WASTE ACCEPTANCE CRITERIA (WAC); DOMAIN INSIGHT

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OVERVIEW

Radioactive waste needs to be safely managed in a regulated manner, compatible with nationally and internationally agreed principles and standards. Implementing a proper radioactive waste management system needs organisational and administrative arrangements that define competencies, responsibilities and activities of the responsible institutions involved.

Well-established waste acceptance criteria (WAC) and related systems help to define a radioactive waste management strategy and are an important prerequisite for waste management routes to be effectively implemented. They apply to waste handling activities during all stages of the waste life cycle, from pre-treatment, treatment and conditioning, through transportation, storage and disposal. They also govern the transfer of waste liabilities and responsibilities from one organisation to the next in a stepwise process involving many different activities, facilities, responsible entities, and organisational arrangements (Figure 1).

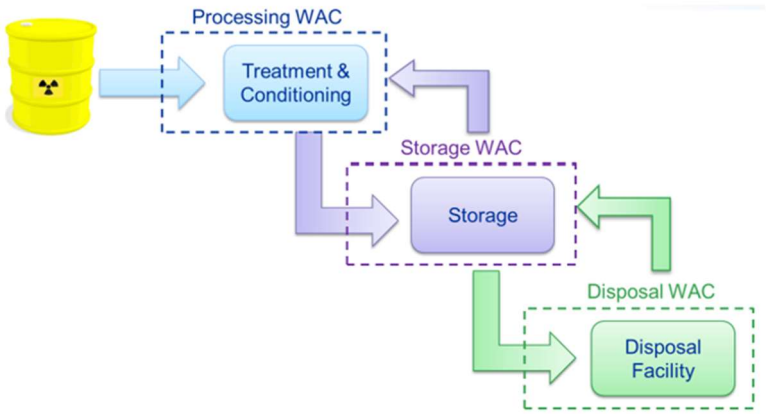

Figure 1 – WAC are the link between radioactive waste management operations at different stages of the waste life cycle [Robbins and Guskov, 2021].

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The IAEA defines WAC as "*quantitative or qualitative criteria specified by the 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*" [IAEA, 2022]. WAC specify the radiological, mechanical, physical, chemical and biological characteristics of waste or waste packages that are conditions for acceptance at a particular facility. They also act to:

- Ensure compliance with safety requirements.
- Assist with the selection of appropriate processing and packaging options.
- Prevent technological problems during processing.
- Standardise waste management operations.
- Assure waste tracking.

The EC PREDIS project defines a waste acceptance criterion as the combination of a parameter to be measured (e.g., alpha activity); the permitted value of the parameter (e.g., an activity limit) and the method by which a value of this parameter is determined (e.g., alpha spectroscopy) [Nachmilner, 2023].

This document provides an overview of issues relating to the development, implementation, and update of WAC.

KEYWORDS

Assurance, categorisation, characterisation, classification, conditioning, criteria, disposal, inspection, inventory, non-compliance, oversight, package, pre-disposal, qualification, quality, safety, specification, storage, treatment, WAC, wasteform.

KEY ACRONYMS

AMR	advanced modular reactor
CHANCE	Characterization of conditioned radioactive waste (EC project)
EC	European Commission
EGOS	(NEA) Expert Group on Operational Safety
ERDO	Association for Multinational Radioactive Waste Solutions
EURAD	European Joint Programme on Radioactive Waste Management
GBS	goals breakdown structure
IAEA	International Atomic Energy Agency
IDKM	information, data and knowledge management
IGSC	(NEA) Integration Group for the Safety Case
ILW	intermediate-level waste
LILW	low and intermediate-level waste
LWC	legacy waste characterisation
LLW	low-level waste
MS	Member States
NEA	Nuclear Energy Agency, part of OECD
NPP	nuclear power plant

PREDIS	Pre-disposal Management of Radioactive Waste (EC project)
QA / QC	quality assurance / quality control
RD&D	research, development and demonstration
ROUTES	Waste management routes in Europe from cradle to grave (EURAD work package)
RWM	radioactive waste management
SMR	small modular reactor
SQEP	suitably qualified and experienced person
SRA	Strategic Research Agenda
THERAMIN	Thermal treatment for radioactive waste minimization and hazard reduction (EC project)
TRU	transuranic
VLLW	very low-level waste
WAC	waste acceptance criteria
WIPP	Waste Isolation Pilot Plant (USA)
WP	work package

1 TYPICAL OVERALL GOALS AND ACTIVITIES IN THE DOMAIN OF WAC

The EURAD Roadmap is a representation of a generic radioactive waste management (RWM) programme, enabling users and waste management programmes to access existing knowledge, ongoing work and future plans. Knowledge and generic activities are organised into a series of themes, sub-themes and domains, each formulated as goals [EURAD, 2021a].

This section provides the overall goal for the WAC domain (2.1.2), extracted from the EURAD Roadmap goals breakdown structure (GBS) [EURAD, 2021b]. This is supplemented by typical domain activities, according to phases of implementation needed to achieve the domain goal. Activities are generic and are common to most disposal programmes (and to all types of disposal facility). Each of these phases of activity is discussed later in this report.

