the treatment zone acts as a thermal insulator, conserving energy at the melt depth and keeping surface equipment significantly cooler. Planar melting can be applied from the sides of buried tanks and is ideal for narrow treatment zones such as trenches.

6.1.3.3. System specific benefits

— In situ disposal;
— Applicable to both radioactive and conventional hazardous materials;
— Low personnel exposures;
— The matrix of waste (glass) has a very low leachability rate;
— Easy to decontaminate and to demobilize.

6.1.3.4. System specific limitations

— High cost;
— ISV is performed under a complex regulatory framework;
— Complicated off-gas treatment.

6.1.3.5. Key screening considerations

Table 20 identifies key screening considerations for ISV systems.

TABLE 20. KEY SCREENING CONSIDERATIONS FOR ISV SYSTEMS

Consideration	Description
Characteristics of incoming and source waste (volume, type, activity, form)	— Radioactive soils (in situ); — Activity: no limitations, except elements producing volatile radionuclides (e.g. Cs).
Characteristics of secondary waste generated by process (volume, type, activity, form)	— Scrubber liquids; — Spent filters; — Decontamination waste; — Solid waste can be recycled into subsequent melts.
Characteristics of final waste form (container type, activity, form)	— Vitrified blocks, up to 1200 t, diameter up to 12 m, height up to 7 m; — Activity not limited because the form is typically 5–100 times more durable than borosilicate glasses.
Regulatory and legal considerations (national, local, licensing, operation, and waste movement and transport)	Local, regional and national regulations may apply for transport, operation, effluent monitoring, control and waste disposal.
Transport requirements (system operation, waste shipments, access roads)	Four trailers and lifting equipment.
Mode of use: batch or continuous processing (system, secondary waste)	Batch processing.
Cost: contractual arrangements (leased/procured); periodic (monthly/annual/campaign/volume) installation; consumables; staff; equipment removal and disposal; shipping; final waste disposition	— US $40 000–80 000 fixed mobilization cost and US $450–900/m^3 operating cost (1990s values). — Indirect costs such as project management, design and engineering, vendor selection, home office support, permit preparation and fees, regulatory interaction, site characterization, treatability testing, performance bond and contingencies are not included in the estimated cost range. — 2–3 weeks each for mobilization and demobilization.
System configuration (mobile or skid mounted)	One part is mobile and the other part is skid mounted.

TABLE 20. KEY SCREENING CONSIDERATIONS FOR ISV SYSTEMS (cont.)

Consideration	Description
Footprint or physical size of the mobile system (maximum dimensions, media handling/replacement/repair space)	— >30 m × 12 m; — Off-gas hood: >150 m^2.
Total weight (for floor loading and movement)	>100 t.
Staffing (number, contracted staff, technical qualifications, operations, security, maintenance)	Two people for operation.
Maximum or optimal throughput and capacity, and volume reduction	— 3–6 t/h; — Up to 1200 t/melt; — Volume reduction for soils from 25% up to 50%; up to 75% for wet sludges and combustible wastes.
Space requirements (area for consumable storage, waste staging and storage)	>150 m^2.
List consumables required for process (media, containers, parts, chemicals)	For one run: — 150 t of gravel (multi-used); — Water (for scrubbers); — HEPA filters; — Electrodes.
General service requirements (air, water, steam, electricity, ventilation)	— Power: up to 11–13.8 kV, three phase; 900–3500 kW (0.5–0.8 kWh per 1 kg of material vitrified). — Non-potable water.
Handling equipment required for placement, operation, and waste handling and packaging (cranes, forklifts, load capacity)	Forklift and 35 t and 125 t cranes.
General requirements for industrial and radiological safety (barriers, respiratory protection, personnel exposure monitoring, contamination controls, air monitoring)	— No special requirements; — Radiological controls determined by site requirements, including survey, barriers, berms/bunds and effluent monitoring.

Note: HEPA — high efficiency particulate air.

6.2. DISUSED SEALED SOURCES

6.2.1. Dismantling and packaging high activity disused sources

6.2.1.1. Typical system description

The IAEA offers Member States a mobile hot cell facility for conditioning of the disused high activity radioactive sources. The device can be disassembled within the hot cell, and the source can be removed and packaged. After completion of the conditioning operation, the facility can be transported to another site where it is required. The facility is used to handle and condition disused high activity radioactive sources in Member States where there is no appropriate infrastructure for such operations [36–38].

The facility consists of a biological shield with a window for viewing work in progress inside the shield (see Fig. 38). It makes use of master–slave manipulators and an internal crane to handle and to lift various objects

FIG. 38. Mobile hot cell for conditioning of high activity sealed sources.

within the cell. There is a crane outside the shield for 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 storage container for the disused high activity radioactive sources will be coupled to the side of the biological shield for easy and safe transfer of the sources from the cell.

6.2.1.2. Description of individual components and elements

(a) **Biological shield**: This refers to the wall of the cell within which handling of unshielded sources is performed. It is designed to handle radiation levels up to the equivalent of a 37 TBq (1000 Ci) ^{60}Co source at a time. The biological shield performs the role of being the platform on which other components of the conditioning facility are mounted. It consists of a double walled cavity, 1.55 m wide and filled with sand as a shielding material. The working volume of the biological shield is 2.5 m long, 1.6 m wide and 3.0 m high. This gives enough room to accommodate the disused high activity shielded source while allowing free movement of the manipulators. It also accommodates the internal crane.

(b) **Workbench**: A table filling the internal dimensions of the cell at 800 mm from the floor provides a work surface. Its height is adjustable for better view of the work area.

(c) **Biological shield roof**: The biological shield roof is designed to limit the 'sky shine' effect to acceptable levels. It also acts as an entrance for personnel and equipment. The roof is essentially a lid that has to be put in place before an unshielded source is handled. The roof is made up of three 230 mm thick slabs of concrete cast with mild steel corner protection and standard reinforcing bars.

(d) **Window**: The window's purpose is to provide sufficient vision to allow personnel to view the operation area and to provide shielding which is equivalent to that provided by the walls of the biological shield. The window consists of a container filled with a transparent heavy liquid (50% zinc bromide solution) and has transparent end panels.

