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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 final products involved will satisfy given requirements for quality. This is the general objective of quality assurance. 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 quality assurance measures are, to a certain extent, concentrated on waste conditioning in order to provide assurance that the waste package produced will comply with waste acceptance criteria for storage and disposal as well as with transport regulations. Since radioactive wastes arise from diverse sources, their characteristics are diverse as well, and conditioning processes will range from simple practices to full scale production facilities.

This report was prepared as part of the IAEA's programme on quality assurance and quality control requirements for radioactive waste packages. The report provides guidance and rationale for the application of inspections and tests as part of the entire quality assurance programme to verify and demonstrate that waste conditioning is being performed in a manner that protects human health and the environment from hazards associated with radioactive waste. The report is relevant to the Technical Reports Series No. 376, "Quality Assurance for Radioactive Waste Packages" dealing in general with the quality assurance programme of organization consigning radioactive waste to the repository, and elaborates its section devoted to inspection and testing for acceptance.

Preparation of this report was accomplished through two consultants meetings and an Advisory Group meeting. The report was drafted by the following consultants: J. Aerts of Belgium, G. Langlois, J. Bordier, and P. Pinson of France, C.W.E. Addison and D. Haselden of the United Kingdom.

The draft was reviewed by eight experts from eight Member States at the Advisory Group meeting held in November 1996 in Vienna. The report was finalized by J. Aerts of Belgium, P. Pinson of France, C.W.E. Addison of the United Kingdom and M.A. Robinson of the United States of America.

The IAEA would like to express its thanks to all those who took part in the preparation of the report. The officer responsible for the report at the IAEA was V.S. Tsyplenkov of the Waste Technology Section of the Division of Nuclear Power and the Fuel Cycle.

EDITORIAL NOTE

In preparing this publication for press, staff of the IAEA have made up the pages from the original manuscript(s). The views expressed do not necessarily reflect those of the governments of the nominating Member States or of the nominating organizations.

Throughout the text names of Member States are retained as they were when the text was compiled.

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CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

Basic requirements for quality assurance to be fulfilled in Member States to ensure safety in nuclear establishments are set up in the IAEA Code on Quality Assurance [1]. The Code recognizes that all work is a process that can be planned, performed, assessed and improved. The scope of the Code covers such stages as siting, design, construction, commissioning, operation and decommissioning of nuclear power plants and other nuclear installations. In particular, the Code sets up basic requirements for testing and inspection for acceptance (Requirement 8 in Ref. [1]). The recommendations on how to fulfill the basic requirements for inspections and testing are provided in the Safety Guide 50-C-Q13 [2].

In order to implement the general principles of the safety guide to the waste management scenario, a series of more specific publications on quality assurance of radioactive waste packages has been produced by the IAEA, such as Technical Reports Series No. 376 [3] which provides overall guidance on quality assurance for radioactive waste packages, and IAEA-TECDOCs-680 [4] and 864 [5] describing quality assurance requirements and methods for waste package acceptability.

1.2. OBJECTIVE

The objective of this report is to provide technical guidance on the planning and management of the inspection and/or testing activities directed to verify that the waste form, waste container and waste package meet design requirements, product specifications and acceptance criteria for the subsequent stages of the waste management. To this end, inspection and testing procedures are required to provide confidence and objective evidence that conditions that may affect the quality of waste packages are monitored and controlled. The report is intended to identify general procedures, practices and technical issues involved in the inspection and testing of waste packages and recommend the most suitable approach in terms of cost, dose uptake and feasibility. It will also cover issues dealing with the identification of roles and responsibilities on the implementation of the activities in the frame of an overall quality assurance system.

This publication is expected 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 surveillance of the whole process. It is also intended that this publication will promote the exchange of information and will facilitate a greater international harmonization of quality assurance requirements and the application of control methods to the management of radioactive waste.

1.3. SCOPE

Although the quality assurance measures for inspection and testing are extended to all waste management activities leading to a waste package, this therefore also includes the pre-conditioning stages, this document covers the conditioning process itself.

The report mainly addresses qualitative criteria and proposes inspection and testing procedures and methods which should be used in order to contribute to the objective of safe handling, transportation, storage and/or disposal of low, intermediate and high level waste packages, from nuclear power plants, nuclear fuel cycle facilities and nuclear applications.

1.4. STRUCTURE

This report is structured into four further sections:

Section 2 outlines considerations on how inspection and testing activities on the waste package are related to the overall quality assurance system for waste management and points out that different approaches can be adopted and selected, taking into account the level of activity, degree of complexity and cost-effectiveness of the process and product involved.

Section 3 describes the principles which are taken as a basis for planning and performing the inspection and testing activities, and indicates how the responsibilities are shared between the parties involved (operator, independent bodies, inspections and testing personnel). The importance of documentation in the inspection and testing activities is also addressed.

Section 4 identifies the critical areas for inspection and testing in conditioning processes and focuses on the actual implementation of inspection and testing during the production of waste packages including documentation of results. The most common practices and techniques applied are also discussed.

Section 5 contains short concluding remarks.

2. INSPECTION AND TESTING AS AN APPLICATION OF QUALITY ASSURANCE

2.1. GENERAL

The conditioning process of radioactive waste arising from the nuclear fuel cycle and other nuclear activities aims at producing a waste package which allows the safe handling, transportation, storage and/or disposal operations. In order to assure safety, the waste package must comply with the specifications and acceptance requirements/criteria of customers and/or the regulatory authorities for the protection of human health and the environment from hazards associated with radioactive waste. Assurance that the criteria, specifications and requirements are fulfilled by a waste package is given through the establishment of an appropriate quality assurance programme (QAP) covering not only the development, design and production of the waste package, but also extended to the all stages of the waste management. The QAP is implemented for the conditioning operations through the application of a quality plan. This was recognized by a number of Member States and the corresponding work was initiated more than ten years ago. The basic principles and the conceptual approach for such a control by quality assurance means were published in the beginning of the nineties. Since that time the necessary QAP have been developed and are in principle operable in many countries advanced in nuclear power generation and the associated waste management activities. These Quality Assurance Programmes include inspection and testing of specified items, services and processes to be conducted by using established acceptance and performance criteria.

The QAP also provides a systematic approach to verify the quality of processes and products. This includes inspection and testing of processes, monitoring of process parameters, and acceptance of equipment, supply of materials, and final products.

All arrangements made to implement the quality plan, and in particular the inspection and testing ought to be recognized as sufficient by the customers and/or regulatory authorities to provide confidence that the required quality level is reached.

Inspection is the act of examination or measurement to verify whether an item or activity conforms to specified requirements.

Examination means determination of an item's physical, chemical, or radiological properties through indirect or interpretive means.

Testing is an element of verification for the determination of the capability of an item to meet specified requirements by subjecting the item to a set of physical, chemical, environmental and/or operating conditions.

2.2. QUALITY ASSURANCE PROGRAMME

Formal quality assurance arrangements [3] are required in order to provide confidence that:

- Waste management facilities are designed, constructed, operated and maintained to ensure adequate safety;
- Conforming waste packages are produced to a waste specification;
- Waste package acceptance criteria are met;
- Regulatory requirements and all conditions of the licence are met;
- The necessary actions are taken when non-conformance occurs.

An adequate QAP for waste packages would follow the principles below:

- Management provides the support to create an environment within which the required quality can be achieved;
- Operating staff carrying out the work are in charge of achieving the quality required;
- Continuous improvement is undertaken to enhance the effectiveness of management and workers in carrying out their tasks.

Details of the QAP will vary according to the characteristics of the waste to be conditioned, and depend on the intended future arrangements for transportation, storage and ultimate disposal of the waste. Thus, the objective and extent of the inspection and testing procedures will also vary. Section 4 provides guidance towards the identification of appropriate inspection and testing approaches for a variety of waste management activities.

2.3. CONFIRMATION OF PRODUCT QUALITY

2.3.1. General considerations

There are two general approaches to verification of waste package acceptability through inspection and testing. One approach is to verify compliance with Waste Acceptance Criteria (WAC) by inspection/testing of individual packages produced. This approach may be appropriate for discrete inventories of wastes (wastes from R& D activities, small waste generators, etc.). This approach is discussed in Section 2.3.2. A second and recommended technique described in this document as the "envelope approach" focusses on monitoring of conditioning process variables to ensure a product quality. This approach is appropriate for automated, repetitive or continuous conditioning processes. The envelope approach is discussed in Section 2.3.3.

Regardless of which technique for ensuring the acceptability of waste packages is applied, a fundamental objective of the QAP must be to minimize the adverse consequences associated with inspection and testing while still achieving assurance that packages meet acceptance criteria. The negative consequences of direct inspection include personnel exposure to ionizing radiation (dose), costs, and secondary waste generation. Secondary wastes are those generated as a result of inspection or testing activities and may range from contaminated instruments, tools, and clothing to analytical radioactive solutions. It may be stated that any direct inspection of radioactive waste or waste packages always involves negative consequences, and that, particularly, intrusive inspection of waste packages (inspection involving opening or penetrating waste containers for examination of contents or removal of samples) results in an undesirable degree of negative consequences. Furthermore, negative consequences associated with waste inspection are also a direct function of the waste activity, as depicted in Fig. 1.

As the amount of direct inspections required for a waste stream (a waste arising on a continuous basis or a discrete waste inventory) is usually dependent on the degree of confidence achieved related to its characterization and processing, it is important that the QAP be applied to the process in a cradle-to-grave manner (i.e. from waste generation through consignment for disposal). The QAP should be designed to provide sufficient confidence in conditioned waste quality (conformance to acceptance criteria) to allow a minimum of direct inspections and tests.

Finally, it should be recognized that waste management organizations perform inspections and tests for reasons other than assuring waste package quality (e.g., safety, transport regulations, etc.). Programmatic considerations of such inspections and tests are discussed in Section 2.3.4. Control of non-conformances is discussed in Section 2.4.

