Requirements Management

Domain Insight 1.2.6

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Overview

A key activity of a waste management organisation (WMO) is the establishment of a detailed schedule of activities within the national framework. A systems engineering approach, involving the use of a requirements management system (RMS) is needed. The role of the RMS, is to define and assemble all the external (e.g., legal, procedural, regulatory, societal) and internal (e.g., budgetary, technical, systems engineering) requirements that drive a programme, the means for addressing them, the constraints that need to be considered, the targets that show when each requirement has been met and the group responsible for dealing with each requirement.

Requirements management implies addressing the following two issues:

- ‘Doing the right things’ (the ‘needs’ domain) by developing ‘the right products’ and implementing them at the ‘right time’
- ‘Doing the things right’ (the ‘solution’ domain) to arrive at the ‘right product design’ with the product being ‘built right’.

The RMS provides the structure to store the information derived by the requirements management process and to manage this information. In its simplest form, the system can be a set of (written) instructions and predefined templates, but for complex projects there are software solutions to help represent and work with this system. However, establishing the logic, justification and balancing of the requirements is usually the difficult part of requirements management and ‘negotiations’ between different needs and iterative revisions of both specific needs and solutions to ensure that all fundamental needs are satisfied is often required.

There is a hierarchy of requirements, moving from what should be easily understood principles, standards and statements of intent that must attract wide endorsement, down to much more detailed technical standards and specifications that cover what must be achieved in practice. In addition, there are usually several constraints, i.e. conditions that cannot (easily) be changed, such as existing/planned waste or siting options, that will affect the requirements.

An RMS is the means to ensure that all goals related to waste management will be met satisfactorily. For example, a deep geological repository (DGR) is established to ensure a final management of radioactive waste that is safe, secure and has acceptable environmental impacts. However, before one can use the system, it has first to be designed and implemented. Before implementing and using the system its implementation and its use has first to be planned, corresponding decisions need to be made and the system (objects/facilities, equipment, operational procedures, etc.) has to be designed and the necessary licenses and permits have to be acquired. While each programme must identify and develop its own requirements, to account for national boundary conditions and constraints (national regulations, different spent fuel types, different packaging concept options, different host rock environment, etc.), it is still possible to list some broad types of requirements related to these overall needs and these are mentioned in this document.

Keywords

Requirements, management, needs, solutions, systems engineering

Key Acronyms

DGR – Deep geological repository

RMS – Requirements management system

WMO – Waste management organisation

1. Typical overall goals and activities in the domain of requirements management

In radioactive waste management, the fundamental safety objective is to protect people and the environment from harmful effects of ionising radiation. The fundamental safety objective applies for all facilities and activities and for all stages over the lifetime of a facility or radiation source, including planning, siting, design, manufacturing, construction, commissioning and operation, as well as decommissioning and closure. This includes the associated transport of radioactive material and management of radioactive waste.

The IAEA safety principles (IAEA, 2006) provide fundamental guidance to help national programmes to develop rational and defensible policies for waste management. On the basis of this guidance, safety requirements can be developed and safety measures can be implemented in order to achieve the fundamental safety objective. The safety principles form a set that is applicable in its entirety; although in practice different principles may be more or less important in relation to particular circumstances, the appropriate application of all relevant principles is required.

While radiological safety is a fundamental requirement for a DGR or for other means of managing radioactive waste, there are many other factors related to both the DGR itself and how a DGR programme should be developed that impose requirements on the programme. These include, although are not limited to, political and societal acceptance, operational safety considering both radiological and other hazards, environmental impacts, technological feasibility, time schedules and costs. Furthermore, there are several constraints to consider, such as types and amounts of waste or available potential siting environments. A RMS should be developed and applied in order to identify, organise and manage all these requirements and their interactions.