(e) **Master–slave manipulators**: These are telescopic manipulators capable of lifting up to 20 kg.

(f) **Cranes**: An internal crane is designed to lift the objects that are too heavy for the master slave manipulators, such as teletherapy or blood irradiator drawers. It is a jib crane type mounted on the internal wall of the biological shield. The external crane is a gantry type crane that has four large rubber wheels for moving across even surfaces.

(g) **Ventilation system**: All potential sources of airborne contamination will be trapped by HEPA filters. The ventilation system is a stand-alone system that consists of a fan, prefilters fitted with fire arrestors, HEPA filters and an exhaust hose. The system maintains an internal cell pressure of 200 Pa and five air changes per hour.
(h) **Long term storage shield**: The long term storage shield is a container based on and compatible with the design of an existing transporter. The storage container is designed to last for a period of 75 years. It also provides shielding, which allows for the container to be handled without requirements for further shielding.

6.2.1.3. System specific benefits

— Recovery of disused high activity beta/gamma sources from their respective shielding and conditioning for long term safe and secure storage.

6.2.1.4. System specific limitations

— Due to the high radiation risk of handling high activity radioactive sources, the dismantling and conditioning operations are to be carried out by well trained local personnel or by a specialized team sent from abroad.
— The long term storage shield needs to be certified as a transport container to enable its transportation for repatriation or to an operational disposal site when this becomes available without further need of conditioning.

6.2.1.5. Key screening considerations

Table 21 identifies key screening considerations for systems intended for dismantling and packaging disused sources.

TABLE 21. KEY SCREENING CONSIDERATIONS FOR SYSTEMS INTENDED FOR DISMANTLING AND PACKAGING DISUSED SOURCES

Consideration	Description
Characteristics of incoming and source waste (volume, type, activity, form)	Disused high activity beta/gamma sealed radioactive sources with activity up to the equivalent of a 37 TBq (1000 Ci) ^{60}Co source.
Characteristics of secondary waste generated by process (volume, type, activity, form)	Secondary waste production is expected to be small, except if a source is found to be leaking. Should any source be found to be leaking while dismantling operations take place, further dismantling would not continue. The unit will be closed and further arrangements will be made for placing the head or unit in a special overpack. This will be arranged by the IAEA.
Characteristics of final waste form (container type, activity, form)	The conditioned source is designed for long term storage up to 75 years.
Regulatory and legal considerations (national, local, international, licensing, operation, waste movement and transport)	End user will: — Prepare and apply for any licence, permit or authorization required for the conditioning operation; — Prepare and apply for any licence, permit or authorization required to store the conditioned sources in a local storage facility; — Assist in custom clearance of all necessary equipment and tools; — Provide handling, storage or disposal of all radioactive and non-radioactive materials generated by the operation; — Define and implement security arrangements during the operation to protect people and equipment; — Report to the regulatory body on results of the operation after its completion.

TABLE 21. KEY SCREENING CONSIDERATIONS FOR SYSTEMS INTENDED FOR DISMANTLING AND PACKAGING DISUSED SOURCES (cont.)

Consideration	Description
Transport requirements (system operation, waste shipments, access roads)	— Transfer of the source to the operational site; — Preparation of the access road to the operational site that will allow for easy movement of large vehicles; — Provision of transport for the contractor's staff.
Mode of use: batch or continuous processing (system, secondary waste)	Batch processing.
Cost: contractual arrangements (leased/procured); periodic (monthly/annual/campaign/volume) installation; consumables; staff; equipment removal and disposal; shipping; final waste disposition	The cost varies depending on the local conditions, but it is covered by the IAEA.
System configuration (mobile or skid mounted)	Skid mounted, with a 120 mm thick concrete slab (7.6 m × 8 m) with steel reinforcing to be constructed. It is necessary for it to be absolutely level (horizontal).
Footprint or physical size of the mobile system (maximum dimensions, media handling/replacement/repair space)	15 m × 30 m.
Total weight (for floor loading and movement)	30–40 t.
Staffing (number, contracted staff, technical qualifications, operations, security, maintenance)	— The operation is carried out by the contractor (a team of five members). — At least ten local labourers are required to assist the contractor during assembly and disassembly. — At least two highly specialized personnel trained for working with manipulators.
Maximum or optimal throughput, capacity, decontamination factor and volume reduction	4–8 sources per day, depending on the source.
Space requirements (area for consumable storage, waste staging and storage)	7 m × 15 m.
List consumables required for process (media, containers, parts, chemicals)	Consumables: — Tools for stripping teletherapy heads, constructing and stripping of biological shield, and other general applications; — Welding rods; — 90 m^3 of unsieved river sand for the biological shield; — A cylinder of high purity (99.999%) Ar welding gas; — Containers for the collection of domestic as well as potential radioactive waste (e.g. dustbins). Provisions are to be made for additional equipment: — Fully automatic welding equipment; — Leak testing equipment; — Radiation protection equipment; — Sand loading equipment; — Transport container; — Vibrators; — Vacuum cleaner.

TABLE 21. KEY SCREENING CONSIDERATIONS FOR SYSTEMS INTENDED FOR DISMANTLING AND PACKAGING DISUSED SOURCES (cont.)

Consideration	Description
General service requirements (air, water, steam, electricity, ventilation)	— Running water; — Three phase electrical power.
Handling equipment required for placement, operation, and waste handling and packaging (cranes, forklifts, load capacity)	A crane (3–5 t capacity) for the movement of the units and the sources from the source store and container.
General requirements for industrial and radiological safety (barriers, respiratory protection, personnel exposure monitoring, contamination controls, air monitoring)	Personnel protective clothing and other controls defined by the host site.

7. WASTE CHARACTERIZATION SYSTEMS

Characterization of waste is an essential activity that is required at every stage of radioactive waste management. It involves determination of the physical, chemical and radiological properties of the waste to establish the requirement for further adjustment, treatment and conditioning, or its suitability for further handling, processing, storage or disposal [39, 40]. A wide range of destructive and non-destructive techniques is available for the characterization of raw waste, waste forms and waste packages. This section presents a brief description and key features of a non-destructive assay using gamma scanning systems commonly used in a mobile configuration to characterize waste packages. Mobile systems are also available that are based on a passive and active neutron assay for determination of transuranic isotopes [41].

