Deliverable D12.6

Guidance on Developing, Using and Modifying a Requirements Management System for a Generic Waste Management System

An Introduction (G-RMS)

WP12

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Executive summary

The activities within Work Package 12 (Guidance) of EURAD (European Joint Programme on Radioactive Waste Management) aim at developing a comprehensive suite of instructional guidance documents that can be used by EU Member States with radioactive waste management programmes, independent of the content and of the stage of implementing their programme.

In the course of EURAD, based on a review made by Work Package 12, it was decided to develop guidance on requirements management, because requirements management is recognised to be a crucial activity for implementing waste management programmes / systems. The work package board together with the editorial board agreed to develop such guidance in a process with active involvement of end-users through a number of workshops and a training event. During this process, it was decided to develop three documents:

- a guidance document for generic waste management systems (this document),
- a document describing in more detail the development of requirements for disposal systems with a discussion of the post-closure safety case and its interaction with requirements management (EURAD 2024a),
- a guidance document for specific waste management programmes and with their different system systems, taking the stepwise implementation of these systems into account (EURAD 2024b).

As all three documents are ‘stand-alone’ documents and each of them describing the same methodology (‘the way of thinking’), but each of them looking at requirements management from a slightly different angel, there is some overlap between them when it comes to the basics of the requirements management methodology.

This document is for a generic waste management system. The main aim of this document is to provide an introduction to requirements management for waste management; it should allow the reader to become familiar with the key characteristics of requirements management, independent of what the reader wants to use the requirements management system for. Thus, this document focuses on an introduction on methodological aspects (‘*the way of thinking*’) and describes the basic thoughts to be made when getting started with implementing and using a requirements management system. This guidance document is not related to any specific application.

In an appendix (Appendix C) the document also contains a literature review on existing requirements management documents as a stand-alone document authored by Peter Ormai.

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1. Introduction

1.1 Aims of the guidance document

In **EURAD** (European Joint Programme on Radioactive Waste Management), it was decided to develop guidance on requirements management, because requirements management is recognised to be an important activity for implementing waste management programmes / systems. It was agreed to develop such guidance in a development process with **active involvement of end-users** through a number of workshops and a training event. In this process, it was decided to develop **three documents**:

- a guidance document for generic waste management systems (this document),
- a document describing requirements management for disposal systems with a more extensive discussion of the post-closure safety case and its interaction with requirements management (EURAD 2024a),
- a guidance document for specific waste management programmes and with their different system systems, taking the stepwise implementation of these systems into account (EURAD 2024b).

As all three documents are **'stand-alone' documents** and each of them describing the same methodology ('the way of thinking') but each of them looking from a slightly different angel, there is some overlap between them on the more basic issues related to the requirements management methodology.

The development of these documents profited very much from the lively interactions during the workshops and the training event and from the feedback through reviews of the draft versions of the reports. As the discussions continue in applying requirements management in waste management programmes, most likely these documents will see some further updates – thus, they should for the time being be seen as **'living documents'**.

This document '**Guidance on Developing, Using and Modifying a Requirements Management System for a Generic Waste Management System – An Introduction** (G-RMS)' is for a generic waste management system. The main aim of this document is to provide an introduction to requirements management for waste management; it should allow the reader to become familiar with the key characteristics of requirements management, independent of what the reader wants to use the requirements management system for. Thus, this document focuses on an introduction on **methodological aspects** ('***the way of thinking'***) and **describes the basic thoughts** to be made when getting started with implementing and using a requirements management system (RMS). This guidance document is **not related to any specific application**.

As an appendix (Appendix C), it also contains a **literature review on requirements management** as a stand-alone document prepared by Peter Ormai.

This guidance document wants to be useful mainly for **radioactive waste management programmes at an early stage** but could also be informative for more advanced programmes. It should be applicable for programmes with **small and large inventories** with low and high complexity. This guidance document can also be applied in programmes where **implementation is already advanced without having used a requirements management system** but where such a system is planned to be used for managing future activities (e.g. implementation of additional elements and their optimisation).

