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Requirements and methods for low and intermediate level waste package acceptability

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FOREWORD

Radioactive waste management requires, as any other industrial activity, planned and systematic actions to provide adequate confidence that the entire system, processes and the products involved will satisfy given requirements for quality. The primary responsibility for the quality in terms of the achievement of specified requirements rests with the waste producer. To achieve the overall protection goals set by the regulatory authorities, quality assurance has to take place in every phase of waste management. At present, efforts to implement such measures are, to a certain extent, concentrated on waste conditioning in order to provide assurance that a waste package produced can comply with waste acceptance criteria developed for a repository and thus the safety of waste disposal is ensured.

The present report was prepared as part of the IAEA's programme on quality assurance and quality control requirements for radioactive waste packages. It outlines the quality assurance requirements and methods for the processes of conditioning low and intermediate level waste and complements IAEA-TECDOC-680, "Quality Assurance Requirements and Methods for High Level Waste Package Acceptability". Both publications are relevant to the Technical Reports Series No. 376, "Quality Assurance for Radioactive Waste Packages", which provides general guidance on the application of quality assurance to the waste conditioning process irrespectively of the activity level of radioactive waste. Emphasis in the present text is placed on appropriate quality assurance actions to be taken in order to avoid the need to carry out extensive non-destructive examination and, possibly, destructive examination of these packages.

A draft of this report was prepared by consultants to the IAEA with the assistance of V. Tsyplenkov of the IAEA Division of Nuclear Fuel Cycle and Waste Management. It was reviewed by the Technical Committee in October 1993 and finalized by M. Robinson of the United States of America and C. Thorns of the United Kingdom. The IAEA would like to express its thanks to all those who took part in the development of the report.

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1. INTRODUCTION

1.1. BACKGROUND

The handling, storage and treatment, including minimization and volume reduction, of radioactive waste[1] arising from all types of nuclear and other waste generating activities is of great importance. The subsequent conditioning, transportation, interim storage and disposal of this waste needs to be managed in such a way so as to protect human health and the environment in accordance with the ICRP recommendations and national regulatory standards, and without imposing undue burdens on future generations. Appropriate methods of quality assurance (QA) must be applied to all activities prior to and following generation of waste right through to its acceptance at a repository for disposal in order to assure the safe management of radioactive waste including disposal.

To assure the safety of waste disposal, radioactive waste undergoes some form of immobilization and packaging, in a controlled and properly managed manner. Both the waste form and container are important for the safety of waste packages during handling and interim storage, as well as the post-closure phase of a repository. Their performance needs to be specified and assured if the waste package is to be accepted for disposal.

The parameters of a waste package can be specified in a document usually referred to as a "waste package specification". This document can be used to address points arising from the consideration of:

- the "waste acceptance criteria" (WAC) established by the repository operators governing the disposal of waste packages;
- regulations covering the transportation of radioactive packages issued by appropriate regulatory bodies;
- requirements arising from safety assessments covering the handling and storage of waste packages prior to their dispatch to a repository for disposal.

Assurance that a waste package can meet and thus comply with the requirements of a waste package specification can only be provided if the development and design of the conditioning process and waste package, as well as the actual production of waste packages, is carried out under a QA programme covering all stages of waste management.

The IAEA has already published information on the subject of quality assurance for waste packages [1], the principles and objectives of a quality assurance programme [2] and quality assurance requirements and methods for high level waste package acceptability [3]. It is recognized by the IAEA that guidance on the quality assurance requirements and methods for assuring the quality of low and intermediate level waste packages is also necessary, and this report is intended to fulfil this purpose.

1.2. OBJECTIVE

The objective of this publication is to provide guidance on arrangements and process controls to be applied for the conditioning process in order to assure that the waste packages produced meet identified waste acceptance criteria governing their disposal. Guidance is also provided on the establishment of waste acceptance criteria and the development of waste

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[1]The term "waste" used hereinafter will mean "radioactive waste" unless otherwise specified (i.e., exempt waste, non-radioactive waste, hazardous waste, etc).

package specifications to demonstrate how compliance with these criteria will be achieved for different packages.

This publication shows how the application of appropriate QA methods and practices can be used in conjunction with the effective control of the conditioning process to assure the quality of waste packages produced for both interim storage and disposal, thereby avoiding the need to carry out extensive non-destructive examination and, possibly, destructive examination of these packages.

This publication is intended to be used by all organizations involved in the waste management process, including waste generators, operators of conditioning facilities and repositories and the national authorities and regulatory bodies responsible for overseeing the whole process. It is also intended that this publication will promote the exchange of information and greater international harmonization of QA requirements and the application of control methods to the management of low and intermediate level wastes.

2. WASTE CONDITIONING, WASTE FORMS AND CONTAINERS

2.1. INFLUENCE OF DISPOSAL STRATEGIES ON WASTE CONDITIONING REQUIREMENTS

Waste conditioning requirements are derived from waste disposal strategies and associated disposal facility assessments. In general, it may be stated that solid or solidified low level waste (LLW) is intended for disposal in near surface disposal facilities and intermediate level waste (ILW) containing significant amounts of alpha emitting radionuclides is intended for geologic repositories[2].

Near surface disposal facilities generally establish waste stabilization and confinement requirements based on the activity and half-life of radionuclides in individual waste types to be accepted for disposal. For near surface disposal facilities, stabilization and confinement requirements generally define three categories of low level waste:

(1) waste not requiring stabilization,
(2) waste to be stabilized due to physical form, and
(3) waste to be stabilized due to activity and half-life of radionuclides.

Unstabilized low level solid waste is usually comprised of relatively innocuous materials (laboratory and industrial trash, activated metals, decommissioning waste, etc.) contaminated with low activity, short lived radionuclides. Such wastes are expected to decay to harmless levels prior to the end of the period of institutional control of the disposal facility post-closure phase (i.e. within 100 years).

Low level waste which is stabilized because of its physical form (only) is also expected to decay to harmless levels within 100 years, but require stabilization to ensure the structural stability of the disposal facility itself or because of its amenability to dispersal or migration in the event of a release. Such waste includes liquid and gaseous wastes and waste forms containing significant amounts of respirable particulates.

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[2]It is recognized that low concentrations (i.e. <400 Bq/g) of long lived alpha emitters and short lived ILW below certain activity levels are acceptable for near surface disposal in some Member States [19].

Waste containing radionuclides of sufficient activity or longevity (>30 years half-life) to pose a hazard to inadvertent intruders after the period of institutional control of the disposal facility generally requires stabilization and a specified minimum container life (confinement) in the disposal facility environment. The disposal facility may also introduce additional confinement measures (e.g. engineered barriers) for such waste subsequent to their emplacement.

Intermediate level waste intended for disposal in geologic repositories may also be divided into three categories based on stabilization and confinement requirements:

(1) heterogeneous waste not requiring stabilization,
(2) waste requiring stabilization and confinement due to activity or longevity of radionuclides, and
(3) waste requiring special packaging and shielding due to handling requirements during the operational phase of the repository (e.g. to reduce surface dose rates to below 2 mSv/h as prescribed by the transport regulations).

Some heterogenous wastes may not require stabilization due to the inherent stability of the waste form (decommissioning wastes, contaminated metals, etc.) or the repository design not requiring container integrity in the post-closure phase. Waste containing long lived radionuclides and/or activity levels such that (1) migration to the accessible environment is credible, or (2) the waste might pose a hazard to inadvertent intruders during the post-closure phase are generally required to be stabilized. Wastes of sufficient activity in terms of surface dose rate to pose an operational hazard generally require special packaging (and perhaps shielding or encapsulation in a matrix performing a shielding function) for both operational and transport reasons.

It should also be noted that both LLW and ILW may require treatment and/or stabilization because of non-radiological hazardous constituents or characteristics. This determination will be a function of the disposal facility design and performance assessment, and regulatory requirements of individual Member States.

In some cases, a disposal strategy has not yet been developed for certain wastes, and consequently these wastes are currently packaged for interim storage only. Such wastes include those awaiting further disposition, and wastes in Member States that have not yet constructed disposal facilities. In such cases stabilization and confinement requirements may be directed toward safe storage till the advent of a disposal strategy.

2.2. DERIVATION OF REQUIREMENTS FOR TREATMENT, CONDITIONING AND CONTAINER INTEGRITY

Although in some Member States requirements for waste treatment/stabilization to eliminate non-radiological hazardous characteristics/constituents are fixed by law, in general, waste stabilization and confinement requirements are derived from disposal facility design and assumptions of the performance assessment. If the disposal facility design assumes, for instance, that waste containers provide no confinement in the post-closure phase then container qualification in terms of design life is not important. If, on the other hand, disposal facility performance assessment takes credit for container integrity for an extended period (>50 years, for example) due to its material of construction and the structural stability of the waste form, it is important that this integrity to be assured.

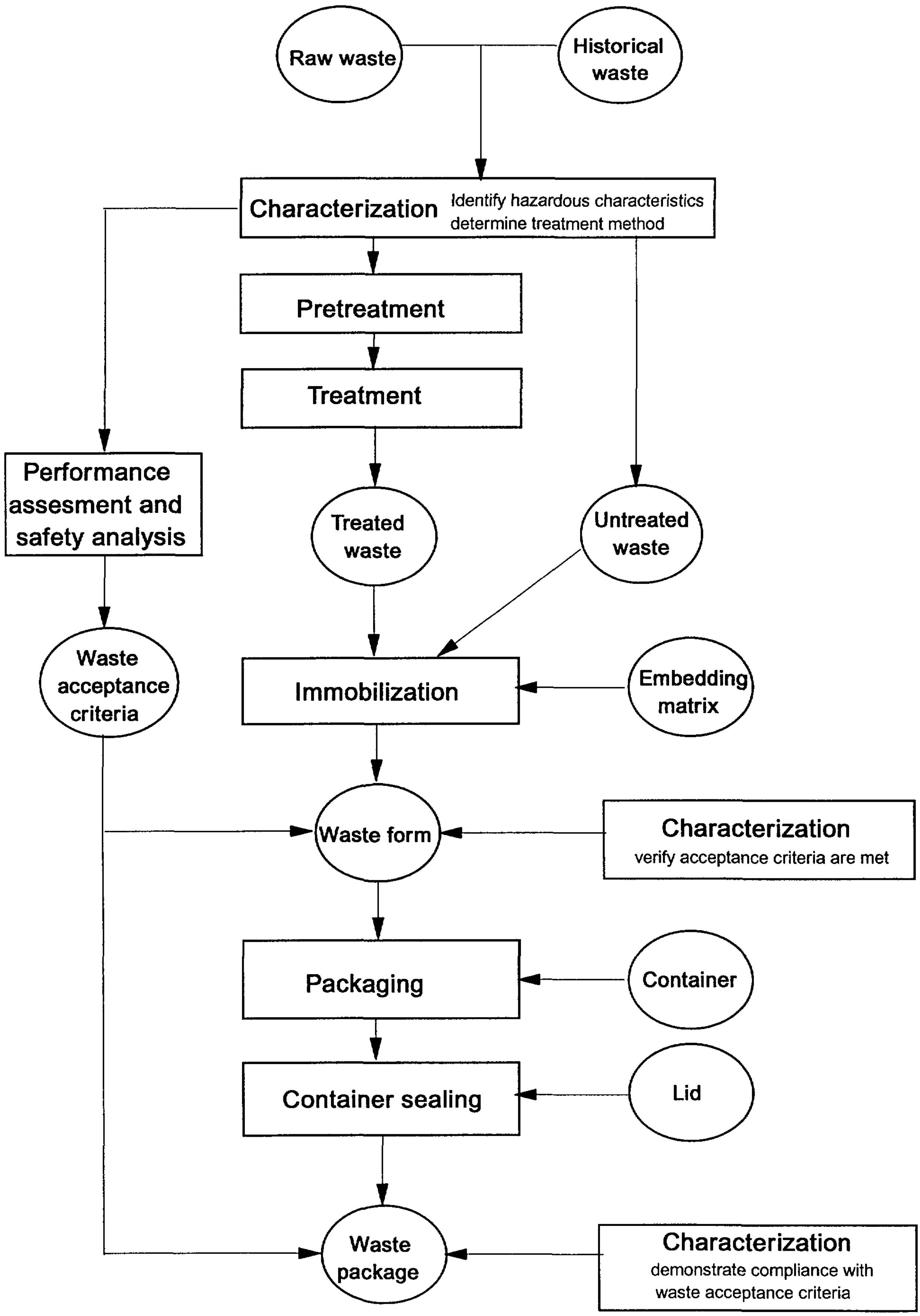


FIG. 1. Simplified diagram of a waste conditioning process.