7.1. NON-DESTRUCTIVE ASSAY

7.1.1. Gamma scanning system

7.1.1.1. Typical system description

A wide range of mobile gamma scanning systems is commercially available. Typical arrangements consist of a detector system that rotates or a turntable module used to rotate the waste packages. A gamma scanner such as the tomographic gamma scanner (TGS) illustrated in Fig. 39 is used to measure gamma radiation emitted by isotopes present in waste packages; normal isotopes of interest are ^{60}Co and ^{137}Cs. These are relatively ‘easy to measure’ and are used to scale radioisotopes which are ‘difficult to measure’ using the scaling factor method [42]. For a full radioactive waste characterization, destructive analysis is often necessary to determine the correlation between easy to measure gamma emitters and alpha or beta emitters. The TGS is an extension of the more commonly used segmented gamma scanner, which makes it possible to measure waste packages containing heterogeneous waste items.

Another option is available which is based on integral scanning of the object. This measuring system uses less complicated hardware (see Fig. 40). The detector is fixed adjacent to the drum to be analysed, taking, in one shot, the total emission of the waste in the drum.

FIG. 39. The WM2900 tomographic gamma scanner (courtesy of CANBERRA).

FIG. 40. The ISO-CART mobile assay system (courtesy of ORTEC).

Similar systems are available installed inside a standard 6 m ISO container, ready for route transport to the site, and provided with all the electromechanical actuators necessary to allow the automation of the process (drum introduction, positioning in the weighing station, positioning in the measuring station, output of the drum) (see Fig. 41).

FIG. 41. Gamma assay mobile system (courtesy of Nucleco).

7.1.1.2. Description of individual components and elements

- A detector with a detector drive module;
- A turntable module for drum mounting;
- A mechanism control system;
- Software and electronics;
- A 6 m ISO standard container;
- Roller conveyors for input and output of the drums;
- An automatic PLC controlled system for drum positioning;
- A weighing station.

7.1.1.3. System specific benefits

- A non-destructive assay solution;
- A small system size;
- Manual or remote operation;
- The possibility to be coupled with mobile equipment for volume reduction or conditioning on-site.

7.1.1.4. System specific limitations

- Limited number of isotopes to measure, but, depending on the features of the waste to be measured, a detector with a different energy range can be used.

7.1.1.5. Key screening considerations

Table 22 identifies key screening considerations for gamma assay waste characterization systems.

TABLE 22. KEY SCREENING CONSIDERATIONS FOR GAMMA ASSAY WASTE CHARACTERIZATION SYSTEMS

Consideration	Description
Characteristics of incoming and source waste (volume, type, activity, form)	This technology is applicable to liquid and solid waste packaging in drums or boxes or even in pipes, cylinders, floors, walls and soils.
Characteristics of secondary waste generated by process (volume, type, activity, form)	Secondary waste is not expected.
Characteristics of final waste form (container type, activity, form)	There is no change in the waste form between before and after the measurement process.
Regulatory and legal considerations (national, local, international, licensing, operation, waste movement and transport)	No special licence is required.
Transport requirements (system operation, waste shipments, access roads)	Conventional transport is required.
Mode of use: batch or continuous processing (system, secondary waste)	Batch operation (by drum or waste package), or continuous operation in the case of 6 m ISO containers.
Cost: contractual arrangements (leased/procured); periodic (monthly/annual/campaign/volume) installation; consumables; staff; equipment removal and disposal; shipping; final waste disposition	Cost is low in comparison with the transport cost required in the case that characterization is made in a stationary waste management facility.
System configuration (mobile or skid mounted)	Mobile or skid.
Footprint or physical size of the mobile system (maximum dimensions, media handling/replacement/repair space)	Variable, ~4–15 m^3, or the dimensions of a 6 m standard ISO container.
Total weight (for floor loading and movement)	Variable, 500–3000 kg.
Staffing (number, contracted staff, technical qualifications, operations, security, maintenance)	One qualified operator is required, and one professional to process the data. In some cases, one person could do both tasks.
Maximum or optimal throughput, capacity, decontamination factor and volume reduction	— Typically single scan systems have 10 min cycle times, and segmented scanners can require up to 1 h per drum. — Several variables affect times, including background radiation levels, container and waste material and targeted lower activity thresholds.
Space requirements (area for consumable storage, waste staging and storage)	Indoor operation.
List consumables required for process (media, containers, parts, chemicals)	Liquid N for the detectors.
General service requirements (air, water, steam, electricity, ventilation)	Low voltage (110/220 V AC).

TABLE 22. KEY SCREENING CONSIDERATIONS FOR GAMMA ASSAY WASTE CHARACTERIZATION SYSTEMS (cont.)

Consideration	Description
Handling equipment required for placement, operation, and waste handling and packaging (cranes, forklifts, load capacity)	Forklifts may be required for drum movement.
General requirements for industrial and radiological safety (barriers, respiratory protection, personnel exposure monitoring, contamination controls, air monitoring)	Standard radiological and industrial safety protections are normally required.

8. CONCLUSIONS

This publication provides information on mobile systems that have recently been increasingly used for radioactive waste processing applications. Examples of some technologies more commonly deployed in mobile applications cover all waste processing steps. Good examples are decontamination, filtration and ion exchange, cementation, polymer fixation of ion exchange resins and supercompaction. Such systems are now commercially available from many vendors, or can be custom built to address specific requirements. Many emerging mobile systems that have been tested or deployed in recent years could become commercially available in the near future. It is noteworthy that emerging nuclear power plant designs (e.g. Gen III+) increasingly rely on using mobile systems for waste processing.

The trend towards increasing use of mobile systems is driven by a variety of factors, for example:

— Avoiding off-site transport of waste by bringing processing technology to the point of waste generation;
— Opportunities to manage waste in a campaign mode in the case of multiple facilities that generate similar waste streams (e.g. spent resin fixation process in France or immobilization of disused sealed radioactive sources in the Russian Federation);
— Possibilities of these systems to be assembled and tested in the factory, easily installed on-site and easily replaced or upgraded with more advanced techniques and processes;
— Possibilities to take advantage of experienced vendor services in processing certain radioactive waste streams.