The **target audience** of the guidance document is mainly organisations that are responsible for developing a waste management programme and/or (some of) its systems. However, the guidance also considers the needs of all other stakeholders. Thus, the document should be of main interest for the implementer, but also interesting for all other stakeholders (regulator and the technical support organization, responsible government agencies, research entities, etc.).

The document '**Developing, using and modifying a requirements management system for implementing a disposal system**' – DS-RMS (EURAD 2024a) has also the purpose to provide guidance on requirements management, on the structure of requirement management systems and on developing, using and modifying a requirements management system, but its focus are **disposal systems,** mainly deep geological repositories (DGR). The document puts much emphasis on the **interaction between requirements management and the post-closure safety case**. This document is mainly for programmes working on disposal.

The guidance document '**Guidance on Developing, Using and Modifying a Requirements Management System for Waste Management Programmes with their Different Systems – WMP-RMS**' (EURAD 2024b) has also the purpose to provide guidance on requirements management, on the structure of requirement management systems and on developing, using and modifying a requirements management system, but **with a clear focus on an overall waste management programme and on its different waste management systems**. As the waste management systems of a waste management programme are developed in a stepwise manner, this document puts in contrast to the other two documents a focus on the stepwise implementation of the different systems, one after the other; however, with having already at an early stage broad concepts for all systems to allow the proper management of the interfaces between them to ensure correct implementation.

As the waste management programmes and their systems differ to some extent in the different countries, also the Requirements Management Systems (RMS) will differ. Thus, each programme will **need its own requirements management system** (newly developed or adapted from an existing requirements management system). Thus, sooner or later, each waste management programme will be confronted with the issue of developing a requirements management system.

As requirements management is a **mature methodology** that is broadly used in many applications, and as a lot of literature exists on requirements management methodology, this guide takes advantage of this **broad body of knowledge and experience**. Thus, the text in this guide relies wherever possible on the literature of that community (see reference list) that has been consulted (in limited depth) when preparing this text.

1.2 Content and structure of the guidance document

The guidance document consists of a number of specific modules (chapters), with all the modules being relevant for requirements management. The order of the modules follows no strict rule, but it is arranged in an order that is considered useful for getting familiar with requirements management – thus, it is suggested that in the first reading one follows the order of the modules in the document; later, one can read each module (described within a specific chapter) as **'stand-alone' text.**

Each module starts with a paragraph with a definition or an introduction / overview and is then followed by one or more somewhat larger paragraphs on 'the issues' (things to be aware of) and ends with a paragraph summarizing the module. There is some overlap between the modules to get the connection between them well established.

Below, a brief description of the content of this guidance document can be found. This part can be skipped by those readers that will go through the full document.

- The first 2 modules in the guidance document cover:
  - **Scope of the guidance documen**t on the development and the use of requirements management systems (chapter 1.1)
  - **Content and structure** of the guidance document (this chapter 1.2)

- The next chapters start with a broad introduction to requirements management to give an overview (chapter 2.1). This is then followed by a more detailed description of each of the elements of a requirements management system (chapters 2.2 to 2.7). The last part is about the process to implement the requirements management system, to use it and to update it in the stepwise approach of implementing waste management activities, including disposal (chapters 3.1 to 3.3).

  Chapter 2.1 – overview:

  – **Description** of requirements management, and of the **benefits of requirements management** (chapter 2.1)

  Chapters 2.2 to 2.7 − Elements of the requirements management system:

  – **Boundaries of the system addressed** with the requirements management system and management of the interfaces to the 'outside world'– in short: system boundaries and management of the **interfaces** (chapter 2.2)

  – **Stakeholders** to be considered in requirements management and their roles and their input (chapter 2.3)

  – Types and hierarchical levels of **requirements** and their definition (chapter 2.4)

  – Key **properties** of requirements (chapter 2.5)

