# Development of a catalogue of characterization methodologies for demonstrating compliance with waste acceptance criteria

- 200 litre waste package -

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**Abstract**

The safe management and disposal of low and intermediate level radioactive waste requires accurate and quality assured characterization by non-destructive and destructive methods, and determination of the radionuclide inventory, chemical, physical properties in the different steps of waste management. Relevant procedures, standards and practices have been developed and continue to be refined in waste characterization facilities in IAEA Member States. Sharing of information between facilities and practitioners underpin the ongoing development of such procedures, standards and practices. The International “IAEA Network of Laboratories for Nuclear Waste Characterization (LABONET)” is focusing its attention on proven practices and successful implementation of these. During the 2019 LABONET Annual Technical Meeting, attended by more than 60 participants from 25 Member States, it was decided to start with the implementation of the project “Catalogue of methodologies to verify that a 200 litre waste package is in compliance with Waste Acceptance Criteria (WAC)”.

This paper will discuss the effort and progress on the following topics: 1) Aim of the Catalogue; 2) Fundamental and additional requirements of WAC; 3) Requirements of type of waste management facility; 4) Executors of verifications; 5) Waste package (waste) characterization (verification) methodologies; 6) Catalogue of characterization methodologies; 7) Work plan and potential working groups to establish the Catalogue.

## INTRODUCTION

In the management of radioactive waste, a waste package is usually designed for coping with one or more components of the engineered components for ensuring and providing safety functions. It also represents a principal unit used as a reference for controlling information, record keeping, and information needs at all the various stages in radioactive management.

Given that disposal is considered the final stage (or endpoint) of safe waste management, developing requirements for safe disposal of waste packages is an important for the entire radioactive waste management process. Thus, waste acceptance criteria (WAC) are most commonly defined as quantitative or qualitative criteria that should to be met by conditioned radioactive wastes, manufacturing packages, to be accepted at an interim storage or a disposal facility.

Moreover, it should be noted that WAC are typically used for all waste management steps. These criteria serve as a benchmark for disposal facility operators who accept radioactive waste for disposal, or storage operators who accept waste for storage or for processors who accepts waste for processing. The acceptability of waste can be judged in relation to the specific conditions of a given waste management step.

The safe management and disposal of low and intermediate level radioactive waste requires accurate and quality assured characterization by non-destructive and destructive methods, and determination of the radionuclide inventory, chemical, physical properties in the different steps of the waste processing.

Verifying that the WAC for immobilization and disposal of radioactive waste has been met is a key action in the complete flowchart of the back-end of the fuel cycle. In this IAEA LABONET project the focus will be as first on criteria relating to the radionuclide inventory of the radioactive waste or waste packages (200 litre waste package), as this is probably the major criteria, and as different methods exist to determine this. Radionuclide inventory of wastes can be determined using non-destructive and/or destructive methodologies, by calculations and by making use of the scaling factor (SF) method. The radionuclides that must be determined may be easily measurable but many of them will be difficult-to-measure. Different methods may lead to different quality in outcome as well as in budget. The preferred characterization methodology will also depend on the kind of waste and waste package, level of radioactivity, homogeneity of the matrix and radioactivity, etc..

## Aim of the catalogue

The aim of this “Catalogue of methodologies to verify that a 200 litre waste package is in compliance with Waste Acceptance Criteria” is to create specific WIKI-articles, based on methodologies (best practices) to demonstrate that a waste package (200 litre drum) is in compliance with the required WAC for processing, storage and disposal of the waste package.

WAC can be specified as a quantitative or qualitative criteria specified by a *regulatory body*, or specified by an *operator* and approved by the *regulatory body*, for the *waste form* and *waste package* to be accepted by the *operator* of a *waste management facility*.