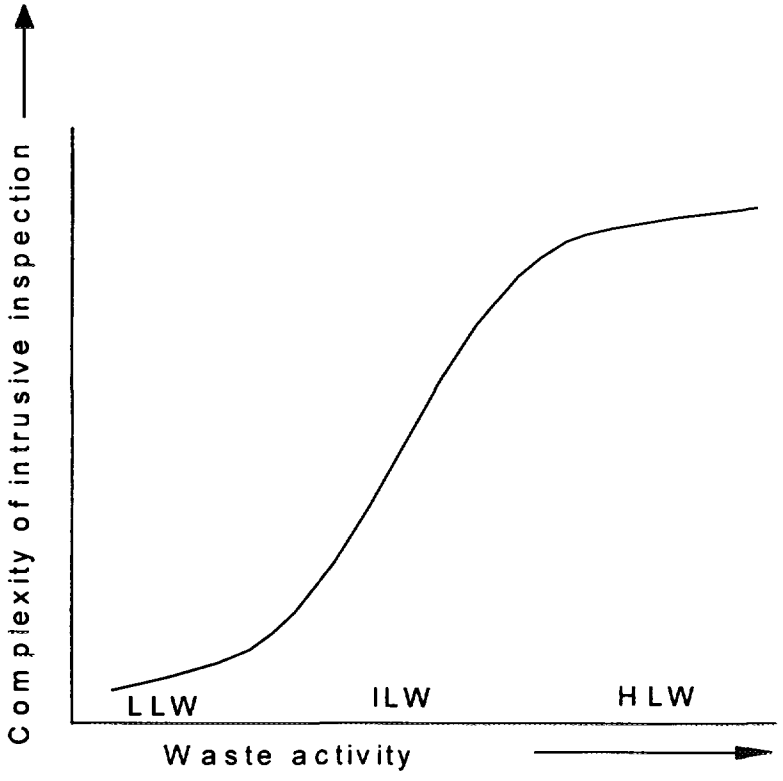


FIG. 1. Relationship between waste activity and complexity of intrusive inspection.

2.3.2. Confirmation of package quality by direct inspection

Where waste arises in discrete quantities not amenable to stabilization or immobilization in continuous processes, or when inventories of wastes exist whose acceptability for further processing or disposal is in question or indeterminate, acceptance of such wastes, at least in part, by direct inspection or testing may be appropriate. In such instances the QAP should provide for systematic evaluation of the waste inventories to determine in advance what inspections and tests are warranted. Evaluations should include consideration of the generation history of the wastes to identify where inspection or test may be used on a statistical basis to either confirm the historical processing knowledge or accept critical characteristics of waste population. Direct inspection and testing should be limited to: (1) those necessary to ascertain package properties which cannot be confirmed by indirect means (such as a document review or evaluation of process inputs to the waste generation process), (2) those necessary to determine prerequisite conditions for further processing are satisfied, or (3) those necessary to demonstrate compliance with regulatory requirements or disposal facility waste acceptance criteria that cannot be confirmed with confidence by other means.

2.3.3. Envelope approach

The "envelope approach" to ensure waste package quality has an application where wastes are immobilized or otherwise processed in an automated, repetitive, or continuous process. This technique specifically has application where it is possible to predict the characteristics of the product through knowledge of process operational variables such as feed composition, operating temperature, pH, etc. Successful application of the envelope approach is dependent on systematic development of a waste conditioning process from research and development through facility commissioning. Consequently, quality assurance should have direct involvement from the conceptual stage of the project through process commissioning and start-up. The net result of the envelope approach is a means of assuring the acceptability of a waste form or a waste package by monitoring of operational variables versus inspection or test of the end product, thereby dramatically reducing personnel exposure and costs associated with inspection and testing.

2.3.3.1. Product envelope

The "product envelope" may be defined as the allowable limits for chemical, physical, and radiological properties of a waste form or waste package. The product envelope will be based on the conditioning process design and should always be selected to fall within other governing constraints such as repository or transport waste acceptance criteria. Thus, a product envelope property limit should always satisfy the other governing criteria. Generally, the results of investigative work with non-radioactive materials or experience with similar processes in other operational facilities will be necessary to adequately quantify property limits of the product envelope.

2.3.3.2. Process envelope and operational process envelope

As a conditioning process technology is developed, the maximum acceptable ranges for the technology in terms of chemical, physical, and radiological properties of the waste form or packages will be determined based on inspection and testing of the product during facility start-up and commissioning. These maximum limits on the properties of the production-basis product represent the "process envelope". The process envelope will reflect the process technological limits, e.g., the maximum activity per glass volume that a vitrification process can tolerate, or the maximum amount of activities that a cementation mixture can retain without precipitation or

other segregation. Consequently, the range of properties in the process envelope (i.e. limits of the process technology) may exceed the target requirements (product envelope). For example, certain high level waste from vitrification processes can contain up to 6 wt% fissile mass. A disposal facility may impose an acceptance criteria limit of 5 wt% for reasons of safeguards or criticality safety. In this case the process envelope exceeds waste acceptance criteria limits and the conditioning facility must control the product within the "operational process envelope". Consequently, as part of facility start-up and commissioning, the operational variables of the process (e.g., operating temperature, waste composition, pH) will be examined to determine the limits for operational variables that result in an acceptable waste form (i.e. a waste form within the "product envelope"). These limits on the operational variables may then be viewed as the "operational process envelope". With this operational process envelope established, it then becomes feasible to monitor operational process variables as a means of assuring the acceptability of the immobilized waste form, as opposed to inspection/test of the waste form itself.

The conceptual phases of development of this "envelope approach" are depicted in Fig. 2. The mechanics of envelope development are described in greater detail in Section 4.5.

2.3.3.3. Consequences of envelope approach

The consequence of the above approach with respect to inspection and testing are:

(a) Inspection and testing is limited to ensuring the conditioning plant operates within its operational process envelope (thus assuring an acceptable product);
(b) Products slightly outside the process envelope may still be within the product envelope and therefore acceptable; part of the inspection and testing function may be to quantify the situation with respect to the envelopes;
(c) Inspection and testing of the final package is not strictly required to show the waste package is acceptable unless the parameters are not totally controllable (e.g., surface contamination) and confirmatory tests may be appropriate.

Extensive development work is required to establish the product quality parameters and to ensure the plant operations remain within the allowable limits. The approach of product and process envelopes, developed jointly with regulatory bodies has proved very successful for waste plants handling a broad range of waste streams. The importance of obtaining acceptance by regulatory bodies and customers, where the envelope approach is to be implemented, cannot be over-emphasized.

It should also be noted that the envelope approach can be extended to accommodate various requirements for the end product imposed by different customers, provided that sufficient process development work is performed to define operational variable limits that will ensure end product properties satisfy these customer-specific requirements.

2.3.4. Inspection and testing with regard to other waste management activities

In addition to confirmation or control of waste package quality, waste management organizations perform inspection and testing for a number of reasons, including confirmation that the facility is operating within its safety/licensing limits, assuring the quality of materials or equipment used in waste immobilization or packaging processes, and ensuring that regulatory requirements for transportation or disposal are satisfied. For example, certain inspections and tests are required by transport regulations [6] and guidance for their implementation exists in

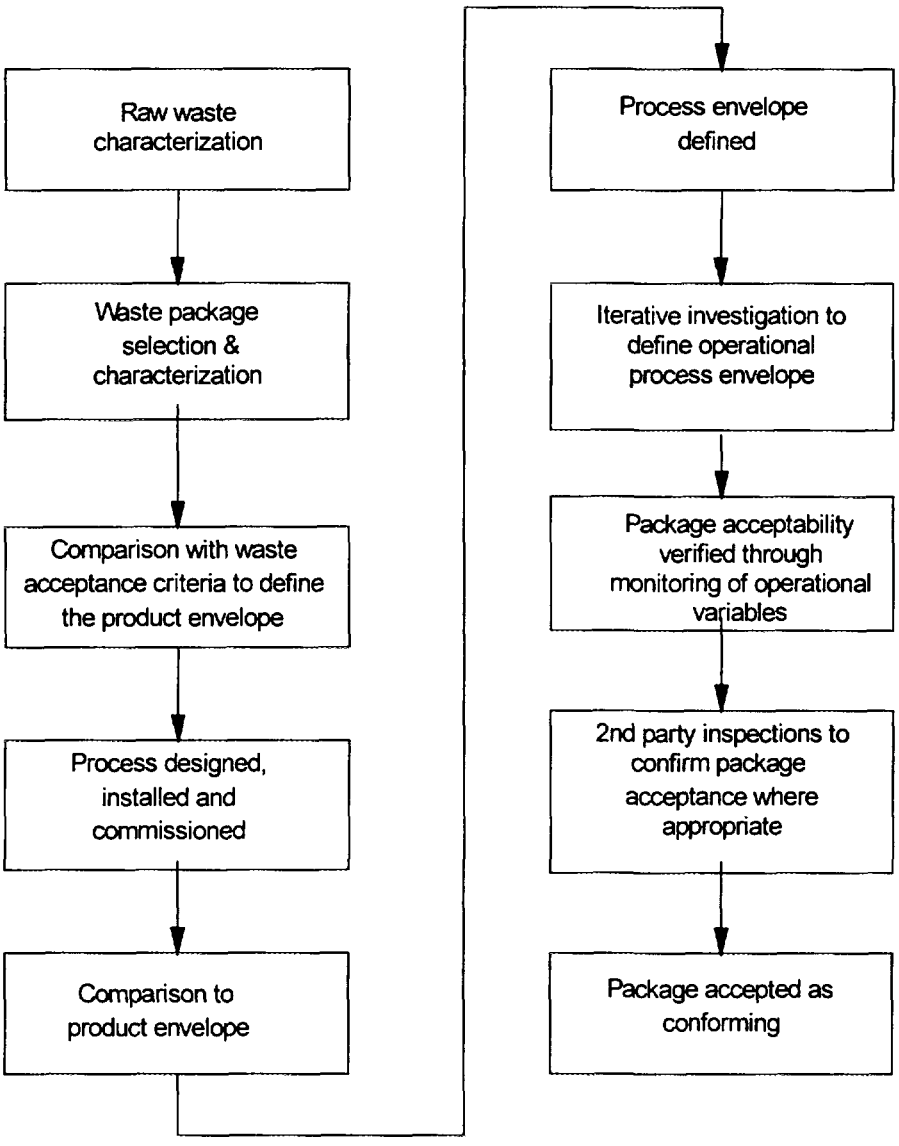


FIG. 2. Schematic representation of an envelope approach to waste package acceptance.

terms of QAP requirements in Ref. [7]. It is important that waste management organizations incorporate controls for such inspections and tests in their QAPs. This is to ensure that they are planned, performed, and documented in a manner that provides confidence in the acceptability of the item or activity, particularly where inspection, examination, or test data are to be relied on future evaluations or analyses (e.g., as input to performance assessments or accident analyses).

Types of inspections, examinations, and tests commonly employed for such purposes are described in more detail in Section 4. The rationale for selection of attributes for inspection and test based on processing logistics is also discussed in Section 4.4.

