United Kingdom Nirex Limited

WASTE PACKAGE SPECIFICATION AND GUIDANCE DOCUMENTATION

WPS/905: Guidance Note on the Packaging of Filters

June 2006
Number: 510774

nirex

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Conditions of Publication

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WASTE PACKAGE SPECIFICATION AND GUIDANCE DOCUMENTATION

GUIDANCE NOTE ON THE PACKAGING OF FILTERS

This document forms part of a suite of documents prepared and issued by Nirex to assist waste packagers condition and package Intermediate Level and certain Low Level radioactive wastes.

The Waste Package Specification and Guidance Documentation (WPSGD) is based on, and is compatible with the Generic Waste Package Specification (GWPS) and therefore provides specification and guidance on waste packages that meet the transport and disposability requirements derived for the Nirex Phased Geological Repository Concept.

The WPSGD is intended to provide a 'user-level' interpretation of the GWPS to assist waste packagers in the early development of plans and strategies for the management of radioactive wastes. Waste packagers are advised to contact Nirex at an early stage to seek detailed assessment of specific packaging proposals.

The WPSGD will be subject to periodic revision and waste packagers are advised to contact Nirex to confirm that they are in possession of the latest version of documentation.

This document has been compiled on the basis of information obtained by Nirex. The document was verified in accordance with arrangements established by Nirex that meet the requirements of ISO 9001. The document has been fully verified and approved for publication by Nirex.

CONTENTS

1 INTRODUCTION

Nirex was established in 1982 with an objective of assisting producers of intermediate level (ILW) and long-lived low level radioactive waste (LLW) to package those wastes in a form compatible with disposal in an underground repository.

Nirex has fulfilled this objective by developing a long-term management concept, the Phased Geological Repository Concept (PGRC) [1], and by developing standards and specifications for the packaging of waste based on this concept. This is important because radioactive wastes in unconditioned form can pose a significant hazard to people and the environment and Nirex packaging standards have been designed to improve the safety and long-term behaviour of the wastes.

The mission of Nirex was strengthened in 2004 and agreed with Government as follows:

> *'In support of Government policy, develop and advise on safe, environmentally sound and publicly acceptable options for the long-term management of radioactive materials in the UK.'*

Four objectives have been set to determine the scope and manner of implementation of this mission and one of these requires that Nirex set standards and specifications for the packaging of waste, and advise waste packagers on how to treat and package radioactive waste in accordance with those standards and specifications, through the Letter of Compliance (LoC) process[1].

In order to facilitate the safe and efficient packaging, transport and disposal of waste, Nirex has defined packaging standards and specifications based on the requirements of the PGRC, involving transport of waste to a phased geological repository, monitored and retrievable underground storage with the option to seal and close the repository in the long term.

The PGRC is underpinned by a suite of documents, including the Generic Waste Package Specification (GWPS) [2]. The GWPS defines and describes the packaging standards and specifications that have been derived from the PGRC and is used in the UK as the basis for the packaging of ILW and certain LLW.

The GWPS is the primary document defining Nirex packaging standards and specifications and is supported by the Waste Package Specification and Guidance Documentation (WPSGD). The WPSGD comprises a suite of documentation primarily aimed at waste packagers, its intention being to present the generic packaging standards and specifications at the user level, together with explanatory material and guidance that users will find helpful when it comes to application of the specification to practical packaging projects. For further information on the extent and the role of the WPSGD, reference should be made to the *Introduction to the Nirex Waste Package Specification and Guidance Documentation, WPS/100*[2].

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1 Formerly known as the Letter of Comfort process.

2 Specific references to individual sections of the WPSGD are made in this document in *italic script*, followed by the relevant WPS number.

The diverse physical, chemical and radiological nature of ILW and LLW in the UK means that particular challenges arise in the packaging of certain wastes. To assist waste packagers with the preparation of proposals for the packaging of such challenging wastes, Nirex has produced, and continues to add to, a suite of thematic Guidance Notes. A full list of the Guidance Notes produced by Nirex, together with an abstract of each, can be found in *Introduction to Nirex Waste Packaging Guidance Notes, WPS/900*.

Filters are used extensively in the treatment of liquid and gaseous effluents in all parts of the nuclear industry. At the end of their service life, when it comes to conditioning filters for long-term management, they present a particular challenge for waste packagers insofar as they may:

- constitute a potentially significant source of activity in loose particulate form;
- be difficult to infiltrate using standard techniques and encapsulants;
- incorporate significant voidage in their design, and;
- incorporate materials and features that evolve in such a way as to weaken the performance of the final waste package.

This document provides guidance relating to the conditioning and packaging of filters and presents a methodology that can be used to determine the treatment and packaging routes for filters that are most likely to minimise the uncertainty associated with a package, and therefore result in the production of packages that meet the requirements of the GWPS. The document should be read in conjunction with the GWPS [2] and the sections of the WPSGD appropriate to the particular waste package being considered.

2 BACKGROUND

2.1 Organisation and Aims of this Document

The principle aims of this document are:

- to identify the particular characteristics of filters that could lead to requirements of the GWPS being challenged if they were not sufficiently addressed by the conditioning process;
- to provide guidance as to which specific conditioning or treatment options can be utilised to help ensure the compliance of packaged filters with the GWPS.

This section provides a definition of filters and of the approaches to packaging that are considered in this document.

Section 3 details the characteristics of filters that will govern the selection of the appropriate treatment and packaging route for different filter types.

Section 4 identifies the key areas where the required performance of a waste package is challenged by the presence of filters in their conditioned form and which would require re-evaluation to determine their effect on the performance of the waste management system.

Section 5 identifies design characteristics that can be incorporated into new or future filters that can provide an improvement in the ability to successfully package and dispose of these wastes.

Appendix A contains information on the types of filters typically used in the UK nuclear industry.

2.2 The Nirex PGRC and Letter of Compliance Assessment Process

The PGRC [1] has been developed by Nirex as a viable option for the long-term management of ILW and certain categories of LLW in the UK and, as such, forms the basis for Nirex waste packaging standards and specifications which form the GWPS [2]. The PGRC envisages that, following a period of interim surface storage at the site of arising, packaged wastes would be transported to a national repository constructed in stable geology deep underground to provide long-term isolation of the radioactivity in the wastes in order to protect human health and the accessible environment. The PGRC allows for the facility to be operated in a phased approach with the ultimate aim of sealing and closure. Each phase would be reversible and time would be available to build confidence at each stage before moving to the next.

The safety philosophy adopted in the PGRC is one of containment of radionuclides by multiple barriers of which the containment provided by the waste package is a key component. The waste package can be considered as two independent but complimentary barriers, the waste container and the wasteform, each of which plays an important role in containment. In consequence of this the GWPS sets performance requirements for both of these components against which the overall performance of the waste package is judged as part of the LoC assessment process.

The Nirex LoC assessment process[3], has been developed as a means of assessing the disposability of packaged wastes, by assessment against safety and environmental assessments that underpin the PGRC. In undertaking LoC assessments Nirex determines whether wastes when packaged will have characteristics compliant with plans for transport to, and operations at the repository site, and ultimately whether the wastes could be accommodated within the repository long-term post-closure safety case. As described in regulatory guidance [3] this assessment of disposability is required to provide a component of overall safety case for the operators packaging plant and the waste packages that will ultimately be produced.

The Nirex assessment of a packaging proposal for any waste, by way of the LoC assessment process will consider the performance of the final waste packages against the requirements defined by the GWPS. Upon completion of an assessment of a packaging proposal, Nirex will provide an Assessment Report relating to the further progression of the proposed packaging route, which may be accompanied by the issue of a LoC endorsing the packaging proposal.

The Assessment Report may recommend prior treatment of the waste to deal with specific concerns and particular uncertainties and risks arising from the chosen packaging method(s) will be highlighted in the Assessment Report, as Action Points. Subsequent to the issue of an Assessment Report, Nirex will continue to monitor progress with the resolution of such issues.

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3 See *Guide to Nirex Letter of Compliance Process, WPS/650* for an explanation of this process.

The widely varied physical and chemical form of UK ILW/LLW is such that a single waste conditioning process would not always result in waste packages compliant with the GWPS and compatible with the PGRC and, in some cases, special packaging strategies and/or processes will have to be devised for wastes which present particular challenges. Whichever packaging approach is adopted waste packagers are required to provide a robust technical case, as part of a LoC submission, that waste packages produced as a result of that approach are consistent with the requirements of the GWPS. This document identifies those properties of filters, and of wasteforms[4] incorporating filters, that may influence the performance of the waste package.

2.3 Definition of Filtration and Filters

Filtration involves the mechanical separation of a fluid from any particles entrained in it. Filters effect filtration, and a range of filter types and filtration mechanisms are used throughout the nuclear industry in a variety of settings and for a variety of purposes.

The use of filters is widespread throughout the UK nuclear industry, Appendix A identifies those in most wide use and provides some basic information on each. The two most common types are cartridge filters and High Efficiency Particulate in Air (HEPA) filters and within these two a wide range of designs and material are used. These typically include mild and stainless steels, glass fibre, neoprene, silicone, polyurethane, paper, wood, charcoal and ceramics. Appendix A contains some general information on the type of filters used in the nuclear industry, their designs and materials of construction.

The range of radionuclides associated with filters is also wide, depending on the nature of the plant in which they have been employed. These will include fission and activation products, isotopes of plutonium and uranium, and tritium in the form of tritated compounds.

Other methods for the removal of particulates from liquids and/or gases include devices such as ion exchange columns, which trap particles adventitiously rather than by design, and separation technologies such as cyclones and precipitators, which do not use filtration. These categories of device are not the subject of this guidance.