Requirements management is an integral part of systems engineering with systems engineering being defined as (INCOSE, 2015): '*Systems engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem: operations, cost and schedule, performance, training and support, test, manufacturing, and disposal. Systems engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation.*'

1.1 Overall goals and activities

As stated in the Programme Management Theme overview (see EURAD, 2021) a key activity of the WMO is the establishment of a more detailed schedule of activities within the national framework. A systems engineering approach, involving the use of a RMS linked to a work breakdown structure (WBS), is essential to identify and organise activities, ensuring the timely delivery of the required outputs against project milestones.

The role of the RMS is to define and assemble all the external (e.g., legal, procedural, regulatory, societal) and internal (e.g., budgetary, technical, systems engineering) requirements that drive a programme, the means for addressing them, the constraints that need to be considered, the targets that show when each requirement has been met and the group responsible for dealing with each requirement. As further elaborated by IAEA (2020a) the process of requirements management is used by many WMOs to:

- Clearly define the requirements and assumptions pertaining to the disposal system and its individual components (e.g., engineered barriers);
- Make linkages and interdependencies explicit;
- Identify conflicting requirements and potential resulting trade-offs;
- Record formally the justification for decisions in support of design substantiation;

- Support design change control, by enabling tracking and recording of changes to either the requirements or the knowledge base and identifying how these are to be reflected in design changes.

Extensive guidance on requirements management, on the structure of RMS and on developing, using and modifying a RMS, is provided in the document DS-RMS (EURAD, 2024). The current domain insight is strongly based on this document but aims to be a short introduction to the subject and to put it into the framework of the EURAD Roadmap (EURAD, 2021a). General guidance can also be found in IAEA (2020b).

As further elaborated in DS-RMS (EURAD, 2024), and illustrated in Figure 1, requirements management implies addressing the following two issues:

- *'Doing the right things'* (the 'needs' domain) by developing 'the right products' and implementing them at the 'right time'
- *'Doing the things right'* (the 'solution' domain) to arrive at the 'right product design' with the product being 'built right'.

Doing the right things starts with defining 'why' is 'what' wanted by 'when', where 'what' is a product: generally, some component or activity within the disposal system. The 'why' consists of the high-level goals, needs and expectations on the product, as defined by the external stakeholders that initiate the development of the project. The 'what' results from decomposing/breaking down the 'why' into more detailed and tangible requirements. Doing the things right consists of specifying 'who' (the needed products) must be implemented 'how' to fulfil the 'what'. By its very definition, this means that that requirements management is a means to ensure that safety functions and implementation goals of a waste management project are met. It also provides a framework for option identification and decision-making during the process of optimisation of engineering, operational procedures, cost, scheduling and other requirements. In this process, it has been found that many of the requirements established for the design of the disposal system evolve continuously and that many iterative loops between "needs" and "solution" usually are needed. Requirements management, optioneering and decision-making are thus closely intertwined.