2.4. NON-CONFORMANCE AND OPERATING VARIANCES

2.4.1. Process envelope deviations

"Non-conformance" may be defined as a deficiency in characteristic, documentation, or procedure that renders the quality of an item or activity unacceptable or indeterminate. In spite of the fact that the conditioning plant has a QAP for the process, occasions may arise when waste packages have in fact been produced outside the process envelope parameters. Two situations could then exist:

(a) The operational variables were outside the operational process envelope limits, but still produce a product with properties within the product envelope limits. In this case, the product will be satisfactory and processing can continue without remedial actions;

(b) The properties of the product exceed product envelope limits. In this case, the package is non-conforming and remedial action or further evaluation is required.

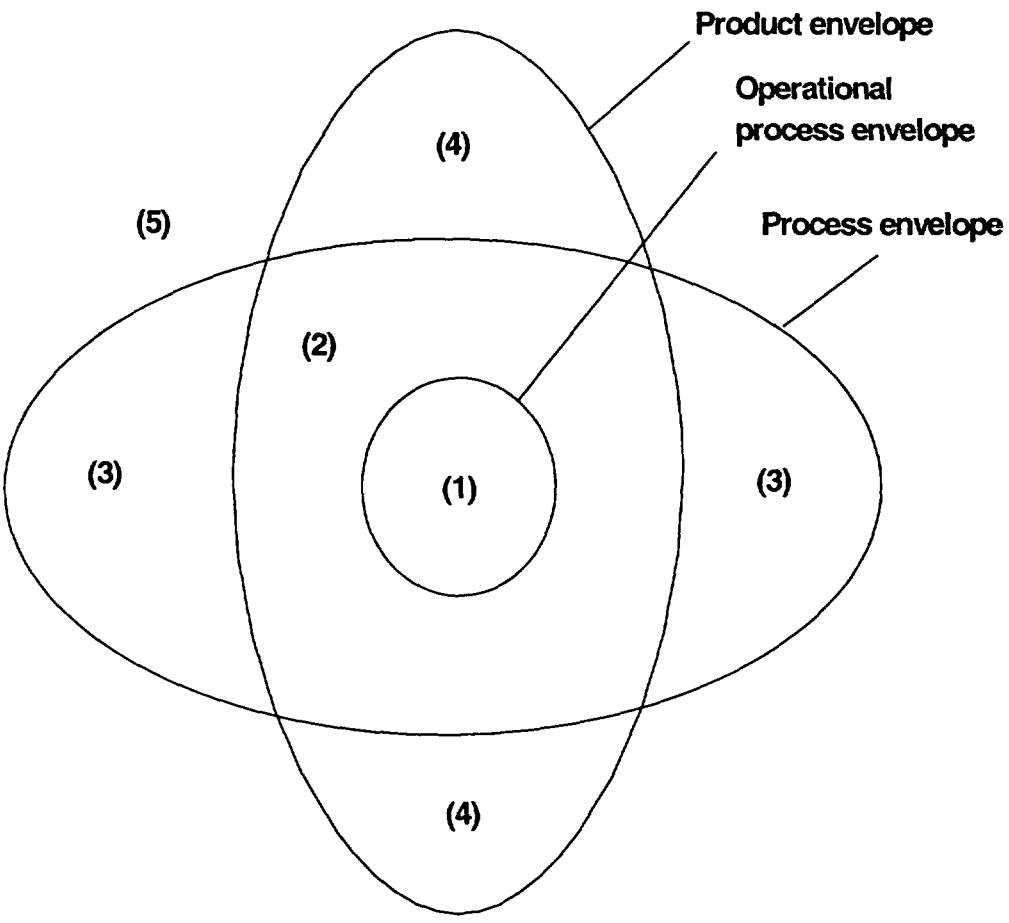
These situations are shown diagrammatically in Fig. 3.

Implicit in the product/process envelope approach is that inspections, if necessary, are carried out to identify potential non-conformance early in the production process, so that opportunity exists to recover the package by some form of remedial action.

Also implicit in this approach is that the data pertaining to the waste package are regarded as part of the final product since it is the data collected during processing that demonstrates compliance with acceptance criteria. Non-conformance is therefore possible where data are missing so that it is not possible to demonstrate that the package has been prepared within the product envelope or acceptance criteria.

2.4.2. Non-conformance control

As previously stated, packages exceeding product envelopes are non-conforming. Furthermore, where repository waste acceptance criteria or type B package (see Ref. [6]) limits are used for waste acceptance, any deviation in characteristic or documentation would constitute a non-conformance. Waste management organizations should adopt a positive system of non-conformance control as described in Safety Guide 50-SG-Q12 [8] to ensure that non-conforming packages are properly dispositioned and that corrective action is taken as appropriate. The process should provide a mechanism for obtaining disposal facility concurrence when "use-as-is" dispositions are proposed for non-conformances that exceed waste acceptance criteria. The process should also provide complete traceability from inspector records of identification of deviation or non-conformance to verification of the completion of disposition implementation.



(1) conformance

(2) process deviation leading to product conformance after investigation (waste form or package properties remain within both process and product envelopes)

(3) process deviation leading to product non-conformance after investigation (properties outside product envelopes)

(4) process deviation which may lead to product conformance after comprehensive investigation (properties remain within product envelope but exceed established process envelope limits)

(5) process malfunction non-conformance

FIG. 3. Schematic representation of process deviation types.

3. MANAGEMENT OF INSPECTION AND TESTING

3.1. GENERAL

In order to implement the inspection and testing approaches mentioned above, the operator of the conditioning facility needs to have a QAP. This QAP should describe the basic principles of inspection and testing, the responsibilities of the waste conditioning plant operators and inspection personnel and the interfaces, hold points, independence, authority and the qualification of the inspection personnel, and the methods for a review of documentation.

3.2. BASIC PRINCIPLES

The following principles provide guidance for the inspection and testing process:

- The scope of operations of the conditioning facility determines the type of work and items that require inspection and testing. Management should determine which operations and items should be inspected and tested by process operators and which should be inspected or tested by personnel independent of the process. This decision should be based on the importance of the operation or item to safety and the ability to verify the quality of the attribute subsequent to further processing.
- Inspection and testing should be scheduled and the important aspects of these activities, such as item characteristics, work process, testing techniques, frequency, sampling and quality records should all be defined in the quality plan.
- Testing may be part of the waste package inspection process, however, where possible, inspection of a waste package should be based on information confirming that the plant process is operating within acceptable envelopes, so testing is not necessary and can be reduced.
- The extent and scope of inspection and testing depends on the complexity of the waste form, of the waste conditioning process and of the waste package.

3.3. RESPONSIBILITIES AND INTERFACES

3.3.1. Responsibilities

In general practice, the following parties can be involved in waste package inspection and testing:

- The operator of the conditioning facility;
- The inspection and testing personnel;
- Third party inspection and testing personnel.

Their respective responsibilities could be outlined as follows:

- The operator of the conditioning facility should be responsible for:
  - definition of the parameters of the waste conditioning process and the specifications of the waste packages to be accepted for transport, storage and disposal;
  - incorporation of the specifications into the quality plans, which are part of the QAP;

- production of waste packages according to the specifications;
- allocation of the responsibility for monitoring plant performance and recognizing long term trends that may require a preventive action to the department(s) or group(s) or person(s) to be considered as the most adequate;
- allocation of the responsibilities for inspection and testing;
- definition of all inspection and testing necessary to demonstrate conformance to the specifications;
- meeting the requirements defined in the quality plans and accordingly in operating procedures.

– The inspection and testing personnel should be responsible for:

  - verification of compliance of the waste form, waste container and waste package with the specifications;
  - co-ordination of remedial actions in case of non-conformances.

– Third party inspection and testing personnel could be responsible for:

  - verification of waste package conformance to the acceptance criteria for transportation, storage or disposal;
  - verification of quality records conformance to process parameters according to the process envelopes.

3.3.2. Interfaces

The inspection and testing personnel of the conditioning facility will normally interface with:

– The waste conditioning facility operators;
– The third party inspection and testing personnel;
– Research and development or engineering departments in the scope of reporting and control of non-conformances;
– Internal and external auditors performing audits on the implementation of the QAP.

3.4. INDEPENDENCE AND AUTHORITY OF THE INSPECTION AND TESTING PERSONNEL

Inspection personnel should be independent of the management in charge of the waste package production process, but may work within the waste conditioning facilities organizational structure, especially in smaller organizations where waste conditioning personnel may be assigned to perform inspection and testing for well defined periods or conditioning campaigns, provided they have been qualified to do this.

Alternatively, the operator of the conditioning facility may choose to employ second party inspection and testing personnel, independent of the waste conditioning plant but working for the same overall organization. In addition, third party inspection and testing personnel completely independent of the organization may intervene on behalf of the customer or regulatory authorities.

The inspection and testing personnel should have the authority to identify and report non-conformance to the operator of the conditioning facility. If requested by the operator of the

conditioning facility or the regulatory body or the customer, they may verify the correct implementation of corrective and preventive actions.

3.5. QUALIFICATION OF THE INSPECTION AND TESTING PERSONNEL

Inspection and testing should be performed by trained and qualified personnel. Qualification of the personnel should be documented and the qualification process should be performance-based (i.e. inspection and testing personnel should be required to demonstrate knowledge in their discipline, and demonstrate qualification, for example by identification of known defects in surrogate materials equivalent to those to be inspected in the field).

As a general rule, the inspection and testing personnel should be as qualified as the waste conditioning facility personnel and should be equally or more knowledgeable in the technical basis for acceptance criteria.

Inspection and testing personnel may be qualified on the basis of experience; in such cases, the rationale for qualification should be documented.

When third party inspection is used, the inspection and testing organization should have appropriate accreditation.

Waste management organizations should recognize that the rigor of this qualification process lends credence to their inspection records as evidence of product acceptability. Waste management organizations should also recognize that inspector's errors are directly related to qualification and training (see Ref. [9]).

3.6. REVIEW OF DOCUMENTATION FOR INSPECTIONS AND TESTING

The inspection and testing personnel should have at its disposal all the data and documentation concerning the waste package and its constituents necessary to verify the conformity of the waste package.

Data and documentation could consist of, but are not limited to, the following quality records:

- The characteristics of the raw waste, such as nuclide activities, fissile mass, homogeneity, and chemical, physical, mechanical and biological properties;
- The waste container, such as verification results on dimensions, visual aspects, identification, thickness of protective layers tightness, material certificates and homologation of the waste container for transport;
- The waste form and its constituents, such as verification results on chemical properties, physical properties, thermal properties;
- The monitoring of the operating parameters of the conditioning process which are relevant to the quality of the waste package to fulfill the specifications and hence to the acceptance criteria;
- The characteristics of the waste at intermediate stages that will determine some of the characteristics of the waste package which are difficult or impossible to verify after subsequent processing;
- The characteristics of the final waste package, such as declarations of nuclides activities, dose rates, surface contamination, fissile mass, weight, dimensions, visual aspect, identification, and chemical composition.