Domain Goal	
2.1.2 Identify parameters and metrics for waste acceptance criteria through whole life cycle (Waste Acceptance Criteria)	
Domain Activities	
Phase 1: Planning and Programme Initiation	Define functional specification for waste processing facilities; identify target inventories; set expectations on consignments (e.g., treatment, containerisation, transport routes, documentation). Initial derivation of WAC linked to facility safety case and national RWM framework; ensure compatibility with requirements for subsequent management steps.

Domain Activities	
Phase 2: Programme Implementation	Establish and implement WAC within a wider management and acceptance system that also establishes responsibilities, and specifies requirements relating to demonstrating compliance, characterisation, waste form qualification, IDKM and records management, and managing non-conformances.
Phases 3–4: Programme Operation / Optimisation and Closure	WAC implementation, review and update in response to a range of drivers. Ongoing IDKM including management of records and competencies for WAC implementation.

The WAC domain falls under Theme 2 of the EURAD Roadmap (Pre-disposal) and under Sub-theme 2.1 (Planning pre-disposal management of radioactive waste in close cooperation with waste producers). However, the development and implementation of WAC cuts across all phases of the waste life cycle and WAC[1] apply at each stage of waste processing. WAC applicable to predisposal activities should support safe disposal of the waste in due course, and must not compromise disposal requirements (so far as these are known). Moreover, whilst WAC development is a crucial aspect of waste management planning, effective waste acceptance systems will undergo review and update through programme implementation and waste management operations. Figure 2 highlights factors informing the scope of WAC applicable at different stages of the waste life cycle.

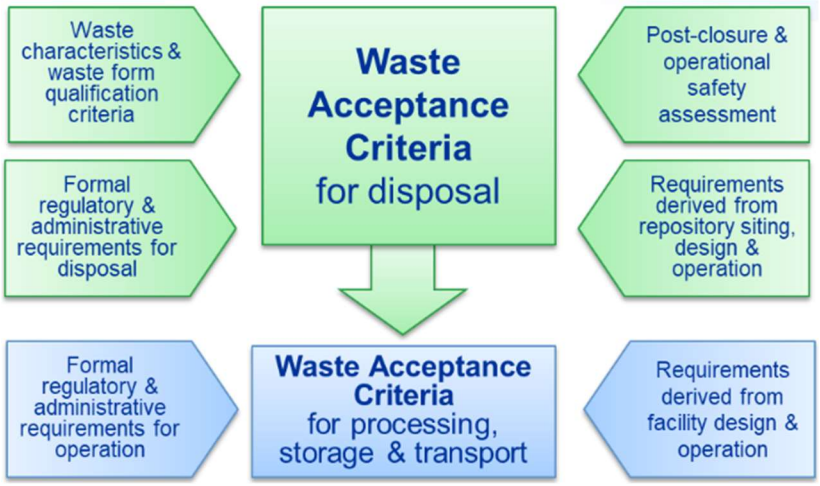

Figure 2 – Factors informing the scope of WAC at different stages in the waste life cycle [Robbins and Guskov, 2021].

[1] The term 'WAC' is in widespread international use. However, other terms are also used in relation to analogous requirements, including conditions, rules, procedures, policies, decrees, regulations, and specifications. The terminology in use varies from country to country and depending on the application. The term 'WAC' is used throughout this report.

2 INTERNATIONAL LEGISLATION, REGULATION, AND REQUIREMENTS

International regulations on the safe management of radioactive waste are in place to ensure protection of people and the environment, and security of radioactive materials and waste. For example, Directive 2011/70/EURATOM, adopted by the Council of the European Union on 19 July 2011 [EU, 2011], establishes a Community framework for the responsible and safe management of spent fuel and radioactive waste. This provides binding legal force to the main internationally endorsed principles and requirements in this field. It requires all EU Member States (MS) to have a national policy for spent fuel and radioactive waste management and to draw up and implement national programmes for the management of these materials. MS are required to report progress to the EC against their implementation programmes every three years.

Directive 2011/70/EURATOM does not explicitly call for the use of WAC and there is no other international legislation on WAC for radioactive waste. However, the Directive identifies the IAEA's system of Safety Standards and Fundamental Safety Principles (which were jointly sponsored by the European Community, the NEA and other international organisations) as key to ensuring consistent application of waste management arrangements between EU MS. The IAEA's Safety Standards for pre-disposal management and for disposal of radioactive waste both call for WAC to ensure that waste management activities are conducted safely, in accordance with the relevant safety case, as indicated in the following requirements:

- Requirement 12 relating to radioactive waste acceptance criteria during predisposal [IAEA 2009]: "*Waste packages and unpackaged waste that are accepted for processing, storage and/or disposal shall conform to criteria that are consistent with the safety case.*"
- Requirement 20 relating to waste acceptance in a disposal facility [IAEA, 2011]: *"Waste packages and unpackaged waste accepted for emplacement in a disposal facility shall conform to criteria that are fully consistent with, and are derived from, the safety case for the disposal facility in operation and after closure."*

National entities are responsible for determining how to implement these requirements within their respective national waste management programme. The scope of WAC applicable to RWM is not mandated in international legislation.

The Council of the European Union *does* set out the need for, and scope of, WAC for the acceptance of (non-radioactive) waste to certain types of disposal facilities, e.g., landfills [EU, 2003]. These requirements can sometimes apply to certain classes of radioactive waste destined for disposal therein, e.g., very low-level waste (VLLW).