3 GUIDANCE ON THE PACKAGING OF FILTERS

The purpose of the ensuing section is to outline what methods are available to ensure effective conditioning of filters and to allow the most suitable means of packaging for any particular design of filter to be identified.

3.1 Characterisation of Filters and Identification of Means of Conditioning

The nature and properties of some filters are such that they present a challenge to the achievement of waste package performance that is compatible with the requirements of the GWPS, and therefore with those for long-term waste management as defined by the PGRC.

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4 A wasteform being defined as the waste, together with any conditioning medium and container furniture, but not including the waste container or any inactive capping material.

Standard industry practice is to condition ILW either by intimate encapsulation or, when appropriate, by supercompaction and grouting. Waste conditioning in such a manner provides isolation and containment of the waste and its potentially hazardous constituents. Furthermore, the response of the waste to normal and accident conditions is thereby modified so that the required isolation and containment will be maintained at all stages of long-term waste management.

Although the GWPS does not explicitly require the conditioning of wastes by intimate encapsulation, the guidance provided by Nirex places strong emphasis on such conditioning as a means of providing the performance required of the packaged waste. However, it is also recognised that some wastes packaged in standard containers using different means of conditioning may also meet the performance requirements of the GWPS.

Because of their function, when taken out of service and presented for packaging, filters are likely to hold a significant source term of particulate activity. Waste packagers wishing to package filters will need to demonstrate that any such particulate burden is isolated and immobilised to prevent unacceptable release under normal and accident conditions. Many filters include isolated or intricate areas in which the bulk of particulates are held, and any such regions may not be expected to be infiltrated by the standard range of cementitious encapsulants. Any such un-infiltrated area may represent a source of releasable radioactivity, as well as being a potential focus for more rapid or unpredictable package evolution such as increased rates of corrosion, formation of microenvironments in which microbial activity is concentrated, or the build up of flammable, toxic or radioactive gases.

Many designs of filter in use within the UK nuclear industry incorporate materials that have the potential to evolve in such a way as to threaten the long-term performance of the wasteform, and therefore the waste package performance. These include a range of organic materials, notably cellulosic materials, and reactive metals such as aluminium. Waste packages are required to be stable and to provide isolation and containment of their radionuclide burden for periods coincident with their management, so any unpredictability or uncertainty relating to their evolution is regarded as undesirable.

The following general approaches to the packaging of filters have been identified:

- **Compaction:** volume reduction and consolidation of the filter by force (i.e. supercompaction) followed by encapsulation;
- **In situ conditioning:** intimate infiltration of the filter and immobilisation of the particulate source term by the use of a suitable conditioning agent, followed by encapsulation;
- **Grout-enclosing:** direct encapsulation of the filter by placement of the intact filter in a waste container and the addition of a cementitious grout or polymer encapsulant that will surround, but not necessarily infiltrate, the filter;
- **Destruction:** processing or dismantling of the filter followed by the encapsulation of its components by appropriate means. The components could include liquors arising from chemical dissolution.

Whichever packaging method is used, the resulting waste package will be required to conform with the GWPS in that its performance must be consistent with that required of all waste packages subject to the long-term management regime defined by the PGRC.

3.2 Properties of Packaged Filters

A waste package comprises two independent barriers, the container and the wasteform which together provide physical containment, the first of several safety barriers within the PGRC as a whole. The wasteform is the primary means by which the raw waste is made passively safe and is therefore an essential component of the waste package. Effective immobilisation of radionuclides, which will exist in a variety of physical and chemical forms, is therefore a fundamental requirement for the wasteform. The design and performance of the wasteform has a significant influence on the performance of the waste package as a whole under normal and accident conditions.

Specifically, the wasteform specification of the GWPS requires that:

'During the production of the wasteform and the interim surface storage of the waste package, all reasonable measures shall be taken to ensure that:

- *radionuclides in the waste are immobilised;*
- *loose particulate material is minimised;*
- *free liquids are excluded;*
- *hazardous materials are excluded or made safe;*
- *toxic materials are minimised;*
- *any gases generated do not result in pressurisation of the wasteform; and*
- *the presence and volume of voids (e.g. ullage space) is minimised.*

The measures taken to achieve these objectives should include an anticipation of the effects of ageing on the performance of the wasteform.'

The principle functions of the wasteform are therefore to contain radionuclides and to render hazardous materials passively safe. These criteria, as they relate to the properties of the wasteform, have been reviewed for this document and, where appropriate, issues specifically affected by the presence of filters have been identified.

Guidance is presented for each criterion and identifies the characteristics of filters that are likely to determine the most appropriate packaging route for any given filter to yield a product that is compliant with the requirements of the GWPS. In addition, undesirable waste characteristics are identified together with suggested means of treatment to render them compliant with the relevant criteria, or at least of minimising the risk that they will be non-compliant.

The key points in the decision process can be summarised as:

- Can the activity be fixed by either in situ conditioning or compaction? This approach may not offer a significant improvement in product performance if the source term is low, or because it is not technically feasible. The beneficial volume reduction afforded by compaction should be noted;
- Grout-enclosing may be appropriate (again, noting the beneficial volume reduction afforded by the compaction option), particularly where the particulate source term is low;
- It may be possible and beneficial to reduce the activity associated with the filter, for example by back flushing, thus making one or more of the options feasible;

- It may be deemed most appropriate to 'destroy' a filter by dismantling or other mechanical processes, although compaction and in situ conditioning are likely to be the most attractive options. Some forms of pre-processing of filters that are consistent with the definition of destruction used in this document may increase the suitability of the filters for either compaction or infiltration. It should be noted that component parts of the dismantled filter may be subject to the same decision process as whole filters and that all operations should be consistent with the requirement to ensure that operator dose uptake is ALARP.

It is considered that the most beneficial treatment of filters will be achieved through fixing the radioactivity by the application of compaction or in situ conditioning. Compaction affords significant benefits in terms of volume reduction and consolidation of the waste and, when the resulting pucks are subsequently encapsulated will ensure the immobilisation of particulate radioactivity. In situ conditioning with a suitable agent will ensure that radioactivity is immobilised and voidage minimised. Where these options are not deemed appropriate because of the properties of a given filter, encapsulation without infiltration, grout-enclosing, may meet requirements of the GWPS. Such an approach may however require additional treatment of the filter.

Destruction of the filter, including partial or complete dismantling, is likely to be the least favourable of the options in many cases because of the potential for associated increased dose uptake, complexity and cost, and therefore to be pursued only where no other option is practicable. This will need to be judged by waste packagers on a case-by-case basis.

Filters may arise as a separate waste stream or as a part of a larger, mixed waste stream. In either case the requirements for packaging will be the same, insofar as it will need to be demonstrated that the filter and its particulate burden, and all other components of the wasteform, are packaged in a way that is compatible with the requirements of the GWPS. The guidance provided in this document is therefore relevant to the packaging of filters regardless of whether they are segregated or part of a larger waste stream. It should be noted that co-packaging of filters with other wastes may give rise to a range of waste-waste interactions that may result in deleterious evolution of the filters or other components of the wasteform or waste package. The evolution of filters is considered in Section 4.2. Proposals that involve the co-packaging of filters with other wastes will need to address the effect of all of the waste materials on the performance of the wasteform and waste package, both at the time of production and throughout its management.

3.3 Characterisation of Filters

As shown in Appendix A, filters come in a wide range of shapes, sizes and constructional materials and techniques. As discussed above, this results in the need for a number of packaging strategies from which the one most suited to a particular fileter needs to be chosen. The flow diagram in Figure 1 summarises the important properties of filters that could be used to determine the appropriate packaging method or methods for any given filter type.