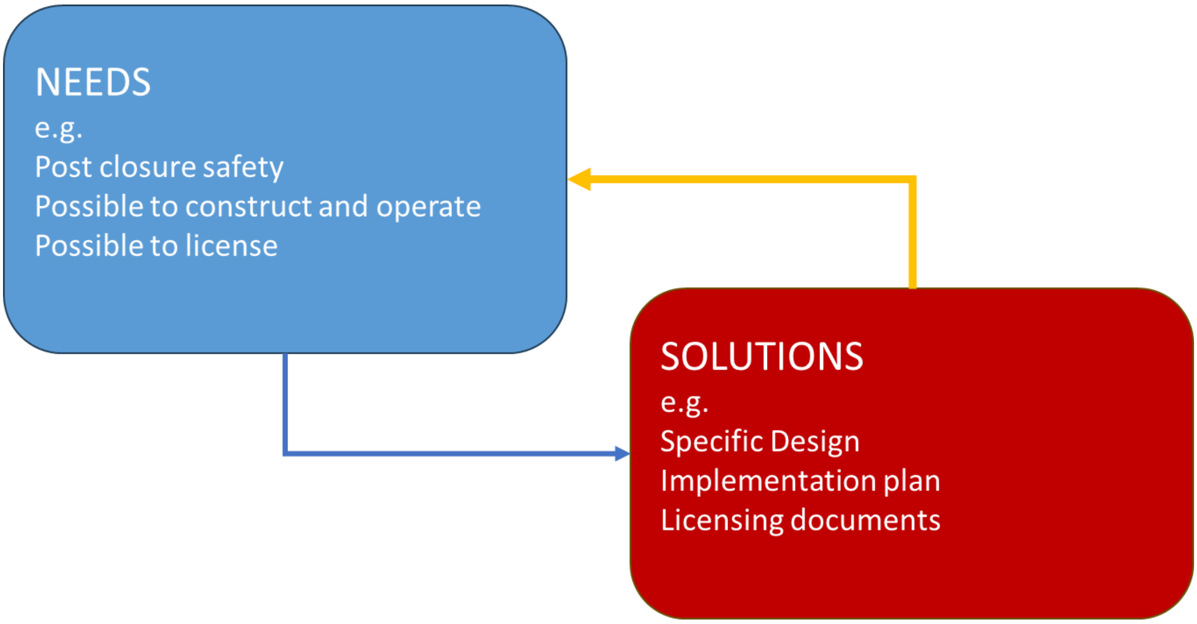

Figure 1. Requirements management for a DGR involves an iterative assessment between the needs and the solutions to the needs.

The RMS provides a structure to define, classify, store and correlate each element of the information derived by the requirements management process and to manage this information by assigning attributes, links, responsibilities, etc. In its simplest forms the system can be a set of (written) instructions and predefined templates, but for complex projects there are software solutions to help represent and work with this system.

1.2 Requirements hierarchy and constraints

In waste management applications, as in most other complex projects, there is a hierarchy of principles and standards, moving from what should be easily understood statements of intent that must attract wide endorsement, down to much more detailed technical standards and specifications that cover what is expected in practice. A collection of scientific, technical, administrative and managerial arguments and evidence in support of the safety and the potential for implementation of a disposal facility is addressed in the continuously evolving design and safety case, addressing the suitability of a DGR site and the design, construction and operation of the facility, the assessment of radiation risks and assurance of the adequacy and quality of all of the work associated with the disposal facility.

At a national level, regulators define safety principles, criteria and regulations, based on national legislation and international guidance, and the implementor, based on the needs of the waste producers, manages the waste safely at all stages, identifying appropriate disposal solutions and developing appropriate claims, arguments and evidence to show that it complies with national safety regulations and specified requirements. Furthermore, once a facility license is granted, the more detailed and specific requirements can only be changed by the implementor after approval by the regulator.

Requirements management is a systematic process:

- To elicit and extract the ‘needs’ in terms of legal requirements and goals of external stakeholders,
- to decompose these goals into requirements in the form of functions, characteristics and corresponding targets of the disposal system and its management,
- to develop a functional architecture of processes and components of the disposal system that have to fulfil the requirements,
- to allocate each requirement to a specific process or component, to define loads and conditions acting on that element,
- to develop a pre-design based on design input requirements,
- to develop a detailed design for each element such that it fulfils the design input requirements, i.e. a design output specification for a product and for its production,
- and to consider the life-cycle of each system process and component (planning, implementing, using, managing end-of-life), including its verification and validation.

For example, a requirements hierarchy typical of an advanced geological disposal programme could include several levels:

- High-level external requirements - High-level goals, principles and external requirements related to managing the waste: international agreements, government policy, regulators (e.g., national dose or risk thresholds), local community, etc.
- Waste management system requirements - Qualitative and quantitative requirements that define how the total waste management system satisfies the high-level external requirements
- Sub-system requirements - Specific requirements for each of the major structures, systems and components (SSC) of the waste management system, and the activities associated with them, where appropriate expressed as safety functions and performance targets for each SSC, (see also, 1.5.2 Options and Concept Selection).
- Design requirements - A requirement on the design of the initial state of a repository component (once it has passed QA/QC, and can no longer be influenced through additional actions), that can be expressed in terms of a measurable parameter and that is shown to imply that the performance targets will be met.
- Design specifications - Detailed specifications for the design, construction and manufacturing of each component or activity in order to meet the design requirements (see also, 5.1.1 Design Specification,
- Manufacturing requirements - Requirements used in procurement and drawn up so that the components meet the design specifications. The manufacturing requirements create the

margins required for the manufacturing to meet requirements for proven, reliable and capable technology.