There are cases where mobile systems have clear advantages under specific circumstances involving:

(a) Non-routine problematic wastes with a smaller volume, which require case specific solutions using a combination of techniques;
(b) Accident and incident situations, when systems need to be deployed in an emergency;
(c) Decommissioning situations, where building new permanent nuclear facilities, such as a waste processing facility, are to be avoided.

This publication systematically compiles information and examples of deployed mobile processing systems for pretreatment, treatment, conditioning, combined treatment and conditioning, and waste characterization. Various examples of mobile processing for solid, liquid, gaseous and multiphase waste streams are provided to give a feel of the actual application of mobile systems. For every example, information includes descriptions of typical system and components, system specific benefits and limitations. Key factors to be considered in assessment of applicability of the mobile system are presented for every example in standardized tabular form.

A decision to use mobile systems versus fixed on-site or off-site systems requires an iterative approach for selecting the appropriate processing option for the specific application, determining whether a mobile system has advantages over a fixed installation, and for determining feasibility for deployment.

A methodology for the applicability assessment of the mobile waste processing system and for the decision process for the selection of one that is applicable is proposed. It illustrates the two distinct steps of execution of the iterative assessment. Step 1 includes evaluation of all relevant non-technical and technical factors, including processing goals, regulatory framework, safety requirements, waste stream characteristics, selection and screening of technologies, transport regulations, design and operational requirements and limits, and cost. Data for preliminary technical screening of candidate mobile systems are presented in tables for every example in the publication to help to determine whether such a system is a viable option for implementation. Step 2 includes detailed technical screening, followed by thorough economic analysis to justify fully the implementation of a mobile system by technical and financially sound decisions. Detailed technical information for two widely used mobile applications is presented in Annexes I and II to illustrate the major data types and content required for detailed technoeconomic analysis.

Numerous sources of information were used to develop this publication, including IAEA publications and an international team of radioactive waste management experts. In addition, other recognized industry reports and standards were also consulted.

This publication is primarily intended for waste management professionals responsible for selecting, designing and deploying waste processing systems to take advantage of existing and emerging mobile systems. It could also assist regulators responsible for reviewing and licensing mobile waste processing systems and possible bilateral agreements related to sharing such systems.

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Annex I

EXAMPLE OF MOBILE PROCESSING SYSTEM DETAILS: SUPERCOMPACTION OF SOLIDS

Tables I–1 to I–7 illustrate the types of information that are gathered during the applicability determination process which can be used as part of the screening process and for the development of technical specifications for the supercompactor.

TABLE I–1. TECHNOLOGY OVERVIEW

Consideration	Description or value(s)
Throughput, capacity, decontamination factor and volume reduction	— Throughput: up to ten 200 L drums per hour. — Capacity: in the range of 750–2200 t. — Volume reduction factors: up to 10, depending on waste type.
Incoming waste characteristics (activity, form)	— 200 L drums filled with waste materials; — Dose rates up to 15 mGy/h (higher dose rate would require shielding and remote handling); — All types of low to medium density wastes, in-drum compacted wastes, asbestos and highly active wastes.
Final waste characteristics (activity, form, chemistry)	— Medium to high density waste forms with crushed drums; — Repackaging of pucks may be required to contain activity.
Final waste form acceptance criteria and limitations for waste disposal or storage	— Waste acceptance criteria of individual States or regulatory authority; — Compaction is a widely accepted process for volume reduction and accepted as a disposable waste form in most cases.
Secondary waste characteristics generated by the process (activity, form, chemistry)	Liquids or sludge generated from the compaction process or dust generated during compaction operations. Liquids are collected and pumped to utility storage tanks, and dust in exhaust air is filtered. The unit design contains the locally generated liquid and air.
Requirements for outside support (equipment or resources)	Supercompaction systems are available in skid or trailer mounted configurations. It is essential that the installation is suitable for transmission of the unit's weight and the shock loads generated during compaction operations. The mobile systems are designed to transmit the loads; however, a rigid platform is required at the site.
Staffing (operating times, number, contracted staff, qualifications to operate technology, operations, security, maintenance)	A system operator for the mobile unit, an operator for the material handling system and a part time radiological safety support. Corrective and routine maintenance requires a mechanic. Minimal operator training is required.
Industrial and radiological safety (barriers, respiratory protection, personnel exposure monitoring, contamination controls, air monitoring)	— Compaction operation is typically locally contained and ventilated to avoid spread of any contamination. — Area radiation and continuous air monitoring, as required. — Personnel monitors and protective clothing, for example, are required per site requirements. — Respiratory protection may be required for decontamination and maintenance. — Industrial safety protection includes eye protection and safety shoes.
Regulatory and legal considerations (national, local, international, licensing, operation, waste movement and transport)	Supercompaction is typically not affected by legal or regulatory processes. The engineering and radiological safety aspects of the process are well known and standardized, and it may be possible to deploy such a system with minimum delays for regulatory clearances. Final waste form may be dictated by national or local requirements. Waste will require movement in accordance with national and local regulations.

TABLE I–1. TECHNOLOGY OVERVIEW (cont.)