  – **Structure of the requirements management system** and a description of key dependencies as well as the overall logics of how the requirements management system is used (chapter 2.6)

  – **Evolution** of the requirements management system and of the waste management system analysed in the stepwise approach of developing and implementing a waste management system (chapter 2.7)

  Chapters 3.1 to 3.3 − the process to implement, to use and to manage the stepwise refinement of the requirements management system:

  – Process **steps to implement** the requirements management system (chapter 3.1)

  – Process **steps to use** the requirements management system (chapter 3.2)

  – Process **steps to manage** the evolution of the requirements and of the waste management system analysed in the stepwise implementation process (chapter 3.3)

- Finally, the appendix contains:

  – A **glossary** for key terminology (Appendix A)

  – List of **abbreviations** with explanations (Appendix B).

  – An extensive **literature review** as a ‘stand-alone’ text (Appendix C)

2. Important issues of requirements management

2.1 Description of requirements management and of the benefits requirements management offers

2.1.1 Introduction

Waste management systems are systems that consist of many elements that need to properly interact to make the systems functioning properly. Furthermore, most of the elements of waste management systems have several life cycle stages that need to be considered. The **implementation of waste management systems** is thus a process that covers a broad range of interrelated issues involving a range of different disciplines; the corresponding waste management programme is thus a challenging process. Based on the positive experiences in many other complex projects (e.g., aerospace, aviation, communication, computer, energy (nuclear, other), defence, software development, etc.), **systems engineering** is considered to be a key element for being successful with such complex projects. Systems engineering can be defined as follows (quote from 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[1]. 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.'

There is broad agreement in systems engineering (see e.g., INCOSE, 2015; NASA, 2020) that **requirements management** is an important element to support the implementation process of complex (interrelated) systems such as waste management systems.

Requirements management supports effective leadership and efficient management (as defined e.g, by Drucker, 2001) in developing a waste management system and its implementation (as defined e.g. in INCOSE, 2022a) by addressing the following two issues:

- *'Do the right things'* (a key element of leadership) and develop '*the right products'* and implement them at the *'right time'*.

  In other words, doing *the right things* starts with defining *'why'* is '*what'* wanted by *'when'*. The 'why' consists of the high-level goals, needs and expectations on the waste management system as defined by the external stakeholders that initiate the development of the waste management system. The *'what'* results from decomposing / breaking down the *'why'* into more detailed and tangible requirements.

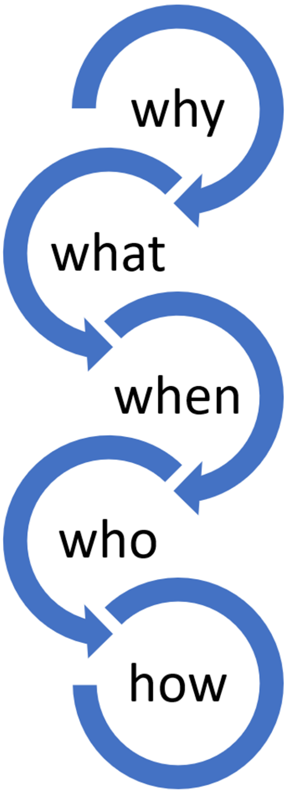
- *'Do the things right'* (a key element of management) to arrive at *'the right product design'* with the *'product' being implemented right'*.

  In other words, doing the things right consists of specifying *'who'* (the needed elements of the waste management system) must be implemented *'how'* to fulfil the 'what'.

The *'why'*, *'what'*, *'when'*, *'who'* and '*how'* (underlined in the paragraph above) are the **cornerstones of the requirements management process** documented in a requirements management system, see also Fig. 1.

[1] In our terminology, this corresponds to managing the 'end-of-life'.

Good practice in system engineering and requirements management requires to work systematically in a structured manner and with discipline according to the rules defined by the specific requirements management methodology applied.