Assumptions of the performance assessment and disposal facility design requirements related to waste conditioning will address all waste radiological, physical, chemical, and biological characteristics which must be quantified in order to demonstrate that waste can be safely disposed of over the period of time that it remains hazardous. These assumptions are generally synthesized in waste acceptance criteria as discussed in Section 3 of this report.

2.3. PRETREATMENT, TREATMENT AND IMMOBILIZATION TECHNOLOGIES

A number of methods exist for the pretreatment, treatment and immobilization of LLW and ILW to be disposed of in both near surface and deep geological repositories. These methods generally involve some form of initial waste treatment, including volume reduction, and immobilization, including micro or macro encapsulation, followed by placement of the waste in a container. A general management scheme is shown in Fig. 1.

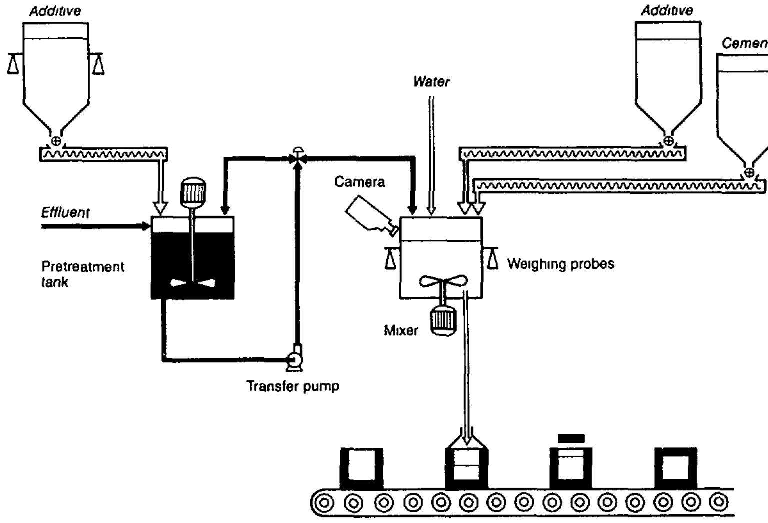
Initial treatment processes for liquid waste may include chemical processes to eliminate hazardous constituents (e.g. reduce Cr^{+6} to Cr^{+3}) or neutralize hazardous characteristics (i.e. corrosivity or reactivity). Other pretreatment methods may include incineration (volume reduction), thermal stabilization (i.e. oxidation of pyrophoric materials such as plutonium hydrides or elemental calcium) and various dewatering processes. Pretreatment to render materials suitable for further immobilization processes may involve several homogenization techniques including shredding (at ambient and low temperature) or other size reduction processes.

The most commonly used waste conditioning processes are:

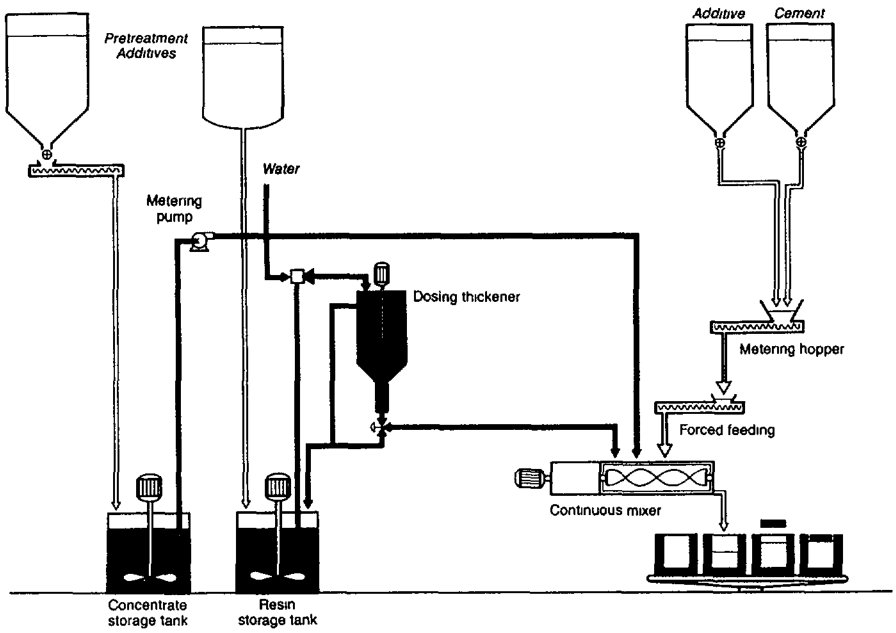
(a) Placement of solid waste in a container with or without compaction.
(b) Placement of solid or liquid waste in a container and immobilizing it within a suitable matrix (bituminous, cementitious, polymerous, etc.).
(c) Mixing of liquid waste with an immobilization matrix and pouring the mix into a container.
(d) Supercompaction of containers already filled with solid waste which has not been immobilized and then placing several of them at a time in another container with or without the addition of an immobilizing matrix.

For LLW and ILW a number of immobilization processes are available including cementation, bituminization, polymer fixation, vitrification and supercompaction. All immobilization processes should be performed in accordance with systematic procedures that use appropriate controls and instrumentation to demonstrate that the solidification system can operate within the specified boundaries. Brief descriptions of immobilization processes are provided below.

(a) Cementation is the most widely applied technique for the immobilization of low and intermediate level radioactive waste. An extensive review of cementation methods currently used is given in Ref. [5]. The quality of the final cemented waste forms depends very much on the composition and the type of the waste. Various kinds of additives and chemicals are used to improve the cemented waste form. Cementation processes include both automated in-line and in-container mixing, as well as manual glovebox procedures for batch processing of small volumes of wastes. Examples of the advanced batch and continous systems are given in Fig. 2. Batch processes often require more scrutiny and control to assure a satisfactory product. The sensitivity of the cementation process to changes in waste composition, proportions of the mix and



(a) The advanced batch system



(b) The continuous system

FIG. 2. Waste cementation processes.

variation in any pretreatment chemistry must be known, since they affect the degree of measurement and control required in feed systems for cement, waste and other components of the mix. The presence of organic materials (oils and solvents) in the waste form, in particular, can be very detrimental to curing of cement. A set of bounding values should be established for the system and waste parameters within which satisfactory solidification can be expected to occur.

(b) The bituminization process is currently being applied to a variety of wastes [5]. Discontinuous (batch) and continuous bituminization processes are used for solidification of evaporation concentrates, spent ion exchange resins, filtration sludges, sludges from chemical precipitation and concentrates from membrane processes. Simplified diagrams of the both processes are shown in Figs 3 and 4. While QA procedures must be included throughout the entire process, it is important to identify those steps which require special consideration. Generally, the process consists of mixing bitumen with the waste at elevated temperatures. The water, if present, is evaporated and the residual particles are uniformly coated with a thin layer of bitumen. Subsequently, the mixture cools and solidifies. Parameters to be considered are chemical composition of the waste and drum filling operations. For example, treatment of a waste containing certain chemicals may result in an undesired exothermic reaction.

(c) The polymer fixation process consists of mixing a polymer with the waste [6]. The polymerization processes do not really solidify the waste; the long chained molecules of the organic polymer are linked together to form a porous sponge that immobilizes the waste. Polymer encapsulation has proven particularly effective in encapsulation of boric acid, sodium sulphate, and ion exchange resins, all of which are not amenable to cement or bitumen encapsulation. The solidification of the waste can be either at ambient temperature with suitable catalyst to promote polymerization or at higher temperature to achieve rapid reaction times. A flowsheet of incorporation of ion exchange resins into polymers is shown as example in Fig. 5.

(d) Vitrification was developed mainly for liquid HLW [7] but it is also applicable for ILW. Use of molten glass furnaces is also being investigated a means of volume reduction for combustible LLW and ILW wherein ash is incorporated in a glass matrix [8]. Liquid waste solution is evaporated and mixed with silicates and borates or other suitable meltable salts. After homogenization, the mixture is melted and poured to special containers to cool and solidify. The glass produced exhibits extremely low leachability and good thermal and radiation stability. A further advantage of this process is a large total waste volume reduction.

(e) Supercompaction provides both volume reduction and a certain degree of stabilization of heterogenous wastes [8]. Supercompaction of existing waste containers often provides as much as 16:1 volume reduction. When supercompacting wastes containing fissile materials it is important that criticality safety analysis considers increased reflectivity of plastic in waste matrices as well as geometry changes accompanying compaction. It is also important to consider overall container limits on thermal heat output and gas generation when consolidating multiple containers (packs) into one.

(f) Other conditioning processes under development include micro-wave melting, oxygen sparging and various pyrochemical and chemical processes, the processes formerly used for actinide recovery in production facilities [8].

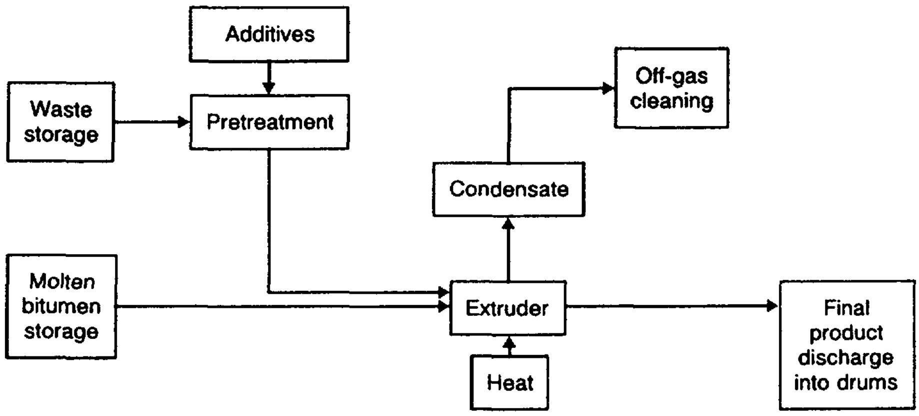


FIG. 3. Simplified diagram of an extrusion bituminization process.