Consideration	Description or value(s)
Cost: contractual arrangements (leased/procured); periodic (monthly/annual/campaign/volume) installation; consumables; staff; equipment removal and disposal; shipping; final waste disposition	— Supercompaction systems are expensive. — It is essential to evaluate a lease versus purchase option. — Consider sharing with other users to reduce the financial burden. — Equipment is large and heavy, resulting in high mobilization/demobilization and transport costs.
Impact on fire protection and fire loading	— General use does not pose unique fire protection risks. However, it is necessary for fire protection to be made available. — Equipment and transient combustible loading should be considered. — Compression of unknown waste content may result in exothermic reactions.
New media	
Quantity or volume per year	Air filtration media differential pressure rate of increase is dependent on the waste and the behaviour of the drum during compaction. The design of the equipment reduces the airborne activity. A filter bank of two standard filters (prefilter and HEPA) should last for 2–3 months operation. Waste stream specific performance is to be monitored to determine replacement rate.
Storage space	Typically 2 m^3 space for storage of filter media.
New waste containers	
Quantity or volume per year	Varies by waste volume, and includes drums and overpacks.
Storage space	Varies: 1000 m^3 should be adequate for most applications assuming short procurement lead time for new containers.
Other consumables	
Quantity or volume per year	— Hydraulic oil has to be collected and treated in accordance with site requirements. — Spacers and hold down discs may be required for some types of compactors.
Storage space	Minimal.
Process related waste collection, staging and storage (per year): consider full and in-service containers	
Quantity or volume per year	Solid LLW volumes to be treated by supercompaction vary according to site. Storage or staging areas may be required for the waste to be treated and the post-treatment waste pucks/overpacks. LLW arisings include, for example, water from the compacted mass, decontamination solutions, personnel decontamination or cleaning.
Storage space	— Varies by site, depending on volume to treat and reduction factor achieved by the process. — Liquid waste will require collection and storage in drums or tanks prior to treatment.
Integrated, final system information	
Mobile or skid mounted	Both versions are available.
Total dimensions	Typical mobile system requires 20 m × 16 m with a working perimeter of 5 m.

TABLE I–1. TECHNOLOGY OVERVIEW (cont.)

Consideration	Description or value(s)
Total volume	Typically a trailer mounted system is 4.5 m high, 11.3 m long and 2.5 m wide; compactor: ~2 m × 2 m base area.
Total weight	Weight of the compactor unit is ~35–60 t, and with trailer and accessories, it can be 55–80 t.

Note: HEPA — high efficiency particulate air; LLW — low level waste.

TABLE I–2. SYSTEM COMPONENTS

Individual subsystems and components	Technical details (features, parameters, values)	Comments
Piping	— 50 NB seamless hydraulic line; — Pressure rating: 60 MPa; — Length: ~50 m.	Typical values are shown.
Valves	— Valving included in hydraulic power pack; — Includes control, pressure regulating and relief valves.	None.
Controls	— Controls for compactor operation and for other associated systems (e.g. exhaust ventilation, nuclear instrumentation displays, alarms); — Control of material handling systems included.	Computer based data acquisition system provided. PLC controls available with manual override provision. Safety systems are included. Local operation of material handling system from pendant push button station.
Vessels (filter, ion exchange)	None.	None.
Pumps	— Positive displacement hydraulic oil pumps: 40 MPa; — Centrifugal LLW transfer pump: discharge pressure = 0.3 MPa. — 25 NB line.	— Included in the mobile system; — Temporary connections to be made to site tank.
Hoses	High pressure hoses for hydraulic systems.	Supplied as a part of the hydraulic system.
Tanks (feed and collection, output and effluent, chemical, mixing)	1 m^3 stainless steel effluent collection.	Liquid from mobile system collection tank is transferred to site drums or waste tank. Mobile system liquid collection line can also be directly connected to site systems.
Ventilation ducting	Filter frame with 600 mm × 600 mm prefilter/ HEPA filters.	Part of the mobile system.
Other	None.	None.

Note: User should modify table as required for multiple components. NB — nominal bore; PLC — programmable logic controller; LLW — low level waste; HEPA — high efficiency particulate air.

TABLE I–3. HARDWARE INTERFACES

Service	Type	Technical details (features, parameters, values)	Comments
Electrical	Electrical feed.	480 V AC, 300 A, three phase; 110 V AC, 20 A, single phase.	— Power for compactor and controls of hydraulic system and mobile system operation. — Complete power pack comes with the mobile system. Only power connections to be made on-site. — Power requirement is based on the tonnage.
Water	Service water.	— Used for cleanup; — Up to 1000 L/d; — 0.2–0.3 MPa.	Water for decontamination of compaction chamber and equipment, as required.
Air	Service air.	Oil and water free.	None.
Liquid feed line(s) to process	None.	None.	None.
Liquid return line(s) to disposition	None.	None.	None.
Liquid drains	Water from compaction and decontamination drain.	Gravity flow using 25–40 NB piping.	Small quantity.
Processed waste (e.g. compacted waste pancake pucks) transfer to waste container	Hoists and forklifts for movement of pucks and container.	— 2 t capacity forklift; — Typical weight of pucks: 200–250 kg.	Grippers for puck handling are available.
Secondary waste transfer and movement to secondary process or waste container, gaseous effluent collection, routing and monitoring	— Liquid waste; — Solid wastes such as mops.	— 1 m^3 gravity drain effluent tank; — 200 L drums.	— To be connected to the site liquid waste tank; — Fewer than one drum per month.
Ventilation (heat, air capture, air-conditioning)	Air-conditioned control area.	Typically 1 t wall mounted air-conditioning system, depends on room size.	Heating may be required for some locations.
Gaseous effluent collection, routing and monitoring radiation monitoring (dose rate, personnel, air)	Exhaust ventilation of compaction chamber.	Directional flow fan/filter system: — 50 mm water negative pressure in the chamber; — Ten air volume turnovers per hour. Prefilter/HEPA filter combination prior to local exhaust or exhaust to site system.	— Chamber ventilation needs to be reviewed for each application. — Designs with relay based controls are available. — If mist is expected, the mist eliminator is to be added prior to the filter.
Communication (phone, Internet, data capture, controls)	Control and communication.	— Programmable compaction process for progressive compaction of varying waste types; — Telephone in control room.	Interface with plant controls can be accomplished if required.

TABLE I–3. HARDWARE INTERFACES (cont.)

Service	Type	Technical details (features, parameters, values)	Comments
Radiation monitoring (dose rate, personnel, air)	— Area gamma monitor; — Continuous air monitor; — TLD.	— Area gamma monitor up to 0.01 Sv/h; — TLD for monitoring personnel exposure.	Routine surveillance by radiation protection staff and support for maintenance and decontamination activities.
Outside system and service requirements for support equipment and systems (power, blending equipment, air capture)	None.	None.	None.
Fire protection	Fixed firefighting equipment for hydraulic oil fire.	Local fire extinguishers and CO_2 gas types.	To be provided by the site.
Other miscellaneous items	None.	None.	None.

Note: NB — nominal bore; HEPA — high efficiency particulate air; TLD — thermoluminescent dosimeter.