The inspection and testing personnel should have a list of the data and documents to be verified, and preferably carry out the verification with the aid of manuals or checklists in order to ensure nothing is overlooked. These checklists could be joined to the final compliance document which contains all data and documents relevant to the conformance of the waste packages, helping to prove, if necessary, the traceability of the inspection and testing work.

If applicable, the inspection and testing personnel should maintain the data and documents described above in an adequate environment as to prevent deterioration, damage, or loss before they can be finally transferred to the customer or another party taking charge of the waste packages and the associated documentation.

3.7. DOCUMENTATION OF INSPECTION AND TESTING

3.7.1. Inspection and testing duties

The authority, tasks and responsibility of the inspection and testing personnel should be defined in documents that are part of the QAP for the waste conditioning facility. These documents should define the following:

- The authority and responsibility of the inspection and testing personnel;
- The tasks to be performed (e.g., the programme and frequency of checking);
- The procedures and methods to be used;
- The contents of the reports to be produced.

The applicable documents should be approved by conditioning facility management.

As for the third party inspection, when operating, the same type of document should be established depending on the request of the customer or authority on behalf of which the inspection body has to operate.

3.7.2. Inspection and testing programmes

Items and activities to be accepted by inspection or tests should be selected based on their importance to safety, susceptibility to failure, and degree of difficulty of verification of an attribute subsequent to further processing. Further guidance for selection of attributes for inspection or tests is provided in Section 4.4. Where the envelope approach is used, operational variables to be monitored should be selected based on the influence of variations on the conditioned waste properties. In most cases, the items to be inspected/tested and the frequency of inspection/test should be specified in quality plans.

Primarily, three types of data will be reported under the inspection approaches described in this publication:

- "Real-time" observations of instrumentation used to monitor or control conditioning process variables, or records of operational parameters;
- Inspection, test, analytical, examination, and measurement data produced for purposes of characterization of waste physical, chemical, thermal, and radiological properties;
- Inspection observation of the condition, configuration and identification of waste packages as they are received, conditioned, handled, stored, and transported;
- Inspection observations and/or records of tests performed for container qualification purposes;
- operability observations performed for safety envelope maintenance.

Inspection and tests should be performed in accordance with written procedures or instructions which should also provide quantitative or measurable acceptance criteria for the item or activity under observation.

An inspection and testing programme focus should be performance-based-that is, i.e. it should aim at verification of attributes important to an item's ability to perform as intended in service, not on verbatim compliance with procedures or details of paperwork that do not affect the acceptability of hardware or activities.

There should be a formal mechanism to track adverse conditions recorded in inspection reports through completion of corrective actions.

Inspection and test reports form a part of the permanent records of the waste management facility and a part of the final compliance document for waste packages, when applicable. Inspection and test records should be complete, accurate, and traceable to all associated items, activities, and documents, as they may be the basis for later analyses or investigations for numerous purposes.

3.7.3. Inspection and testing certificate

The organization responsible for demonstrating compliance with contractual requirements or for consigning the waste to the disposal facility (as applicable) should in most cases provide a certification that all governing requirements have been satisfied. The certifying organization will make this certification based on confidence derived in large part from the results of inspections and tests performed to confirm waste acceptability regardless of whether the envelope approach or the direct approach is employed. It is important therefore that records of inspections and tests are maintained in a manner traceable to individual waste packages, or batches of waste packages, as applicable.

4. INSPECTION AND TESTING PRACTICES

4.1. GENERAL

There are numerous types of inspections, examinations, and tests that may be performed over the course of the "cradle-to-grave" (i.e. from waste generation through disposal) waste management process, which are described briefly in the following sections.

All inspections, examinations, and tests should be performed to established procedures and quantitative acceptance criteria. Where acceptance of an item or activity requires inspector judgement or interpolation of data (as in welding, non-destructive examination, or non-destructive assay) the inspector should be certified as qualified in the discipline of the inspection.

4.2. TYPES OF INSPECTION

4.2.1. Source inspection

Source inspection means inspection of items or activities at a supplier's facility. Source inspection is performed where the quality of an item would be difficult to verify after delivery, where first-hand knowledge of an item's performance is necessary for further evaluations, and where the conditioner's QAP is being extended to cover activities of a less sophisticated facility.

Examples of such situations may include witnessing of container qualification tests (see Ref. [6]), performance of non-destructive examination of a package at a facility that does not possess such examination capabilities, or examining a small generator's waste at his facility to ensure it is correctly packaged and characterized prior to its transportation to the conditioning facility. Qualifications for source inspectors will vary with the nature of the item or activity being accepted.

4.2.2. Receipt inspection

Receipt inspection is performed to accept items that are relatively simple in design and amenable to relatively standard inspections or tests. Where standard commercial grade items are to be used in a safety-related application, the facility design organization should specify the critical characteristics of the item and the method of acceptance. Procurement or other contractual documents should specify the documentation to be provided with the item being received. Receipt inspection of radioactive materials should include surveys for surface contamination, surface dose rate, and verification that documentation of radionuclide inventory is provided and packaging type is as required by Ref. [6].

4.2.3. In-process inspection

In-process inspections are performed for a number of reasons including:

(a) Providing documentary evidence that items or activities conform to requirements;
(b) Ensuring that an item meets specified requirements where it would be difficult or impossible to verify after further processing (as in verification of piping joint fit-up or preheat temperature prior to welding);
(c) Providing expert's technical description of item or process conditions as input to disposition or design processes;
(d) Control of critical process parameters to ensure the quality of conditioned waste forms (e.g., verification that a fissile mass or volume is within process limits prior to cementation).

In-process inspections most frequently involve verification that processes conform to procedural requirements. Consequently, the in-process inspector should be qualified to perform the work being inspected and trained in implementation of the governing procedure.

Where wastes are conditioned in batch operation, as may frequently be the case where wastes are received from small generators or where discrete inventories of historical wastes are being conditioned or in a facility that generates many diverse waste streams (e.g., a research and development facility), in-process inspection should be directed toward ensuring that all critical parameters meet process requirements. Such inspection provides a control mechanism to ensure that the final product meets waste acceptance criteria.

Use of in-process inspections for control of continuous conditioning processes is discussed in Section 4.5.

4.2.4. Special process inspection

A special process is one where results are highly dependent on the control of the process, or the skill of the operators, or both, and in which specified quality cannot be readily determined by instrument or test of the product. Common examples of special processes include welding and

heat-treating. Inspections should be performed on special processes where the product is to be used in a safety-related waste management application. In the field of welding this could be fabrication of storage racks for spent fuel or high level waste, where maintaining storage geometry is necessary for criticality safety and/or cooling, or fabrication/repair of a type B transport container. Special process inspectors should be certified. References [10] and [11] provide guidance for qualification and certification. However, in many cases the national competent authorities will specify qualification requirements in such disciplines.

4.2.5. Non-destructive examination

Non-destructive examination (NDE) means a technique for evaluating item characteristics which (1) usually involves augmenting normal visual activity, and (2) does not affect the usability of the item being examined. There are numerous NDE techniques for examination of metal items including liquid penetrant (PT), magnetic particle (MT), eddy current (ET), ultrasonic (UT), and radiographic (RT) testing. Beyond the familiar application of these techniques to safety-related items, several NDE techniques have specific application to waste processing. Ultrasonic testing, for example, is utilized to identify voids or cracks in immobilized waste monoliths, particularly cement and glass. Other NDE methods have greater application as described in the following Sections. Reference [12] provides guidance for qualification of NDE examination personnel.

4.2.5.1. Visual examination

Visual examination is considered to be an NDE technique for several reasons. First, because visual examination is used to monitor the condition of waste packages in interim storage and to determine the extent/progress of material degradation by corrosion or other means the process needs to be carefully controlled. Secondly, remote visual inspection is also conducted where visual activity is augmented through optical means such as telescopes, borescopes, fiber optics and cameras. Remote visual examination is an important technique for monitoring wastes in interim storage that emit a significant radiation field. Guidance for control of visual examination processes may be found in Ref. [10].

4.2.5.2. Real-time radiography

In real-time radiography (RTR) waste packages are subject to an intense X-ray field and the attenuated rays are translated to a cathode ray monitor in a manner reminiscent of security scanning systems used in airports. Modern enhancements to RTR designs also incorporate cathode ray tube enhancement of certain material types. RTR is utilized to investigate the contents of drums in a non-intrusive manner. It is particularly useful for heterogenous waste streams or where drum contents may be unknown as when waste is received from off-site. A singular feature of RTR systems is the addition of a mechanical fixture which tips containers at an angle and simultaneously rotates the container. This motion allows an operator to detect liquids in the drum (or inner containers) by the surface ripples created.

4.2.5.3. Tomography

Tomography is a computer technique applied in conjunction with both X-ray systems and gamma/neutron assay systems. Drums are subject to multiple access radiation fields which are then translated to 3-dimensional images of drum contents. When incorporated with non-destructive assay systems tomography is very useful in the visual identification of radioactive material within the drum. Not only the location but the radioactive material particle size may be

determined. This is very useful in the interpolation of assay results, as particle size and radionuclide dispersion within a matrix, have a marked influence on assay results.

4.3. TYPES OF TESTING

There are numerous types of testing techniques that may occur in radioactive waste management facilities, including hydrostatic and pneumatic testing of aqueous processing systems and operability tests for various safety systems. Of particular importance to waste processing are start-up testing (commissioning) of conditioning processes, leak testing of type B containers, container qualification testing, and analytical testing associated with waste characterization. In most cases, test requirements and acceptance criteria should be provided for tests by the responsible design organization. Test objectives and provisions for ensuring test prerequisites are met, should also be established. Provisions for ensuring that adequate monitoring instrumentation is used and that suitable environmental conditions (temperature, pressure, humidity, etc.) are maintained are also vital to test performance in most cases. A complete description of the numerous test methods that may be applicable to testing of waste forms and packages may be found in Ref. [13].

4.3.1. System start-up

Start-up testing for treatment, immobilization, or packaging processes will often be the culmination of sequential tests of a surrogate material (i.e. "cold testing") as part of a process qualification regime. In such cases, inspections and data acquisition are very important to process qualification and ultimately to an operational process control, as further discussed in Section 4.5. In all cases, start-up testing should take cognizance of potential energies involved, both kinetic and chemical, provide for use of calibrated measuring and test equipment and utilize trained and qualified test personnel. Where start-up should be evaluated against facility safety analyses to ensure that the potential for an accident not previously analyzed or an increase in accident consequences is not created.