Figure 1 Filter Properties and Packaging Routes

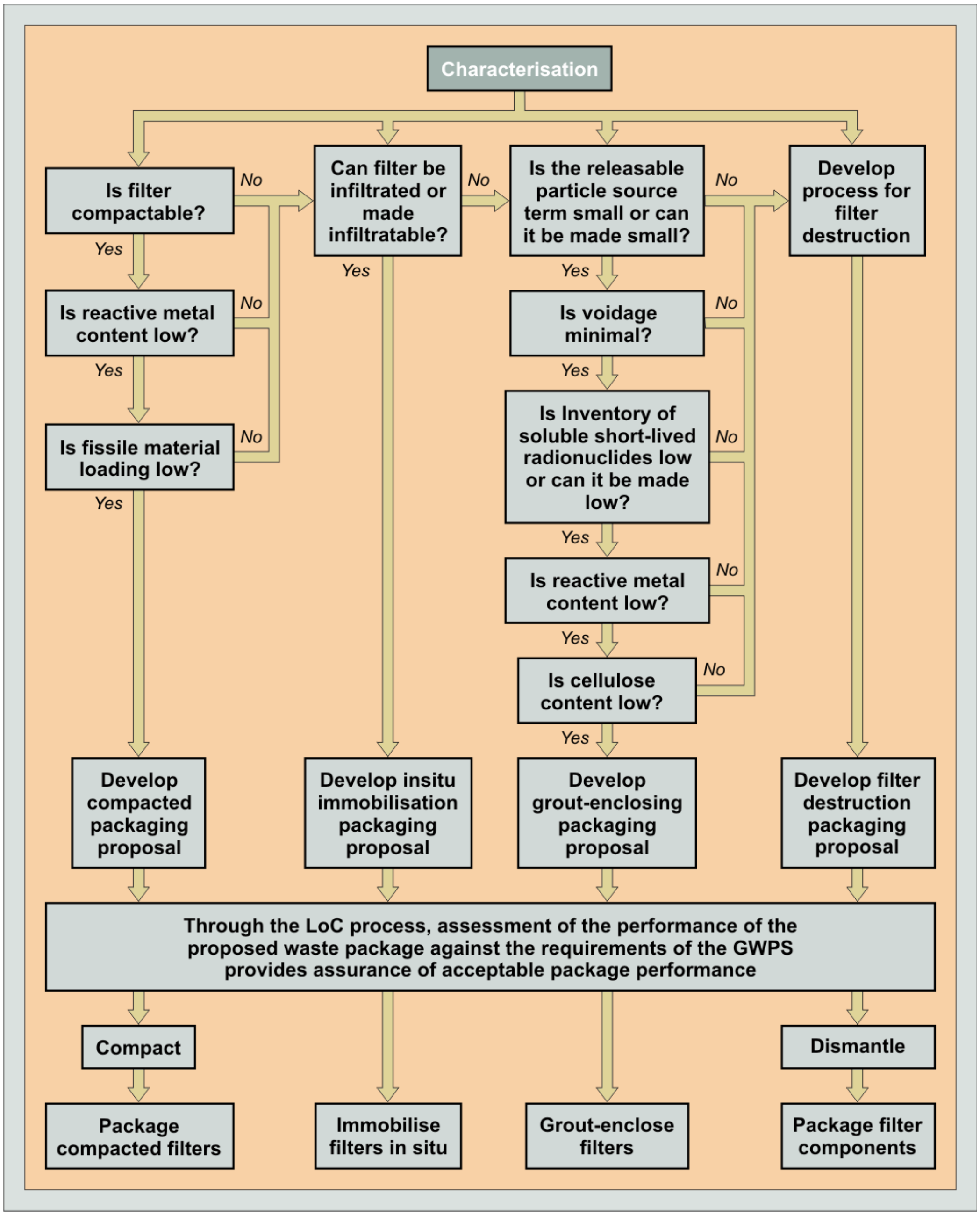


Figure 1 shows the key characteristics that need to be defined before the packaging method for a particular filter can selected, namely:

- Specific design features;
- Material(s) of construction, including;
  - reactive metals
  - cellulostic materials
- Radionuclide inventory, including;
  - particulate activity

- short-lived soluble activity
- fissile materials.

Initially, characterisation of the filter to be packaged will be required in order that waste packagers can make informed decisions about the most appropriate treatment and packaging methods available. In addition, Nirex will require that an adequate description of the physical, chemical and radionuclide characteristics of any waste be supplied as a part of a packaging proposal in order to facilitate assessment. Further, during and subsequent to packaging, there is a requirement for waste packagers to produce and maintain adequate records relating to the contents and properties of all waste packages, and this necessitates an appropriate degree of characterisation (see Section 4.7).

Quantification of the radionuclide inventory of some filters by direct measurement may be rendered difficult by the intricacy of the filter and the presence of isolated voids containing radioactivity. It is considered undesirable to sample the filter in order to determine the radionuclide inventory, where such an operation may result in a loss of possible beneficial properties provided by the intact filter. Further, such operations are likely to involve additional operator dose uptake and cost.

Characterisation may be made more difficult where the radionuclides associated with a filter are difficult to measure, such as α- and weak β-emitters.

Because of the potential difficulties associated with the direct determination of radionuclide inventory, it may be preferable to utilise operational records relating to a specific filter or plant in order to derive a suitable radionuclide inventory. This is likely to be particularly suitable where radionuclides are difficult to measure. However, this approach may also be useful in judging the quality of radionuclide assay of a filter and vice versa.

Operational records alone are likely to be limited in terms of their usefulness in determining a radionuclide inventory for a given filter. Information that may be available includes the period for which a filter was used, the nature of the operations conducted whilst that filter was in use, typical flow rates experienced, the inventory of the fluid and the decontamination factor (DF) achieved.

It may be appropriate in some cases to perform destructive testing, for example taking a core from the filter, in order to facilitate the determination of radionuclide inventory. The sample could be dissolved to allow analysis. Alternatively, the complete filter could be analysed using, for example, High Resolution Gamma Spectroscopy (HRGS) or neutron interrogation for fissile materials, e.g. Passive Neutron Coincidence Counting (PNCC).

The development of plant-specific fingerprints would allow the radionuclide inventory of a filter to be determined using relatively limited analysis, for example HRGS results. This is likely to be particularly useful where many of the radionuclides associated with a filter are difficult to measure, or if the filter properties are such that obtaining a sample is undesirable. 'Fingerprints' may also offer advantages in terms of minimising operator dose uptake. Where it is proposed to utilise such fingerprints, they would require justification and should be demonstrably robust to plant variation. Direct sampling could be used to develop or validate a fingerprint, as could plant operational records, noting the limitations of operational records identified above. The development of fingerprints for the generation of filter radionuclide inventories will only be of use in cases where routine operations have been conducted in an area. In the case of filters from glove-boxes used for a range of experimental work, for example, it is likely that the development of a fingerprint that is applicable to a large number of individual filters will not be appropriate.

In practice, the chosen method of characterisation is likely to reflect the availability and completeness of operational records and the features of the filter that determine the ease with which direct sampling can be achieved.

It should be noted that the link between the inventory of a filter and the selection of an appropriate packaging option will be an important justification for any proposed waste package.

3.4 Suitability for Compaction

In all cases, Nirex assessment will consider the performance of the proposed wasteform and waste package against all of the criteria identified in the GWPS. This section considers only those properties of filters that are most likely to determine whether compaction can yield an acceptable product. Wasteform and waste package properties that are a more complex function of the nature, properties and evolution of the filter, any co packaged waste, any binder or encapsulant and the waste container working in concert, are considered in Section 4. It should be noted that, in general, waste loading will be increased by compaction, so that limits on individual materials in addition to those identified specifically may be required.

3.4.1 Compactibility

Relevant GWPS criteria: *6.1.1 Immobilisation of Radionuclides and Particulates*

6.1.2 Response to an Impact Accident

6.2.2 Voidage

6.6 Wasteform Evolution

High-force compaction or supercompaction, is a process by which wastes are reduced in volume by mechanical compaction, using large forces; typically 2000 tonnes. Compaction offers beneficial volume reduction of wastes, thereby offering a potentially significant reduction in the costs associated with downstream management of wastes. Compaction also generates, in many cases, a coherent solid waste that acts to immobilise the radionuclides and prevent release.

Compaction operations in the UK have routinely been applied to achieve volume reduction of compactable LLW in 200 litre drums to form ‘pucks’. Supercompaction of drummed Plutonium Contaminated Material (PCM) has also been applied, notably at the Sellafield Waste Treatment Complex (WTC), where a 500 litre drum waste package contains an average 1m^3 raw ILW. For ILW, significant cost benefit may still be derived in cases where less than 30% volume reduction is achievable. It is therefore considered that compaction should be adopted where facilities are available and the characteristics of filters are such that the compacted product is compatible with the downstream waste management requirements.

Examples of typical restrictions on the wastes that are suitable for compaction are listed below. These restrictions may be applicable to some filters. Actual limits placed on wastes will depend on the specification of individual compaction facilities.

- Physical size; as limited by the dimensions of the compaction facility;
- Massive metallic items; these have the potential to jam inside the compactor, causing damage to the press and drum;

- Presence of particulates; where significant quantities of particulates are present in a waste intended for compaction, simple remedial measures may be required, such as placing the relevant items in cotton bags to allow controlled release of air whilst offering containment to particulates. It should be noted that any additional materials should be compatible with the requirements of the GWPS;
- The presence of liquids; compaction will result in the displacement of liquids from waste items. The tolerance of compaction facilities to liquids can be increased by the installation of liquid collection and subsequent treatment facilities.

Further consideration will need to be given to the characteristics of a filter once compacted. These characteristics will, in part, be determined by the nature of the container in which a filter is compacted. This may include 200 litre steel drums containing multiple filters, small cans containing single filters or essentially uncontained filters, possibly inside bags.

The choice of container will depend on a number of factors. Of significance is the potential for spring-back or reassertion of the waste, which is known to be more severe when compacted wastes are wetted or not sufficiently restrained, for example by a steel drum. Reassertion may cause the lid to be dislodged, thereby reducing containment during operations and subsequently. Some designs of filter may be particularly prone to reassertion, such that the potential for dimensional instability and puck lid-loss through this mechanism should be evaluated when considering the suitability of filter items for compaction. It is noted that reassertion is typically associated with ‘soft’ wastes exposed to excessive compaction forces and that the potential for such dimensional instability can be reduced in packages that have not experienced excessive compressive force and contain a mixture of ‘soft’ and ‘hard’ wastes. Wastes that require a high compaction force in order to achieve the required minimisation of voidage may not be suitable for compaction if the use of such forces renders the puck prone to dimensional instability.

It is not uncommon for filters to be plastic-wrapped prior to storage. In cases where filters are wrapped, it is considered that, for the purposes of compaction, it would not be beneficial to remove such wrapping prior to compaction, unless determination of radionuclide inventory necessitated it. Again, it should be noted that waste packages containing any additional materials should be compatible with all requirements of the GWPS.

Waste packagers should be able to demonstrate that the volume of voidage remaining after compaction is minimised and not incompatible with the requirements for long-term waste management. Voidage will be significantly reduced by compaction, but may still be present, depending on the construction of the filter, the compaction force and the presence of other wastes. Waste packagers will therefore be required to demonstrate that the resulting package properties are consistent with the wasteform and waste package specifications relevant to voidage. For example, a quantification of the particulate release following impact accident will be required. Voidage may be reduced if filters are co-compacted with soft wastes such as plastics and rubbers. The potential for free liquids to be present or to collect within any voids should also be considered as the GWPS requires that all reasonable measures shall be taken to exclude or immobilise them. The quantity of free liquid is likely to be related to the volume of voidage in the pucks and the moisture associated with the filter and any co compacted waste.