TABLE I–4. SPACE CONSIDERATIONS

Consideration	Technical details (features, parameters, values)	Comments
Operation	Minimum 3 m working clearance around the mobile system.	— Movement around the drum and puck handling system; — Operation of the compactor is generally from the control station in the mobile system.
Media replacement	— Movement around the filter bank; — Filter handling with a hoist.	Dedicated platforms are provided for handling of contaminated filters, including packaging for transport to waste area or container.
Maintenance	— Routine preventative and corrective maintenance; — Hydraulic oil and filter changes.	— Routine maintenance is covered in the above clearance; — Major maintenance will not be at the site.
Component replacement	None.	None.
Waste movement	5 m perimeter around the compactor.	Space for movement of the forklift is included in the area indicated for the system.
Power cable, water line, service or instrument air line routing and clearances	Power cable, drain line and ventilation duct routing are to be considered relative to movement of material and personnel.	None.
Barriers (personnel, security, liquid, contamination control)	Barriers to prevent unauthorized personnel entering the work site.	None.
Radiation protection monitoring stations or equipment	No specific space requirements.	None.

TABLE I–5. WEIGHT DISTRIBUTION

Consideration	Technical details (features, parameters, values)	Comments
Process system (skid or integrated components)	16 m × 5 m concrete compactor support platform. Floor loading: — General = 2000 kg/m^2; — Compactor base = 15 000 kg/m^2.	None.
Off standard weight increase	None.	None.
Access controls (doors, gates, fencing and walls)	None.	None.
Shielding	None.	Shielding may be required for higher activity wastes.
Pre and postprocessing collective waste weight (waste and containers)	150–200 kg per drum.	None.
Equipment lay down area	20 m × 16 m.	5 m perimeter.

TABLE I–6. PHYSICAL CONTROLS

Consideration	Technical details (features, parameters, values)	Comments
Access controls		
Doors or gates	None	None
Fencing or walls	None	None
Barriers to control liquid and loose contamination		
Berm/bunds, curbs or wall	Local barrier around the system	— Barriers for radiological and industrial safety considerations — Some sites may require berms to contain contamination or liquid

TABLE I–7. WASTE AND MATERIAL MOVEMENT

Operation	Equipment (type, access requirements, capacity)	Load and unload space	Load and unload height
Equipment delivery	— Main equipment is trailer mounted — Accessories in two top load trucks	— Trailer space — 50 m^2 storage area	— Truck platform is 2 m high — Maximum equipment height is typically 2.5 m
Equipment set-up	— Top load trailer — 10 t capacity field crane	3 m wide access drive way required	Installation and set-up on concrete platform at ground level
Routine process system operation	Forklift, 2 t capacity, for side access	Turning radius of equipment	Lifting height of equipment
Equipment lay down area required for assembly and installation	20 m × 16 m	20 m × 10 m area	None
Waste delivery to and removal from site (transport cask and individual components such as covers or lids)	Waste drum movement by forklift	Dependent on forklift, container and packaging requirements	Dependent on forklift, container and packaging requirements
Special road permits or notification requirements for national and local agencies (overwidth, overweight and oversize)	— In accordance with national and local regulations — Transport weight and size are to be carefully considered — No challenges expected for this equipment		
Transport security considerations (describe)	No special security measures are normally required		

Note: User should modify table multiple components as required.

Annex II

EXAMPLE OF MOBILE PROCESSING SYSTEM DETAILS: FILTRATION AND ION EXCHANGE

Tables II–1 to II–7 illustrate the types of information that are gathered during the applicability determination process which can be used as part of the screening process and for the development of technical specifications for the filtration and ion exchange system.

TABLE II–1. TECHNOLOGY OVERVIEW

Consideration	Description or value(s)
Throughput, capacity, decontamination factor and volume reduction	— Throughput is determined by process volume and bed volume requirements. — Typically 10–20 bed volumes per hour.
Incoming waste characteristics (activity, form)	— The technology is applicable for a wide range of volumes of aqueous waste. — Low to high concentrations of chemical impurities. — Typical conductivity 50 –500 µS/cm, but higher values are possible for special ion exchange media. — Activity up to several hundred MBq/L, with a high proportion of ^{134}Cs and ^{137}Cs. — Liquid waste transferable by pumps to the mobile unit.
Final waste characteristics (activity, form, chemistry)	Clean process aqueous liquid that requires monitored disposition, either directly or after further treatment: — Very low activity; — pH6–9.
Final waste form acceptance criteria and limitations for waste disposal or storage	— Varies by location and intended disposition; — Spent ion exchange and filtration media may require conditioning to meet criteria for disposal.
Secondary waste characteristics generated by the process (activity, form, chemistry)	— Cartridge filter cylindrical media: varying sizes (typically not larger than 150 mm diameter × 760 mm long). — Ion exchange media in bead and powder form in a water slurry. — Ion exchange media can be very low to high in dose rate (0.1–150 mSv/h). — Cation media is typically higher activity than anion resin (the same is true for some isotope selective media). — Volumes of all waste will vary as a result of influent water chemical impurities and activity levels, system configuration, media type and desired effluent quality.
Requirements for outside support (equipment or resources)	— Not normally required (nuclear facility common capability); — Secondary solid waste requires conditioning and packaging in a suitable final waste form; — Replacement media, waste containers and transportation are required.
Staffing (operating times, number, contracted staff, qualifications to operate technology, operations, security, maintenance)	— Varies by process volume, rate and application specific requirements; — Three operators can work on the system for 8 h shifts if time or volumes dictate that need.
Industrial and radiological safety (barriers, respiratory protection, personnel exposure monitoring, contamination controls, air monitoring)	— Radiation barriers required around plant interface equipment. — Loose contamination must not be present. — No airborne activity is typically present. — Shielding is typically required around the filter and ion exchange vessels. — Sky shine is also to be analysed for the specific application.

TABLE II–1. TECHNOLOGY OVERVIEW (cont.)