- Design qualification - This concerns the order of review, control and testing that must take place by the implementor, the suppliers' own control, so-called third-party control through independent bodies and the regulator's follow-up through reviews and inspections (see also 5.1.2 Design Qualification).

There are usually also constraints that need to be taken into account: i.e., conditions that cannot, or cannot easily be changed that will affect the requirements. Typical constraints in waste management include the existing/planned waste inventory to be managed, existing waste management facilities or planned new facilities that will generate wastes, DGR siting options and high-level decisions that might already have been taken.

During the course of a repository project, iteration between the different requirement levels is needed to ensure both safety and engineering feasibility. This includes input during each iteration with the latest RD&D knowledge considered necessary to understand and support the basis on which the safety of the facility depends. In fact, establishing the logic, justification and balance of the requirements is usually the difficult part of requirements management and 'negotiations' are often required between different requirements and their owners, with revisions of both specific needs and solutions to ensure that all fundamental needs are satisfied.

1.3 Developing the RMS during different roadmap phases

The requirements management process consists of several steps, starting with clarifying the legal requirements and goals of external stakeholders for the overall waste management system under consideration, breaking down of these legal requirements and 'goals' into functions with the corresponding performance targets, identification of the products (documents, decisions, etc., as result of activities / processes and objects) that are needed and eventually by refining and detailing both the goals and solutions leading to implementation and use of the system elements using the specifications developed: see DS-RMS (EURAD, 2024). Finalising all these steps usually requires many feedback loops and iterations, where, for example, solutions suggested at an early stage typically are quite conceptual and qualitative that for the later steps would need detailing and specification. Early conceptual solutions may even be found inappropriate when at later stages in the programme are reached, or where early step requirements are found inappropriate or unnecessarily strict.

Development and use of an RMS involves activities in all different DGR roadmap phases (Table 1). For example, in the case of early-stage programmes, after having developed concepts for the activities in and components of the disposal system to be implemented, these concepts can be used to manage/define the interfaces with the systems outside the system analysed (e.g., by defining waste acceptance criteria). Then, the work can concentrate on those elements that need work in the planning horizon; the work on the other activities and components can wait until they are closer to the planning horizon and need attention. However, RMS development is a stepwise and iterative process, and such iterations may imply that even high-level requirements of some processes and components need to be revised at later stages. Furthermore, the drivers for 'early' requirements may be very general and not sufficient to plan a complete DGR project.

Table 1 Goal of developing and using an RMS and key activities at different roadmap phases (developed from the "Programme Management" Theme Overview)

Domain Goal	
7.1.1 Establish the requirements that must be met to ensure the protection of people and the environment, both now and in the future (Safety requirements) and 5.1.1 Based on regulatory requirements, safety criteria, and a high-level safety strategy, establish a transparent procedure finally leading to design requirements for the preferred concept option (Design requirements).	
Domain Activities	
Phase 1: Programme Initiation	Obtain and clarify the goals of external stakeholders, i.e. Clarify the legal requirements, including security, safeguards, occupational safety, health and environmental regulations, that are involved in these different steps. Identify key constraints such as waste inventory and potential siting environments. Identify high-level products (components and activities), needed for the disposal system. Find early-stage solutions in terms of concepts for high-level components and activities. Use findings to inform strategic decision-making: e.g., to support preliminary safety and feasibility analyses of generic DGR options, to identify and organise activities, ensuring the timely delivery of outputs against project milestones. As specific projects/facilities are identified, formulation of detailed requirements will develop iteratively, based on feedback from, e.g. safety case development (see, Theme 7 Safety Case) and engineering (see, Theme 5 Design).
Phase 2: DGR Site Identification	Update the RMS based on the knowledge gained from the initial assessment of key design and safety aspects. Revise constraints and external stakeholder requirements based on the progress of the siting programme. Develop revised and more detailed designs. Perform safety evaluations for the range of potential design options and siting environments. Manage iterative review and update of requirements to respond to latest RD&D, design developments and safety analysis.