* WAC specify the radiological, mechanical, physical, chemical and biological characteristics of waste packages and unpackaged waste.
* WAC might include, for example, restrictions on the activity concentration or total activity of particular radionuclides (or types or radionuclide) in the waste, on their heat output on the properties of the waste form or of the waste package.
* WAC are based on the safety case for the facility or are included in the safety case as part of the operational limits and conditions controls.

## Basic and Additonal requirements of wac

The technical requirements in the waste acceptance criteria can be divided into two categories (see Table 1 for examples of requirements to LLW). “Basic requirements” and “Additional requirements” depending on the circumstances according to the progress of technical studies of both the waste packages and facilities (at each stage of the feasibility study (conceptual design), basic (preliminary) design, detailed design, and so on).

**Basic requirements**. A basic (fundamental) requirement is a “Performance-based requirement” to be met under the assumption of general conditions and the characteristics of waste packaging, e.g. fundamental requirements do not depend on the design of waste management facilities and waste packaging processes. These requirements can be determined early in the development cycle.

**Additional requirements (specific requirements).** An additional requirement is a “Specification-based requirement” to be met by the detailed conditions applied in the design and safety assessment of waste management facilities, taking into account individual circumstances (e.g. nature of waste packaging, technical details of the design of the facility, geological characteristics of surrounding rock, etc.) and to specific requirements that depend on the facility design and safety assessment, and waste packaging process used.

## requirements RELATING TO the type of waste management facility

The required items of WAC are different for the following waste management facilities. WAC depends on waste type, primary role, target protection exposure, etc. Table 2 provides examples of points to consider for various waste management facilities:

* Waste treatment & conditioning
* Waste storage
* Waste disposal

Further, Table 3 presents a more detailed summary of typical WAC’s specific for various waste management facilities as well as for “Transport”.

TABLE 1. EXAMPLES OF LEVELS OF REQUIREMENTS TO LLW

|  |  |  |
| --- | --- | --- |
| **Requirement category** | **Basic requirements**  **(Performance-based)** | **Additional requirements by type of disposal**  **(Specification-based)** |
| **Regulation limit** | • Upper limit of activity concentration of LLW | • Maximum activity concentration of nuclides must be declared for LLW disposal |
| **Stability of waste package** | • Physical stability  - Waste package has stability to withstand load and drop impact tests, | • Physical stability  Specification of solidified material, mixing condition, etc.  - Container specification  - Limit of weight of waste package (e,g <1,000kg)  - Size of waste package  - Limit of harmful void in waste package (Protection of subsidence in facility) |
| • Chemical stability  - waste package does not contain any substances that have an effect on the waste package and the facility. | • Chemical stability  Waste treatment or segregation method for obtaining stability  - Limit of mixture of aluminium (Protection against effected H2 gas generation)  - Limit of mixture of natural organic material (Maintain the performance of barriers) |
| • Biological stability  (NPP waste does not contain biological waste) | − |
| **Measures for preventing /controlling leakage /migration of nuclides from package** | • Limit of surface contamination | • Value of surface contamination limit  - Beta & gamma: < 4 Bq/cm2 |
| • Short term measures to prevent/control leakage of nuclides from the package | • Long term measures to prevent/control migration  - Required performance of waste package for first barrier (e.g. partition [distribution] coefficient)  - Properly-closing of container. |
| **Radiation protection** | • Label  - Warning to workers | • Label  - Safety label that is specified by default. |
| − (Shielding is required from transportation) | • Shielding  - Specific maximum surface dose rate of a waste package (e,g. <10mSv/h) |
| • Remoteness  - Safe handling of waste package | • Remoteness  - Safe remote handling system is required. |
| **Recording** | • Record of waste packages and waste  • Identification number of waste packages  • Traceability of record of waste packages and waste by identification number | |