Consideration	Description or value(s)
Regulatory and legal considerations (national, local, international, licensing, operation, waste movement and transport)	National and site design requirements and quality assurance controls need to be considered for equipment fabrication. In accordance with national and local regulations, variations may be significant for liquids and secondary wastes. Regulations may impose limits or restrictions on system effluent water: — Activity; — Chemical impurities; — Rate of release; — Release period (when can liquid be released); — Ban on release. Secondary waste transport may include requirements related to: — Activity; — Package type; — Shielded cask use (licensed with 450–600 mm of steel and lead); — Transportation type (typically truck); — Contact and general area dose rates.
Cost: contractual arrangements (leased/procured); periodic (monthly/annual/campaign/volume) installation; consumables; staff; equipment removal and disposal; shipping; final waste disposition	Leased (typically flat monthly fee or a fee based on the liquid volume processed) or procured. Systems can cost US $50 000–500 000. Cost is dependent on system complexity: — Number of vessels; — Types of media; — Process rate requirements; — Materials of construction; — Level of automation; — Shielding requirements; — Skid versus stand-alone installation (individual components placed on existing floor). Furthermore: — Low cost compared with fixed installation; — Can be leased or operated on periodic campaigns based on treatment volume; — Trained and qualified staff are required; — Specialized skills or knowledge are generally not required; — Technical, chemistry and radiological support is required; — Easy to clean, dismantle and remove; — Transportable on trailers and trucks. Replacement media costs will vary according to system design, influent liquid characteristics, effluent liquid requirements and secondary waste pretreatment, treatment, conditioning, transport and disposition requirements.
Impact on fire protection and fire loading	New media may require fire loading analysis (particularly for resin).
New media	
Quantity or volume per year	— Varies from 1 to 30 filter elements; — Resin volume can be in the range of 1–3 m^3; — Volumes are highly dependent on influent chemistry and activity and effluent requirements.
Storage space	28 m^3 maximum (3 m × 3 m floor area).

TABLE II–1. TECHNOLOGY OVERVIEW (cont.)

Consideration	Description or value(s)
New waste containers	
Quantity or volume per year	— Dependent on media use; — Dependent on final waste form requirements; — Up to 20 drums (200 L per drum).
Storage space	28 m^3 maximum (3 m × 3 m floor area).
Other consumables	
Quantity or volume per year	Spare parts.
Storage space	Minimal.
Process related waste collection, staging and storage (per year): consider full and in-service containers	
Quantity or volume per year	Same as new waste containers.
Storage space	60 m^3 maximum (to account for shielding and lifting device access).
Integrated, final system information	
Mobile or skid mounted	Typically on floor versus on skid.
Total dimensions	28 m^2.
Total volume	90 m^3.
Total weight	Up to 4500 kg (depending on size and number of vessels and shielding requirements).

TABLE II–2. SYSTEM COMPONENTS

Individual subsystems and components	Technical details (features, parameters, values)	Comments
Piping	Pressure: 1.0 MPa.	Typical.
Valves	Pressure: 1.0 MPa.	Typical.
Controls	Power and air requirements vary according to control type and application.	None.
Vessels (filter, ion exchange)	— Pressure: 1.0 MPa. — Flow: 114 L/min.	Varies from much lower to much higher values.
Pumps	— Pressure: 1.0 MPA. — Flow: 114 L/min.	Varies from much lower to much higher values.
Hoses	— Pressure: 1.0 MPa. — UV and oil resistant.	— Varies from much lower to much higher values; — No value for resistance factors.

TABLE II–2. SYSTEM COMPONENTS (cont.)

Individual subsystems and components	Technical details (features, parameters, values)	Comments
Tanks (feed/collection, output/effluent, chemical, mixing)	Volume: 0.010–227 m^3.	Larger tanks are typically at the processing site included in that facility's equipment. Small process applications and chemical feed tanks are typically smaller volume tanks.
Ventilation ducting	None.	None.
Other	None.	None.

Note: User should modify table as required for multiple components.

TABLE II–3. HARDWARE INTERFACES

Service	Type	Technical details (features, parameters, values)	Comments
Electrical	Power	— 220 V AC — 200 A — 3 phase — 60 Hz	Pumps and controllers
Water	Demineralized	1.0 MPa	Flush and sluice media
Air	Oil and water free	1.7 m^3/min	Sluice media and blowdown filter housings
Liquid feed line(s) to process	Influent water	— 1.0 MPa — 114 L/min	None
Liquid return line(s) to disposition	Effluent water	— 100 KPa — 114 L/min	None
Liquid drains	Leak collection, vessel draining	One or a berm/bund	Atmospheric
Processed waste (e.g. compacted waste pancake) transfer to waste container	None	None	Effluent water line to disposition point (same as above)
Secondary waste transfer/movement to secondary process or waste container	Spent ion exchange media sluice	— 1.0 MPa — 65 mm	Minimum diameter required for successful transfer of ion exchange slurry
Ventilation (heat, air capture, air-conditioning)	None	None	— None typically required — Dependent on local environment and regulations
Gaseous effluent collection, routing and monitoring	None	None	— None typically required — Dependent on local environment and regulations
Communication (phone, Internet, data capture, controls)	Phone	One or more	Connection to facility

TABLE II–3. HARDWARE INTERFACES (cont.)

Service	Type	Technical details (features, parameters, values)	Comments
Radiation monitoring (dose rate, personnel, air)	— Gamma — Beta	— One or more — One or more	— To monitor activity buildup on media — To monitor personnel and area contamination
Chemistry monitoring	None	None	— Inlet and outlet conductivity, pH, composition of the solution
Outside system and service requirements for support equipment and systems (power, blending equipment, air capture)	None	None	— None normally required — May require power for removing residual water from depleted media or for secondary waste form processing — Refer to encapsulation and solidification, in Section 5, for details
Fire protection	None	None	— Not normally required — Dependent on national and local requirements
Other miscellaneous items	None	None	Availability of site laboratory

TABLE II–4. SPACE CONSIDERATIONS

Consideration	Technical details (features, parameters, values)	Comments
Operation	2 m	Each side to support monitoring
Media replacement	2 m	Each side to support replacement
Maintenance	2 m	None
Component replacement	2 m	None
Waste movement	3 m	None
Power cable, water line, service or instrument air line routing and clearances	Minimal, bundled or cable tray use is desirable	None
Barriers (personnel, security, liquid, contamination control)	To outline boundaries based on dose rates and application specific limits	None
Radiation protection monitoring stations or equipment	4 m^2	Personnel monitoring area