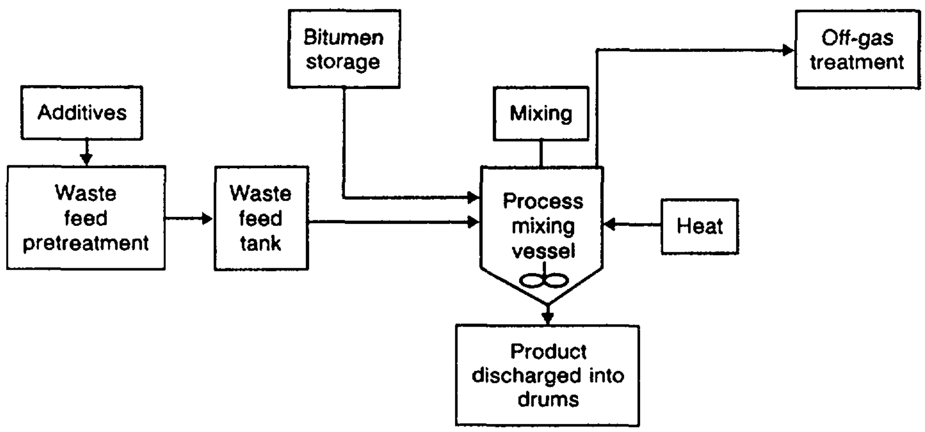


FIG. 4. Simplified diagram of a batch bituminization process.

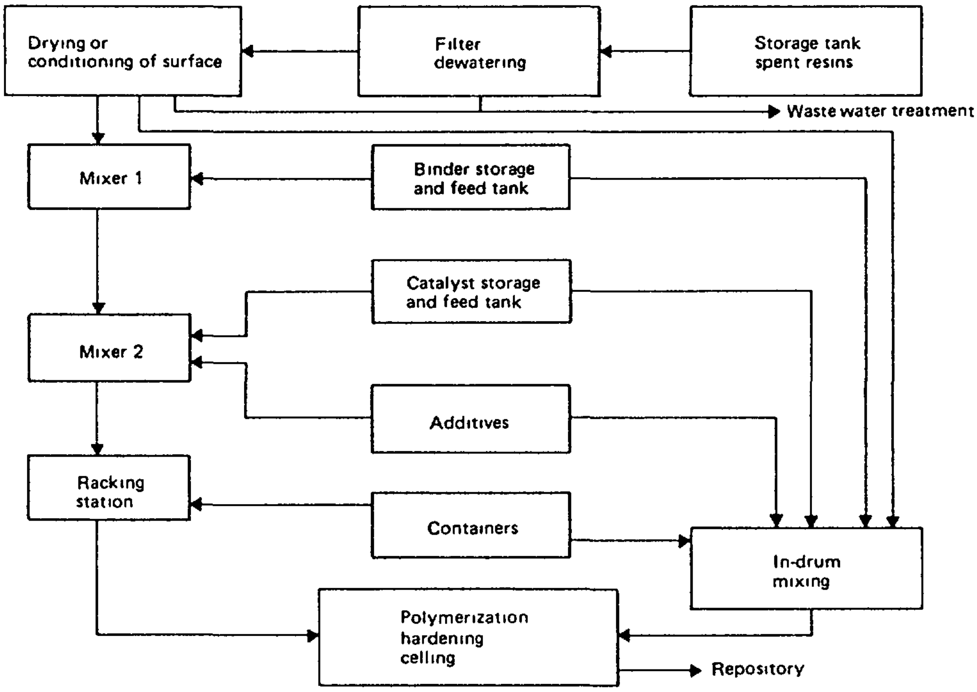


FIG. 5. Principal flowsheet for embedding spent ion-exchange resins into polymers.

2.4. CONTAINERS AND WASTE PACKAGES

The waste package consists of the waste form and container. The function of the container is to provide a fixed volume into which the waste, either raw or encapsulated in a matrix, can be fed during the conditioning process. Also, the container can be used as a processing vessel, as a filter housing during the dewatering of sludges and ion exchange resins, or it can be used for the compaction of solid waste. Regardless of intended life in the disposal facility, containers must provide confinement during conditioning, interim storage, transport, and disposal during operational phase of the disposal facility. The container must meet specifications and be compatible with the waste form, as further detailed in Ref. [9].

Where containers are required to provide a confinement function in the disposal facility environment for extended periods (e.g. >50 years), container integrity becomes more important and more stringent, controls should be applied to its design, manufacture and testing. Such containers generally are intended for longer-lived radionuclides and are typically of stainless steel or concrete construction.

Waste packages must be designed in such a way as to comply with safety and waste acceptance requirements. Waste packages are generally designed considering both waste form stability and container durability and analyzed in relation to their synergistic responses to interaction with the near field disposal facility environment.

Where the disposal facility does not require containers to provide confinement in the post-closure phase, containers are typically classified as non-durable and their qualified life is only a few tens of years (up to 50). Such containers are generally used for relatively short lived wastes or where the repository is assumed to provide the primary confinement function.

Examples of typical waste packages include supercompacted wastes in a cement matrix in a steel drum, debris placed into a container without treatment or immobilization, encapsulated debris in a concrete container (see Fig. 6).

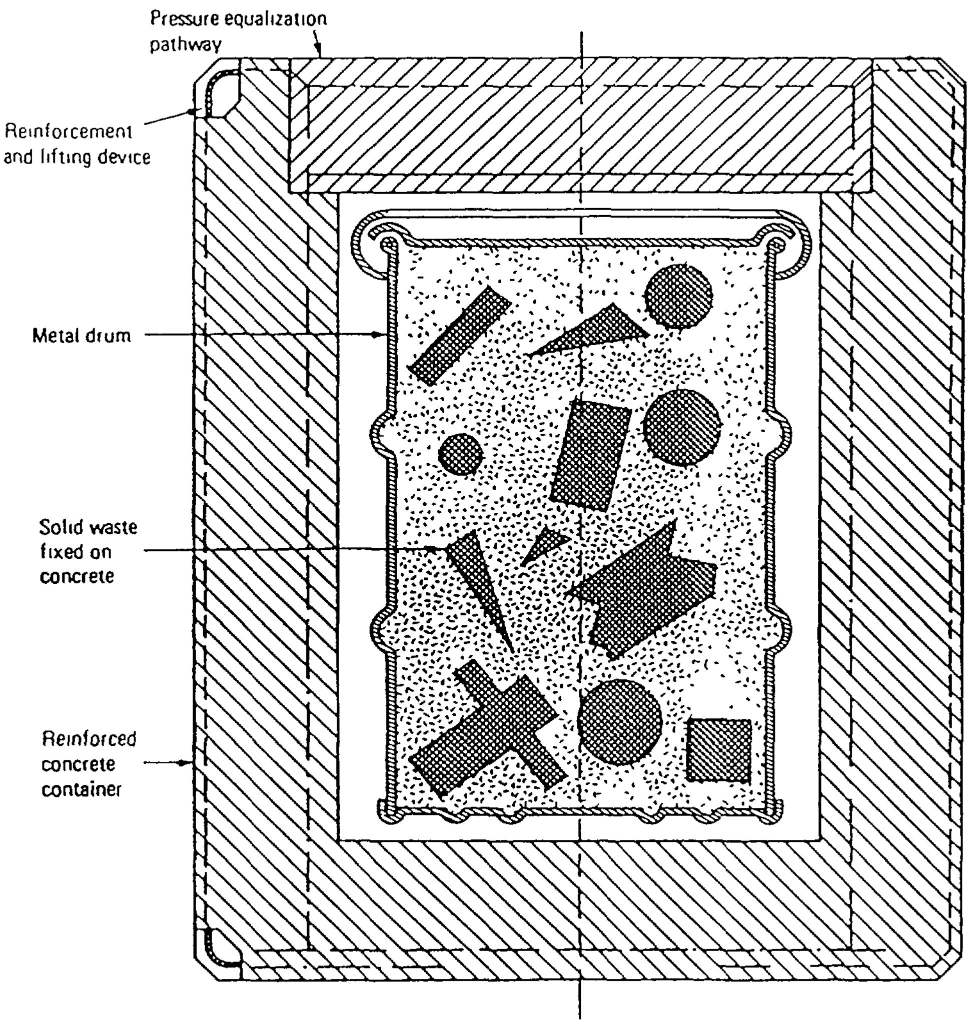


FIG 6. Concrete container with a steel drum inside.

3. WASTE ACCEPTANCE CRITERIA

3.1. BASIC CONSIDERATIONS

Waste acceptance criteria should be developed to ensure the safe transportation, handling, storage and disposal of waste packages. They are generally facility or site specific and may embrace many different types of package. Establishment of these criteria is the responsibility of the repository or interim storage facility operator in conjunction with the relevant national authorities/regulatory bodies.

A waste package specification on the other hand is specific to a particular type of package, and used to define the characteristics and attributes of a waste package. Where a final disposal route (i.e. repository) has been chosen, these specifications should embrace the requirements of the waste acceptance criteria for that facility. Hence, any waste package which meets the requirements of the waste package specification automatically satisfies those relating to its disposal or storage. Establishment of these specifications is generally the responsibility of the operator of a conditioning facility. Where they embrace the waste acceptance criteria of a repository or interim storage facility, then approval of these specifications by the disposal facility operator may be sought.

Where the establishment of waste acceptance criteria for the disposal of waste packages is not possible, due perhaps to the absence of a final disposal route, then the waste package specification should be used for determining the quality of packages produced. In such circumstances, these specifications should anticipate, in so far as it is possible, eventual waste acceptance criteria, so as to minimize any future re-conditioning needs.

3.2. DEVELOPMENT OF WASTE ACCEPTANCE CRITERIA

Development of waste acceptance criteria should be carried out in parallel with the development of the disposal route for the waste. Waste acceptance criteria should be derived from consideration of both operational requirements (e.g. handling) as well as those contained in the safety assessment for the repository necessary to achieve the safety of waste disposal. These criteria should be quantitatively or qualitatively based such that conformance can be either assessed by direct measurement and/or assured by application of appropriate management methods and controls during the conditioning process.

Once formulated, waste acceptance criteria should not be subject to unnecessary change, to avoid imposing further requirements on waste conditioners which might prove difficult to comply with once conditioning facilities have been designed and built and waste package specifications established.

Guidance on the establishment of these criteria is available in Ref. [10].

3.3. COMPLIANCE WITH WASTE ACCEPTANCE CRITERIA

Compliance with waste acceptance criteria generally requires a two stage approach, namely:

(i) Definition of a waste package's characteristics and attributes, including performance data (compressive strength, load bearing capability, resistance to impact, corrosion, fire resistance, etc.) and identification of quality related parameters which need to be controlled, including details of the arrangements for controlling them, in order to provide assurance of conformance to identified waste acceptance criteria.

(ii) Confirmation of the conformance of individual waste packages to the requirements of a waste package specification.