TABLE 2. EXAMPLES OF POINTS TO CONSIDER FOR VARIOUS WASTE MANAGEMENT FACILITIES

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Waste Treatment  & conditioning** | **Waste storage** | **Waste disposal** |
| **Waste type** | Raw, pre-treated, treated and conditioned waste. | Waste package | Waste package |
| **Primary role for facility** | Control, limit and segregate the incoming wastes to types that can be handled by the installed equipment and processes.  The role of WAC is also to ensure safe and effective operation of operating facilities and meeting of design and performance requirements. | Control and limit incoming waste packages to those that can be safely stored for the required period of time (protection of workers, public and the environment).  Provide for handling, stacking, inspection and retrieval of waste packages. | Control and limit incoming waste packages to those that can meet the short-term and long-term safety requirements of the facility (protection of workers, public and the environment) |
| **Target protection exposure** | Radiation protection from strong gamma emitter. | Radiation protection from strong gamma emitter. | *Short term*: Radiation protection from strong gamma emitter  *Long term*: Protection exposure by migration to the environment of nuclide. |

TABLE 3. SUMMARY OF TYPICAL WASTE ACCEPTANCE CRITERIA

| **Type** | **General Requirement** | **Waste Processing Facility** | **Waste Storage Facility** | **Waste Disposal Facility** | **Transport** |
| --- | --- | --- | --- | --- | --- |
| Administrative | Waste/container identification and tracking | ✓ | ✓ | ✓ | ✓ |
| Use of standardized containers |  | ✓ | ✓ | ✓ |
| Reporting requirements | ✓ | ✓ | ✓ | ✓ |
| … |  |  |  |  |
| Qualification | Characterization requirements | ✓ | ✓ | ✓ | ✓ |
| Acceptable waste types/classes/forms | ✓ | ✓ | ✓ | ✓ |
| Restrictions on or specification of allowable conditioning methods |  | ✓ | ✓ |  |
| … |  |  |  |  |
| Technical – design / operational | Minimum/maximum dimensions | ✓ | ✓ | ✓ |  |
| Maximum mass | ✓ | ✓ | ✓ |  |
| Mechanical properties of waste form / package |  | ✓ | ✓ |  |
| Waste package handling |  | ✓ | ✓ | ✓ |
| Accidental handling tolerance… | ✓ | ✓ | ✓ | ✓ |
| Technical safety related | Chemical stability of waste form |  | ✓ | ✓ |  |
| Radiation stability of waste form |  | ✓ | ✓ |  |
| Durability of waste package / container |  | ✓ | ✓ | ✓ |
| Restrictions on waste form |  | ✓ | ✓ |  |
| Restrictions on chemical or other hazardous constituents | ✓ | ✓ | ✓ |  |
| Restrictions on biological, pathogenic, and/or infectious materials | ✓ | ✓ | ✓ |  |
| Restrictions on free liquids |  | ✓ | ✓ | ✓ |
| Restrictions on combustible materials |  | ✓ | ✓ |  |
| Restrictions on heat generation rate | ✓ | ✓ | ✓ | ✓ |
| Restrictions on radionuclides | ✓ | ✓ | ✓ | ✓ |
| Restrictions on fissile content | ✓ | ✓ | ✓ | ✓ |
| Restrictions on gamma radiation dose rates | ✓ | ✓ | ✓ | ✓ |
| Restrictions on fixed and/or removable surface contamination on waste packages |  | ✓ | ✓ | ✓ |

## eXECUTORS OF VERIFICATIONS

The verification that a waste flux or a waste package is in compliance with the applicable WAC (e.g. by means of characterization) is carried out in several stages from waste generation up to final disposal. The following organizations have primary roles in this process.

* Waste producer: Inspection and characterization of generated wastes and waste packages proving that wastes fulfil the WAC of the “Waste Processing Facility”
* Operator of Waste Processing Facility: Verification that received wastes fulfils the WAC for accepting these wastes. Next, the Waste Processing Facility, itself has also to perform verifications on processed wastes in order to verify that these processed wastes are in compliance with WAC e.g. for storage, disposal
* Regulator (third party): Verification of the processes at the waste producer as well at the Waste Processing Facility, as at the Waste Storage/disposal Facility if processed wastes fulfil applicable WAC’s.