For transport between nuclear licensed sites / users, countries operate in accordance with IAEA transport regulations, European Council Directives and international agreements concerning the carriage of dangerous goods as WAC for transport. Directive 2006/117/EURATOM lays down a system for supervision and control of transboundary (international) shipments of radioactive waste and spent fuel [EU, 2006]. This is supplemented by Commission Recommendation 2008/956/EURATOM, which sets out the need for, and scope of, criteria to be defined for the export of radioactive waste and spent fuel [EU, 2008]. International requirements are often reflected in national legislation, sometimes, with extensions or additions to reflect the national context. Elsewhere, elements are applied directly, without such promulgation.

Transfer of waste between facilities on the same site is often not subject to formalised WAC, although there may still be export / receipt requirements at the origin and destination facilities, respectively.

3 GENERIC SAFETY ISSUES RELATING TO WAC

This section describes how safety and security are considered in relation to WAC during each of the three phases noted in Section 1. They are described with respect to a waste management programme addressing pre-disposal activities (prior to final disposal).

3.1 Planning and Programme Initiation

The definition of facility-specific WAC typically progresses through multiple iterations, alongside wider planning and development of the waste management facility. Throughout, it is crucial to promote dialogue between waste consigners, facility operators and regulators so that waste consignment approaches and WAC are defined in a way that meets all stakeholder requirements. A key objective of such interactions is to ensure that WAC will underpin safe and efficient operation without precluding the consignment of wastes that a facility is intended to manage.

Initially, WAC play a fundamental role in communicating the functional specification for the facility (i.e., what it is supposed to do). As such, their definition early-on helps guide development of the facility design, as well as prior processing of wastes to be handled there. Typical considerations captured in WAC at this stage include:

- Compatible inventories and their origins (e.g., waste classes and/or categories; quantities; consigning sites). The inventory can encompass legacy wastes, waste that are continuing to be generated and/or future inventory arisings, depending on what a facility is intended to receive.
- Expectations on the chemical and physical properties of the waste on receipt and any associated pre-treatment requirements (e.g., drying and/or sorting / segregation).
- Requirements on how consignments of waste should be received to be compatible with the design and operating specifications for the facility (e.g. container types; transport routes; supporting documentation).

Later, as planning matures, the WAC become increasingly linked to the safety case underpinning safe operation of the facility and, in the case of disposal, the long-term safety provided by the facility[2]. They typically become more detailed, and focus on waste properties that could pose a risk to fulfilment of the safety case, as informed by safety assessment calculations. WAC typically evolve to include:

- Limits on the amounts of radioactivity present, the activities of particular radionuclides, package dose rates and/or surface contamination.
- Limits on non-radiological contaminants (e.g., chemotoxic species).
- Controls on physical, chemical and biological hazards posed by the waste, e.g., on flammable materials, putrescible materials, voidage, free liquids, organics, reactive materials, complexants, and/or discrete items.

[2] This, in turn, will depend on the nature of the disposal route (e.g., surface, shallow depth, deep geological repository, borehole, …) and the disposal environment.

- Requirements on waste processing to minimise contaminant release, by ensuring sufficient integrity of the waste package, container and waste form under disposal conditions.
- Quality assurance and control (QA/QC) requirements, e.g., package labels and tracking measures, and supporting documentation including those required for radiation protection, safeguarding, and to fulfil characterisation requirements.

For geological disposal, long-term safety relies on limiting releases to the accessible environment and spreading these in time. The host rock and geological environment play key roles in providing the isolation and containment to ensure this. Nevertheless, WAC still set out specific requirements and/or values for the integrity of the waste package, container and waste form under disposal conditions, reflecting the assignment of long-term safety functions to these barriers as well. This may influence the selection of treatment / conditioning processes or technologies, so as to minimise the mobility of radionuclides and chemical contaminants, within the framework of wider optimisation activities.

The typical scope of WAC included in national programmes is summarised elsewhere [Harvey *et al.*, 2020; Section 5], [Nachmilner *et al.*, 2021]. The exact scope varies depending on the nature of the facility and applicable national requirements. Regardless of the basis for their derivation, there must be a clear justification for how a suite of WAC has been developed and why each criterion is necessary.

During the planning phase, issues relating to WAC closely link to the other EURAD roadmap domains of inventory (2.1.1), characterisation (2.2.1), treatment and processing (2.2.2), conditioning (2.2.3), storage (2.2.4), transport (2.2.5), optimisation (2.3.2), IDKM (7.2.2), and requirements management (1.2.6).

3.2 Programme Implementation

During programme implementation the focus of WAC shifts towards demonstrating and checking compliance. The successful implementation of WAC depends on their application within a wider management system that needs to include:

- Clearly defined responsibilities for all involved parties[3], including their roles in WAC development; approval; application; inspection against WAC; acceptance/rejection of consignments; oversight; and review and update.
- Qualification of waste forms to be consigned for storage and disposal, aligned with the facility design and requirements of the safety case.
- Application of data and information from waste characterisation in order to demonstrate compliance with WAC.
- Clearly defined expectations on how to demonstrate compliance with WAC, which could include mandated characterisation approaches to demonstrate that numerical limits / thresholds are met, and/or justification of waste management measures based on risk-informed evaluation in keeping with the principle of managing risks to be as low as reasonably achievable.
- Plans for information, data and knowledge management (IDKM), including documentation of compliance checks and approvals, and records management systems.