3.4.2 Reactive Metal Content of Filters for Compaction

Relevant GWPS criteria: *6.2.2 Voidage*

6.5 Gas Generation

6.6 Wasteform Evolution

Reactive metals such as aluminium and magnesium may corrode rapidly under certain conditions that may exist in waste packages. Corrosion may generate gases, e.g. hydrogen, which may pose a flammability or toxicity hazard, or cause pressurisation of the wasteform or waste container, thus threatening package integrity. Corrosion may also lead to the formation of solid corrosion products that occupy a greater volume than the parent metal and thereby result in the potential for damage to the wasteform.

Compacted pucks are typically not infiltrated by encapsulating grouts. Rapid corrosion is not expected, therefore, to significantly affect the properties of the resulting wasteform at early age (see also Section 3.6.4). Following repository closure, groundwater ingress into packages is expected. Re-saturation by high-pH groundwater that may contain significant concentrations of chloride and exceed temperatures of 50ºC may cause rapid corrosion of any reactive metals present. Corrosion could lead to puck expansion and the release of significant quantities of gas.

Packaging proposals involving compaction of filters should present a quantification of the likely gas generation rate, including those following re-saturation, for assessment by Nirex as part of the LoC assessment process. This may include the results of experimental work involving gas measurements on compacted pucks contacted by high pH groundwater simulant.

3.4.3 Fissile Material Loading

Relevant GWPS criterion: *4.8 Criticality Safety*

High loadings of fissile material could be expected on filters that have arisen from certain sources, for example, fuel fabrication and handling lines. The potential for such filters to present a criticality hazard when packaged is increased by compaction because of the higher packing density and waste loading that can be achieved within a package.

The Nirex approach to criticality safety [4] is based upon the production of 'benign' packages containing insufficient fissile material for criticality to occur during all routine transport or repository operations. This approach has resulted in the derivation of a generic screening level of 50g Pu-239 or equivalent, defined as a level, below which Nirex standard packages containing undefined waste, are safely sub-critical under all circumstances, both individually and in arrays. More recently the methodology behind the derivation of the generic screening level has been updated with the aim of deriving screening levels that are based on more realistic scenarios and waste package inventories. This has led to the derivation of screening levels for a number of common categories of fissile material (i.e. irradiated natural uranium, low enriched uranium (LEU), highly enriched uranium (HEU) and PCM), which are less restrictive than the generic screening level. Further information can be found in the GWPS.

To cater for packages with fissile contents higher than the relevant screening level, Nirex has developed an approach that will allow a Safe Fissile Mass (SFM) for such packages to be determined.

The values above refer to unshielded waste packages (i.e. 500 litre Drums and 3 cubic metre Boxes and Drums). In the case of shielded packages (i.e. the 2 metre and 4 metre Boxes) limits are placed on their fissile material content to allow them to be excepted from the requirements for packages containing fissile material in the IAEA Transport Regulations [5]. Generally this places a limit of 15g on the quantity of fissile material in such packages.

The particular challenge presented by filters from the point of view of criticality safety derives from the difficulty involved in establishing a reliable fissile material inventory. This results from the inherent intricacy of some filters, combined with the properties of some fissile radionuclides, which make them difficult to measure (i.e. uranium and plutonium isotopes that are α-emitters). The advice presented in Section 3.3 should be considered.

3.5 Suitability for in situ Conditioning

This section considers only those properties of filters that are most likely to determine whether in situ conditioning can yield an acceptable product. Wasteform and waste package properties that are a more complex function of the nature, properties and evolution of the filter, any co packaged waste, any binder or encapsulant and the waste container working in concert, are considered in Section 4.

It is desirable for waste items to be in intimate contact with a conditioning agent since this limits the quantities of macro-voidage (i.e. >1mm) present within a package (see voidage) and ensures that particulate radioactivity is adequately immobilised. The immobilisation of radioactivity is of particular significance in the case of filters since radioactivity associated with filters is expected to be predominantly particulate in nature. Any un-immobilised pockets of particulate radioactivity could be released under impact accident conditions that may be encountered during transport or the repository operational phase.

Some filter designs incorporate areas that will not be adequately infiltrated by the agents that are typically used for the packaging of ILW. Examples of filter properties that may prevent the adequate infiltration of the waste by cementitious grout are:

- the distribution of the filter element, which may cause a colloidal grout to separate into solid and liquid phases, resulting in poor infiltration and free liquids;
- the presence of tortuous paths or deep, dense corrugations containing radioactivity;
- the incorporation of isolated voids in the filter design;
- the presence of absorbent materials, which dewater the grout and prevent infiltration.

Alternative conditioning agents such as polymeric materials may afford adequate infiltration of filters, since they may not be subject to physical separation by the filter and can offer increased fluidity relative to cementitious grouts. Nirex has produced guidance on the potential use of such materials in *Guidance Note on the use of Organic Polymers for the Encapsulation of Intermediate Level Waste, WPS/901*. Methods such as polymer injection and vacuum infiltration are available and may offer superior immobilisation. The compatibility of any such agents with all requirements of the GWPS would require demonstration or reasoned argument, and Nirex should be contacted at an early stage in development if polymeric encapsulants are considered for packaging filters.

Demonstration of adequate and consistent infiltration of voids will be required in support of packaging proposals. Demonstration will include the quantification of any remaining voidage in inactive test pieces infiltrated using the proposed method and conditioning agent. Quantification may be achieved by sectioning of conditioned simulant products.

The modification of filters by simple means such as puncturing may facilitate the infiltration of filters that would otherwise fail to meet the criteria for in situ conditioning.

3.6 Suitability for Grout-Enclosing

In all cases, Nirex assessments will consider the performance of the proposed wasteform and waste package against all of the criteria identified in the GWPS. This section considers only those properties of filters that are most likely to determine whether grout-enclosing can yield an acceptable product. Wasteform and waste package properties that are a more complex function of the nature, properties and evolution of the filter, any co packaged waste, any binder or encapsulant and the waste container working in concert, are considered in Section 4.

3.6.1 Releasable Particle Source Term

Relevant GWPS criteria: *6.1.1 Immobilisation of Radionuclides and Particulates*

6.1.2 Response to an Impact Accident

6.2.2 Voidage

The GWPS requires that all reasonable measures are taken to minimise the presence of loose particulate material in waste packages. In practice, this is typically achieved by the intimate encapsulation of the waste by a cementitious or other matrix. In the case of filters that cannot be compacted or adequately infiltrated, immobilisation by intimate encapsulation will not be achievable without modification of the filter.

If the particulate source term associated with a filter item is either below the release limit identified in the relevant Nirex specification or demonstrably trapped within the filter under impact conditions, then intimate contact between the particulate radioactivity and the conditioning agent may not be required and grout-enclosing of the filter may therefore be an appropriate option. Alternatively, it may be possible to reduce the particulate source term such that the remainder is sufficiently small that the release limits cannot be exceeded. In assessing proposals to grout-enclose filters, Nirex would assume that the entire particulate source term associated with a filter would be released under impact conditions unless evidence was provided to support an alternative position. For example, credit may be taken for the following:

- retention of particulates by the filter itself;
- the integrity of the waste package as a whole.

Some filters may have been designed specifically to retain any activity they contain. It may also be demonstrable that other filters will retain any associated particulates following an impact accident. It may therefore be possible to argue that the beneficial properties of a filter are adequate to ensure that particulates would be retained following impact. The persistence of those beneficial properties after grout-enclosing and a period commensurate with those defined by the PGRC will require demonstration. Wasteform evolution and degradation is addressed in Section 4.2.

In order to conduct impact assessment, Nirex will require that the impact performance of the package as a whole be investigated. If credit is taken for the ability of the filter to limit the release of particulate radioactivity, then demonstration of the impact performance of the raw filter will be required.

It may be possible to reduce the particulate source term associated with a filter in order to render it suitable for grout-enclosing. It is considered unlikely that back flushing with a fluid will offer significant benefits unless a filter has been specifically designed to allow radioactivity to be removed in this way. Leaching of radionuclides using a suitable leachant may allow for a reduction in contamination. Where the use of such a technique is judged beneficial, waste packagers should consider the nature and quantity of the resulting liquor and any implications for its management.

In cases where a filter cannot be infiltrated to such an extent that particulate radioactivity is demonstrably fixed, it may be beneficial to apply an agent that offers some degree of immobilisation, for example, a spray adhesive or thermosetting resin coating. If credit is taken for the application of a fixing agent, it must be demonstrable that the process and product are sufficiently consistent to assure both acceptable and predictable performance.

3.6.2 Voidage

Relevant GWPS criterion: *6.2.2 Voidage*

Nirex will not endorse any packaging proposal that does not demonstrate that voidage has been minimised or where justification cannot be provided that the presence of voidage does not compromise waste package performance against the GWPS. A quantification of residual voidage will be required by Nirex and this could be obtained by the sectioning of treated simulant products. Voidage should be quantified for simulant products that have been treated using the same process as will be used for the treatment of the actual waste.

The presence of excessive voidage in a wasteform has a number of disadvantages, this sub-section considers each of these disadvantages and the impact that filters may have in terms of voidage.

The inclusion of voidage may make the package weaker and so more susceptible to damage and break-up in the event of an impact. The mechanical properties of packages containing grout-enclosed filters will need to be addressed. It is considered that, given a suitable matrix, wasteforms containing grout-enclosed filters can perform adequately in this respect. The ability of packages containing grout-enclosed filters to meet impact release limits will not be precluded by the presence of voidage if the particulate source term is insufficient to allow impact release limits to be exceeded. Notwithstanding this, the impact release will be reduced by the minimisation of voidage.

Locally enhanced corrosion of the container material can result from the presence of voidage close to the container wall, particularly when the material is stressed and when condensation may form in the void. Appropriate arrangement of filters in the container prior to the addition of the enclosing matrix could prevent the formation of voids near to the container wall, thus negating the issue of enhanced container corrosion caused by voidage. Such arrangement may rely on the use of container furniture or pre-casting an annulus. The adequacy of any arrangement to prevent the formation of voids adjacent to the container walls will need to be demonstrated in cases where this is deemed a concern.