## Waste Package (waste) characterization (verification) methodologies

This Catalogue aims to show appropriate waste characterization method(s) for a 200 litre waste package and its detail against waste streams, waste management facilities and waste acceptance criteria items. The following methods can be applied for waste characterization to comply with waste acceptance criteria:

* Destructive analysis (DA): radiochemical analysis, chemical analysis, …. Destructive analysis provides an accurate and unbiased way of radioactivity determination. However, it should be noted that this will only be on a sample of the waste rather than on the whole volume of the waste.
* Non-destructive analysis (NDA): gamma scanning, surface dose rate, …. The most widely used NDA technologies for radiological characterization of wastes that are in use today are based on the detection of gamma photons and neutrons, and in some exceptional cases on calorimetry.
* Evaluation: Scaling factor method, finger print method, …. Scaling factor method is often referred to when producing an activity assessment during the characterization of radioactive wastes. This Scaling factor method combines several waste characterization methods such as DA, NDA and calculation methods [1, 2].
* Process control program (PCP): review/assessment on operation record(s)/registration(s) based on the pre-examination test(s) instead of inspection, …. PCP identifies the administrative and operational controls for waste handling, process parameters, and monitoring requirements that ensure that the final waste product meets the requirements (e.g. compressive strength, homogeneity, etc.) of WAC for controlling and checking for “control index” that are selected by pre-operational testing of waste management facility (e.g., waste processing facility, mixing ratio of solidification material and liquid waste, mixing speed, mixing time, etc,) rather than measuring WAC items directly.

## Catalogue of characterization methodologies

WAC will generally differ between Waste Processing Facilities and countries, these differences are to differences in environment, facility, stage of development of facilities, etc. However, this does not necessarily mean that *characterization methodologies* should also differ in IAEA Member States.

To be able to setup such a “Catalogue of methodologies/best practices currently applied in Member States (MS) to prove that wastes are in compliance with WAC, a questionnaire has been developed. The aim of this questionnaire is to collect information from MS’s about specific WAC’s and the applied methodologies to prove that wastes are in compliance with these WAC’s. It must be made unequivocally clear that the catalogue, which will be based on completed questionnaires received, does not have the intend or purpose to “develop waste acceptance criteria” or to provide information to third parties about unique values of criteria from a specific responder that has been used in the development of this catalogue.

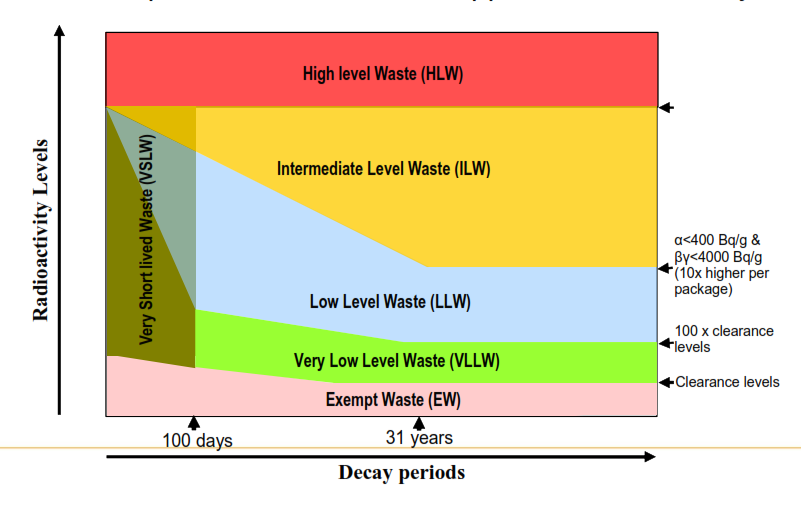
### Questionnaire

The developed questionnaire concerns the safe management and disposal or storage of very low-level waste (VLLW), very short-lived waste (VSLW, low-level waste (LLW) and intermediate level waste (ILW) and is applicable for all 200 drums that are falling in the mentioned IAEA waste categories (see Figure 1).