Phase 3: DGR Site Characterisation	Establish site specific safety requirements that can be used to evaluate detailed design and perform safety demonstration. Formulate detailed requirements for the license application and further development and construction of the repository. Develop (and agree with the regulatory agencies) plans for the qualification and quality control needed to ensure that the repository construction and the manufacturing of the EBS meet these requirements. Manage iterative review and update of requirements to respond to latest RD&D, design developments and safety analysis. This includes obtaining regulatory approval of changes if permits and license is affected.
Phase 4: DGR Construction	The WMO to update the RMS for the DGR based on the knowledge gained from the assessment of key and safety aspects from Phase 3 (See, 5.1.1 Design specification). Qualify constructions and procedures, including quality control plans and commissioning tests. Explore possibilities to optimise the concept while maintaining the safety requirements. Manage iterative review and update of the RMS to respond to the latest RD&D, design developments and safety analyses. This includes obtaining regulatory approval of changes if permits and license is affected.
Phase 5: DGR Operation and Closure	Maintain and update the RMS regarding quality control of repository construction, EBS manufacturing and deposition activities. Assess conformity of requirements and 'as built' to be used as a key input for safety case for final repository closure. Develop and optimise designs and the organisation further for industrial operation.

2. Contribution to generic safety functions and implementation goals

An RMS is the means to ensure that all the goals of waste management will be satisfactorily met. While the provision of post closure safety of the DGR is the ultimate objective of the project, it is also necessary to ensure a safe, feasible, practical and optimised implementation of the repository and to succeed in the corresponding licensing. This section describes how the development, and the use of an RMS (and its associated information, data, and knowledge), contributes to high-level disposal system requirements using EURAD Roadmap Generic Safety and Implementation Goals (EURAD, 2021b). It further illustrates, in a generic way, how such safety functions and implementation goals are fulfilled. It is recognised that the various national disposal programmes adopt different approaches on how disposal system requirements are specified and organised.

Each programme must develop its own requirements, to suit national boundary conditions and constraints (e.g., national regulations, different spent fuel types, different packaging concept options, different host rock environment, etc.). The generic safety functions and implementation goals developed by EURAD and used below are therefore a guide to programmes on the broad types of requirements that are considered, and are not specific or derived from one programme, or for one specific disposal concept.

2.1 Examples of generic requirements related to the purpose of a DGR, i.e. requirements related to post-closure safety, security and environmental impacts

A DGR is established to ensure that final management of radioactive waste is safe, secure and has acceptable environmental impacts. Below are some examples of how these high-level external requirements can be broken down into generic waste management systems requirements, sub systems requirements and (generic) design requirements, eventually to be used for the formulation of more quantitative solutions in terms of design requirements for components of the DGR system and specific design specifications, etc.

2.1.1 Isolation

Waste management system requirement: Ensure isolation of waste from people and the accessible biosphere.

Sub systems requirements: The DGR is sited, designed and implemented to isolate the wastes from the human environment for thousands of years into the future in a stable environment that is unlikely to be disturbed by human activities, even when the location of the disposal facility may have been forgotten: e.g., by future climate (glacial erosion) or by dramatic changes in future society.

Design Requirement(s): The DGR is located at an appropriate depth in a stable geological formation that provides protection of the facility from the disruptive effects of geomorphological processes such as erosion and glaciation. The DGR is located away from known areas of underground mineral resources and other valuable resources will reduce the likelihood of inadvertent disturbance of the geological disposal facility.

2.1.2 Containment

Waste management system requirement: Ensure complete containment of radionuclides in the DGR until they have sufficiently decayed.

Sub system requirement(s): Complete containment within a specific barrier component for a minimum period of time, e.g.: no loss of integrity of the engineered barriers during (e.g.) the period of significant heat emission.