4.3.2. Leak testing

Leak testing is required by many type B package approval certificates (see Ref. [6]). Leak testing by vacuum means is a very well developed technology and involves very precise measurements. Guidance for leak testing and personnel qualification may be found in Ref. [14]. These leaks are also applicable to other types of packages, as "industrial packages", or to packages assigned to be transported, stored and disposed of in type B flasks.

4.3.3. Container qualification testing

Type B packages require very specific qualification testing as described in section VI of the Regulations for the Safe Transport of Radioactive Material [6]. These tests include those that are prescribed (drop tests, water spray tests, stacking tests, penetration tests, and water leakage tests). Furthermore, additional testing may be required that is derivative of assumptions and accident scenarios analyzed in the container licence application. Such testing will be performance- based (i.e. intended to demonstrate that the container can withstand postulated accident conditions). All such testing must be accomplished in a formal and rigorous manner to demonstrate adequacy of the design to the regulatory authorities. Consequently, it is essential that qualified test personnel are utilized and that the testing is well planned and proceduralized.

Less rigorous qualification testing is performed for type A packages. Qualification testing of waste packages may also be performed by the conditioning facility for other reasons such as determining package mechanical strength or "stackability". Numerous other mechanical tests may also be performed as part of waste form or waste package characterization. Test methods for characterization are described in detail in Ref. [13].

As for leak testing, container qualification testing can be implemented on other type of package, such as industrial packages, or packages liable to be transported in type B flasks, and store and inspect in those flasks, if applicable.

4.3.4. Analytical testing

Numerous analytical tests may be performed on waste forms and waste packages for the purposes of waste characterization. Analysis of container headspace gases may also be performed to determine potential for generation of flammable gases through radiolysis of constituents in the waste form or potential for volatilization of chemicals in the waste form. All such testing should be performed in accordance with analytical methods, sampling techniques, and statistical data analysis methods that are controlled through a rigorous laboratory QAP. Acceptability of characterization data will be a direct function of the formality of the sampling and analysis protocol. Guidance for analytical testing for waste characterization purposes may be found in Ref. [13].

4.3.5. Destructive testing and intrusive sampling/inspection

There are numerous tests which are performed on the waste form, container or package itself which are destructive in nature. The act of sample removal for analytical purposes is destructive to the substrate being analyzed, for example. Even seemingly minor physical tests can be destructive in nature. For example, use of surface penetrometer for hardness testing can create a stress point that could lead to component failure in service. Care should be taken to ensure that items subjected to destructive testing are formally evaluated and dispositioned (if they are not obviously destroyed by the test and could be inadvertently used subsequently before they are released to further processing).

The area of destructive testing that is of greatest importance to waste management organizations is that applied to stabilized waste forms and completely conditioned packages as either a means of waste acceptance or a means of investigation of defects identified or suspected to existing population of waste containers. In some facilities packages are destructively tested or examined on a periodic basis to ensure the continuing adequacy of the conditioning process. For example, one out of very 50 containers of a cemented waste may be cut apart to visually verify that there is no water exudation, no voids, complete curing, or proper distribution of the waste matrix within the cement monolith. This destructive test constitutes a quality control measure which is expensive, may contribute to excessive contamination of working areas, and requires reprocessing and repackaging of the waste material and container. Although such a technique provides a positive means of quality control, the negative consequences of its application (exposure, cost, secondary waste) can be minimized by careful statistical analysis of the process, formal process monitoring and possibly more rigorous qualification of the stabilization method using surrogate (non-radioactive) waste materials.

Where conditioned waste packages are suspected or known to have a defect, destructive testing may be used as an investigative tool to identify the size of the population involved and the actual nature of the defect. In such cases, assessment of production records to establish a

statistical basis for the testing scope becomes important as a means of limiting the test programme to the extent possible while still providing valid results. In such a test programme rigorous planning of test methods, sample extraction, and test/inspection documentation is important to assure validity of the test programme. One important feature of such an investigation is to ensure that all attributes that will be necessary for the problem assessment are within the scope of the destructive test as it may be prohibitively expensive if some important attributes are not examined during the initial test and the test must be repeated. For example, if the cause for inadequate curing of cement may be the presence of organic solvents in the waste matrix, the test should include analytical sampling for this solvent. If this data are not requested until after the tests are complete, then expensive resampling would be required.

Finally, in performance of testing which requires intrusive sampling of the container (e.g., headspace gas sampling where radiolytic generation of hydrogen is suspected, or extraction of core samples from the waste substrate) it is important to consider the potential hazards associated with the process before initiating the process. The most obvious hazards include detonation of explosive concentrations of headspace gases upon container penetration, or a contamination release where containers may be pressurized, or reactions which may occur with reactive materials when atmospheric oxygen or humidity are introduced to containers.

4.4. IMPORTANT WASTE PACKAGE ATTRIBUTES AMENABLE TO VERIFICATION BY INSPECTION OR TEST

Important for acceptance characteristics of radioactive waste forms and packages are described in detail in Ref. [3]. Waste form and waste package attributes which should be ascertained at each stage in the cradle-to-grave waste management process are described here for consideration by responsible waste management organizations. As the attributes described are important for several reasons including facilitating further processing, safety of waste management operations, compliance with waste acceptance criteria, and lessons learned from mishaps at waste management facilities in several Member States, responsible waste management organizations should consider verification of the acceptability of these attributes as an objective of their QAP. Inspection and testing as elements of the QAP should be applied, where applicable, to achieve an adequate measure of confidence that waste management operations can be performed as intended — that is safely, expeditiously, and achieve the final objective of emplacing compliant waste packages in a disposal facility.

Figure 4 graphically depicts the overall cradle-to-grave waste management process along with attributes which should be verified as in-process inspections, attributes which should be verified as compliant as a process or product acceptance measure, and attributes which should be confirmed as acceptable as prerequisites to further processing. It is important to note here that the role of inspection and testing is to verify and document conditions and data. Determination of the adequacy of conditions may be the responsibility of waste management organizations and regulatory authorities in some of these cases.

4.4.1. Waste generation

Waste generation processes are diverse. What is universal is the need to know the chemical, physical, and radiological characteristics of waste before it can be handled safely or conditioned properly. The foundation of most characterization data is what may be referred to as process knowledge — that is those procurement documents and procedures that provide information as to the source of the waste constituents and the processing that produced the waste form. Inspections should be performed on an ongoing basis to verify that (1) generators maintain

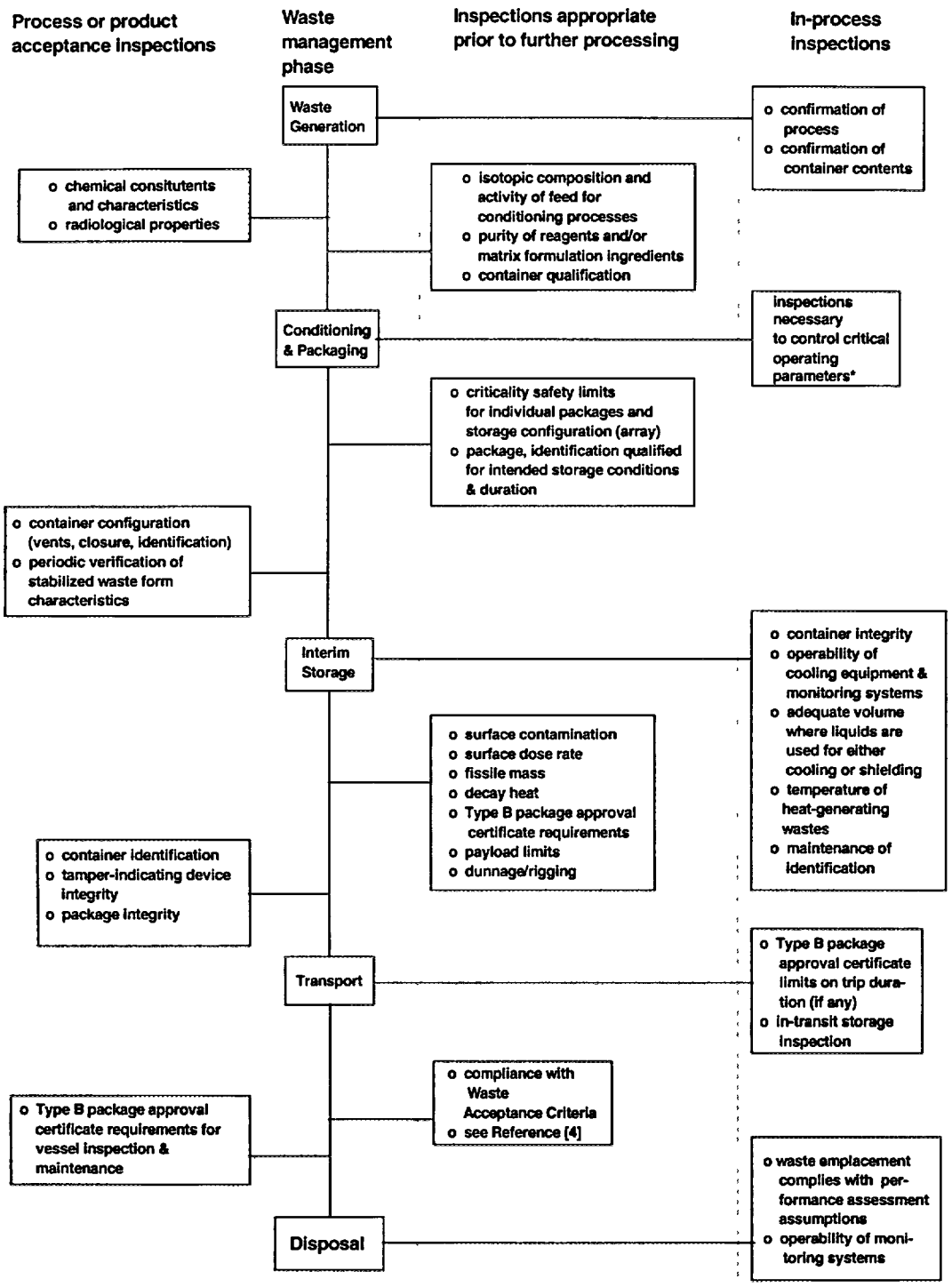


FIG. 4. Attributes/activities appropriate for inspection or other verification.

documentary process knowledge, and (2) generators maintain controls to ensure that the contents of waste containers are known with confidence when they are provided to the waste conditioning organization. If the process knowledge cannot be substantiated as valid in this manner, the result may be an increase in the amount of intrusive sampling and analysis required to adequately characterize waste.