Information on waste packages characteristics and attributes is usually contained in the waste package specification prepared by the operator of a waste conditioning facility. Separate specifications should be used for each waste source and each type of container and immobilizing matrix. Each specification should include:

- an introduction describing the purpose and scope of the specification;
- details of the procedures for ensuring compliance with the requirements of the specification;
- details of the contents of the raw waste (e.g. the results of a waste characterization programme);
- a description of the container and details of the manufacturing specification;
- a description of the processes used to treat/condition the waste, including in the latter case, details of the specifications for all immobilizing matrices used;
- the results of work carried out to assess and demonstrate the integrity of the waste package;
- a table summarizing those quality related parameters identified as critical to the achievement of waste package quality, with details of either the limiting values or range of acceptability assigned to them;
- an example of the data sheet to be prepared for each waste package.

Each specification should be uniquely identified and controlled in respect of its issue and revision.

Waste package specifications should be submitted to the repository operator for acceptance prior to the dispatch of any waste packages for disposal. The nature and content of the information contained should be sufficient for the repository operator to confirm that waste packages conforming to this specification will satisfy the waste acceptance criteria.

Confirmation of the conformance of individual waste packages to the requirements of a waste package specification can usually be addressed by the preparation of a data sheet for each waste package, which can then be included with the documentation accompanying each consignment of waste packages dispatched to a repository.

A list of the full range of information which might need to be provided for individual waste packages is given below:

- Package identifier/number
- Type and variant
- Specification (e.g. waste package specification reference)
- Name of the conditioning plant and site
- Date of conditioning
- Raw waste content and details on:
  · category (i.e. ILW or LLW)
  · source
  · description
  · radiological characteristics

  - physical characteristics
  - chemical characteristics
  - biological characteristics
  - typical waste content (weight) per container (kg)
- Container details
  - type and variant
  - manufacturing specification reference
- Immobilizing matrix details (where applicable)
  - type
  - specification
- Capping matrix details (if applicable)
  - type
  - specification
- Activity content
  - total alpha (Bq)
  - total beta-gamma (Bq)
- Dose rate
  - at the surface (Gy/hour)
  - at 1 metre (Gy/hour)
- Heat rating (watts)
- Surface contamination
  - total alpha (Bq)
  - total beta-gamma (Bq)
- Overall package weight (kg).

However, where conformance to the requirements of a waste package specification can be demonstrated, then it will usually be sufficient to list only that information which is specific to a single package (e.g. values of radionuclides above the specified threshold recording level (TRL), and allow the description in the waste package specification to cover the remaining information.

Table I lists the key waste acceptance criteria which need to be addressed by both the waste package specification (to demonstrate a general compliance with the waste acceptance criteria for a specific type of package to be consigned to a particular repository or interim storage facility), and the waste package data sheet (to demonstrate compliance of individual waste packages with the requirements of the waste package specification). The methods which may be used to address these criteria are described and discussed in Section 4.

3.4. SPECIAL CASES WHERE FULL COMPLIANCE WITH WASTE ACCEPTANCE CRITERIA CANNOT BE DEMONSTRATED

Some waste packages may not be capable of meeting some or all of the identified waste acceptance criteria. This can be the case for wastes that have been produced before the disposal route has been fully established or for those wastes produced in small quantities, for which all the required information for acceptance for disposal or interim storage cannot be provided.

Acceptance of these waste packages for disposal or interim storage cannot therefore rely on pre-established requirements, such as waste acceptance criteria. A "case by case" approach on their suitability for final disposal should be adopted, using all available information and taking into consideration the number of waste packages concerned.

TABLE I IDENTIFICATION OF CRITERIA THAT NEED TO BE ADDRESSED BY
(I) WASTE PACKAGE SPECIFICATION AND
(II) WASTE PACKAGE DATA SHEETS TO DEMONSTRATE COMPLIANCE WITH WASTE ACCEPTANCE CRITERIA

Waste acceptance criteria	Waste package specification (General demonstration of compliance)	Waste package data sheet (Individual demonstrations of compliance)	Cross references to relevant paragraphs in Section 4
1 GENERAL			4 2
Quality Assurance Programme	A description of the arrangements established by the operator of a waste conditioning facility to ensure the effective management and control of all parameters identified as critical to the achievement of waste package quality, including details of the arrangements for the certification of waste packages against the requirements of the waste package specification and independent verification of this This description should cover all activities, events and resources necessary to ensure compliance with the requirements of this specification	Certification by those responsible for the operation of conditioning facilities or the conformance of individual waste packages with requirements identified in the waste package specification	
Compliance with statutory and regulatory requirements	Arrangements to ensure compliance with identified statutory and regulatory requirements should be included within the quality assurance arrangements described above		
2 WASTE CHARACTERIZATION			4 3
General description of the raw waste Physical, chemical and biological properties - Radionuclide content - Fissile content	A written description of the waste should be provided along with details of its source, ownership volume (m^3) and weight (tones) The characteristics and composition of the raw waste should be identified and where possible quantified with sufficient accuracy to allow compliance with the waste acceptance criteria to be determined Limits should be established for those radionuclides and other properties which could adversely affect the suitability of a waste package for disposal Where appropriate, threshold recording levels (TRL's) may be used to identify when quantified information on individual radionuclide is recovered For all components present in the waste, average and limiting values for an individual waste package should be defined along with a maximum limit of fissile content to safeguard against criticalities	Confirmation that the raw waste content of a waste package is within the limits defined in the waste package specification should be given Actual values for those radionuclides and other critical components of the waste which exceed the identified TRL's should be recorded Where fissile material is present, then it should be confirmed that it is within the permitted fissile mass limit	

Waste acceptance criteria	Waste package specification (General demonstration of compliance)	Waste package data sheet (Individual demonstrations of compliance)	Cross references to relevant paragraphs in Section 4
3 CONTAINER			4 4
Description (including dimensions) Properties Weight	A description of the waste container to be used to hold the conditioned waste should be provided, using drawings where possible, along with details of its mechanical and physical properties Reference to a manufacturing specification should be included and the weight of the container empty given	Confirmation that the container conforms to the requirements of the manufacturing specification should be given, with reference to a manufacturing release certificate where possible (to provide access to manufacturing records if necessary) and details of any manufacturing concessions granted	
4 TREATMENT/CONDITIONING			4 5 and 4 6
Details of the conditioning process, including arrangements for controlling the following - Free liquids - Powders - Explosives and compressed gases - Toxic metals and compounds - Hazardous materials - Complexing agents - Organics - Fissile materials - Activity content Plus details of any treatment carried out on the waste before conditioning	A technical description of the conditioning process, illustrated by process flow diagrams where possible, should be given Parameters critical to the achievements of waste package quality should be identified and a description of the arrangements for monitoring and controlling them given If the waste is to be subject to any pretreatment then the purpose and nature of it should be described Where any of the substances listed opposite are likely to be present in the waste then a description of the arrangements for controlling and limiting their inclusion in accordance with any limits specified in the waste acceptance criteria should be given Likewise, where the waste includes fissile material, then the quantity that can safely be incorporated into a package should be determined, and shown to comply with any limits specified in the waste acceptance criteria The arrangements for controlling the amount of fissile material in individual packages should be described Finally, the average and maximum activity content for individual packages should be specified Where the maximum expected activity could exceed any limit specified in the waste acceptance criteria or regulations governing the safe handling, storage and transportation of packages, then arrangements for monitoring and limiting the activity content of individual packages should be described	The date of conditioning of the waste, the site and plant in which it was carried out, should be recorded on the data sheet with confirmation that the package was conditioned in accordance with the requirements of the conditioning process	

TABLE I (cont)

Waste acceptance criteria	Waste package specification (General demonstration of compliance)	Waste package data sheet (Individual demonstrations of compliance)	Cross references to relevant paragraphs in Section 4
Details of any immobilizing matrix used including the matrix specification and arrangements for control of quality related parameters	A description of any matrix used to immobilize the raw waste, or elements within it, comprising, - identification of the waste to be immobilized - details of any pretreatment carried out on the waste - *specification for the immobilizng matrix including* its composition ratio rate to immobilized product percentage voidage and degree of homogeneity within the final product compressive strength - results of tests to assess the aspectablity of final product to leaching and release of included radionuclides - identification of those parameters where need to be controlled in order that the final product conforms to the specification and a description of the arrangement for monitoring and controlling them The degree of detail included in this description should be sufficient to allow a technical assement of matrix's compliance *with the requirements of the waste acceptance criteria to be* carried out	Confirmation that any immobilizing matrix used meet the requirements of the specification concermed should be given	
5 WASTE PACKAGE			4 7
Package type and variant	The package type and variant should be defined	The package type and variant should be recorded on the data sheet	
Demonstration of package integrity covering - Mechanical strength - Resistance to impact - Radiation stability - Fire resistance - Voidage - Durability - Resistance to leaching	The results of work carried out to assess and demonstrate the integrity of the waste package against each of the identified requirements should be reported		
Package identification, labelling and marking	The system to be used to mark/label packages should be described along with details of the assignment of a unique identifier (numeric, alpha-numeric or bar code) to each package	The package identifier should be clearly marked on at least two faces of the container and recorded on the data sheet	

Waste acceptance criteria	Waste package specification (General demonstration of compliance)	Waste package data sheet (Individual demonstrations of compliance)	Cross references to relevant paragraphs in Section 4
Records	Those records essential to demonstrating conformance of the waste package to requirements contained in the waste package specification should be identified and both the format and information to be provided for indivdial packages defined	Completion of the data sheet as defined in the waste package specification	
6 HANDLING, STORAGE AND CONSIGNMENT			4 8
Package weight	The maximum weight of an individual package should be specified and shown to be compatible with any limit specified in the waste acceptance criteria and/or requirements for the handling of waste packages The method of determining this limit should be defined Arrangements for determining the weight of each package or verifying that it is within the limit specified should be described	The weight, surface contamination levels and dose rate of each package should either be measured or confirned as being within the limits given in the waste package specification, and recorded on the date sheet on completion of conditioning	
Surface contamination	The maximum limit for surface contamination of a package should be defined This should be shown to be compatible with any limit specified int he waste acceptance criteria and/or requirements for the same handling, storage and transportation of the package The method of determining the limit should be defined Arrangements for determining the surface contamination levels of each package on verifying that they are within the limits specified should be described		
Dose rate	The average and maximum dose rates for an individual package should be specified These are usually quoted for both the surface of the package and at a distance of 1 metre from it The method of determination should be defined and the specified dose rates shown to be compatible with any limit specified in the waste acceptance criteria and/or handling, storage and transportation requirements Arrangements for determining the dose rate of each package, or verifying that they are within the limits specified should be described		
Storage	Where a package is to be held in interim storage prior to disposal, then a description of the storage facility and the arrangements for monitoring the condition of packages and minimizing any deterioration in their condition should be described	The period of any interim storage of a package should be recorded on the data sheet together with details of where it has stored	

TABLE I (cont)

Waste acceptance criteria	Waste package specification (General demonstration of compliance)	Waste package data sheet (Individual demonstrations of compliance)	Cross references to relevant paragraphs in Section 4
Transport	Arrangements for preparing the package for transport to the repository and demonstrating complinace with national and if necessary internatinal regulations governing the transport of waste packages should be described Any documentation in addition to the package date sheet required by those regulations should be identified	Compliance with national (and where necessary international) regulations governing the transport of radioactive materials should be confirmed on the relevant documentation	
Consignment documentation	All documents and records to be handed over to the repository operator when a package is consigned for disposal should be identified and samples attached, where necessary Except where the consignment documentation used is that specified in the waste acceptance criteria, it should be shown how the documentation concerned fulfills and meets the requirements of those criteria A description of the arrangement for completing this documentatin should be given, along with details of those personal authorized to sign them	Completion of consignment documentation as described in the waste package specification	
	7 INTERIM STORAGE		4 9
Minimization of deteriorating during storage Safety during storage Retrievability	Where a package is to be held in interim storage prior to disposal then a description of the storage facility and the arrangements for monitoring the condition of packages and minimizing any deterioration in their condition should be described	The period of any interim storage of a package should be recorded on the data sheet together with details of where it has stored	
	8 RECORDS		4 10
Package data Record procedures Data traceability	The data should be determine and agreed woth the interim storafe or disposal facility operator At each stage of the waste package production	A data sheet should be produced for each waste package Information in the data sheet should be available as requested by the repository operator	

It should nevertheless be recognized, that the suitability of these wastes for acceptance in a disposal or interim storage facility should be based upon specific safety assessments, taking into account the uncertainties inherent due to the lack of available information. If the determination is made that such wastes require additional treatment, characterization, conditioning, etc., they should be controlled in accordance with para. 4.2.1.5.