Design requirement(s): For example, the container should withstand specified mechanical, chemical and biological loads imposed by physical processes occurring in the material surrounding it for part of the post-closure period. Siting should be in a weakly dynamic hydrogeological natural barrier, e.g., low host rock permeability, limited availability of mobile water, limited driving forces to give low local and regional groundwater fluxes, no fast geosphere pathways today or in the future, low permeability of EBS components or lack of corroding agents in the EBS.

2.1.3 Retention

Waste management system requirement: Contain contaminants within the total disposal system by retention or retardation for as long as necessary.

Sub system requirement(s): Achieve long-term radiological impacts that are below specified targets by limiting the release and migration of many radionuclides. For example, to ensure that migration of detrimental substances to the waste package is low and that migration out from the waste form is low;

establish favourable chemical properties for low retention in the near-field porewater; or ensure hydrogeochemical conditions that would imply a low degradation rate of the waste form.

Design requirements: For example, selection of low permeability EBS components, selection of EBS (materials) that degrade slowly or siting in a low permeability host rock with limited availability of mobile water and low driving forces.

2.1.4 Long term stability

Waste management system requirement: Ensure long-term stability with respect to external events and environmental evolution.

Sub system requirements: Ensure that disposal system performance is not significantly affected by external disturbances, e.g.: evolution of geological and surface environment due to tectonics and climate change.

Design requirement: For example, that the facility's site is located where the groundwater compositions would not dramatically change even if the surface environment changes and that it is sited to avoid major geological structures that could host large seismic events.

2.1.5 Stability with respect to internal processes

Waste management system requirement: Ensure long-term stability with respect to internal evolution.

Sub system requirements: The DGR is designed and implemented in such a way that the disposal system performance is not significantly affected by internal disturbances, e.g.: compatibility of the barrier of components; evolution of the host rock due to repository excavation, operation and closure; evolution of the EBS with time; low likelihood of post-closure criticality or only with tolerable consequences.

Design requirements: For example, where relevant, to prevent unacceptable build-up of internal gas pressure by allowing the passage of gas from the waste form into the surrounding engineered barrier system, for fissile material employ controls/limits (including burn-up credit for spent fuel and detailed understanding of the package (and facility) evolution over relevant post-closure timescales.

2.1.6 Sufficient space

Waste management system requirement: Ensure that the DGR has sufficient space for intended waste.

Sub system requirements: The DGR is sited, designed and implemented in such a way that there is sufficient space for the intended waste.

Design Requirement(s): The DGR host formation is sufficiently large in relation to the DGR layout and design.

2.2 Generic requirements for practical implementation of a DGR

Before one can use the system, it has first to be designed and implemented. Below are some examples of how these very high requirements can be broken down into generic waste management systems requirements, sub systems requirements and (generic) design requirements, eventually to be used for the formulation of more quantitative solutions in terms of design requirements for components of the DGR system and specific design specifications, etc.

2.2.1 Practicability and reliability

Waste management system requirement: Provide technical practicability while ensuring that design confirms to technical design requirements.

Sub system requirements: Reliability of implementation according to specifications (requirements) in the safety case. Design for easy and reliable underground operations and package handling, e.g.: possibility for corrections and adaptation with a system that is amenable to continued optimisation (e.g., to manage reliability of materials supply).

Design requirement: Validate that the design shown to comply with safety requirements can actually be manufactured/implemented and be quality assured.

2.2.2 Flexibility

Waste management system requirement: Allow operational flexibility.

Sub system requirements: Possibility for adaptation to manage, for example, varying rates of waste disposal; future or modified types of waste or packaging; evolving programme boundary conditions, such as total DGR inventory or changes in the supply chain.

Design requirements: For example, solutions compatible with standardisation, ability to extend the system to adapt to inventory changes, ability to manage new waste package types or dimensions or ability to adapt the system to incorporate improved (or new) materials.

2.2.3 Optimisation

Waste management system requirement: Allow optimisation of disposal system design and operation.

Sub system requirements: Optimisation, within the boundary conditions to implement within reasonable time at reasonable cost, for example, by efficient use of resources or to ensure complete implementation in reasonable time.