The 'why' gives the reasons for developing / implementing a waste management system by defining the 'goals', 'expectations', 'needs' to be fulfilled

The 'what' provides direct input for developing / implementing a waste management system and its elements by decomposing the 'why' into more detailed and tangible requirements

The 'when' defines at which stage of implementing the waste management system the 'what' must be fulfilled

The 'who' defines the element of the waste management system that must fulfil the allocated 'what'

The 'how' defines the design of the element of the waste management system such that all the allocated 'what' are fulfilled

Figure 1 The cornerstones of requirements management: the sequence of issues that need to be addressed.

2.1.2 Nature and challenges of requirements management

Our understanding on **requirements management** (sometimes also called requirements engineering) and on the corresponding requirements management system is summarised below:

- A requirements management system **applies to a specific system** (in our case a specific waste management system or – at an early stage in the programme – the overall waste management programme), with the waste management system looked at being broadly defined through all the elements needed for its successful functioning when being used, but it also includes its planning, implementation and the management of its end-of-life; thus, it includes all stages of the life-cycle of an industrial facility. The waste management system looked at is delineated from other systems by its boundaries − the system boundaries (see chapter 2.2).
- As the name already indicates, one of the key issues is the definition of **requirements** that apply to the waste management system of interest – thus, the identification and management of requirements is very important (see chapter 2.4). For the development and documentation of requirements certain criteria apply, see chapter 2.5. As many requirements **address specific stakeholder needs**, the identification and involvement of stakeholders from the beginning on is very important, see chapter 2.3.

- In the approach to requirements management described in this document, the **strong link between systems engineering and requirements management** is explicitly acknowledged – requirements management as used in this guidance thus looks at (i) defining the needs, goals and expectations and the resulting requirements for the waste management system looked at (the **'needs domain'**), (ii) developing the **'functional architecture'** as the interface between the 'needs domain' and the 'solution domain', and (iii) developing the design (resulting in specifications) and implementation process that leads to a waste management system that meets the needs, goals and expectations (the **'solution domain'**), see chapter 2.6. The **basic structure** of a requirements management system is depicted in Fig. 2 as an illustration for the introduction to requirements management in this chapter.
- To acknowledge the **stepwise approach** in implementing a waste management programme with its systems (incl. implementing deep geological repositories), requirements management and the requirements management systems used for waste management are of **evolutionary character**. This is briefly discussed in chapter 2.7.
- The purpose of requirements management is to ensure that the development of a waste management system will successfully **meet all the requirements** set. Requirements management consists of a set of techniques to elicit / extract, discuss / negotiate, decompose and document requirements such, that those in charge of developing the design of all stages of the lifecycle of the waste management system (planning, building / construction, use / deployment / operation, decommissioning / dismantling (and closure)) always have all requirements needed at that stage of the project. This needs to be ensured when implementing and using a requirements management system (see chapters 3.1 and 3.2).

  Then, requirements management also includes the measures taken to ensure that the waste management system implemented, used and eventually decommissioned / dismantled or closed (for a disposal facility) is in agreement with the requirements derived in the design process. Thus, when using a requirements management system, the different process steps of using the requirements management system, including **verification** (the system-elements are correctly planned and implemented) and **validation** (the correct waste management system / sub-system is planned and implemented) are very important and require the definition of workflows (see chapter 3.2).
- Requirements management as discussed in this guide takes the **evolutionary character** of the implementation of waste management systems into account (see chapter 3.3). It acknowledges that the process of developing the requirements ('needs domain'), the 'functional architecture' and the design and the eventual implementation of the waste management system ('solution domain') will – besides the stepwise refinement of the waste management system – also experience a 'learning curve' with the **opportunity to optimise** a waste management system; thus, it explicitly includes managing refinements and change (*'learning by doing and accepting that things will change'*). For **managing refinements and change**, but also as a general principle, full **traceability** is an important issue in requirements management.
- Besides its links with system engineering, requirements management for a waste management programme has **interfaces** with and supports activities in many areas. This includes:
  - Initiation and periodic refinement of the **waste management programme** as required by EU Council Directive 2011/70/Euratom 'the so-called Waste Directive' (based on the waste management strategy)
  - Development of the different **pre-disposal** activities and facilities (thoughtful use of radioactive materials (e.g., avoidance / minimisation of radioactive waste at the source), collection / characterisation and segregation of raw waste, treatment / solidification / packaging of waste, handling / transportation of waste packages, interim storage of waste).