The selection for this 200 litre (drum) waste package is based on existing practices in the different MS’s that more than 90% of all Waste Management Organisations and MS’s are applying this type of waste package. The 200 litre drum may contain the following wastes and eventual liners:

* *compacted* raw waste and with- or without an additional non-radioactive liner
* *super*-*compacted* raw waste and with- or without an additional non-radioactive liner.

As can be observed from Table 3 waste acceptance criteria include a large number of different topics spread over multiple technical and scientific disciplines, for optimizing the user-friendliness and the ease of filling in this questionnaire, the questionnaire has been split-up based on technology and scientific discipline.



*FIG. 1. Schematic diagram of the IAEA waste classification system.*

In order to cover all technologies and disciplines the questionnaire contains the following topics:

* Part 1: General information on the Waste Management Organisation and facility
* Part 2: WAC: General information on the type of 200 litre waste package and visual inspection
* Part 3: WAC: Mechanical properties of the 200 litre waste package
* Part 4: WAC: Physical properties of 200 litre waste package
* Part 5: WAC: Chemical properties of 200 litre waste package
* Part 6: WAC: Biological properties of 200 litre waste package
* Part 7: WAC: Radiological properties of 200 litre waste package: Dose rate and surface contamination properties
* Part 8: WAC: Radiological properties of 200 litre waste package: Total radioactivity limits for alpha radiation
* Part 9: WAC: Radiological properties of 200 litre waste package: Total radioactivity limits for beta and beta/gamma radiation
* Part 10: WAC: Radiological properties of 200 litre waste package: Total radioactivity limits for fissile content
* Part 11: WAC: Radiological properties of 200 litre waste package: Nuclide specific limits.

### Example of a best practice/methodology reported in the catalogue (current proposed layout)

The example given (see Table 4) is about the WAC “surface contamination” and which best practices/methodologies can be applied to demonstrate that the surface contamination is in accordance with the WAC.

It is intended, for the ease of reading and interpreting of the information provided, that the headings in the Catalogue will be identical for all Waste Acceptance Criteria. At this moment, it is suggested that the header expands six columns with the following respective headers:

Column 1: *Waste Acceptance Criterion.* In this column the topic of the waste acceptance criterion is described in a generic way.

Column 2: *Dimension.* The dimension of the criterion is based on the “System of Units –International Standards (SI) units.

Column 3: *Value.* The reported value is the outcome of a reviewing and interpretation process of the received questionnaires. The reviewing and interpretation will be made by experts in the field. In the case of a quantitative value, this value should to be seen as a limit set by an authority.

Column 4: *Applied best practice / methodology.* The reported methodology(ies) is the outcome of an equal process as for the *“Value”* of the criterion. Multiple methodologies/best practices can be reported, in such a case they will be ranked by experts in order of “best methodology/best practice”.

Column 5: *Reference(s) to applied methodology(ies).* In this column reference codes are presented of references that provides detailed information of the applied methodology.

Column 6: *Reference(s) to applied (ISO)standard(s) or an approved procedure(s).* These reference(s) have to be taken into account at applying this methodology in a verification process.

TABLE 4.. EXAMPLE OF A REPORTED APPROPRIATED “BEST PRACTICE/METHODOLOGY” TO VERIFY A TYPICAL WASTE ACCEPTANCE CRITERIA

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|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Waste Acceptance criterion** | **Dimension** | **Value** | **Applied**  **best practice / methodology** | **Reference(s) to applied methodology** | **Reference(s) to applied (ISO) standards or an approved procedures** |
| Surface contamination:   * Alpha * Beta | [Bq/cm2]  [Bq/cm2] | < 0.4  < 4 | Wipe test,  1) Alpha-beta Low-Level counter  2) Contamination monitor | IAEA-2007a  IAEA-2007b | ISO 7503a; ISO 7503b; …..  XXX-2019; ….. |