Design requirements: For example, options for new material choices possible.

2.3 Generic requirements for planning and licensing the implementation and use of a DGR

Before implementing and using the disposal system, its implementation and its use has to be planned, corresponding decisions need to be made, the system (objects/facilities, equipment, operational procedures, etc.) has to be designed and the requisite licences and permits have to be acquired.

2.3.1 Post-closure safety

Waste management system requirement: Show that DGR meets all regulations related to post-closure safety.

Sub system requirement: Assess post-closure safety of the DGR.

Design requirements: Demonstrate post-closure safety in a safety case in accordance with international and national standards and best practices and that consequences comply with regulations.

2.3.2 Operational safety

Waste management system requirement: Satisfy operational safety.

Sub system requirements: The safety of workers, the public and the environment can be managed during the construction, transportation and emplacement during the operational phase. For example, non-radiological risks and radiological risks can be managed, consequences of accident scenarios and external events can be tolerated.

Design requirements: For example, durability maintained in foreseen operational environmental conditions, such as physical and chemical robustness against fires and impact accidents, limited gas generation in foreseen operational environmental conditions or fissile material controls/limits.

2.3.3 Environmental impacts

Waste management system requirement: Reduce environmental impact of construction, operations and post-closure in accordance with applicable legislation.

Sub system requirements: For example, limited use of scarce materials in EBS and DGR components, energy requirements for fabrications, construction and operations, and carbon-footprint management of waste materials from excavation and operation, compatibility with nature and the environment (e.g., longevity of operational period), compatible with land use planning or limited noise.

Design requirements: Specified limits of the functional requirements and specific rules on managing operations in vicinity of designated conservation sites or protected habitats and species.

2.3.4 Security and safeguards

Waste management system requirement: Ensure security and safeguards.

Sub system requirement: All nuclear materials can be handled appropriately from a security and safeguards perspective. For example, by a system that prevents diversion both during pre- and post-closure periods a system where security of surface and underground facilities can be assured in the pre-closure phases.

Design requirement: For example, a system that satisfies international standards and guidance.

3. International examples of requirements management

Requirements management is practiced by advanced WMOs and aspects of it are documented primarily in the safety case documentation used. Many advanced disposal programmes have described their requirements, along with their rationale, in high-level reports, such as the Design Basis report (Posiva 2012) that is part of Posiva's safety case for the disposal of spent nuclear fuel at Olkiluoto, the CIGEO Safety Options Report (Andra, 2016) and the SKB safety case for the spent fuel repository in Sweden (see chapter 5 of SKB, 2021). A more detailed account of the safety functions, performance targets and design requirements of the SKB's and Posiva's safety case is provided in Posiva and SKB (2017). To support programmes in a generic phase (prior to selection of a specific host rock) mature examples exist of generic specifications for illustrative disposal facility designs. For example, the UK (RWM, 2016) includes a list of generic safety functions for six illustrative disposal concepts compatible with a range of waste types (high heat generating waste/low heat generating waste) and three geological environments (higher strength host rock, lower strength sedimentary rock, and evaporite host rock).

4. Integrated information, data or knowledge from other domains that impacts understanding of requirements management

Since an RMS concerns most aspects of a waste management project, key aspects of its development and use relate to many other domains of the EURAD Roadmap. Examples of such domains include:

- 1.1.3 Public information and participation: Ensure that public information on radioactive waste and spent fuel and opportunities for public participation are available. The information needs may influence the specification and demonstration of safety requirement to make the documentation of the safety case broadly understandable.
- 1.2.2 Licensing criteria: Establish regulatory criteria for waste management facilities, based on international standards will include regulatory guidance on how a national programme should satisfy safety requirements, as specified and defined by the national regulator. These will populate much of the high-level external requirements level (Level 1) of the requirements hierarchy.
- 1.3.2 Skills and competence management: Develop and maintain a technical and management skill base within the programme (core capability), meeting national regulatory competence requirements that will include a number of competencies and prime responsibility for safety that

the implementor must maintain in order to operate as a licensee and/or intelligent customer. This extends to the specification and demonstration that safety requirements are met.