The accumulation of flammable mixtures in voids may be an issue of concern, particularly where a filter includes quantities of reactive metals or organic materials, whose degradation could result in the generation of flammable gases such as hydrogen and methane adjacent to the void (see Sections 3.6.4 and 3.6.5). For example, the presence of voidage may increase the potential for the formation of microenvironments in which microbial activity could be concentrated and increased microbial activity may lead to the formation of gases and soluble complexants. Similarly, voidage may allow for the accumulation of free liquids, which could increase the rate of reactive metal corrosion.

The inclusion of voidage in the repository, will lead to increased groundwater flow. Packages containing grout-enclosed filters may contain significant voidage, thus introducing a short circuit pathway for groundwater. The GWPS notes that benefit is afforded where wasteform permeability is down to one tenth that of the Nirex Reference Vault Backfill (NRVB); a design permeability of 10^{-16} m^2. However, encapsulating agents should also be sufficiently permeable to gas to prevent pressurisation of the wasteform.

In presenting waste packaging proposals, consideration should be given to these factors and their relative importance on a case-specific basis. It is recognised that grout-enclosing processes are likely to result in the production of wasteforms in which there is some residual voidage. However, it is also apparent that, for some filters at least, it should be possible to consistently and demonstrably reduce voidage to a point at which it can be argued that its inclusion does not have a significant adverse impact on wasteform and waste package properties and evolution.

3.6.3 Soluble Short-lived Radionuclides

Relevant GWPS criteria: *6.2.3 Mass-transport Properties*

6.3 Chemical Containment

Best practicable means (BPM) should be applied to the physical containment of soluble radionuclides. The conditioning of waste, and in particular encapsulation in a matrix such as cement, provides a barrier to the release of such radionuclides.

Containment can be quantified by the radio-toxicity of the repository pore solution arising from the soluble radionuclides released from the waste package. It is generally accepted that BPM has been applied if the physical form of the waste package provides containment of soluble, short-lived radionuclides until the radio-toxicity attributable to them has decayed to below the long-term average value of radio-toxicity expected within the repository.

The radionuclides Sr-90 and Cs-137 commonly dominate the estimated radio-toxicity of fresh wastes because of their solubility, abundance and biological impact. However, other radionuclides also may be important, depending on their specific activity in the waste, biological impact and chemical behaviour in the disposal environment. Advice may be obtained from Nirex on the radionuclides of importance for a particular waste. Where the inventories of soluble species are such that the radio-toxicity cannot exceed the long-term background value for a repository, performance will be comparable with that of conditioned waste containing lesser voidage even if no additional credit is taken for retention in the container. In this case, no further argument may be necessary to demonstrate that grout-enclosing is consistent with BPM.

3.6.4 Reactive Metal Content of Filters for Grout-Enclosing

Relevant GWPS criteria: *6.2.2 Voidage*

6.5 Gas Generation

6.6 Wasteform Evolution

Aluminium is an example of a reactive metal that is used in the construction of filters; other examples of reactive metals encountered in ILW streams are zinc and magnesium, and these may be used in some filters. Filters may contain, as a function of their design, quantities of reactive metals with a potentially large surface area. The presence of such filter components may have implications for processing, and for the properties and characteristics of the waste package.

A consideration of the importance of reactive metals for proposals to compact filters has already been presented (Section 3.4.2). In the case of compacted filters, it is considered that any significant effect will occur on re-saturation of the wasteform after repository closure. In contrast, reactive metal components of grout-enclosed filters may be subject to corrosion at the time of packaging because of the contact between, for example, a wet grout and reactive metal.

The corrosion of some metals under certain conditions can generate gaseous products. Where such corrosion is rapid and occurs on addition of a conditioning agent, the generation of gaseous products will have implications for the quality of the wasteform produced, with the potential for the resulting product to fail to meet the requirements as defined in the GWPS. In particular, the generation of significant quantities of gas during the encapsulant addition stage of packaging may lead to:

- a waste/conditioning agent interface with significant localised voids giving poor bonding and a weak wasteform;
- gas channelling through to the surface of the wasteform resulting in poor immobilisation of particulate radioactivity;
- a friable layer at the wasteform surface giving rise to increased levels of particulate material.

In the longer term, continued corrosion of metallic waste items may threaten wasteform integrity by the formation of corrosion products that occupy a greater volume than the parent metal or by the generation of gases. The formation of corrosion products and the resultant expansion can cause the physical degradation of the encapsulating matrix. The generation of gases may have implications for wasteform integrity where the encapsulating matrix does not allow the release of that gas at a rate sufficient to prevent pressurisation of the wasteform. The ability of a wasteform to release gas generated by it should be demonstrated in cases where this is deemed an area of concern.

When considering the suitability of filters for grout-enclosing, it will be necessary to evaluate the potential effects of any reactive metals present in the filter, including:

- the generation of gaseous reaction products during packaging operations;
- the generation of gaseous reaction products during storage, transport and the repository operational phase;
- the formation of solid corrosion products at all stages of waste management.

The magnitude of these effects will be dependant on the nature of the metals in terms of their corrosion reactions and rate under conditions encountered during packaging, storage, handling and disposal. Such conditions may include essentially wet conditions where the filter can absorb or separate mix water from the grout and accumulate voids.

Waste packagers should be able to demonstrate that any reactive metals present in packages are not in sufficient quantity or distributed in such a way that they pose a threat to the dimensional stability or integrity of the package. Guidance on corrosion rates and mechanisms is available from Nirex. For grout-enclosed filters, the effects of expansive corrosion product formation and pressurisation caused by gas generation may be reduced as a result of the presence of greater voidage in the region of the corroding metal surfaces; noting that voidage should be minimised.

It should be noted that a metal's corrosion behaviour would be modified by the presence of voidage adjacent to it. Therefore, this will need to be addressed if grout-enclosing is proposed as the preferred packaging route for filters that incorporate reactive metals.

3.6.5 Cellulose Content

Relevant GWPS criteria: *6.3 Chemical Containment*

6.6 Gas Generation

The degradation of cellulosic materials, including paper, wood and cotton, can generate non-radioactive gases, primarily carbon dioxide and methane. Further, soluble species which can be produced as a result of the alkaline hydrolysis of cellulosic materials can increase the solubility of key radionuclides. Intimate contact between alkaline cement and organic wastes will ensure that microbial activity is minimised. Filters conditioned by grout-enclosing may not achieve intimate contact between any organic component of the waste and the cementitious matrix. Further, separation of the grout may yield 'wet' voids. Microbial degradation of cellulose may therefore proceed more rapidly, yielding carbon dioxide and methane.

Some filters may incorporate significant quantities of cellulosic material, and where they are present, their effects on wasteform and package properties will need to be addressed as a part of packaging proposals. Cellulose content may be considered 'low' if it is below the levels identified in, for example, *500 litre Drum Wasteform Specification: Explanatory Material and Guidance, WPS/800*. Proposals for the packaging of filters that incorporate cellulosic materials should consider the impact of those materials on the performance and evolution of the proposed wasteforms and waste packages. This consideration should include an assessment of the potential for gas generation. Waste and wasteform degradation is considered further in Section 4.2.

3.7 Destruction of Filters

Where it cannot be argued that compaction, in situ conditioning or grout-enclosing will provide waste packages containing filters that will be acceptable to Nirex, or where significant uncertainties still remain, consideration will need to be given to destroying the filter and packaging the resultant materials.

Because of the dose uptake, complexity and cost that may be associated with the destruction of filters, it is considered that the minimum processing required to render the filter and its components suitable for packaging should be undertaken. Destruction is therefore likely to address specific components that would otherwise prevent a filter from being packaged to achieve an acceptable product. Methods of destruction considered for implementation will reflect this.

Examples of procedures that may be applicable include partial dismantling, those based on cutting techniques such as shredding or cropping, pulping of the filter medium, baking to remove organic binders, acid leaching or dissolution and incineration.

Destruction is considered to be an intermediate step that allows the challenges posed by particular filters to be mitigated or reduced, thereby allowing the secondary products yielded by any such processing to be packaged in an acceptable manner. It is expected that these secondary products may, depending on their nature, be packagable by one or more of the routes already described in this guidance document, or by in-drum mixing. The ease with which all components and materials liberated or generated by destruction can be packaged should be considered. For example, the removal of aluminium plates from filters may render the partially dismantled filter suitable for grout-enclosing, but the aluminium plates themselves may be difficult to package without further treatment; incineration of filters may increase the fissile loading of the resultant ash.

3.8 Nirex Assessment

Nirex will assess waste packagers' proposals as part of the LoC process. The decision points identified in Figure 1 are concerned with those properties of filters that will determine the most appropriate packaging route for filters. Additional criteria will be of relevance to Nirex, however. Nirex assessment will be concerned with ensuring that all of the relevant requirements of the GWPS will be met when a packaging process is implemented. Section 4 provides a summary of the key issues that Nirex will consider in assessing specific proposals. This does not represent the full range of potential issues, but those discussed are likely to be particularly relevant.

4 ADDITIONAL FACTORS RELEVANT TO PACKAGING PROPOSALS

Section 3 has addressed the key properties of filters that will need to be considered when determining the most appropriate processes for their treatment and packaging. Once a packaging proposal has been made and justified, Nirex will assess it against all of the requirements of the GWPS. The major concerns of relevance for packaged filters have been identified and discussed in Section 3. Other areas of uncertainty that will be of interest to Nirex are addressed in this section. It identifies important properties and performance characteristics of waste packages containing filters that will affect the acceptability of the package, but which may not be directly relevant to the selection of a packaging route.