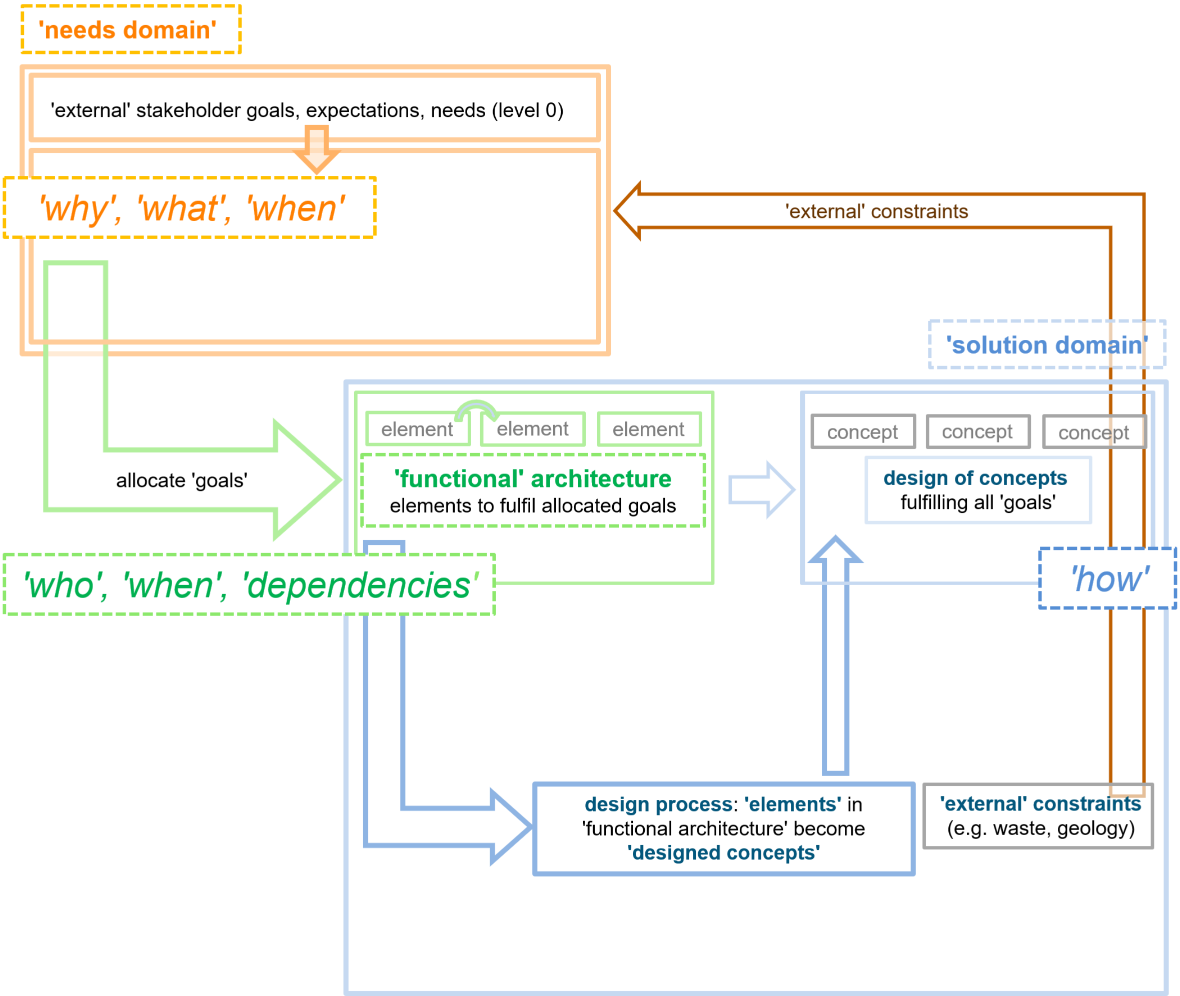


Figure 2 A scheme with the domains of the requirements management system (the 'needs domain' – describing the 'why', 'what' and 'when'; the 'functional architecture' – capturing the 'who' and the 'when' and dependencies between elements; the 'solution domain' – defining the 'how') and the flow of information and the workflow (arrows).

The scheme shows the elements of a programme at an early stage, where the main aim for the 'needs domain' is on the goals, needs and expectations of the 'external' stakeholders and where the 'functional architecture' only contains high-level elements and the 'solution domain' only concepts for the high-level elements. However, 'external' constraints (e.g. waste, existing facilities) need to be considered from the beginning on.

- Development of **disposal solutions**, including:
  - managing post-closure safety: developing the safety concept and the corresponding concept of the disposal system as well as the criteria related to geology (e.g., input site selection and site characterisation) and the requirements on the system of engineered barriers, taking the properties of the waste into account,
  - site selection (natural barrier / geology, surface),
  - project development, licensing (stepwise development, RDD, …) & optimisation,

    - assessment of implementation feasibility,
    - ensuring operational (nuclear) safety, radioprotection, security, safeguards, occupational health, protection of the environment, land-use planning,
    - construction / building, operation and closure of the disposal facility,
    - role of uncertainties, risks & reliability (… and measures to be taken, if needed),
    - etc.
  - Informing interest groups / stakeholders on all issues of the waste management programme,
  - etc.
- The requirements management **process** and the requirements management **system** use a **hierarchical structure**. The hierarchical structure of the requirements ('needs domain'), the hierarchical structure of the 'functional architecture' of waste management system to be implemented as well as the hierarchical structure of the specifications needed for implementation, use and managing the end-of-life ('solution domain') are discussed in chapter 2.6.
- If needed or considered useful, it is possible to use the information in the requirements management system to assess the importance of **uncertainties and risks**. This issue is briefly mentioned in chapter 3.2.