- 1.5.2 Options and concept selection: Perform iterative evaluation of options and concepts at each stage of programme development taking account of international technological advances will drive more specific safety requirements (Sub-system requirements at Level 3 and design requirements at Level 4).
- 5.1.2 Design specifications, facility-scale: Based on the design requirements, perform layout calculations to define detailed specifications for the design of the underground facilities.
- 5.1.3 Design specifications, component-scale: Based on the design requirements and safety assessments, define detailed specifications for the design of the geotechnical barrier system ,
- 5.1.4 Design qualification: Develop and establish qualification procedures, especially with regard to manufacturing and testing requirements, as well as safety demonstration concepts to confirm that structures, systems and components will perform their allocated safety function(s) in all normal operational, fault and accident conditions identified in the safety case and for the duration of their operational lives. ()
- 5.2.2 Optimisation: Perform a continuous assessment and review exercise with requirements and technical solutions to balance the project risks among the different barriers. Keeping in mind that there is no endeavour with zero risk, determine which project risks can be (reasonably) accepted and which cannot. Any balancing need to include a cost assessment (involving the optimisation of design requirements).
- 5.2.3 Manufacture, inspection and testing: Establish reliable manufacturing routes to produce facility barriers and components, and inspections plans for how to test for unacceptable defects, and overall quality assurance against specified design tolerances and industry standards (Manufacture, inspection and testing to meet design specifications).

The work and activities described in these, and other domain insights, are essential for the development of the content of an RMS, but are not repeated here.

5. Maturity of knowledge and technology

Requirements management is well established as part of systems engineering (INCOSE, 2015). Section 3 noted that most advanced WMOs also apply it, although to date there only few programmes have experience on the final uses of an RMS to steer actual production, implementation and qualification of a DGR, owing to the fact that few national programmes have got that far. Consequently, there is the opportunity to learn more from mature application of RMS in other fields of industry. For programmes at early phases of implementation, it is important to maintain flexibility for design adaptation and optimisation until after site selection and concept selection is confirmed. It is therefore important, when using illustrative designs (designs borrowed from advanced programmes), that sub-system level requirements are specified as illustrative, so that changes can be easily made to adopt different solutions once there is less uncertainty in the key boundary conditions.

A number of software tools and formal procedures have been developed to support information and requirements management, although there is no software designed specifically for radioactive waste management. Most applications are aimed at the pharmaceutical, aeronautical, automotive, software development or other industries. Most of the available software solutions will be able to support the needed approach and offer sufficient functionality but may be overly complex for the early stages of a programme and will, in any case, need to be tailored to the WMOs working procedures.

While the RMS structure and logic are essential, and could be much aided by software solutions, the really difficult part of requirements management lies in establishing the logic, in devising appropriate approaches to the balancing and justification of requirements and in finding viable solutions that can be quality controlled during production and installation. Formulation of requirements is not a trivial task - iteration and negotiations between the ‘owners’ of requirements within a WMO and the various discipline groups (safety assessment, engineering, design, resource management, etc.) is required.

6. Guidance, training, communities of practice and capabilities

Guidance
IAEA: www.iaea.org *EURAD: https://euradschool.eu/eurad-knowledge-management-and-roadmap/* *INCOSE www.incose.org*
Training
IAEA: www.iaea.org *EURAD: https://euradschool.eu/events/category/eurad-training-course/*
Active communities of practice and networks
EURAD: https://euradschool.eu/eurad-knowledge-management-and-roadmap/ *OECD/NEA: www.oecd-nea.org* *IAEA URF Network nucleus.iaea.org/sites/connect/URFpublic/Pages/default.aspx* *INCOSE www.incose.org*
Capabilities (Competences and infrastructure)
See above

7. Further reading, external links and references

7.1 Further reading

EURAD, 2024, Guidance on Developing, Using and Modifying a Requirements Management System for Implementing a Disposal System, DS-RMS, https://www.ejp-eurad.eu/.

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7.2 External links

See section 6.

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