4.1 Response to a Fire Accident

Waste packages should have the ability to retain their radionuclide burden within given limits and maintain integrity to allow handling under fire accident conditions defined in the GWPS. There is a risk that packages containing filters will not fulfil the criteria relevant to fire accident performance, or that there will be significant uncertainty regarding the fire performance of packages containing filters. In either case, a package may not be considered acceptable for transport and the repository operational phase.

Factors relevant to the assessment of the fire accident performance of packaged filters are:

- radionuclide speciation;
- wasteform specific activity;
- distribution of the filters, for example, they may be close to the drum wall and therefore subject to a more pronounced temperature excursion
- distribution of radioactivity and voidage within the wasteform; retention of activity by the waste, short circuit pathways for steam-entrained or volatilised radionuclides through voids;
- response of encapsulating agents to temperature increase; for example, novel conditioning agents used for in situ conditioning must not support combustion
- amount and form of water in the package; that is gel and pore water in cementitious encapsulants, and free liquid and absorbed liquid in grout-enclosed filters
- thermal properties of the wasteform and its components
- particle size distribution of any particulate radioactivity, where smaller particles will be more readily entrained in evaporating pore water.

Fire performance will be improved by ensuring that there is an adequate grout annulus surrounding the waste, such that radionuclides are essentially insulated against excessive heating. This could be achieved by the use of a pre-cast grout annulus or container furniture. The addition of a grout cap to the wasteform will also act to limit the radionuclide release from packages in the event of fire. It is considered that un-vented drums are unlikely to be appropriate for grout-enclosed filters because of the need to release gases generated by the wasteform.

For novel conditioning agents, the thermal properties and response to heating should be reported in proposals to Nirex.

4.2 Wasteform Evolution

Waste packages are assessed in terms of their performance under the conditions and timescales pertaining to all of the stages of long-term waste management, as defined by the PGRC. Consideration is given to the ability of the package to continue to meet the requirements of the GWPS. Essentially, the outcome of waste and wasteform evolution could be the loss of beneficial wasteform properties, or a loss of any beneficial property or properties of a filter for which credit has been taken. For example, the ability of a filter to retain particulate radioactivity could be cited by the waste packager in support of the impact performance of a waste package, but any such beneficial property could be lost through the chemical degradation of the filter or the embrittlement of filter components following irradiation. Waste packagers must consider the effect of filter evolution on the performance of the waste package and should demonstrate that potential modes of degradation and the effects on the properties of the waste and wasteform have been adequately addressed.

Factors relevant to assessment and likely to be of relevance when considering the degradation of filters are:

- corrosion of solid metallic items or components and the coincident gas generation and formation of corrosion products during waste package production and subsequent stages of waste management;

- microbial degradation of cellulosic and other organic materials, which may be present in filters as the filter element, binders, frames, or as wrapping applied to filters before storage or packaging. Microbial degradation may result in the formation of harmful gases and degradation products that may be aggressive towards an encapsulant or increase the solubility of radionuclides;
- degradation of filter materials by irradiation resulting in loss of beneficial properties and formation of reactive degradation products that may further degrade components of the waste package, or increase the solubility of radionuclides within a disposal facility;
- voidage; may have implications for the formation of acid micro-environments, and for the rate of cellulose degradation and reactive metal corrosion. Voidage may be formed following the degradation of filters within the wasteform;
- long-term performance of encapsulating agents; their response to irradiation and other environmental conditions during long-term management, and the compatibility of any degradation products with the requirements defined by the GWPS;
- reassertion of compacted pucks.

The mode, rate and outcome of waste and wasteform evolution will be different where filters have been co-packaged with other wastes. If co-packaging is proposed, then consideration should be given to the potential interactions between filters and other items.

The radiation stability of encapsulants should be demonstrated. Guidance on the typical dose and dose rates that will be experienced by packages during the waste management cycle is presented in the WPSGD.

Factors pertinent to the reassertion of compacted pucks are presented in Section 3.4.1.

4.3 Thermal Properties

Thermal properties, particularly thermal conductivity and specific heat capacity, will determine the ability of packages to dissipate heat generated by the wasteform or in a repository without significant temperature rise; a requirement of the GWPS.

Relevant factors determining the thermal properties of a wasteform are:

- voidage - air-filled voids may reduce the ability of a package to dissipate heat;
- water - the form and distribution of water in the wasteform may affect the thermal properties of the wasteform as a whole;
- thermal properties of the waste and encapsulating agent - cementitious wasteforms in general are expected to perform adequately in terms of dissipating heat. The thermal properties of any novel encapsulants used should be determined;
- degree of wasteform heterogeneity - wasteforms that incorporate significant volumes of materials with relatively low thermal conductivity or high heat capacity may result in the development of significant wasteform temperature gradients. This could arise, for example, in packages containing compacted filters that are composed largely of organic materials, particularly when present as a convoluted membrane.

4.4 Chemical Containment

The long-term performance of novel encapsulants and filter components and contaminants under conditions and timescales pertaining to the different stages of long-term waste management as defined by the PGRC, including their degradation products, will be of relevance to repository performance post-closure. Examples of important potential filter contaminants are non-aqueous phase liquids (NAPLs) such as oil, and cellulose.

The use of large volumes of polymeric encapsulating agents in place of cementitious materials constitutes a significant variation from common practice and may challenge the assumptions made in the assessment of the post-closure performance of a repository. Waste packagers should, therefore, contact Nirex at an early stage should they wish to exercise this option.

4.5 Hazardous Materials

Filters may contain hazardous materials in their construction or as a function of the nature of the filtrate, for example, asbestos, sodium or potentially pyrophoric metallic fines. Nirex would require any such materials to be identified, quantified, limited, and rendered safe.

Packaging proposals for filters which include hazardous materials as a component or a contaminant should demonstrate that the proposed waste package offers adequate containment of hazardous materials under all conditions that it may reasonably be expected to encounter.

4.6 Waste Product Specification

An important component for the safe long-term management of waste packages is the production and maintenance of a complete and effective ‘package record’ that will be accumulated by the waste package throughout its lifetime. One key element of the package record is the Waste Product Specification (WPrS) which is a specification of what the waste packager is setting out to achieve and which is assessed as part of the LoC process. Guidance on the requirements for WPrS can be found in *Guidance on the Structure and Format of Waste Product Specifications, WPS/620.*

There is a clear need to ensure that filters, as presented for treatment and packaging and when packaged, are compliant with the WPrS developed during packaging proposal development. If the WPrS fails to adequately identify the factors of relevance, then assessment of the packages against the Waste Acceptance Criteria (WAC) for a future disposal facility may be unnecessarily challenging.

In addition to the standard features of a WPrS, the key features for packages containing filters are considered to include:

- justification of the packaging route, including a demonstration of how the compatibility of a filter waste stream with a particular treatment route was shown;
- the required location and orientation within the wasteform of filters for grout-enclosing, if this has been shown to be necessary to ensure minimisation of voidage. Any method used to ensure a specific filter configuration, for example container annulus or furniture, should also be identified;
- details of any compaction applied, for example, target and acceptable ranges for the force used and volume reduction achieved;

- target and acceptable range for the nature and volume of any in situ conditioning agents used;
- target and acceptable ranges for the package inventory of materials important in determining package evolution and degradation, for example, cellulose or aluminium;
- typical values and limits on the package inventory of any hazardous materials, as applicable;
- acceptable range of total particulate material contents for individual filters and whole packages;
- acceptable range of voidage associated with packages containing grout-enclosed filters;
- reference to any operational records and radionuclide fingerprints used to determine package radionuclide inventory;
- methodology and results of any direct assay of radionuclide inventory.

The exact requirements for the WPrS for a particular waste package type containing filters will vary according to the specific properties and characteristics of the relevant filters and waste packaging process. As a minimum, the WPrS should seek to demonstrate that the properties that have been of key importance in determining the choice of packaging route and the details of the packaging process have been adequately addressed.

4.7 Waste Package Data

In addition to data that needs to be recorded for waste packages (as defined in *Waste Package Data and Information Recording Requirements, WPS/400*) for the disposal record, the data recorded should allow the compliance of any given waste package with the WPrS to be demonstrated.

5 ADVICE ON THE PREFERRED CHARACTERISTICS OF FILTERS

The properties and characteristics that make filters potentially difficult to package in a manner compliant with the GWPS can be summarised as:

- the presence of potentially large quantities of particulate radioactivity;
- the inclusion of inaccessible voidage;
- complex morphology and radionuclide inventory, which can hamper adequate characterisation;
- the use of materials prone to rapid degradation under conditions likely to be encountered during the waste package lifetime.

Future designs that generate more ‘packager friendly’ filters should seek to address these concerns, without compromising the functionality of the filters.

Because of the nature and function of filters, particulate radioactivity will inevitably be present. By using filters that are designed to allow particulates to be removed by simple measures such as back flushing, filters could be reused, thus reducing the number requiring disposal, or rendering a greater proportion acceptable for grout-enclosing. A reduction in the particulate loading on filters would also reduce operational complexity during compaction and make compliance with impact release limits easier to demonstrate.

Particulate activity could be fixed on a filter after use by incorporating a polymeric or other coating to the filter design. The coating could then be activated by the application of heat or a catalyst to cause the agent to fluidise, and fix the particulate load; a self-conditioning filter. Polymers that cure on heating may have implications for the response of filters to heating or fire in-service. An alternative curing method that is emerging for some polymers is electron-beam curing, which could be considered.

By providing a mechanism that would allow the filter element to be essentially closed; a collapsible filter element; the ability of the filter to retain particulate activity would be increased, and voidage minimised. The mechanism could involve a 'concertina' approach whereby a design feature allows the filter element to be self-compacting or twisting of pleated filter elements to effectively seal the activity and minimise the extent of voids.