[3] The principal entities involved in radioactive waste management are the waste generator, facility operator(s) and regulatory bodies. Detailed responsibilities in relation to WAC vary from country to country [Harvey *et al.*, 2020; Sections 3 and 6].

- Approaches to identify and manage non-compliances with WAC, acknowledging the likelihood that unforeseen events are likely to occur at some point during waste management activities.
- Training to ensure competent implementation and oversight.
- Flow down of requirements to all parties involved in RWM.

Case studies are available that highlight the importance of ensuring the effective implementation, as well as definition, of WAC. For example, inadequate flow down of WAC was a factor contributing to an incident in 2014 at the Waste Isolation Pilot Plant (WIPP) in the USA, which resulted in radioactive releases from transuranic (TRU) waste containers into the mine and the environment [Dunagan, 2018].

The waste acceptance system should also reflect the need to make best use of (often limited) available disposal capacity and encourage application of the waste hierarchy, i.e., the principles of waste reduction, reuse and recycling to ensure that waste management activities are sustainable as well as safe and secure.

An important element of an effective waste acceptance system is waste form qualification. This is the process for demonstrating that a proposed waste form is suitable for disposal [Konopásková *et al.*, 2022]. It requires testing and/or modelling the behaviour of a waste form under disposal conditions in order to understand and quantify mechanisms for contaminant release, and to determine whether its performance is compatible with the requirements of the repository safety case. Waste form qualification should inform development of the safety case so that waste processing requirements can be optimised alongside development of the disposal facility design and definition of safety functions on wider systems, structures and components of the disposal system.

Waste characterisation is essential to demonstrating compliance with WAC. Characterisation at the time of waste generation or retrieval helps to minimise the need for more extensive characterisation at a later stage (which is often more challenging to implement). Alongside this, an adequate records management process to store, and facilitate reference to, characterisation data needs to be implemented at an early stage, and to endure throughout the waste life cycle.

Product specifications may be developed by waste producers as a means for systematically demonstrating compliance of waste consignments against a set of WAC. Meanwhile, before any waste can be accepted to a facility, the operators need have established procedures for inspection and approval of consignments against WAC, and protocols for management of non-conformances (including the potential for return of consignments if necessary).

Compliance checking may include:

- Package checking on receipt (including visual inspection of consignments, labels and documentation, and checking readily measurable characteristics through non-destructive tests, e.g., dose rate monitoring).
- Analysis of samples of waste to be processed.
- Random destructive tests of accepted packages.

Non-conformance protocols should include:

- The approach to identify the relevant waste / batch / package and to describe the non-conformance.
- Methods(s) or suggestion(s) for correcting the non-conformance, i.e., corrective action, including designation of responsible parties. Options

could involve return of a waste consignment or acceptance with additional processing / packaging.
- Impact evaluation on the processing, storage or disposal system.
- Schedule for completing the corrective action.

Suitably qualified and experienced persons (SQEP) need to be assigned to manage and oversee these processes, and arrangements need to be agreed with the relevant regulatory bodies. Those involved in accepting / rejecting waste consignments and defining corrective actions need to be readily identifiable.

During implementation, issues relating to WAC closely link to the other EURAD roadmap domains of establishing regulatory criteria for RWM facilities (1.1.2), allocating responsibilities for RWM (1.2.3), implementing a waste management system (1.2.4), characterisation (2.2.1), treatment and processing (2.2.2), conditioning (2.2.3), storage (2.2.4), transport (2.2.5), optimisation (2.3.2) and IDKM (7.2.2).

3.3 Programme Operation and Closure

During operation of a facility the WAC defined during programme initiation will be implemented to manage the receipt and processing of waste. The WAC will be implemented in accordance with waste management systems established by the operator and approved by the relevant regulatory bodies.

It is standard for WAC to undergo updates and iteration both before and during their implementation. Beforehand, updates are typically associated with the progression of waste management plans, development of facility designs and operating procedures, and advancement of the facility safety case, as discussed in Section 3.1. During implementation, updates may be made in response to:

- Changes to the legal or regulatory framework for waste management.
- New waste types, waste containers or waste forms being considered for acceptance, or other modifications to the waste inventory being consigned.
- Facility refurbishment or reconstruction associated with ongoing maintenance or replacement when a facility reaches its design lifetime.
- Revision of technical design requirements associated with optimisation to account for new technical solutions, or in response to the outcomes of monitoring activities.
- Broadening the scope of WAC to encompass newly identified hazards, e.g. additional consideration of toxic substances.
- Developing requirements for verification of compliance.
- Applying learning from experience.

It is also good practice to undertake review and update of WAC at key milestones in the implementation of waste management programmes, as well as periodic review of compliance against established WAC. Consequently, the idea of WAC being 'final' once they come into force can be rather misleading.

The relatively long timescales for waste receipt and package inspection / monitoring highlight the importance of implementing an IDKM and records management systems so that early characterisation data and records of waste processing, consignment and inspection can be easily retrieved whenever needed. There is also an ongoing need to maintain competencies relating to WAC implementation through training.

WAC have limited relevance during facility decommissioning or repository closure since wastes are not being received during these phases of activity. However, the WAC for a storage or disposal facility need to account for the inventory of wastes to be consigned that will arise from decommissioning of upstream wastes processing facilities, not just the conditioned wastes arising from operation of these facilities. Typically, such decommissioning wastes would comprise some of the last waste receipts to a storage or disposal facility.