4. METHODS FOR DEMONSTRATING COMPLIANCE WITH WASTE ACCEPTANCE CRITERIA

4.1. BASIC CONSIDERATIONS

In this section, the waste acceptance criteria identified in the previous section are discussed, and methods which may be used to demonstrate compliance with individual requirements recommended. In making these recommendations, it is recognized that there may be other or alternative methods for demonstrating compliance not identified here, and that further methods may become available in the future. It should also be noted that these recommendations do not attempt to address all the statutory and regulatory requirements of Member States, which should always take precedence and be complied with fully.

Where methods are recommended to obtain quantitative information they generally fall into four distinct approaches:

- Direct measurement of the waste package or its constituent parts during or at the end of the process;
- Calculation, by suitable computational methods, from direct measurement of the raw waste or the waste package;
- Determination, by correlation with measured values, which cannot be directly calculated;
- Estimation or calculation by correlation to basic research, development or commissioning information and data.

These approaches may be used either individually or in combination to demonstrate compliance with an individual waste acceptance criterion. To be valid, these approaches should be applied in accordance with accepted QA methods and practices, and be able to sustain independent assessment by both review and audit.

The precision with which measurements can be and are taken, and the accuracy of determination of parameters, whether by direct measurement or calculation, are important factors in assessing the acceptability of determined values. The more hazardous the waste the more accurate these measurements and calculations should be in order to minimize the risk that the errors present in their pose. It should be noted that as experience is gained through operation of conditioning processes, and as further technological improvements become available, such precision and accuracy can be expected to improve. The requirements which need to be considered will vary depending on the nature of the waste concerned and the method adopted for disposal.

The following sections as well as identifying the requirements which need to be considered, also contain examples of the methods which can be used to address them.

4.2. COMPLIANCE WITH STATUTORY AND REGULATORY REQUIREMENTS

4.2.1. Quality assurance programme

The waste conditioner should prepare, in writing, a QA programme detailing the arrangements to ensure the effective management and control of waste from its generation or acceptance for conditioning, as appropriate, right through to acceptance for disposal by the repository operator. The programme should detail all activities and events necessary to ensure compliance with the relevant waste acceptance criteria and all applicable statutory and regulatory requirements. Establishment of a QA programme is an important requirement of the IAEA's Safety Standards on Establishing a National System for Radioactive Waste Management [11]. (It should be noted that there may be more than one QA programme in operation for the complete waste management cycle.)

Quality assurance has a key role to play in the conditioning of wastes to produce packages which are suitable for disposal and is fundamental to the successful demonstration of compliance with identified waste acceptance criteria.

The role of quality assurance in waste conditioning is:

(a) to provide confidence that the quality of waste packages meets the requirements contained in a waste package specification through the application of appropriate arrangements;
(b) to provide assurance and information upon which the compliance of waste packages to identified waste acceptance requirements can be confirmed, thereby facilitating their disposal in a repository or storage in an interim storage facility, and
(c) to ensure compliance with the relevant statutory and regulatory requirements of individual Member States.

Quality assurance needs to be applied throughout the design and development of conditioning processes, as well as during the actual production of waste packages.

Where waste acceptance criteria for the disposal of low and intermediate level waste packages have not yet been established, then QA efforts should be directed either towards compliance with preliminary waste acceptance criteria or the waste package specification approved by the repository operator.

Method: Establishment of a QA programme and associated procedures and instructions which address all applicable waste acceptance criteria requirements and conforms with the IAEA's Code on the Safety of Nuclear Power Plants [12] taking into account the guidance contained in Ref. [1].

Quality assurance programmes should address all activities that may affect quality including compliance with waste package acceptance criteria, including research and development of the waste package and associated conditioning process, conditioning facility design, construction, testing and commissioning, as well as the production, handling, storage and transportation of waste packages to an interim storage or a disposal facility.

Quality assurance programmes should meet the requirements of national authorities, regulatory bodies, applicable national and/or international codes and standards. For the packaging of waste it is recommended that the QA programmes should include the following elements:

- organization and responsibilities;
- training and qualification of personnel;
- procedures and instructions;
- document control;
- research and development;
- design, construction, testing and commissioning of conditioning facilities;
- procurement;
- process control;
- inspection and testing of conditioning facilities during operation;
- non-conformance control and corrective actions;
- records;
- audit;
- management review.

Guidance on the establishment of a quality assurance programme is provided in Ref. [2] and should be referred to as necessary, whilst specific information on how to address those elements unique or of special interest to waste packaging is given in the following paragraphs.

4.2.1.1. Responsibilities

Responsibility for the achievement of the waste package quality rests with those responsible for the operation of the conditioning facility (operators) and, more specifically, with those individuals who perform the actual work. Certain aspects of the QA programme including auditing and review whilst carried out by facility personnel (or other delegated organizations) should be conducted independently from production interests.

All activities may be subject to the inspection/surveillance by the responsible national authorities and regulatory bodies. However, these regulatory inspections should not be considered as dismissing the responsibilities of the operator.

Where the waste generator employs the services of a contractor to carry out activities in respect of the waste conditioning and, possibly, storage of waste on his behalf, the contractor is responsible to the waste generator for the establishment and application of appropriate quality management procedures and controls. The waste generator should satisfy himself as to the adequacy of the contractors QA programme.

The waste conditioner has a responsibility to ensure and thus demonstrate that his conditioning process can produce waste packages which meet the waste acceptance requirements of the repository or interim storage facility imposed by the operator. The QA programme of the operator of a conditioning facility should include:

(a) a description; and
(b) details of the arrangements for verifying conformance of waste packages to the identified waste acceptance requirements.

The repository operator should ensure that the waste packages comply with the waste acceptance requirements before accepting them for disposal. This may be achieved by:

(i) approving the conditioning process and the associated procedures for controlling it, and ensuring package quality, and then carrying out periodic audits of these arrangements to confirm compliance;
(ii) performing analyses and tests on samples taken from key stages of the waste conditioning processes and from waste packages; or
(iii) a combination of these two approaches.

Verification by sampling may be performed at either the repository, the conditioning facility, or an independent laboratory. Likewise, auditing of consignors QA programmes may be carried out by the repository operator or by a contractor employed by him. Alternatively, independent third party certification of these arrangements may be used to avoid the need for compliance auditing by the repository operator and duplication of audits, verification of this being left with the certification body instead. In accepting a waste package, the responsibility for its safe disposal is usually transferred to the repository operator.

4.2.1.2. Pre-operational activities

Work carried out to characterize a waste stream and develop a conditioning process to produce a waste package acceptable for safe handling, storage and disposal should be undertaken within an established set of procedures. Work associated with the design, construction, testing and commissioning of conditioning facilities should also be subject to QA programme. The results of all this work should be reported fully and documented.

4.2.1.3. Process control

The arrangements for managing and controlling the conditioning process need to be set down in a quality control plan. This document should detail all the activities, resources and events necessary to control those parameters identified to achieve waste package quality. A programme of process development and testing should be carried out to identify the parameters concerned and establish methods for their control. The effectiveness of these arrangements and controls in achieving compliance with the identified waste acceptance criteria should be demonstrated during the commissioning of the conditioning facility. The results of this work, and that associated with characterization of the conditioned waste, must lead to the availability of sufficient information to confirm that the waste package is in compliance with the waste acceptance criteria. The conditioning process should be sufficiently instrumented to achieve this. If necessary, sampling may be performed to verify the performance of these process controls.

4.2.1.4. Sampling and testing

Measures applied to confirming the waste package quality can be non-destructive and/or destructive testing of the waste forms or waste packages. Testing of ILW may require hot cells with equipment for statistically representative sampling, sample analysis and re-conditioning of the waste package. It will almost certainly produce secondary wastes, and may lead to additional radiation doses to personnel. It is recommended therefore that destructive testing of waste packages should only be used if the required information is not available and cannot be obtained by other means or for limited verification purposes.

4.2.1.5. Non-conformance and corrective actions

During or at the end of waste conditioning some individual waste packages may be found not to comply with every aspect of the waste acceptance criteria. In such situations, the waste conditioner must identify and formally document these non-conformance and identify appropriate remedial measures. These measures may include:

(a) reassessment of the parameters and the input data;
(b) re-conditioning of the waste package.

Where remedial action can be taken which will bring the waste package back within the waste acceptance criteria, then the operator of a waste conditioning facility should have the freedom to carry out such corrective actions without reference to the repository operator provided that:

(a) the proposed corrective action does not compromise other aspects of the waste acceptance criteria;
(b) the body responsible for these decisions is independent of those with direct responsibility for operation of the conditioning facility; and
(c) full records are kept of all decisions made and corrective actions taken.

Where remedial action cannot be undertaken to bring the waste package fully within the waste acceptance criteria, then resolution of the non-conformance should be discussed and agreed with the repository operator and/or the responsible national authority.

In all cases of non-conforming waste packages, full records must be kept detailing the non-conformance and any decisions/corrective actions agreed.

4.2.1.6. Records

The data obtained from the application of the overall QA programme shall be recorded and maintained (e.g. with the help of electronic data processing) by the waste generator and operators of the conditioning and disposal facilities in accordance with approved document control procedures. It should be established which records shall be permanent or non-permanent, and which data are to be exchanged between the parties involved. The storage, safekeeping, preservation and accessibility of the records has to be planned and controlled in such a way that the records cannot be lost or destroyed. Modifications must only be made in accordance with approved document control methods.

4.2.1.7. Miscellaneous

Information and guidance on other topics which need to be addressed within the QA programme, such as training and qualification, procedures and instructions, document control, procurement, audit and management review can be obtained from the IAEA's Safety Guide on Establishing and Implementing a Quality Assurance Programme [2] and the Technical Report on Quality Assurance for Radioactive Waste Packages [1].

4.2.2. Compliance with statutory and regulatory requirements

The waste conditioner should ensure that all applicable statutory and regulatory requirements are identified and addressed within the QA programme. The arrangements made to address these requirements should be acceptable to the bodies responsible for their regulation and demonstrate to the satisfaction of the repository operator, if required.