A proactive approach to the maintenance of operational records relating to filters would aid in the characterisation of filters. For example, consideration should be given to the recording of in-service times, flow rates and the operations conducted that will affect the radionuclide inventory of a filter.

The length of time that filters are in service for is of relevance to packaging. Generally, filters with long service lives will have a greater radionuclide inventory than filters used for a similar purpose for a shorter period. Consequently, if filters are changed frequently, the result will be a larger number of filters, each with a smaller radionuclide inventory and vice versa. The practicality of adopting shorter in-service times for filters will depend upon the accessibility and cost of the filter, including the operator dose uptake associated with replacement. An outcome of adopting minimal in-service times would be that a greater proportion of filters would have a small radionuclide source term although this would also result in a greater number of filters for treatment.

The use of materials that are difficult to package, e.g. cellulose, should be avoided where possible. Alternatively, problematic materials should be rendered easy to remove as appropriate, for example, end plates comprising aluminium.

It would be of benefit for filters to be segregated from other wastes as they are removed from service and transferred for storage, i.e. at source of arising. Segregation would make the generation and maintenance of an inventory of filters easier. Furthermore, separately stored filters would be easier to retrieve, as there would be no need to sort them from other wastes, thus facilitating characterisation. Segregation at source of arising could also be used to ensure that filters with a radionuclide inventory that is characteristic of a single use (plant) are kept together, so that the development of an appropriate radionuclide fingerprint would be relatively simple to achieve and demonstrate.

APPENDIX A INFORMATION ON FILTERS TYPICALLY USED IN THE UK NUCLEAR INDUSTRY

Filtration is a method of solid-liquid and solid-gas separation that is widely employed in the UK nuclear industry. In general filtration plays two main roles in nuclear power plants, fuel cycle activities and research facilities:

- removal of solid radioactive material from liquid and gaseous effluents prior to their discharge to the environment;
- recovery of solid products from liquid and gaseous process streams.

Table A.1 provides an illustrative, although by no means exhaustive, list of examples of where filtration is used as an integral part of processes operated at different stages of the UK civil nuclear fuel cycle.

Table A.1 Typical Filter Usage in Nuclear Facilities

Fuel cycle stage	Examples of use of filtration
Uranium conversion, enrichment and fuel manufacturing	• Clarification of product liquor from dissolution of uranium ore concentrates. • Filtration of UF_6 gaseous product to remove entrained UF_4 particulates.
Power station operation	• Clarification of irradiated fuel storage pond water. • Maintenance of purity of reactor water coolant.
Reprocessing and associated activities	• Recovery of precipitated plutonium oxalate. • Recovery of floc from liquid effluent treatment.

Filters can be designed to be ‘reusable’ (i.e. by virtue of some mechanism whereby the separated solids can be removed from the filter medium) or ‘disposable’ (where the separated solids cannot be removed from the filter medium) although, at the end of their operational lifetime, ‘reusable’ filters will have become contaminated and will, therefore, require disposal as either LLW or ILW in the same way as ‘disposable’ filters.

For liquid filtration, the most widely used kinds of disposable filter are cartridge and bag filters. For gaseous filtration, HEPA filters, panel filters and bag filters are the most commonly encountered type of disposable filter.

A1 Liquid Filtration

A1.1 Surface and Depth Filtration

Surface filtration involves the use of a perforated screen with openings of a size governed by the physical nature of the materials used to fabricate the screen (usually woven fibres or sintered particles). Such filters will retain all particles with a size larger than the minimum size of the openings, the filtration mechanism being known as sieving. The particles will collect on the surface, forming a filter cake. Particles smaller then the opening size will not tend to be captured and accordingly the process of surface filtration is strictly dependent upon the particle size / pore size relationship.

Depth filtration allows particles to penetrate the filter matrix and become captured throughout the depth of the medium. Some depth filters have a gradient pore structure, with tighter pores near the centre core, to maximise mechanical retention.

A1.2 Macro- and Micro-filtration

Macro particles are visible to the naked eye and range in size from 50 to 1000μm. Examples of particles in this size range include: beach sand, granular activated carbon, human hair, mist, pollen and milled flour. To filter constituents of this size, particle filtration is used.

Filters that are designed for particle filtration are usually pre-coat filters, screen, sand, bag, plate and frame, activated carbon, and depth filters. Pre-coat filters use a filtration media pre-coated with diatomaceous earth that will remove very small particulate matter including some bacteria. They are only practical for limited volume applications. Screen filters use a coarse screen to filter out large particles at the intake point. This type is prone to blinding. Sand filters are able to process large volumes rather inexpensively. The location of fine sand on top of the coarse sand causes the filter to clog quite quickly. The coarseness of sand and lack of uniform packing allows many smaller impurities to pass through. Bag filters are constructed of non-woven media such as polypropylene in the shape of a bag. Fluid is placed in the bag and filtered through the bottom by gravity or pressure while the impurities are left behind. The bag eventually fills up with impurities and is discarded. Plate and frame filters consist of thick woven materials such as cotton or polypropylene mounted on a frame. Rows of the filters are lined up and fluid is pushed through them. The filters tend to drip and leak and are not effective for high precision filtration. Active carbon (AC) filters remove large particles and adsorb low molecular weight organics and chlorine but must be backwashed frequently and changed periodically to avoid bacterial growth and maintain efficiency.

Depth filters are the most common type of particle filter and the most suitable for the majority of applications. The water flows through the thick wall of the filter media where the particles are trapped throughout the complex openings in the media. The filter may be constructed of cotton, cellulose, synthetic yarns or ‘blown’ microfibres such as polypropylene. The most important factor in determining the effectiveness of depth filters is the media density throughout the thick wall. The best depth filters have lower density on the outside and progressively higher density toward the inside wall. The effect of this ‘graded density’ is to trap coarser particles toward the outside of the wall and the finer particles toward the inner wall. Graded-density filters have a higher dirt-holding capacity and longer effective filter life than depth filters with single-density construction.

Generally, depth filters are not an absolute method of purification since a small amount of particles within the rated range may pass into the filtrate. However, there are an increasing number of depth filters in the marketplace that feature absolute retention ratings.

The nuclear industry uses depth cartridges in several ways including: bulk particle removal, pre-filtration, waste treatment and incoming water treatment. Depth filters may be used to filter chemicals as long as all the materials that are used in the filter are compatible with the chemical. Depth cartridge filters are cost-effective and the filter materials are disposable.

Micro particles are not visible to the naked eye; an optical microscope is needed. These particles range in size from about 0.05µm to over 2.0µm.

Examples of particles in this size range include: yeast cells, some bacteria, coal dust, red blood cells, blue indigo dye, milled flour, and latex/emulsion. Microfiltration is used to filter particles of this size.

Surface filters are used to filter particles in the micro particle range although occasionally a high-grade depth filter is used. Surface filters tend to be very precise, providing a barrier, which only certain size particles may pass through. Since there is a definite barrier, the filter is prone to blinding and the service life is rather short. To overcome this problem, many surface filters have been designed with as much surface area as possible, in the form of pleats, folds or as a spiral. Pleated cartridge filters typically act as an absolute particle filter, using a flat sheet media, either a membrane or specially treated non-woven material, to trap particles. The media is pleated to increase usable surface area. When used to trap larger particles of more than a single size, pleated filters are usually not cost-effective for bulk water filtration without the use of pre-filters. However, pleated membrane filters serve well as sub-micron particle or bacteria filters in the 0.1 to 1.0µm range and are often used to polish liquids in critical applications. The submicron pleated filters are constructed with a polymer membrane which is disposable. Some cartridges have been designed to perform in the ultra-filtration range: 0.005 to 0.15µm.

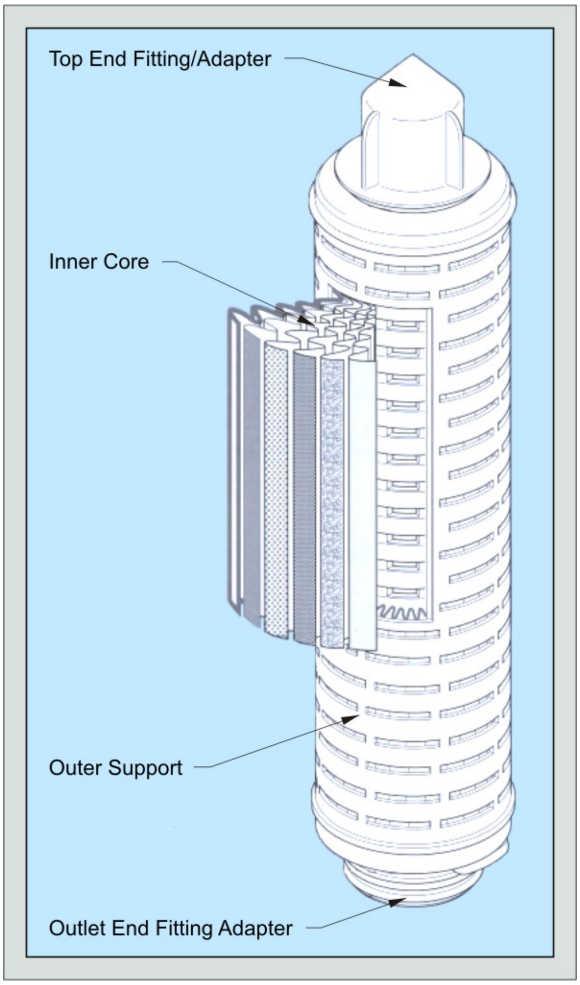
Industry uses depth or surface cartridge filters in several ways including: final filtration, post-treatment, point-of-use, and precise particle removal.