**References:**

IAEA-2007a Strategy and Methodology for Radioactive waste characterization TECDOC 1537, page xxx *(dummy reference)*

IAEA-2007b Strategy and Methodology for Radioactive waste characterization TECDOC 1537, page yyy *(dummy reference)*

ISO-7503a ISO 7503-1:2016: Measurement of radioactivity — Measurement and evaluation of surface contamination — Part 1: General principles

ISO-7503b ISO 7503-2:2016: Measurement of radioactivity - Measurement and evaluation of surface contamination — Part 2: Test method using wipe-test samples

XXX-2019 Determination of the alpha- and beta-contamination at the surface of a 200 liter drum, organization XXX, doc nr. 2019-0000 *(dummy reference*)

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## work plan and potential working groups to establish the Catalogue

This IAEA LABONET project is structured over a number of years. The aim of this first stage (e.g. the subject of this paper) was to set up: i) the structure and general content of the catalogue; ii) preparing the first version of the questionnaire (to be send to as many MS’s as possible) on wastes of interest (e.g. 200 litre waste packages (drums)) and related waste acceptance criteria; iii) propose a work plan and potential working groups (WG) to establish the catalogue (see Table 5) .

TABLE 5. PROPOSED WORKING PLAN’S FOR WG’S, WG-COMPOSITION AND PROVISIONAL TIME SCHEDULE

| **Provisional Time Schedule** | **Proposed working plan for WG’s** | **Meeting, WG composition and outcome** |
| --- | --- | --- |
| First year:  2020 | - Drafting 1st version of the Catalogue (structure, format and contents)  - Drafting 1st version of questionnaire  - Provisional work plan | - Draft of 1st version of the questionnaire as well of the Catalogue (this work) |
| Second year;  2021 | - Reviewing process of the questionnaire before it is send to MS’s  - Try-out: Send 2nd version of questionnaire to 2-4 organisations / MS’s  - Review and analyse received filled in questionnaires  - Process the information obtained from the received completed questionnaires in the 2nd version of the Catalogue | - WG1 composition: Characterization specialists covering different fields of science, others e.g. WMO’s  - Draft of 2nd version of the questionnaire and Catalogue  - Selection of 2-4 organisations/MS’s for try-out exercise  - Draft of an eventual 3rd version of questionnaire  - Draft of an eventual 3rd version of Catalogue |
| Third year:  2022 | - Send 3rd version of questionnaire to organisations and MS’s  - Review and analyse received filled in questionnaires  - Finalizing structure of the Catalogue.  - Process the information obtained from the received completed questionnaires in the 3rd version of the Catalogue  - Review 1st draft of final Catalogue  - Discussing on system structure for Wiki Catalogue.  - Drafting work for Wiki Catalogue conform structure and adding contents into Wiki (WAC and characterization methodologies) | - WG2 composition: Characterization specialists covering different fields of science  - 1st draft of final Catalogue to be transferred into a Wiki catalogue  - 2nd draft of final Catalogue  - WG3 composition: Characterization specialists covering different fields of science, WMO, IT-Wiki specialist |
| Fourth year:  2023 | - Reviewing and finalizing work for Wiki Catalogue. | - WG4 composition: Characterization specialists covering different fields of science, IT-Wiki specialist |
| Fifth year  2024 | - Issue Wiki Catalogue and final report. | - WG5 composition: WG-leaders, IT-Wiki specialist |

REFERENCES

[1] Determination and Use of Scaling Factors for Waste Characterization in Nuclear Power, IAEA Nuclear Energy Series No. NW-T-1.18, Vienna, (2009)

[2] ISO 21238:2007, Scaling Factor Method to Determine the Radioactivity of Low- and Intermediate-Level Radioactive Waste Packages Generated at Nuclear Power Plants, International Organization for Standardization (ISO).