In the majority of cases, wastes require radiological measurements and may require at least some confirmatory analytical characterization even where process knowledge is very complete. Certainly if process knowledge indicates the potential presence of toxic chemicals or hazardous chemical characteristics (pyrophoricity, reactivity, incompatibility which other materials used in further processing or storage, corrosivity, or flammability), analytical characterization or examination and use of records will be necessary to determine what further processing is needed to eliminate the hazardous characteristic, immobilize or destroy the toxic constituent, and render the waste form amendable to conditioning processes. Consequently inspection should verify that characterization data is complete as part of the acceptance process of the conditioning facility or organization.

4.4.2. Immobilization and packaging

A number of prerequisites to the conditioning process are appropriate for verification by inspection and testing. Generally, low level waste will be conditioned and packaged in type A containers (see Ref. [6]) or in order to produce an industrial package (types 1–3). Intermediate level wastes may be initially packaged in type A containers (and later transported in a type B package) or may be conditioned in a container specifically designed for the conditioning process. High level waste is universally packaged in containers specifically designed for the conditioning process and subsequently transported in type B packages. In all of these cases it is necessary to verify the qualification of containers prior to use. Type A containers procured from manufacturers possessing approval certificates (see Ref. [6]) may generally be accepted by receipt inspection. Other containers generally possess conformity certificates and are also subjected to receipt inspection. An increased level of inspection is appropriate for acceptance of containers specially designed to interface with the conditioning process; critical characteristics to be verified should be specified by the design organization.

The "purity" (conformance to specification) of reagents to be used in the waste treatment and ingredients in the conditioning (stabilization or immobilization) process should also be verified prior to use to ensure an acceptable product is ultimately produced. The quality assurance organization should determine the comprehensive methods of acceptance of such materials, but it is likely that some testing of such material may be necessary to demonstrate compliance with a specification. Personnel performing such tests or reviewing test documentation for the purpose of material acceptance should be knowledgeable of material production processes and test methods.

In addition, inspection at the supplier's facility should be made in order to ascertain his ability to produce conformed products. Waste frequently must be rendered to a form acceptable as a feed material to the conditioning process by physical and/or chemical means after it is accepted from the generator. It is expected that each conditioning process will have radiological, physical, and chemical acceptance criteria for this feed material. Inspections may be appropriate on a frequency determined from processing experience to verify that the feed meets processing specifications.

Each conditioning process will have critical operating parameters (i.e. process limits that must be met to achieve a satisfactorily stabilized, immobilized, or treated waste form). For batch processes and relatively simple processes, such as cementation (grouting) these parameters may be relatively straightforward (i.e. volume and pH of liquid additives, volume and particle size of solids to be entrained, fissile mass, activity, and heat limits for radionuclides, etc.). Compliance with these operating factors should be verified by inspection, or confirmation by periodic or statistical testing of the product waste form. Control of continuous conditioning processes is discussed further in Section 4.5.

Once conditioning is complete, inspection of those container characteristics that bear on the integrity and safety during further handling, storage, and transportation is important. Examples of such characteristics include the adequacy of container closure device configuration, container identification, and the proper installation of venting devices where waste packages may generate gases from radiolysis of the waste forms. Analysis and trending of problems found during inspections of packages in interim storage will provide insight as to which specific attributes are important for inspection verification at individual facilities.

4.4.3. Interim storage

When packages are to be placed in interim storage, a number of inspections are appropriate (e.g., for packages that contain readily fissile isotopes, verification that criticality safety limits are met and that the proposed storage array is in accordance within the allowed geometry for criticality safety). Such inspections become more important where interim storage facilities threaten to fill beyond the original design capacity and operators may consider modifying container storage arrays.

Experience at numerous nuclear facilities shows that a number of inspections are prudent during interim storage. This is especially true as interim storage has evolved into prolonged storage where repositories have not become available in the time frame originally anticipated. Attributes that should be monitored include the adequacy of identification and the physical condition of the container. Such inspections may be performed remotely using optical aids (cameras, telescopes, etc.) in order to minimize personnel exposure. The adequacy of such remote inspection techniques should be demonstrated (see Ref. [8]), particularly if they are relied on as the sole means of detecting container degradation. Also, inspectors should have specific training in visual examination of materials to identify evidence of failure mechanisms in progress.

Other attributes of importance to be monitored include the operability of cooling equipment where heat-generating wastes are stored, as well as the operability of monitoring instrumentation.

The temperature of the waste package should be periodically monitored where thermal power of waste forms is sufficient to initiate accidents if active cooling systems fail in absence of possible natural cooling. Also, where liquids are utilized for either cooling or shielding, periodic inspection of liquid levels should be performed. Frequency of such inspections should be derived from storage facility safety analyses but may require modification (increase in frequency) as facilities age or as dictated by operational experience.

Mechanisms should be established to ensure that a corrective action is taken for any deterioration of packages, package identification, or cooling/monitoring systems identified during inspections.

When retrieving packages from interim storage, inspections for evidence of any loss of container integrity should be performed. A primary means of detecting such conditions would be to monitor for surface contamination on retrieved packages. General package physical condition should also be inspected and package identification should be re-verified when packages are retrieved. If the duration of interim storage has been extensive, or if significant changes in administrative practices or organizational structures have transpired during the storage period, verification that package records are also readily retrievable should also be performed. If revisions in the disposal facility WAC or the transport vessel (type B package) approval certificate limits have occurred during the storage period, then re-evaluation of package characteristics against the revised criteria may also be necessary.

4.4.4. Transportation

Application of a QAP to all aspects of the transportation of radioactive waste and inspection to verify compliance with regulations and package limits is specifically required (see Ref. [6]), paragraphs 107 and 209). Consequently inspection of package characteristics and transportation operations must be planned and implemented in accordance with a QAP approved as required by the competent national authority.

Package radiological limits will be specified by the package approval certification. Attributes to be inspected should include surface contamination, dose rate, fissile mass (if applicable) and decay heat. Where a type B package is designed to accept inner containers there may be limits on payload (weight) and payload distribution, as well as limits on dose rate and thermal release (wattage). Where packages contain items retrained by mechanical fixtures (dunnage) the integrity of dunnage should also be inspected. Rigging (attachment of the type vessel to the conveyance) should also be inspected. Where type B packages are designed for multiple waste forms, package approval certificates may also have specific limitations on individual waste forms.

Leak testing of closed packages is required by many package approval certificates. Where such testing is required it should be performed by qualified personnel in accordance with approved procedures (see Ref. [14] for further guidance).

Package approval certificates for packages designed to transport gas-generating wastes may have limits on a trip duration to preclude achievement of a combustible atmosphere in the vessel. Provisions should be established to ensure that the trip duration limits are not exceeded. Inspections should also be prescribed for packages that will be placed in in-transit storage for extended durations.

Generally, the type B package approval certificate will prescribe the requirements for vessel inspection after internal containers have been unloaded. Such inspections will usually entail survey for surface contamination and examination of vessel sealing surfaces. Approval certificates will usually also require specific period maintenance and repair procedures. Inspections to verify the adequacy of all maintenance should be performed using acceptance criteria prescribed by the package design organization. Package repairs should be performed in accordance with the fabrication standard applicable to the original manufacture of the package and repairs should be inspected using methods and acceptance criteria equivalent or more rigorous than applicable to the original package fabrication. Provisions should be established to ensure that packages are not utilized if required inspections, maintenance, or repairs have not been performed.

4.4.5. Disposal

Verification that waste packages comply with WAC is of primary concern for the waste disposal facility prior to acceptance for disposal. Provisions should be established not only to verify compliance by a document review but also to evaluate any non-conforming packages (including non-conformances dispositioned "use-as-is" by the conditioning facility) that may be submitted for disposal. Such evaluations should incorporate package inspection when the discrepancy relates to a physical defect or deviation.

The disposal facility should also conduct receipt inspection of packages to quantify surface contamination, dose rate, and verify the integrity of packages to ensure that handling and emplacement activities can be conducted safely.

The disposal facility will perform a number of activities that should be monitored by inspection including recording of waste emplacement locations, performance of cavity sealing, and on-going environmental monitoring.

4.5. CONTROL OF PRODUCT THROUGH INSPECTION OF CRITICAL PROCESS PARAMETERS

The main task of conditioning plants is to produce waste packages which meet regulatory requirements for transportation, interim storage, and disposal. It is preferable that this is accomplished with a minimum of intrusive inspection in order to minimize personnel exposure and costs. If the product quality confirmation approach (envelope approach) as described in Section 2.3. has been adopted, then inspection and testing for the purpose of ensuring the adequacy of the conditioned product may consist of confirming that the process has been carried out within the operational process envelope.

The characteristics of the waste form cannot be viewed in isolation, as they are a function of implementation of operational procedures and control of various process variables. In view of this processing relationship, it is possible to develop a process control methodology which produces waste packages that consistently meet acceptance criteria.

The following sections discuss the mechanics of operational process envelope development and the manner in which control and inspection of process variables is used to achieve final waste forms whose characteristics fall within the product envelope.

4.5.1. Product and process envelopes

Conditioning facilities develop operational process envelopes to define a production waste form that will be produced within a technology-based profile inside the product envelope (waste acceptance criteria) confines. For example, if the product envelope specifies a limit of 200 grams of a specific fissile isotope per 208 liter drum, the conditioning facility may design a conservative process envelope which will consistently result in 166 grams of this isotope per drum. This operational process envelope will be based on operational variables: for example, the concentration of the isotope in the process feed may be controlled so that a target of 166 grams of the isotope is consistently produced in 208 liters of the product waste form.

Operational process envelopes to be employed on a production scale should be developed during process start-up and commissioning. This can be a cumbersome process as conditioning

plants invariably face "scale up" problems from laboratory-scale to plant-scale. Start-up and qualification of plant-scale conditioning processes involve problems due to thermodynamic and kinetic inefficiencies inherent in larger equipment and increased throughput. Other process differences may arise from usage of commercial grade chemicals for plant operation instead of the analytical grade materials employed during R&D. The job of conditioning plant operators is to take into account these factors and formulate an operational process envelope comprised of control instrumentations, process plans, hold points, procedures, and optimization of process parameters to minimize these effects.

4.5.2. Relationship between product and process envelopes

Elements of product envelope are product characteristics, while elements of process envelope are process variables. For a cementation process, for example, a process envelope will involve variables such as waste composition, cement brand, waste/cement ratio, mixer speed, mixing time, curing time, container dimensions, temperature of waste and cement slurry, and ambient conditions like temperature, humidity, etc. The first and foremost task is to identify functional relationships between two envelopes. This is accomplished by analyzing conditions which affect any particular product characteristic and relating them to operating variables which contribute to these conditions. This investigative process is shown pictorially in Fig. 5 which depicts an example relating leachability of vitrified glass product to plant variables. Determination of the ideal control points for the entire process would be an iterative investigation, evaluating the consequences of varying individual processing parameters, one at a time.