During the operational phase, issues relating to WAC closely link to the other EURAD roadmap domains of implementing a waste management system (1.2.4), treatment and processing (2.2.2), conditioning (2.2.3), storage (2.2.4), optimisation (2.3.2) implementing a monitoring programme (5.5.2), and IDKM (7.2.2). During decommissioning of treatment, conditioning and storage facilities, secondary waste management (2.3.3) also needs to be considered.

4 CRITICAL ISSUES, INFORMATION, DATA OR KNOWLEDGE IN THE DOMAIN OF WAC

Two critical issues in the domain of WAC are discussed below:

- The need to implement predisposal RWM activities in the face of uncertainty over requirements relating to subsequent management steps (for example, if a disposal route and/or associated WAC are not yet available).
- The desire to increase harmonisation of waste management arrangements, including WAC, between countries in order to make best use of available waste processing facilities, and potentially in support of shared disposal.

4.1 Managing uncertainty over future waste management requirements

WAC and operational specifications for predisposal facilities (i.e., those for processing and/or storing waste) must ensure compatibility of packaged waste with requirements (WAC) for the relevant disposal facility. This introduces a significant challenge, particularly for wastes destined for geological disposal: often, the wastes require conditioning to ensure safe ongoing storage and/or to facilitate site decommissioning before their disposal route is known, or before the WAC for this disposal route have been finalised. Thus, their management has to progress in the face of significant uncertainty about future requirements. The dilemma of when to implement final conditioning of radioactive waste in the absence of an established disposal route (or of associated WAC) is summarised in the figure below.

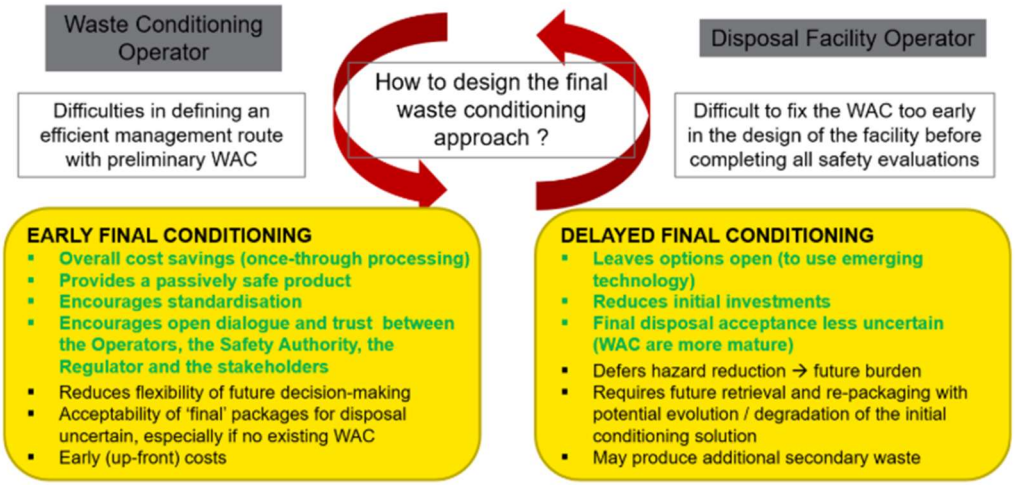

Figure 3 – Summary of the pros (green text) and cons (black text) of early versus delayed final conditioning of radioactive waste from the perspective of developing WAC for disposal (adapted from a figure originally developed by Orano).

Various strategies allow waste retrieval, conditioning and storage to progress despite such uncertainties [De Bock *et al.*, 2023, Section 6.2]. These include:

- Implementing flexible waste processing systems that can be adapted to the characteristics of individual waste streams, to site-specific constraints, and to changes in disposal WAC.
- Applying interim waste management measures that are easily reversible, such as packaging wastes for storage in containers without implementing a conditioning matrix.
- Implementing storage conditions that promote package longevity, thereby reducing the risk that waste packages will require reconditioning.
- Monitoring package performance during storage, so that any requirements to adapt planning can be identified as early as possible.
- Adopting an iterative approach to develop disposal facility WAC, where preliminary WAC are defined at a high level and become increasingly specific as details of the disposal route are established.
- Developing generic criteria[4] for a disposal facility that encompass the range of requirements that might apply at a particular site or facility, when available. A high degree of conservatism is intrinsic to such approaches.
- Pursuing a dual-track disposal strategy (i.e., planning for a national repository whilst pursuing opportunities for a multinational shared facility in parallel).

Such approaches are sometimes referred to as 'no regret' waste management measures since they do not lead to problems later on. Rather, they allow for adaptation of future waste management practices as new information becomes available (e.g., new waste characterisation data), as new technologies are developed (e.g., emerging treatment techniques), or as strategic decisions are made (e.g., progress identifying a disposal site).

[4] i.e., criteria that are not specific to any particular waste, site or facility. The distinction between 'generic' WAC and related terms, such as 'preliminary' and 'final' WAC is discussed elsewhere [Baksay and Takats, 2024; Section 2.1.3].