> *Method:* The above requirement may be satisfied by a schedule (or similar) which identifies the requirements concerned and shows where they have been addressed. Where these requirements are subject to approval by those bodies responsible for their regulation, then reference to documents granting such approvals should be included.

In many Member States, the national and regulatory bodies responsible for the regulation of these requirements, and for ensuring compliance with them, do not always insist upon approving the arrangements made to address them. In such instances however, they generally ensure the adequacy of such arrangements through the performance of inspections and audits to assess their effectiveness and the degree of compliance with them. In the absence of any specific approvals, confirmation of the continuing acceptability of these arrangements to those bodies will suffice to provide the assurance necessary to demonstrate full compliance with this requirement.

4.3. WASTE CHARACTERIZATION

The characteristics including composition of wastes should be known with sufficient accuracy to ensure that the waste package will comply with specified limits.

4.3.1. Origin and description

Precise information on the origin of raw waste is necessary to ensure that the correct characterization/fingerprint is used to determine radionuclide contents.

A knowledge of the origin and description of raw wastes or historical wastes are important to deciding on future conditioning and likely radionuclide contents (e.g. raw waste originating from a nuclear power plant is unlikely to contain alpha emitting radionuclides).

> *Method:* Details of the origin, description, volume and weight of raw wastes should be available from process records, plant design and research and development. When knowledge of the waste production process is necessary for understanding of the waste's physical and chemical properties, this information should also be available.

4.3.2. Radionuclide content

Information on the radionuclide inventory of raw and conditioned wastes is required to ensure that waste packages are produced within specified limits and with known activity contents. Overall package limits will be established from the safety assessment for the disposal or interim storage facility. It should be noted that disposal facility limits may impose restrictions not only on an activity level, but also related to longevity of radionuclides.

In some cases, in order to avoid unnecessary quantification of negligible amounts of individual radionuclides present, the repository/interim storage facility operator may specify threshold values for each radionuclide, below which information, other than confirmation of the presence of a particular radionuclide, need not be provided. In all cases, total package activity should be reported, however. Methods of sampling and analysis to be used by the waste generators should be appropriate and approved by the repository/interim storage facility operator.

Method 1: For automated processes, controls based upon measurement of the weight or volume of raw waste placed in a container, together with neutron and gamma monitoring to control the radionuclide content, may be used in conjunction with data recording to control and record activity content of waste packages.

Method 2: For waste forms produced in a continuous process of consistent radiological properties, radiochemical and physical analytical methods can be applied to a representative sample of the raw waste to obtain direct measurements of radionuclide content.

Method 3: For waste forms produced in a continuous process of consistent radiological properties, radionuclide inventory can be calculated using the spectrum of radionuclides present, derived by sampling and analysis and correlation to an easily measured gamma ray (e.g. ^{137}Cs, ^{60}Co).

Method 4: For heterogenous wastes or waste streams whose radiological properties vary from package to package, non-destructive assay (NDA) of individual packages must be performed. It is important that calibration standards for NDA instruments be representative of the alternative characteristics of the waste matrix and the dispersion of radionuclides within the package. It is also important that the method error be statistically quantified for each waste type and that the error be added to the measurement when determining compliance with safety related limits such as fissile material limits.

Method 5: For spent sources, activity can be calculated in terms of decay and decay products ingrowth from original source activity manufacturer's certification. The manufacturer's certification should accompany the waste package to a repository as a permanent record.

4.3.3. Fissile content

The fissile content of wastes should be controlled to ensure that subcritical conditions are maintained under all conditions likely to be encountered at any time during conditioning and to ensure that the requirements of the waste package specification are met.

Waste package fissile mass must be limited for nuclear criticality control purposes. Those radionuclides which may need to be controlled for criticality reasons include readily fissile isotopes of thorium, uranium, and transuranic elements specifically listed in Ref. [13].

Care should be taken to avoid the concentration of any remaining fissile material in conditioning processes (especially in liquid processing or volume reduction processes), such that uncontrolled quantities are inadvertently fed to individual containers. Criticality safety methods should provide for use of the double contingency principle - that is, a minimum of two independent and unlikely events should be required prior to achieving a condition wherein inadvertent criticality is physically possible. Engineered controls over geometry and spacing are preferred over administrative controls in criticality prevention.

Method 1: The inventory of fissile materials in wastes to be conditioned shall be determined. Criticality calculations should be made to establish limits for fissile materials during conditioning, and the inventory of fissile material in wastes shall be determined. Fissile mass of individual isotopes may be quantified as described in para. 4.3.2. Fissile mass equivalent may be determined in accordance with Ref. [14].

Method 2: The inventory of fissile materials in wastes to be conditioned should be determined from raw waste records. For continuous processes where radiological properties are relatively consistent, instrumental methods should be used to measure fissile material contents to supplement or provide checks in raw waste records. Where radiological properties vary from package to package, individual package fissile content should be measured. When determining the compliance of individual packages with criticality safety limits, the measurement method (e.g. NDA) error should be added to measured values.

4.3.4. Surface contamination

Non-fixed (removable) radioactive contamination on the exterior of waste packages should be maintained within the limits established for interim storage, transportation and disposal. An actual value for non-fixed radioactive contamination on the external surfaces of each waste package shall be in compliance with the established limits. If contamination levels exceed the established level the external surface of the waste package shall be decontaminated.

Method: Determination of non-fixed radioactive contamination shall be performed by direct measurement, adapted to the nature of the surface. Visual inspection of the waste package should be carried out additionally to ensure that no visible amounts of material remain adhered to the external surface of the waste package. Contamination limits are used extensively in nuclear industry practice to demonstrate that surfaces are free of non-fixed contamination. Assurance that the waste package does not exceed the specified contamination limits may be provided by a smear test of the container's external surfaces in the conditioning facility before further handling or transfer to an interim storage facility or a repository.

4.3.5. Dose rate

External radiation dose rates of waste packages should be in compliance with the limits established for the facilities and equipment in which they will be handled, stored and transported until final disposal in a repository. A limit on beta/gamma and neutron (when required or applicable) dose rate levels shall be established. The surface and 1 m distance maximum dose rates shall be determined prior to transport, interim and/or final disposal.

Method: Both gamma and neutron dose rates calculations should be performed during the design of the waste package. Experimental verification of the declared dose rate should be performed by the operator of a conditioning facility and independently verified. During production, dose rates can be measured before the waste package is transferred from the conditioning building to the interim storage facility, and again at the time of shipment, to a repository. Surface dose rate in excess of 2 mSv/h will require special measures during transport [13]. Shielding should not be used to reduce dose rates below 2 mSv/h unless the shielding was incorporated in the container qualification test configuration.

4.3.6. Physical, chemical and biological properties

Information on the physical, chemical and biological properties of raw wastes is required to ensure the safety during waste immobilization and production of acceptable waste packages.

In characterizing the physical and chemical composition of the raw waste particular attention should be paid to identifying and quantifying the presence of any of the following:

- low flash point fixed liquids
- combustible materials
- nitrated ion exchange material
- explosive materials (including pressurized containers)
- toxic materials[3]
- corrosive materials
- complexing agents
- phosphorous
- hydrides
- materials which could react with wastes to produce heat and flammable gases
- strong oxidizing agents
- pyrophoric materials
- materials capable of generation or evolving toxic gases, vapours or fumes (i.e., reactive material)
- notifiable wastes (as defined by the relevant national authority) such as asbestos, polychorinated biphenyls (PCBs), etc.
- putrefible materials
- biological, pathogenic and infectious materials, etiologic agents.

Method 1: The physical, chemical and biological properties can be determined from knowledge of the process which produced the raw waste using process records, process procedures, plant design documents, research and development records.

Method 2: Wastes may be characterized by analytical means [15].

4.4. CONTAINERS

Containers used for the production of the final waste package should be controlled to meet the waste package specifications (containers for transport purposes are dealt with in Section 4.8).

4.4.1. Description, dimensions and weight

The description, dimensions and weight of the container should be controlled to ensure that they comply with requirements for safe handling, storage and disposal as detailed in the waste package specifications. For example, the dimensions and weight should be such as to be compatible with all handling stages, e.g. lifting gear, stacking arrangements and cell access.

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[3]Comprehensive listings of hazardous wastes and hazardous substances are published in regulations of the US Environmental Protection Agency, Title 40, Code of Federal Regulations, Parts 261 and 302, respectively.

Method 1: Conformance of the container to the requirement of a specification may be verified by carrying out independent surveillance and inspection of the manufacturing process.

Manufacture should be carried out within a QA programme in accordance with documented fabrication procedures and inspection schedule. All inspections necessary to ensure that the requirements of the container specification are met should be identified and those where inspection is required before the next activity may begin designated a hold point.

Records showing the materials used, the method(s) of manufacture and the results of the inspections performed should be kept. Any departures from the specification or fabrication procedures should be recorded, along with details of any corrective action taken or concessions granted.

Method 2: Where the manufacture of the container is carried out within the confines of a quality management system which has been independently assessed and certified as complying with an appropriate national or international standard then the manufacturers own certification of conformance may be accepted.

Method 3: Physical checks, including measurement of dimensions and weight, may be carried out by the operator of a waste conditioning facility on receipt of containers.

Generally a combination of methods 1 and 2 and method 3 is employed.

4.4.2. Container properties

The properties of the container, including (where applicable) mechanical properties, leak tightness, durability and radiation shielding should be controlled to ensure they comply with requirements for safe handling, storage and disposal as detailed in the waste package specification.

For example, the container should be sufficiently strong to withstand anticipated handling and stacking and associated possible accidents without breach of containment. Leak tightness includes measures to prevent ingress of water and egress of radioactive substances where confinement properties rely on the container design. Prevention of water ingress is of particular importance for containers bearing fissile materials. This durability is the ability to maintain such properties over time which can include handling, interim storage and the early operational phases of disposal in a repository. For some waste packages dose rate minimization may rely on the radiation shielding properties of the container design.

Method 1: Verification of the mechanical properties relies on standard drop tests [13] carried out on loaded containers. These tests can be done by the manufacturer, customer or a third party and should be carried out in accordance with a qualifying process.

Method 2: Similarly standard tests [13] can be performed to verify the leak tightness of containers. Again whether done by the manufacturer, customer or a third party the tests should be done in accordance with a qualifying process.

Method 3: Durability of the container should be verified by ageing tests, for example, by accelerated corrosion tests and radiation exposure tests. Where containers are required to resist chemical or galvanic corrosion through material of construction or anodic protection, provisions to assure quality of these attributes should be implemented.

Method 4: The radiation shielding properties of a container are usually determined by calculation at the design stage. Surface dose rate should be measured for individual containers which are not filled by a continuous automated process.

4.4.3. Gas evolution control

Containers for waste forms capable of evolution of explosive gases (e.g. alpha emitting radionuclides in an organic waste matrix), must be adequately vented. Vents must be filtered with high efficiency particulate air (HEPA) filters and must be designed not to clog due to corrosion, water intrusion, or due to backfill material intrusion (if applicable).

Method: Vents produced under a QA programme should be installed in containers. Container headspace gases should be periodically monitored to ensure that explosive gas concentrations do not accumulate.