A1.3 Cartridge Filters

The choice of cartridge filter depends on the application. Cartridge filters are preferable for systems with contaminations lower than 100ppm, that is to say with contamination levels lower than 0.01% in weight.

Cartridge filter can be surface or depth-type filter: depth-type filters capture particles and contaminant through the total thickness of the medium, while in surface filters (that are usually made of thin materials like papers, woven wire, cloths) particles are blocked on the surface of the filter.

Figure A.1 Construction of a Typical Cartridge Filter



It can be generally stated that if the size of filter surface is increased, higher flows are possible, the filter last longer, and the dirt holding capacity increases. Cartridge filters are normally designed disposable: this means that they have to be replaced when the filter is clogged.

There are a variety of different kinds of cartridge filter in common usage, including:

- Wound - New fibre materials wound in a precise pattern resulting in depth filtration through progressive smaller flow openings. Materials include cotton, polypropylene, nylon, polyester, glass fibre, PTFE.
- Melt-blown - Depth filtration cartridges of melt-blown polypropylene with graded pores from 1-100μm.
- Pleated - Micro-fibreglass Polypropylene or fluorpolymer media combined with spun bonded polypropylene or Polyester all for nominal or absolute filtration.
- Pleated membrane cartridges with polypropylene or fluorpolymer support and drain layers.
- Carbon - Cartridges with carbon impregnated paper or granular activated carbon.

- Alloy - Multi-layered matrix of micron size stainless steel fibres or wire mesh. Pleated and/or cylindrical.
- Resin bonded - Resin impregnated fibres for viscous liquid. High pressure resistant.

A1.4 Bag Filters

Bag filters are mostly surface-type filters. The flow can be from the outside to the inside of the filter (that means, the separation of particles happens on the external surface of the filter) or the other way around, depending on the application. The particles are normally captured on the internal surface of the bag filter. A bag filter consists of three basic components, as Shown in Figure A.2; filter bag, a restraining basket and a filter vessel. Bags may be made of cotton or plastics.

Figure A.2: A Typical Bag Filter

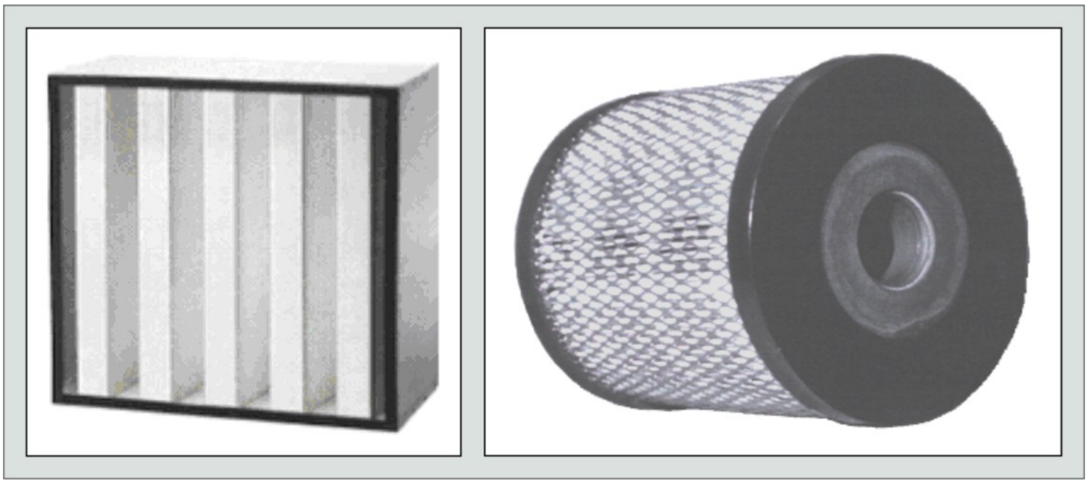
A2 Gaseous Filtration

Air filters of many types have been applied to meet a wide variety of requirements in the nuclear industry. They generally fall into one of three categories:

- Heating, ventilation and air conditioning (HVAC) filters that comprise highly porous beds of resin-bonded glass or plastic fibres which act as targets for collecting airborne particulates;
- High-efficiency particulate air (HEPA) filters comprises of assemblies of glass-fibre impregnating filter ‘paper’;
- Cleanable cloth filters which act in a similar manner to the surface and depth filters described for liquid filtration above.

Most widely used in the nuclear industry are HEPA filters, and although the particle collection mechanism and filter efficiency are generally the same, there are wide variations in casing construction materials, filtration media, casing shapes and sizes. Materials used for HEPA filter casings include a variety of metals (i.e. aluminium, carbon steel and stainless steel), woods and plastics. Other materials used in the construction of HEPA filters include (typically) rubber based sealants and gaskets. Shapes of HEPA filters for large scale air filtration are generally square or circular as shown in Figure A.3

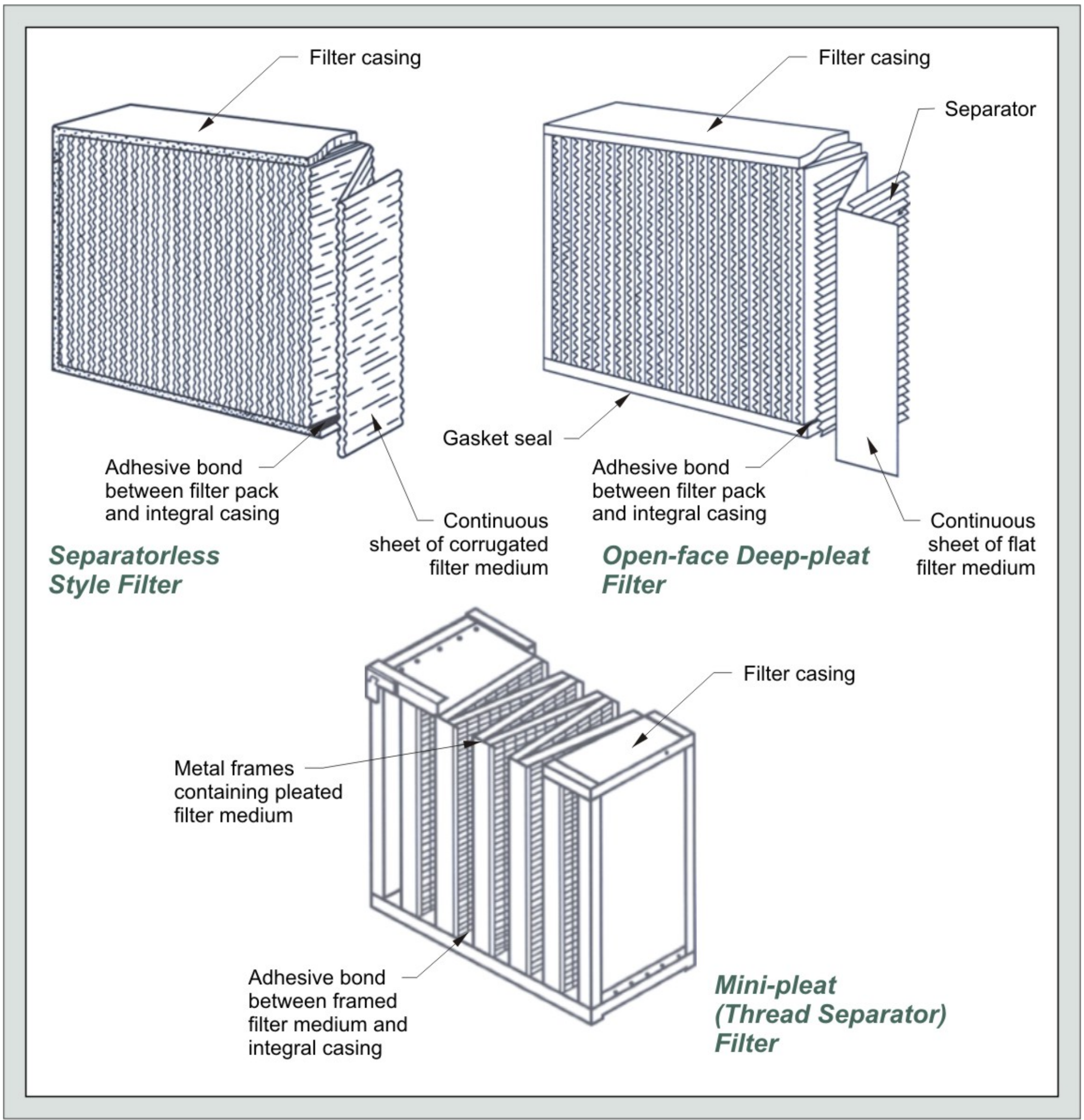
Figure A.3 Square and Circular HEPA Filters



The filtration medium, or 'paper' in HEPA filters is generally woven from glass fibres with a diameters in the range 0.2 to 0.5μm (fibre size being the controlling factor for the minimum size of particle that a filter is capable of capturing efficiently). The fibres may be doped with small amounts of various chemical to impart the paper with particular characteristics (i.e. increased strength, water repellence etc) and some papers include a small proportion (i.e. a few %) of plastic fibres to increase acid resistance. Other materials used for HEPA filter media for filters with particular duties include; acrylics, activated carbon, aluminium wire screen, electrostatic fabric, polyurethane, polyester and poly/cotton.

The filtration elements of most HEPA filters are constructed in the same way – a continuous length of paper folded in pleats with corrugated separators (typically made of thin sheets of aluminium ~0.1mm thick) placed between each fold (Figure A.4). Seperatorless and 'mini-pleat' HEPA filters, which give strength to the medium by corrugation, are used to maximise filter airflow capacity by using greater areas of filter paper in a given filter casing size, although such filters are more susceptible to premature clogging than more conventional designs.

Figure A.4 Typical HEPA Filter Designs



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