For the reasons described above, there are various real-world instances of wastes already having been treated and conditioned without a disposal route having first been established. Some such case studies were examined within the EURAD ROUTES work package (WP) [De Bock *et al.*, 2023, Section 3]. In such instances, once a disposal route is identified, it will be necessary to evaluate the compatibility of the processed wastes against associated disposal WAC (on a case-by-case basis). Sometimes, this might lead to reconditioning of the waste so that it can be accepted for disposal. The nature of the waste requiring disposal may also influence the type and design of disposal facility required to enable such wastes to be safely accepted.

4.2 Harmonisation of waste management activities

Over time, the absence of international legislation on WAC has led to distinctive national approaches to RWM, which hamper efforts towards shared waste management solutions (e.g. the use of treatment facilities in another country). Increased harmonisation of the approach to derive and implement WAC is desirable to ensure that waste acceptance processes are safe, consistent, and follow internationally accepted principles of best practice. A degree of harmonisation would also be a prerequisite for realising a shared geological repository, a disposal route favoured by some MS, particularly those with only small inventories requiring deep geological disposal.

The EC CHANCE project considered WAC in the context of waste characterisation and quality control schemes for conditioned radioactive waste. An important conclusion from this work was that basic assumptions for safety studies or identification of parameters evaluated through WAC could be harmonised across different implementation contexts, but that specific safety relevant parameter values could not, owing to their dependence on the varying national contexts for waste management [Bucur *et al.*, 2019]. Similar conclusions were drawn with respect to WAC in the EURAD ROUTES WP: whilst there is scope for increased harmonisation in approaches to develop and implement WAC, and their broad scope, harmonisation of detailed criteria (particularly quantitative limits) is more challenging, since these are aligned to national frameworks for RWM and/or the design and operating requirements of the process / facility in question [De Bock *et al.*, 2023, Section 3.2.1].

In keeping with the principles of Directive 2011/70/EURATOM [EC, 2011] the EC is seeking to promote cross-border collaboration between MS on sharing technical and licensing practices on final disposal solutions and creating opportunities for the EU-wide market in these areas. An EC study on harmonisation of radioactive waste classification schemes in the EU was completed in 2022 [EC, 2022] and other initiatives are also ongoing, aiming to promote an aligned, harmonised application of the international regulatory framework in RWM and decommissioning. These include the EC HARPERS project [Szöke, 2002], which aims to:

- Establish and clarify the benefits and added value of more aligned and harmonised regulations and standards for prioritised topics related to decommissioning and initial phases of radioactive waste handling.
- Identify the relevant regulatory differences across Member States and Associated Countries, assess the rationale for the identified regulatory differences and establish the potential for their harmonisation relative to cross border services / facilities for RWM, moving to a circular economy in RWM and implementation of advanced technologies in RWM.

A desire for increased harmonisation of WAC, to the extent that is achievable, has been a key driver behind recent international efforts to produce guidance on methodologies for the development of WAC, as indicated in Section 8.

5 MATURITY OF KNOWLEDGE AND TECHNOLOGY

Challenges associated with WAC development and implementation are well understood and there is considerable experience available to draw on from established national waste management programmes and past waste management activities. This is true even in national contexts where there is uncertainty over the eventual disposal route and associated WAC. For example, the United Kingdom has developed an extensive system of generic waste package specifications. These are used as the basis for evaluating the disposability of packaging approaches proposed for wastes destined for geological disposal [NWS, 2022].

The key gap, or need, is establishing tailored waste acceptance systems that address these challenges in the context of a particular waste management objective and in accordance with the relevant national framework. Political, financial, human resourcing, and/or spatial constraints mean that disposal facilities may be unavailable for certain wastes and development of associated WAC may be slow.

The technology and know-how for waste characterisation to underpin compliance with WAC is well established [Veres *et al.*, 2023]. However, characterisation can be costly to implement, particularly to gain a comprehensive or sufficiently representative understanding, and characterisation activities may increase worker safety risks. It may be difficult to access certain wastes prior to retrieval (particularly those associated with ageing or 'legacy' facilities). Moreover, some waste streams are quite heterogeneous and there is a need to ensure that characterisation data are representative of the whole waste stream, not merely the sampled constituents or portions. It can therefore be challenging to decide upon an appropriate and proportionate characterisation strategy. One option here is to benchmark characterisation activities against other countries' programmes, in order to 'future proof' the data collected, and to guard against more prescriptive characterisation requirements that might be incorporated in future iterations of WAC.

6 PAST RD&D PROJECTS ON WAC

The absence of international legislation and requirements concerning the scope of WAC for radioactive waste has been an obstacle for some countries to formulate waste management plans. Consequently, this topic has been a focus of collaborative efforts to provide guidance, and to exchange knowledge and experience, both historically and recently.

Both the IAEA and NEA conduct activities in this field focused on the provision of guidance, training and knowledge dissemination, often in close cooperation. The IAEA produced guidance on the development of WAC linked to the characteristics of radioactive waste forms conditioned for storage and disposal in 1983 [IAEA, 1983], followed by TECDOCs on qualitative acceptance criteria for radioactive wastes destined for geological disposal [IAEA, 1990] and requirements and methods for low and intermediate level waste package acceptability [IAEA, 1996]. It will shortly publish a Nuclear Energy (NE) Series report providing updated

guidance on the development of WAC for low and intermediate-level waste (LILW). Meanwhile, the NEA's Expert Group on Operational Safety (EGOS), a sub-group of the Integration Group for the Safety Case (IGSC), is preparing a report on the role and development of WAC relating to operational safety, planned for publication in 2024. Both organisations hold a range of training activities related to waste management and WAC.