4.5. TREATMENT

Treatment of waste is frequently performed prior to conditioning for volume reduction purposes (supercompaction, incineration, evaporation, etc.) and to eliminate hazardous characteristics (e.g. pyrophoricity is eliminated by thermal stabilization) and constituents (e.g. molten salt extraction of ^{241}Am from plutonium processing residues, ion exchange).

4.5.1. Treatment planning and control

Treatment should be systematically planned and implemented in order to comply with waste minimization principles. All parameters affecting treatment process output should be carefully controlled to ensure the adequacy of the waste product for input to subsequent conditioning processes.

This is particularly true for treatment methods involving emissions or effluents to the environment or destruction of waste hazardous characteristics or constituents.

Method 1: The stoichiometry of planned treatment processes should be evaluated to determine what process parameters need to be controlled to assure the process adequacy. Where waste feed stock is heterogenous, periodic or batch sampling should be performed. For example, Btu (British thermal unit) content, moisture content, and refractory compounds should be identified and controlled in feed stock for incineration to ensure complete combustion.

Method 2: Analytical characterization of the treatment product should be performed on a statistically valid basis where treatment is performed to eliminate hazardous characteristics or constituents.

4.6. CONDITIONING

The key parameters of conditioning should be controlled to ensure that the waste package will be physically and chemically stable and so will meet the requirements of safe handling, storage and disposal.

4.6.1. Prohibited materials and waste forms

Materials that promote migration of released radionuclides or hazardous substances (free liquids), waste forms that promote dispersion in the event of a release (respirable particles), items that could pose safety concerns (containers and pressure vessels within the waste package), and waste form with properties that could contribute to risk (corrosivity, reactivity, pyrophoricity, chemical incompatibility) should be prohibited in the waste package.

Method 1: Management controls should be used to exclude, and if not possible, to identify the presence of free liquids, powders and hazardous materials in raw waste prior to conditioning.

Method 2: Real-time radiography or computer-enhanced tomography may be used to identify prohibited items within the waste package. These processes are generally regarded as "special processes" and require commensurate procedure and operator qualification.

Method 3: Physical and chemical properties may be characterized as described in Ref. [15]. Characterization should be performed on a statistically valid basis and under appropriate analytical quality control programmes.

4.6.2. Immobilization

When immobilization of raw waste is necessary, the parameters which could effect the quality of the matrix, and thus its ability to meet the requirements derived from consideration of package integrity, should be identified and limits for their control established. The manufacturing, placing and curing of the matrix should be controlled within these limits, and records kept as documentary evidence of compliance.

A number of matrix materials are currently in use. These can be grouped for ease into three categories: bitumen, cementitious materials and polymers as illustrated in Table II.

Method 1: Whatever type of matrix is used the first things that need to be controlled are the raw material(s) used in its manufacture. These should be procured against a defined specification, an applicable national or international standard if such a document exists, and controls established to ensure that only conforming material is accepted. Arrangements also need to be made to ensure that these materials are properly stored so as to prevent any deterioration prior to use.

Method 2: During the manufacture, placing and curing of the matrix, those parameters which cannot be controlled through the use of automated process controls, should be subject to full control.

TABLE II. EXAMPLES OF THE PARAMETERS WHICH COULD NEED TO BE CONTROLLED

Bitumen matrix	Cementitious materials	Polymer materials
Cold resistance Content of solids Density Homogeneity Penetration Plasticity Porosity Softening point Viscosity Water content	Weight of individual mix constituents (i.e., OPC, BFS, PFA, water and any additives used) OPC/BFS or PFA ratio Water/solids ratio Powder addition rates Mixing time Quantity of free liquid present in the waste Grout fluidity, temperature and addition rate Container vibration frequency, amplitude and time Grout level Curing temperature Curing time	Tensile strength Compressive strength Elongation Impact strength Hardness

Method 3: Measures should be taken, including review of waste characterization data, to ensure that waste constituents do not include materials detrimental to curing or durability of the encapsulation media (e.g. organic materials in cement, acids in bitumen) are not incorporated in the mix.

Method 4: Records should be kept, for each waste package, of each matrix and immobilized waste contained within it, and conformance of these matrices to the relevant specifications should be confirmed.

4.7. WASTE PACKAGES

The complete integrity of the waste package should be assured during the conditioning process, interim storage, transport to and emplacement in a repository so as to demonstrate that the waste package meets all relevant requirements made in the repository's or interim storage facility's safety assessment.

Assessment and determination of the package integrity should be carried out for each type of container, waste stream and method of conditioning. This will most probably involve some research and development work as well as sampling and testing of waste packages using either stimulants or the waste concerned.

The results of this work should be fully documented and reported, as it will be needed by the operator of a waste conditioning facility to define a waste package specification for each type of waste and package, and identify those parameters which need to be controlled during the conditioning process in order to ensure the quality of the packages produced, and by the repository operator to confirm the suitability of the waste package concerned for disposal in the repository.

Whenever similar specification requirements vary, due to different or multiple specification or regulatory requirements applying, the more demanding requirement should be complied with (e.g. if a repository acceptance criterion demands that the waste package survives a 15 meter drop test and the transport requirement is a 9 meter drop test, then the 15 meter drop test will be dominant).

4.7.1. Mechanical strength and resistance to impact

The waste package must be able to withstand mechanical stresses arising during handling, transport, storage and emplacement in a repository under both normal and predictable abnormal situations.

Method: Mechanical stresses can be calculated and testing carried out using appropriate national or international codes and standards. The ability of the waste package to withstand the calculated stresses can be confirmed through calculation and/or testing of the mechanical characteristics of the waste package. Static and accidental loadings during handling and storage of the waste package can be simulated through appropriate drop tests, penetration tests, compression tests, etc.

4.7.2. Radiation stability

Short and long term influence of radiation, heat and gas generation on the waste package's integrity must be assessed. This requirement is more usually applicable to intermediate level waste.

Method: The assessment of the effects of radiation on the waste package and its contents, previously mentioned mechanism on waste relative to package integrity can be based on mathematical models and R&D calculations and experiments.

4.7.3. Chemical durability

The chemical durability of the waste package should be sufficient to provide the required containment of radionuclides during interim storage, transport and disposal.

Method: Assessments of chemically induced change or attack on the waste package must be carried out and where possible, should be supported by testing (on an experimental or accelerated timeframe basis).

4.7.4. Fire resistance

The fire resistance of waste packages should be demonstrated to comply with all applicable specified requirements, safety assessments and codes covering interim storage, transportation and disposal.

Method 1: Design and manufacture of the waste package should be performed accordingly to appropriate national or international codes and standards.

Method 2: Testing of the waste package should be performed under specified fire conditions. Use of surrogate waste forms in such tests is recommended, unless testing is performed in a confined (e.g. glovebox) environment.

4.7.5. Minimization of voidage

Voids should be minimized and filling levels optimized, to achieve maximum homogeneity and prevent the presence of uneven or excessive stresses, water traps, and occurrences of local "hot spots" developing in the waste package during handling and storage.

> *Method:* Design and process control activities should be applied to ensure that voids are minimized, and appropriate tests should be developed and/or applied to detect the presence of such voids.

4.7.6. Containment

Leakage and other releases such as leaching of the radioactive substances from the waste packages must be within the limits applicable for handling, transportation, storage and disposal.

> *Method:* Assessment of containment performance of the waste package can be achieved by the application of standard or specially developed tests for the detection of leakage, leaching, diffusion or any other escape mechanisms as appropriate. These assessments or tests should also determine the release rates of these escape mechanisms.

4.8. HANDLING AND TRANSPORTATION

The handling, storage and transport operations should be carried out in a quality assured manner, so that waste package integrity is preserved until its emplacement in a final disposal facility. There are requirements arising from certain other regulations and codes which are not directly associated with the functioning of the waste package within the disposal facility. These other regulations and codes such as national radiation protection regulations or national transport regulations/codes must nevertheless be complied with and must be subject to the provisions of the QA programme. The programme must ensure that all transport limits related to radiological and chemical properties described in paragraphs 4.3.2–4.3.6 are satisfied. Additionally, the following requirements should therefore be fully addressed.

4.8.1. Package weight

The weight of a waste package should be controlled so as to be compatible with requirements for handling operations such as lifting and stacking during interim storage, transportation and final disposal. The final package weight shall be determined and recorded.

> *Method 1:* The weight of a waste package should be measured or otherwise determined and documented. The weight of a waste package is an important safety factor which needs to be determined to avoid overloads on mechanical handling equipment. A procedure should be implemented to control lifting of heavy packages in accordance with industry standards. Measures should also be implemented to ensure that where packages are stacked in multiple arrays, heavier packages are placed in the lower arrays. This is especially important when transporting arrays of packages.

> *Method 2:* The package weight can be determined at the conditioning facility by placing the container on a balance after the filling/loading. The weight of a waste package can

also be determined if the weight of empty container is known and the filling/loading is controlled by weight (e.g. control of the bitumen/waste or cement grout/waste weight). Both the total package weight and the container tare weight should be reported on shipping documents.

4.8.2. Transportation

All operations and conditions associated with the shipping of the waste packages must be identified, controlled and documented.

Where a container is only used to transport wastes to a repository or interim storage facility and does not form part of the final disposal package, it must still satisfy requirements for the safe transport of radioactive materials specified in Ref. [13] (e.g. transport cask, etc). Where the container is also to be used as the transport packaging, reference should be made to Section 4.3 in developing the appropriate measures.

Method: The measures to be developed and applied to the shipping/transport operations should be prescribed in appropriate documents (e.g. quality plans). These measures should also produce the necessary records of compliance with the applicable requirements.

4.8.3. Use of Type B packages

The container or packaging used for the transportation of wastes must fully meet the requirements of the applicable transport regulations. For Type B packages, the package license or certificate will impose specific restrictions on payload (i.e. the vessel contents, in compliance with all radiological, physical and chemical limits) and specific requirements for use and maintenance.

Method: The measures to be developed and applied to the design and manufacture of the packaging/container should identify all aspects to be controlled during manufacture, test, and any subsequent repair or maintenance. Organizations independent of the manufacturer who perform repair or maintenance should have an approved QA programme for this work scope. Additional, user organizations utilizing Type B packages should have an approved QA programme governing payload control[4].

4.8.4. Consignment documentation

All documents necessary for the movement or consignment of waste packages must be prepared and issued in time for the actual transportation of those packages to occur.

Method: The type of movement, distances involved, modes of transportation and applicable regulations must be assessed, and the necessary documents must then be identified and prepared. Permissions and approval from the necessary authorities must always be obtained before the actual movement begins. Specific information which must be included in such documentation can be derived from Ref. [13].

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[4]"Payload" in this context means the contents of the type vessel, in compliance with all radiological, physical, and chemical limitations established for the vessel.

4.9. INTERIM STORAGE

Waste packages should be stored in a safe and well organized manner to facilitate later retrieval for transport and final disposal. The IAEA has published guidance on the storage of radioactive waste from nuclear applications [16].

4.9.1. Safe storage

Safe storage should be assured by providing of proper design of waste package and interim store and ensuring adequate storage conditions.

Method 1: Satisfactory durability, including of waste packages should be ensured at the design and production stages and be verified.

Method 2: The design of the interim storage facility should provide for satisfactory protection for waste packages against deterioration (e.g. corrosion by moist salt laden air).