4.5.3. Sensitivity analysis for process variables

After quantification of relationships between elements of the product and process envelopes, the next step is to estimate possible variations in process parameters during plant operation. This is followed by artificially inducing variations in process variables over a range around the target estimate range and then analyzing effects on product characteristics. Parameters can then be classified as critical, not so critical and insensitive. Statistical techniques are then applied to determine repeatability and reproducibility of the analysis. The process envelope is thus generated (usually maintained as a database). Data obtained contains blue prints for future comparisons with operational data to allow the continuing refinement of these variable control points. This methodology is shown in Fig. 6.

A subset well within the region of intersection of process and product envelopes (see Fig. 3) represents the optimum process parameter ranges that consistently result in a product within the operational process envelope.

4.5.4. Inspection during operation

The conditioning plant must operate within the operational process envelope. This is ensured and documented via inspections that:

(1) Verify that processing is carried out within established variable limits;
(2) Verify that calibration of measuring and testing instrumentation is adequate;
(3) Verify product quality by confirmation that recorded process operating data are within the allowable operating range.

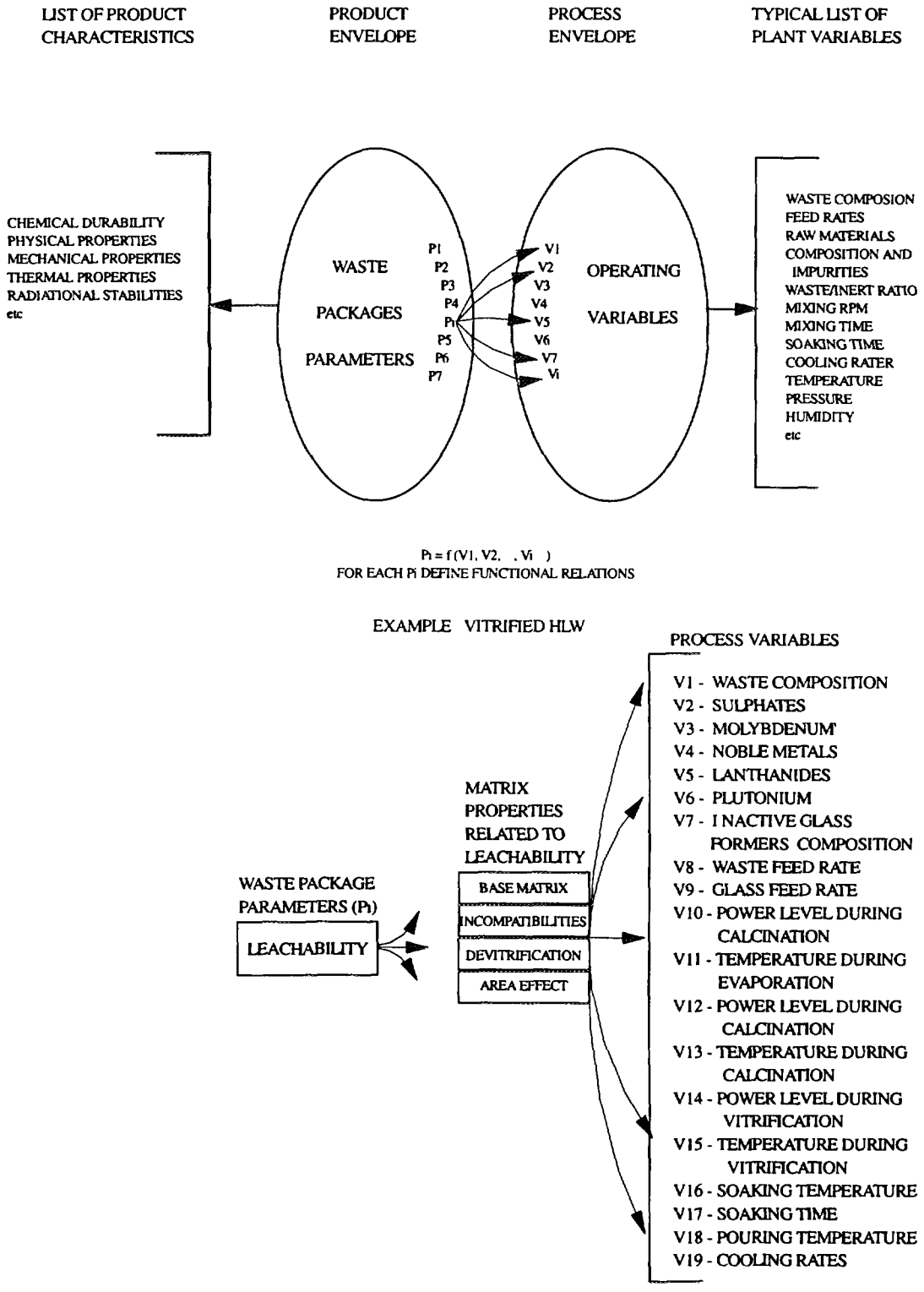


FIG. 5. Functional relationships between product characteristics and plant operating variables.

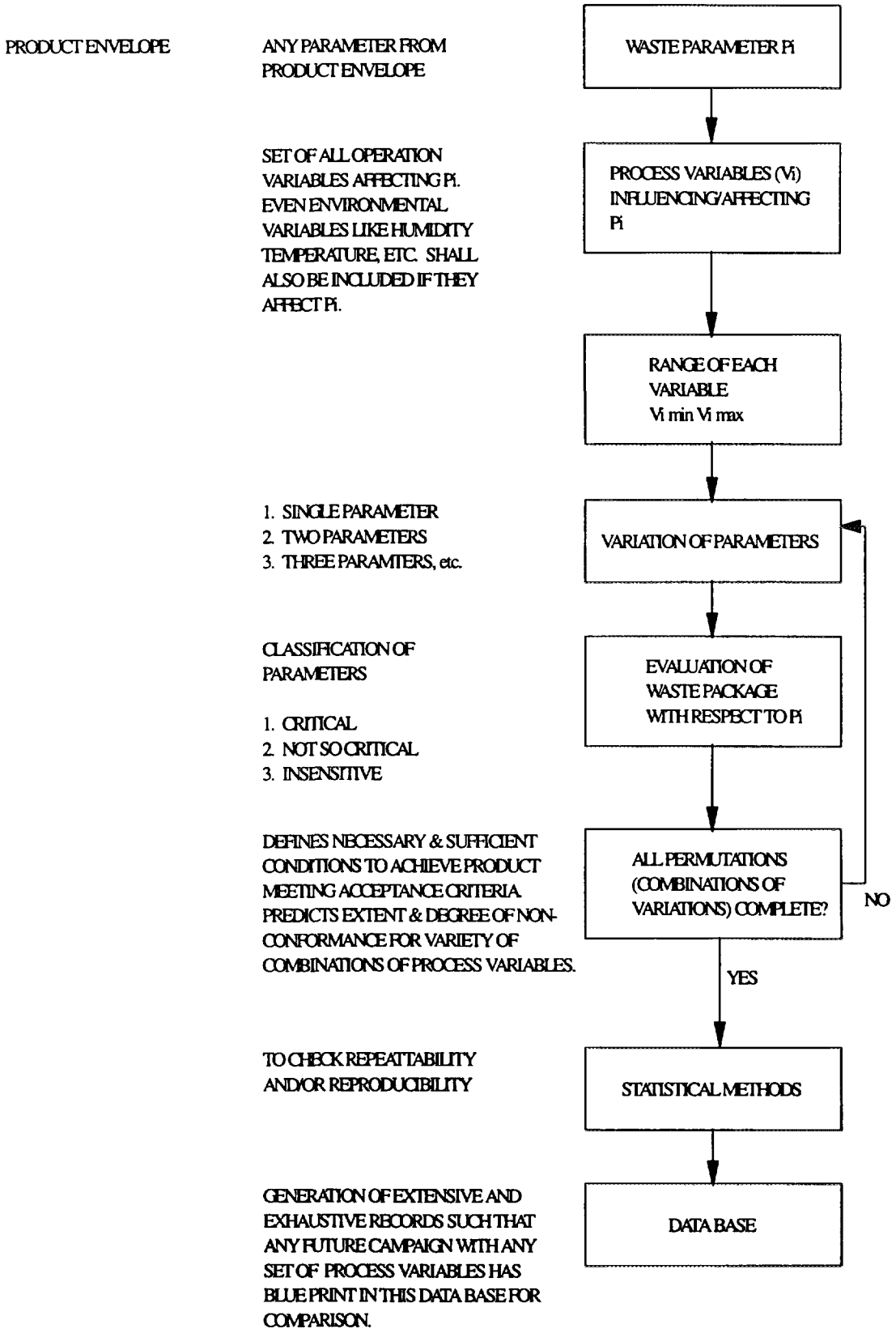


FIG. 6. Methodology for generation of a process envelope.

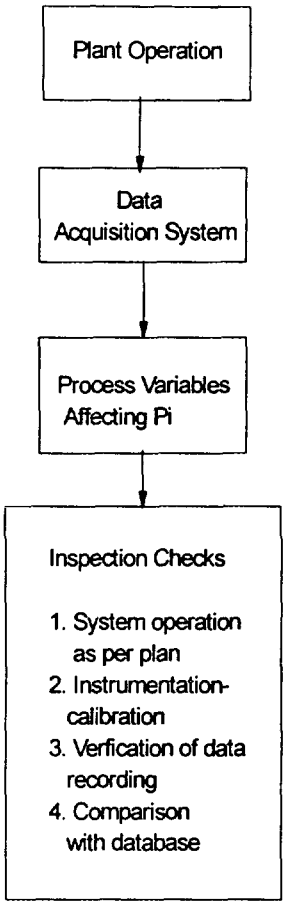


FIG. 7. In-process inspection.

This process control technique is illustrated in Fig. 7. The process envelope concept has been successfully implemented by many Member States and provides confidence that it is possible to produce radioactive waste package meeting acceptance requirement by monitoring and controlling critical process parameters, thus minimizing the need for intrusive inspection.

5. CONCLUSION

Inspection and testing are important tools for waste management organizations in ensuring (1) that conditioned waste packages meet requirements of customers, regulators, and ultimately disposal facility waste acceptance criteria, and (2) that waste management facilities operate within their an approved safety envelope. Inspection and testing can also serve the pragmatic functions of enabling processing, storage, transport, and disposal activities by verification that processing prerequisites are satisfactorily accomplished, and regulatory requirements are fulfilled, and that potential failure mechanisms do not occur. In this last regard, inspection planning should take cognizance of historical waste management experience.