TABLE II–5. WEIGHT DISTRIBUTION

Consideration	Technical details (features, parameters, values)	Comments
Process system (skid or integrated components)	680 kg/m^2	None
Off-standard weight increase	Varies	Forklift to move waste containers or new media
Access controls (doors, gates, fencing, walls)	None	Negligible
Shielding (permanent, additional off-standard)	1360 kg /m^2	Additional shielding as necessary
Pre and postprocessing collective waste weight (waste and containers)	200 kg/m^2	None
Equipment lay down area	None	Varies

TABLE II–6. PHYSICAL CONTROLS

Consideration	Technical details (features, parameters, values)	Comments
Access controls	None	None
Doors or gates	One	Access control gate
Fencing or walls	One to four	To completely control access to process equipment
Barriers to control liquid and loose contamination	None	None
Berm/bunds, curbs or wall	One to four	To completely contain any spillage, leakage or drained liquids

TABLE II–7. WASTE AND MATERIAL MOVEMENT

Operation	Equipment (type, access requirements, capacity)	Load/unload space	Load/unload height
Equipment delivery	End or side truck preferred.	100–350 m^2.	10 m (if crane employed).
Equipment set-up	5–10 t capacity forklift or crane.	37 m^2.	7 m (more if crane employed).
Routine process system operation	1 t capacity forklift or pallet jack.	Turning radius of equipment.	Lifting height of equipment.
Equipment lay down area required for assembly and installation	None.	37 m^2.	7 m (more if crane employed).
Waste delivery to and removal from site (transportation cask and individual components such as covers or lids)	— Forklift or crane; — Capacity varies by national and local regulations and waste container type.	Dependent on truck type, container, cask and packaging requirements.	10 m (if crane employed).
Special road permits or notification requirements for national and local agencies (overwidth, overweight, oversize)	— In accordance with national and local regulations; — High activity wastes may require overweight permit; — Typically not oversize or width.		
Transport security considerations	This waste is typically low activity. Additional security measures may be required for specific types of wastes or concentrations of specific isotopes within the waste being shipped. Varies by national and local regulations.		

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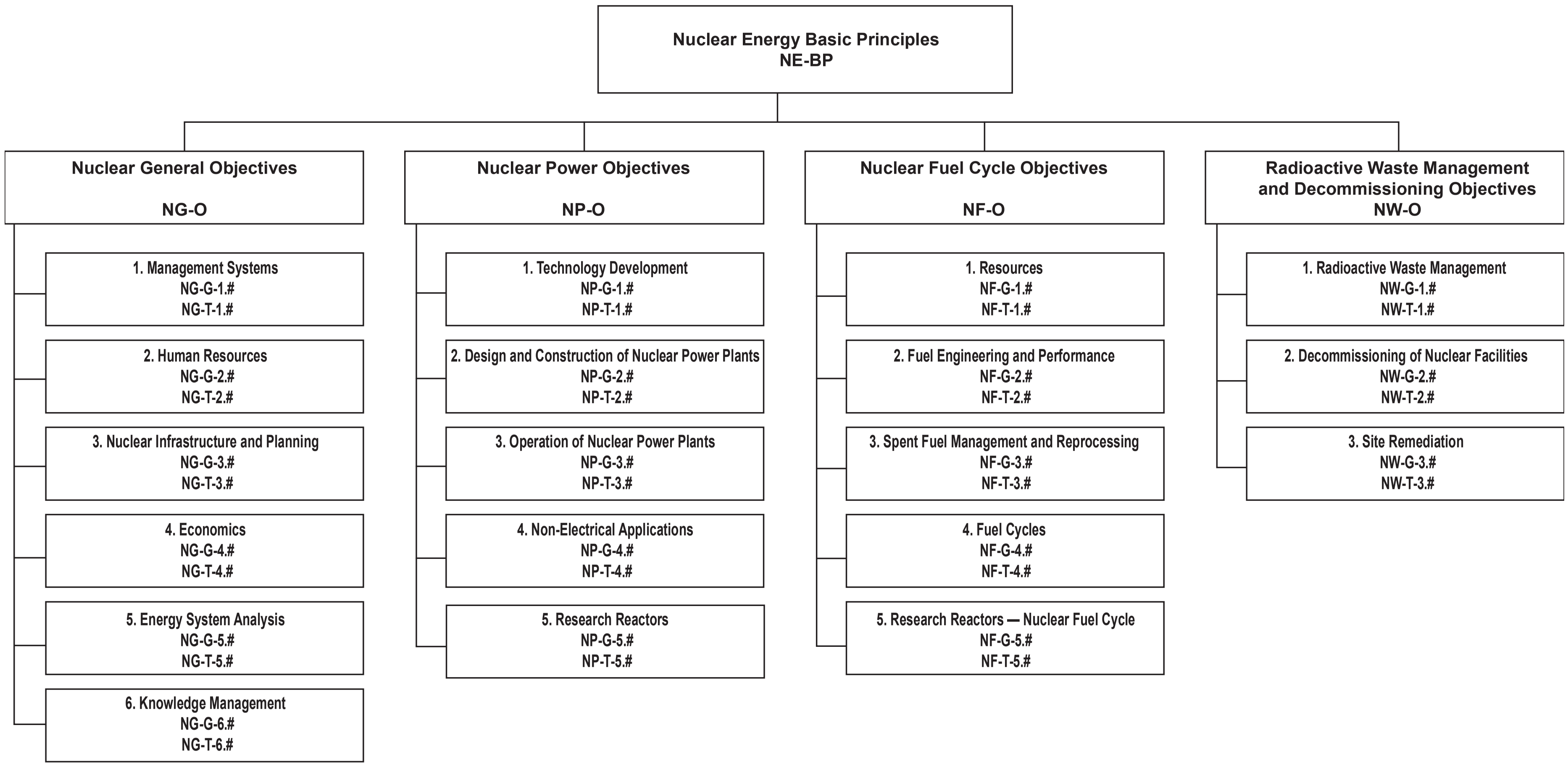

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