Method 3: Waste packages should be inspected periodically by visual examination to detect early signs of deterioration. Interim storage operators should have contingency plans for response to leaks or releases.

Method 4: Interim storage facilities inventorying significant amounts of waste should be subjected to safety analysis to ensure that appropriate administrative procedures are in place to preclude accidents (e.g. separation of potentially incompatible waste forms, control of off-gases, control of storage arrays for fissile materials). Where inventories increase over time due to unavailability of disposal facilities, provisions should be in place to ensure that source terms (e.g. material at risk) does not exceed that originally determined acceptable in the safety analysis.

4.9.2. Retrievability and identification

Retrievability and identification of waste packages should be assured.

Method 1: Storage of waste packages should be well organized taking into account needs for access and handling.

Method 2: Prior to receipt, waste packages should be checked to ensure they have satisfactory identity markings. Several methods of labelling have already been used in different countries including bar codes, number codes, and alpha numeric codes.

The current mediums used for labelling include paper, metal tags, foil and container (direct marking). Information on package identification is included in Ref. [13]. Also, measures should be taken to ensure that labelling methods are qualified for their intended storage life and storage environment. Waste generators, conditioning facilities and disposal facilities should ensure that identification and records systems are co-ordinated so that records for individual containers are easily retrievable by all parties.

Method 3: The record keeping system should be designed to:

(a) accept data on individual waste packages,
(b) maintain this data during the lifetime of the store, and
(c) provide this data to the operator of the final repository.

Data should, in addition to that provided by the consignor, include information on the exact location of waste packages within the storage facility and data of their receipt and dispatch.

4.10. RECORDS

Satisfactory and traceable records covering each stage of the waste management process should be maintained for each waste package to demonstrate conformance with waste acceptance and legal requirements and to provide information to the repository operator.

4.10.1. Required data

The information to be recorded for each waste package should be determined and agreed with the repository or interim storage facility operator. This information should be provided at the time of package is made ready for transport to a repository or interim storage facility.

Method: A data sheet should be produced for each waste package listing information on each of the parameters in Sections 4.2–4.11 above and such other information as may be agreed with the repository operator.

4.10.2. Record procedures

Record procedures should be applied at each stage of the production of waste packages. These records should include in addition to data on individual waste packages information, data on process conditions, tests and all the parameters relevant to the quality of the recorded data.

Method 1: The operator of the interim storage facility or final repository should periodically audit these procedures.

4.10.3. Data traceability

Data provided by the record keeping system to the operator of the interim storage facility and/or final repository should be traceable back to more detailed records retained by the operator of each stage of waste package production.

Method: The operator of the interim store and/or the final repository should periodically audit the record keeping arrangements to ensure that they provide traceable data.

5. INDEPENDENT VERIFICATION

Whilst achievement of the required waste package quality and therefore satisfying the criteria and requirements identified in Section 4, rests with those responsible for operating and controlling the conditioning process, conformance of waste packages to these criteria needs to be independently verified to satisfy repository waste acceptance criteria.

A system of verification, independent of production, therefore needs to be established. The personnel responsible for verification may belong to another part of the organization responsible for conditioning the waste, provided it can be shown that they are organizationally independent of production. Alternatively, they may belong to an independent external organization. In any case they must have the authority to take appropriate action on any matter which is affecting the overall quality of the waste package.

Verification should take place after those responsible for the conditioning process have completed their certificates of the package, to avoid taking away from those conditioning the waste, the prime responsibility for confirming achievement of the required package quality.

The process of verification involves comparing the data collected during the conditioning process against each of the relevant parameters contained in the waste package specification. The information upon which this verification is based should be no different to that used by those responsible for the conditioning process to certify the packages in the first place. To avoid making assumptions about the accuracy and completeness of this information, particularly where the conditioning process involves a significant degree of manual control and recording of data, verification should be supported by a degree of process surveillance. The objective of this surveillance should be to develop a level of confidence in the data collected for each waste package, sufficient to provide assurance that it is a complete and accurate record.

Surveillance should cover the adherence of the conditioning plant to the controls and requirements contained in the process quality plan, particularly the checks carried out on incoming materials to ensure compliance with specified requirements. It should include verifying that the process is being carried out within the operating envelope established to ensure conformance of waste packages to the requirements of the waste package specification.

Where data collected against any of the parameters listed in the waste package specifications is manually recorded, then the collection of this data should be sample witnessed to provide the necessary confidence that it is accurately recorded. Likewise, where data is automatically measured by instruments and recorded on data recorder, the calibration of these instruments and the correct functioning of the data recorders should be subject to periodic checks.

The level of surveillance applied to the conditioning process should be commensurate with achieving an adequate level of confidence in the completeness and accuracy of the data upon which the verification of conformance of waste packages to specified requirement will be based. It should not become a second level of checking, but instead be performed on a sample basis, so as not to take away from those responsible for the operation and control of the conditioning process, the responsibility for waste package quality. Surveillance should however cover all operational hours worked in the conditioning plant, as if the conditioning plant operates continuously, then surveillance should not be limited to day shift hours, to ensure that it is representative of practice across all waste packages.

The process of verification, like surveillance, does not need to be conducted as a second check of all the data collected for each waste package. Statistically base sampling of waste package records can be used instead to provide a similar level of confidence to that obtained by 100% checking. By adopting this approach, a number of waste package records, randomly selected from a batch of packages, which might comprise either a day's, a week's or a month's output (as appropriate), are subjected to a detailed check for compliance with waste package requirements. Provided they all pass this check, and provided the number called for by the sample plan have been checked, then all the waste packages with that batch can be considered as conforming the requirements of the waste package specification within the confidence limit provided for by the sampling plan.

Typically, a confidence level of 95%/95% is used in many countries for situations such as this, where a high degree of confidence is required. Using this particular limit ensures that at least 95% of the time 95% of the waste packages checked will comply with the requirements specified.

Alternatively, a confidence limit may be established from consideration of the probabilities associated with waste packages not meeting one or more of the parameters identified in the waste package specification, and using this to define an acceptable outgoing quality limit (AOQL).

Once a batch of waste packages has been verified as conforming to the requirements of the waste package specification, a certificate should be issued recording this fact. In this way, when the waste package is consigned to the repository for disposal, the repository operator will have evidence of conformance to his waste acceptance criteria.

Finally, verification may identify non-conforming packages. In such cases, the procedure described in Section 4.2.1.5 under "Non-conformance and corrective actions" should be followed.

The Appendix contains, as an example, the primary acceptance criteria, approved determination methods and required quality provisions for the Waste Isolation Pilot Plant (WIPP) [17].

6. CONCLUSIONS

Assurance of the quality of waste packages is an important part of the overall QA programme for radioactive waste management. The application of the recommended QA approaches and methods will contribute to ensure compliance with waste acceptance criteria.

Because of the difficulties associated with sampling and testing of waste packages, it is recommended that verification methods are employed covering all stages of waste package production, including basic research, process and waste package design/development, in-process control, data acquisition and post-conditioning non-destructive checks. Destructive testing of waste packages on random determined items, should only be applied if the required data are not or cannot be obtained by other means or for limited verification purposes.

Appendix

PRIMARY ACCEPTANCE CRITERIA, APPROVED DETERMINATION METHODS, AND REQUIRED QUALITY ASSURANCE PROVISIONS FOR THE WASTE ISOLATION PILOT PLANT (WIPP) [17]

Parameter	Acceptance Criteria	Determination Method	Required Quality Provisions
Container	Type A	Markings	Manufacturer's license Inspection
Container vent	Approved design HEPA filtered	Unvented containers retrieved from interim storage shall be vented and aspirated Any internal liners must be punctured	Qualification testing Procurement specification Inspection
Immobilization	>1% by weight, < 10 micron diameter particles, or >15% by weight, < 200 microns diameter waste forms must be stabilized	Physical test of each waste type	Approved QA programme
Liquids	<1% by volume of container	Real- time radiography Computer-enchanced tomography	Method and operator qualification as a special process Operational procedures prohibiting free liquid or internal containers
Pyrophoric materials	Non-radiological pyrophorics prohibited > 1% by weight pyrophoric radionuclides prohibited	Thermogravimetric analysis < 0.5% loss on Ignition in oxidation testing Process knowledge	Approved analytical quality control programme Approved QA programme governing waste generation
Explosives and compressed gases	Prohibited	Real-time radiography Computer-enhanced tomography	Method and operator qualification as a special process Operational procedures prohibiting explosives and internal pressure vessels
Ignitable, corrosive, or reactive wastes	Prohibited	Analytical characterization Process knowledge	Analytical quality control programme Operating procedures prohibiting ignitable, corrosive or reactive wastes
Chemical compatibility	Incompatible chemicals of >1% by weight prohibited	ASTM D34.07 analysis	Approved QA programme
Hazardous waste constituents	Treatment to eliminate or stabilize hazardous constituents, or demonstration that hazardous constituents cannot migrate to accessible environment while they remain hazardous	Toxic Characteristic Leaching Procedure (TCLP) Acid digestion analytical methods, or Performance Assessment	Analytical quality control programme Approved waste characterization procedures, or QA programme requiring validated modelling software and valid waste characterization data

Parameter	Acceptance Criteria	Determination Method	Required Quality Provisions
Headspace Gases 1 Hydrogen and other explosive gases 2 Limitations on specific organic and elemental gas	 1 <50% of the lower explosive limit during storage and transport 2 Per EPA limits for the Experimental Waste Characterization Programme	 1 a) Gas mass spectroscopy b) Gas generation testing of representative containers c) Conservative calculation using coefficients related to % organics in waste and thermal wattage (decay heat) of individual containers 2 Gas mass spectroscopy	Approved QA programme
Specific Activity	< 100 nCi/g of transuranics	Radiochemical analysis of samples Nondestructive assay	Analytical quality control programme NDA QA programme requiring - Calibration using standard representative of waste matrix attenuative & moderating properties & radionuclide disperson in container - addition of quantified NDA error to assay results when determining compliance with limits (2 x error for shipment in TRUPACT-II) - inter-laboratory qualification using "round-robin" unknown standard
Fissile Mass	< 200 ^{239}Pu Fissile Gram Equivalent (FGE) per 208 L drum, as determined per ANS 8 15 (1981) < 325 g ^{239}Pu FGE per TRUPACT-II shipment		
Thermal Wattage (decay heat)	As specified for individual waste forms in the TRUPACT-II Safety Analysis Report (Nupac, 1981)		
^{239}Pu Equivalent Activity	< 1000 C, ^{239}Pu-equivalent per drum		
Surface Dose Rate	Contact-handled drums < 2 mSv/h at surface and <0 1 Sv/h at 2 m > 2 mSv/h surface dose rate requires packaging in remote-handle cask	Direct measurement	Instrumentation calibration procedure
Removable surface contamination	< 50 pCi/100 cm^2 alpha < 450 pCi/100 cm^2 beta-gamma	Swipe and direct measurement	
Labelling and identification	Approved unique identifier traceable to waste documentation	Barcode label qualified for 10 year life in repository environment	Manufacturer's certification Approved QA programme
Chemical compatibility	Incompatible chemicals of)1% by weight prohibited	ASTM D34 07 analysis	Approved QA programme

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