Inspection and testing can involve adverse consequences including personnel exposure to ionizing radiation, economic costs, and potential secondary waste generation. These negative consequences will increase in direct ("hands on") inspection of radioactive materials and are

highest in intrusive inspection activities. The QAP should provide for adequate planning to ensure that these consequences are minimized to the extent possible.

Quality control that may be applied to continuous or automated conditioning processes to maximize the assurance of quality, and minimize the adverse consequences of inspection and testing (envelope approach). This technique uses monitoring of process operating variables in lieu of inspection of the conditioned product to ensure compliance with waste acceptance criteria. Where the envelope approach cannot be applied, careful analysis of generator process knowledge and records, and application of statistical sampling techniques can be utilized to minimize inspection and test requirements.

Finally, the efficiency of the qualification of inspection and testing personnel is important to both the variability and the credibility of the inspection and test programme.

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analysis, safety. The evaluation of the potential hazards associated with the implementation of a proposed activity, criticality safety limits on fissile mass, package geometry, and storage array intended to prevent inadvertent criticality accidents.

cold (or inactive) testing. Testing of method, process, apparatus or instrumentation designed to handle radioactive materials by using non-radioactive materials or materials which may contain radioactive tracers.

conditioning. Those operations that produce a waste package suitable for handling, transportation, storage and/or disposal. Conditioning may include the conversion of the waste to a solid waste form, enclosure of the waste in containers, and, if necessary, providing an overpack.

container, waste. The vessel into which the waste form is placed for handling, transportation, storage and/or eventual disposal; also the outer barrier protecting the waste from external intrusions. The waste container is a component of the waste package. For example, molten HLW glass would be poured into a specially designed container (canister) where it would cool and solidify.

criteria. Conditions on which a decision or judgement can be based. They may be qualitative or quantitative and should result from established principles and standards. In radioactive waste management, criteria and requirements are set by a regulatory body and may result from specific application of a more general principle.

direct inspection. Inspection requiring either direct physical contact with waste containers or activities in close proximity with radioactive waste such that personnel exposure to ionizing radiation is involved.

drum. A type of waste container similar in appearance to an oil drum which may be sealed by a fitted lid. Typical volumes for drums are 100, 200 and 400 L. (See also waste package). [See IAEA Safety Series No. 6 for the use of various types of drums in transportation].

examination. An element of inspection consisting of investigation of materials, components, supplies, and services to determine conformance with those specified requirements which can be determined by such investigation. Examination as related to waste forms or packages usually involves determination of physical, chemical, or radiological properties by indirect or semi-quantitative means.

exposure. Irradiation of people or materials. Exposure can either be external exposure from sources outside the body or internal exposure from sources inside the body. The exposure can be either normal or potential exposure; occupational, medical or public exposure; and, in intervention situations, temporary, or chronic exposure.

hold points. Steps in processing beyond which work shall not proceed without the approval of a designated organization. If inspection or witness of an operation is required at a hold point, it shall be indicated in appropriate work control documents. Approval to proceed must be documented before the continuation of work beyond a designated hold point.

immobilization. The conversion of a waste into a waste form by solidification, embedding or encapsulation. Immobilization reduces the potential for migration or dispersion of radionuclides during handling, transportation, storage and disposal.

leach rate. The rate of dissolution or erosion of material or the release by diffusion from a solid and hence a measure of how rapidly radionuclides may be released from that material. The term usually refers to the durability of a solid waste form, but also describes the removal of sorbed material from the surface of a solid or porous bed.

leach test. A test conducted to determine the leach rate of a waste form. The test results may be used for judging and comparing different types of waste forms, or may serve as input data for a long term safety assessment of a repository. Many different test parameters have to be taken into account, e.g. water composition and temperature. Dynamic leach tests require a flowing water system. Static leach tests require that the leachant be sampled or changed on a specified schedule.

industrial package. Packaging, tank, or freight container for low specific activity materials or surface contaminated objects as defined in the Regulations for Safe Transport of Radioactive Material; also known as "strong tight packaging" in some Member States.

inspection. Examination or measurement to verify whether an item or activity conforms to specified requirements.

inspection and test personnel. Personnel whose function is inspection examination, or testing to determine conformance with specified requirements.

intrusive inspection. Inspection and/or test involving opening of waste containers for examination of contents or removal of samples for analysis. Intrusive inspection may involve penetration of containers for sample extraction in a manner that degrades container integrity. Intrusive inspection may also degrade the waste form such that additional treatment, stabilization, or repackaging is required.

matrix. In radioactive waste management, a non-radioactive material used to immobilize waste. Examples of matrices are bitumen, cement, various polymers and glass.

non-conformance. A deficiency in characteristic, documentation or procedure that renders the quality of an item or activity unacceptable or indeterminate.

operators. Personnel whose function is the production or conditioning of waste packages.

overpack. A secondary (or additional) external container for waste.

packaging. The preparation of radioactive waste (e.g. spent fuel) for safe handling, transportation, storage and disposal by means of enclosing a conditioned waste form in a suitable container.

peer inspection. Inspection performed by a co-worker that is qualified to perform the work under examination. Peer inspection is intended to serve as a confirmation of the adequacy of work or support the veracity of a certification as in the case of generator certification of the contents of a waste package.

process knowledge. Waste physical and chemical characteristics data derived from knowledge of process input and operations, supported by documented evidence such as process procedures and procurement records.

quality. The totality of features and characteristics of an item, process or service that bears on its ability to satisfy a given requirement.

quality assurance. All those planned and systematic actions necessary to provide adequate confidence that an item, process or service will satisfy given requirements for quality, for example, those specified in the licence.

quality control. Action which provides means to control and measure the characteristics of an item, process, facility or person in accordance with quality assurance requirements.

real-time. An adjective describing an activity or observation made as events are actually occurring, as in real-time data or real-time response.

repository. A nuclear facility (e.g. geological repository) where waste is emplaced for disposal. Future retrieval of waste from the repository is not intended.

responsible organization. The waste management organization that bears responsibility for performance of the activity under discussion. Responsibilities for activities are defined by management of a waste management facility according to their selection of organizational structure.

safety envelope. That combination of technical, administrative, and performance standards which, when applied to govern a hazardous facility or operation, allow the hazardous activity to be performed with consequences that are acceptable for normal and anticipated off-normal events by maintaining the validity of assumptions relating to the integrity of engineered safety systems.

second party inspection. Inspection carried out by inspection personnel who are independent of the waste conditioning plant or facility but work for the same overall organization.

self inspection. Inspection carried out by the operators to demonstrate waste packages are produced within the process envelope and meet acceptance criteria.

storage (interim). The placement of waste in a nuclear facility where isolation, environmental protection and human control (e.g. monitoring) are provided with the intent that the waste will be retrieved for exemption or processing and/or disposal at a later time.

substrate. The non-radioactive material that retains radioactive material as an unstabilized/untreated waste form. Radioactive material may be retained as surface contamination, or it may be physically interspersed within agglomerated particles of the substrate, or it may be chemically bound to the molecular structure of the substrate.

testing. An examination of verification for the determination of the capability of an item to meet specific requirements by subjecting the item to a set of physical, chemical, environmental and/or operating conditions.

third party inspection. Inspection carried out by inspection personnel who are completely independent of the organization.

tomography. The technique of making radiographs of plane sections of a body or an object to show detail in a selected plane while blurring the images of structures in other planes.

transportation. Operations and conditions associated with and involved in the movement of radioactive material by any mode on land, water or in the air. The terms transport and shipping are also used.

use-as-is. A determination that a deficiency in characteristic or documentation for an item will not adversely affect its ability to perform as intended in service even though the item does not fully comply with specified requirements.

waste, high level (HLW). (a) The radioactive liquid containing most of the fission products and actinides originally present in spent fuel and forming the residue from the first solvent extraction cycle in reprocessing and some of the associated waste streams. (b) Solidified high level waste from (a) above and spent fuel (if it is declared a waste). (c) Any other waste with an activity level comparable to (a) or (b). High level waste in practice is considered long lived. One of the characteristics which distinguishes HLW from less active waste is its level of thermal power.

waste, low and intermediate level. Radioactive wastes in which the concentration of or quantity of radionuclides is above clearance levels established by the regulatory body, but with a radionuclide content and thermal power below those of high level waste. Low and intermediate level waste is often separated into short lived and long lived wastes. Short lived waste may be disposed of in near surface disposal facilities. Plans call for the disposal of long lived waste in geological repositories.

waste, primary/raw. Waste unchanged from the form and quantity in which it was generated - waste that has not been processed.

waste, radioactive. For legal and regulatory purposes, radioactive waste may be defined as material that contains or is contaminated with radionuclides at concentrations or activities greater than clearance levels as established by the regulatory body, and for which no use is foreseen. (It should be recognized that this definition is purely for regulatory purposes, and that material with activity concentrations equal to or less than clearance levels is radioactive from a physical viewpoint - although the associated radiological hazards are considered negligible).

waste acceptance criteria. Those criteria relevant to the acceptance of waste packages for handling, storage and disposal.

waste characterization. The determination of the physical, chemical and radiological properties of the waste to establish the need for further adjustment, treatment, conditioning, or its suitability for further handling, processing, storage or disposal.

waste form. The waste in its physical and chemical form after treatment and/or conditioning (resulting in a solid product) prior to packaging. The waste form is a component of the waste package.

waste generator. The operating organization of the facility where the waste is generated.

waste package. The product of conditioning that includes the waste form and any container(s) and internal barriers (e.g. absorbing materials and liner), as prepared in accordance with requirements for handling, transportation, storage and/or disposal.

waste package specifications. The set of quantitative requirements to be satisfied by the waste package for handling, transportation, storage and disposal.

waste processing. Any operation that changes the characteristics of a waste, including waste pretreatment, treatment and conditioning.

CONTRIBUTORS TO DRAFTING AND REVIEW

Aerts, J.	Belgoprocess, Belgium
Addison, C.W.E.	British Nuclear Fuels plc., United Kingdom
Bordier, J.C.	COGEMA, France
Bosser, R.	DSIN/SD1, France
Haselden, D.	British Nuclear Fuels plc., United Kingdom
Kouznetsov, J.	V.G. Khlopin Radium Institute, Russian Federation
Langlois, G.	Agence nationale pour la gestion des déchets radioactifs (ANDRA), France
Lindbom, G.	Swedish Radiation Protection Institute, Sweden
Ozarde, P.	Bhabha Atomic Research Centre, India
Pinson, P.	COGEMA, France
Risoluti, P.	ENEA, Italy
Robinson, M.A.	Los Alamos National Laboratory, United States of America
Tsyplenkov, V.S.	International Atomic Energy Agency

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