WAC have also been considered within various collaborative EC projects and programmes, including the THERAMIN project on thermal treatment of LILW; the CHANCE project on conditioned waste characterisation and quality control; and the MICADO project on non-destructive radiological analysis of waste packages. Most recently, WAC have been considered within:

- The European Joint Programme on Radioactive Waste Management (EURAD), particularly within the ROUTES WP on waste management routes in Europe from cradle to grave.
- The EC PREDIS project on pre-disposal management of radioactive waste.

Such initiatives are beneficial because countries with more advanced RWM programmes, and organisations that have already processed certain radioactive wastes, have valuable practical experience to share with those countries that have similar waste inventories and are yet to do so.

Section 8 provides further information on the consideration of WAC within these and other initiatives, including links to recent guidance documents on WAC.

There are many examples of established WAC and requirements relating to WAC available online, e.g. [ASN, 2017], [CNL, 2012], [DOE, 1996]. Not all national WAC systems or facility-specific WAC are published, but some may be shared on request to the relevant implementing organisations.

7 UNCERTAINTIES

A range of challenges act to hamper the development and implementation of WAC. Sources for those identified below include the EURAD Strategic Research Agenda (SRA) [EURAD, 2023], and knowledge gaps identified by the IAEA [Robbins and Guskov, 2021].

Chief amongst these is the absence of a clear waste management pathway and eventual route to disposal (for example, in cases where the site for a deep geological repository is unknown) and the absence of associated WAC. This leads to uncertainty over requirements for treating and conditioning waste in a manner that will be compatible with the disposal facility safety case. This challenge is common across both large and small inventory MS and waste processing often has to progress despite such uncertainties, in order to reduce the hazard associated with wastes in their raw form and to facilitate decommissioning. Managing the resulting 'tension' between ensuring passive safety now, without unduly reducing future flexibility, requires clear strategic decision-making, recognising that up-front processing could lead to requirements for reconditioning of waste at a later date, potentially leading to increased management costs over the waste life cycle. Established approaches to address this uncertainty are discussed in Section 4.1.

Other important challenges include:

- The absence of international legislation and requirements relating to WAC, which can be compounded by a lack of clear regulations within national waste management strategies.
- WAC imply requirements for characterisation of a range of properties in order to establish an adequate waste inventory. Techniques for waste characterisation are quite mature, but can be costly or challenging to implement, as discussed in Section 5. Moreover, uncertainties on the values of properties obtained via characterisation can give rise to uncertainties over compliance with associated WAC [Mertens and Detilleux, 2023].
- How to ensure adequate methods and standards for waste form performance to demonstrate compliance with WAC, and how to undertake quality assurance of associated waste form testing programmes.
- Application of preliminary or generic WAC facilitate early waste processing when a disposal route is uncertain. However, the inherent conservatisms built into such WAC can result in 'over processing' of waste beyond levels that would be strictly necessary based on the hazard posed by a waste or based on the safety case for disposal in a particular environment.
- Section 3.3 discussed the drivers for update and iteration of WAC after they have come into force. An associated challenge is that wastes already accepted for processing, storage or disposal at a facility may become retrospectively non-compliant with newly updated WAC.
- Disposal facility safety cases rely, to differing extents, on the containment provided by engineered barriers, including the waste form and waste container. Innovative conditioning matrices are proposed to immobilise certain challenging waste streams and/or to realise a widespread benefit in the disposal facility, such as increased waste loading. However, their long-term behaviour is often less well understood than that of more conventional matrices, especially under disposal conditions. There is a clear need to better determine their characteristics and behaviour and associated impacts on facility safety cases and WAC.
- The large number of international projects and activities on this topic (including those under the auspices of the EC, IAEA and NEA, as discussed in Section 6) may give rise to somewhat differing recommendations or conclusions, making it difficult to judge what is required in a particular situation.

Emerging uncertainties relating to WAC include:

- Harmonisation in support of optimised waste management and use of facilities across Europe, as discussed in Section 4.2.
- The potential for novel waste streams to arise in association with new nuclear activities and wider new uses of radioactive materials. Of particular relevance at present is the widespread consideration of employing small modular reactors (SMRs) and/or advanced modular reactors (AMRs) to support security, sustainability and diversity of energy supply in many countries. Associated reactor designs could give rise to wastes with distinct characteristics that not adequately factored into existing WAC. SMR / AMR programmes could also be pursued in countries that hitherto, have not operated commercial nuclear power programmes, and which have less mature national frameworks for RWM.

8 GUIDANCE, TRAINING AND COMMUNITIES OF PRACTICE

This section provides links to resources, organisations and networks that can help connect people with other interested parties also focused on the domain of WAC.

Guidance
The IAEA will shortly publish an NE Series report providing guidance on "*Development of Waste Acceptance Criteria for Low and Intermediate Level Waste*". The NEA's EGOS, a sub-group of the IGSC, is preparing a report on the role and development of WAC relating to operational safety. The EC PREDIS project on pre-disposal management of radioactive waste has produced reports covering the following aspects relating to WAC: o International approaches to establish waste acceptance systems. o A state-of-the-art review on waste form characterisation methods in support of waste classification and acceptance. o An overview of waste qualification approaches . o Guidance on formulating generic WAC [Baksay and Takats, 2024]. The ROUTES WP of EURAD produced an overview of the use of WAC in MS and some Associated Countries . ROUTES also examined experiences managing radioactive wastes with and without WAC being available, performed a gap analysis to identify 'no regret' waste management measures, and made a series of recommendations for R&D needs and opportunities for collaboration relating to WAC. Outputs are collated in ROUTES Deliverable D9.9 . Some national reports produced in response to the requirements of EU Directive 2011/70/EURATOM provide information on WAC applicable in specific MS. The scope and format of the information provided varies. The Association for Multinational Radioactive Waste Solutions (ERDO), which was established to support the development of shared radioactive waste management and disposal solutions for small inventory countries, conducted a task to identify 'minimum WAC' for near-surface disposal of VLLW and low-level waste (LLW), as part of its Legacy Waste Characterisation (LWC) project. The EC THERAMIN project proposed a set of generic criteria for evaluating the disposability of thermally treated wastes. The EC CHANCE project considered WAC in the context of waste characterisation and quality control schemes for conditioned waste .
Training
The IAEA held a webinar in March 2024 on *Developing Waste Acceptance Criteria for all stages of the waste lifecycle.* Available here . Joint PREDIS-EURAD Summer School on WAC, held in Prague, CZ in September 2023. All presentations are available here . Two webinars on WAC jointly organised by PREDIS, ROUTES and ERDO: o The first, in April 2021, provided information and resources relating to WAC. Slides are here ; recording is here . o The second, in May 2021, identified needs, challenges and opportunities relating to WAC. Slides are here ; recording here .

Active communities of practice and networks

The IAEA has a range of ongoing activities relating to WAC, including support provided to MS under its Technical Cooperation Programme (e.g., review of existing WAC; assistance in establishing WAC for pre-disposal and disposal; establishing conceptual or preliminary WAC).
IAEA International Network on Predisposal – IPN is a forum for the sharing of practical experience and international developments on RWM activities before disposal.
IAEA International Low Level Waste Disposal Network .
A successful waste acceptance system depends on effective information, data and knowledge management (IDKM). In 2023, members of the NEA Radioactive Waste Management Committee and Working Party on IDKM produced a Domain Insight report on IDKM for RWM .
The EC is interested in promoting cross-border collaboration between MS on sharing technical and licensing practices on final disposal solutions and creating opportunities for the EU-wide market in these areas. An EC study on radioactive waste classification schemes in the EU was recently completed and other initiatives are also ongoing, aiming to promote an aligned, harmonised application of the international regulatory framework in waste management and decommissioning.
EURAD ROUTES WP and EC PREDIS project; succeeded by EURAD-2. As noted above, both PREDIS and the ROUTES WP of EURAD have conducted a range of tasks relating to WAC. There has been close collaboration between partners involved in these initiatives, which ran in parallel from 2019 to 2024, to widen information exchange and ensure that they deliver consistent and complementary outputs that progress understanding in the field of WAC development and application (summarised in Figure 4).

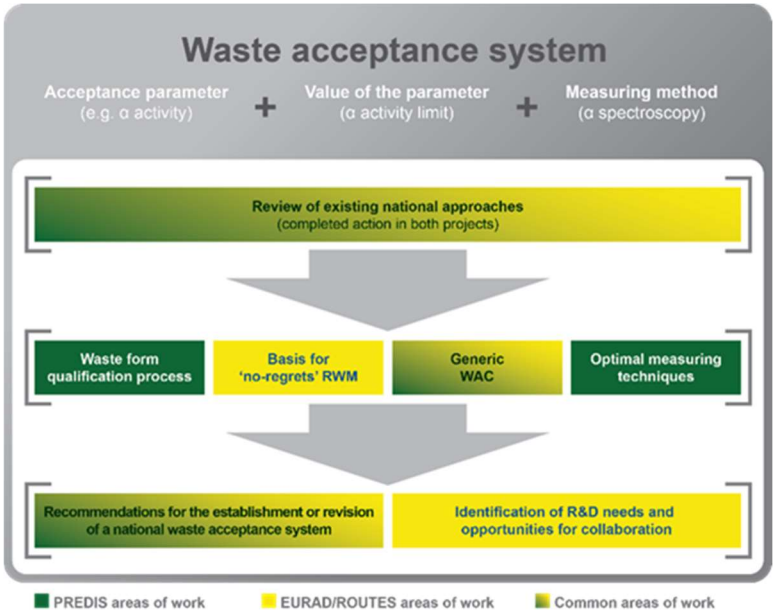

Figure 4 – Collective scope and approach to delivery of complementary WAC-related outputs by the EURAD ROUTES WP and PREDIS project.

Building on the work of ROUTES and PREDIS, WAC will be considered as part of various elements of the EURAD-2 work programme, which runs for five years, starting in autumn 2025.

Key competencies needed in the domain of WAC include: knowledge of waste inventory, waste characterisation approaches, treatment and conditioning options, container / package design and performance, quality assurance and control procedures, the legal and regulatory basis for waste management, understanding of the safety case for a waste management facility as a basis for WAC derivation, package monitoring, IDKM, records management, programme management, periodic review and update, and communication (stakeholder engagement).

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