2.1.3 Benefits of requirements management

Requirements management offers many benefits, e.g.:

- Ensuring **completeness and consistency** of the **information** needed, and of the **decisions** to be taken in the stepwise approach of developing, implementing, using and managing the end-of-life of waste management systems.
- Early detection of **wrong, conflicting and/or missing information and decisions**.
- Development of a **common understanding** of all the persons working in a waste management programme and supporting the structured interaction between them.
- Providing **transparency** at each stage of the project ('*why, what, when, by whom, for whom, how, influenced by whom, …*'), with transparency helping to maintain an overview, and thus **supporting daily management**,
- Providing easy access to the **currently accepted 'oversight' information** as it replaces numerous individual documents by one system and thus increases efficiency,
- Providing **traceability now and in future**. Traceability is needed to **manage refinements and changes** that are **the rule and not the exception** for long-lasting projects such as waste management projects. Traceability allows to identify the features that need to be changed to cope with the refinements and changes needed. Traceability is also needed to investigate the overall effects of suggested / needed refinements and changes before their actual implementation; this allows to make some adaptions to the proposed refinements / changes, if needed.

  Traceability is also important for keeping a record of important decisions made as part of **knowledge management for future generations** to understand the *'know why'*, the *'know what'* and the '*know how'* these decisions were taken.

- Requirements management is a prerequisite for periodically assessing the **performance and the implementation feasibility** of the proposed waste management system and to assess the importance of remaining **uncertainties and risks**.
- Supporting the **setting of priorities** (incl. distinguishing between important and urgent issues),
- Providing the means to **identify the needed capabilities** (either internally within the waste management programme or through support by 'external' service providers) for the successful implementation of the waste management system,
- Requirements management also provides a proper basis for **estimating development effort and cost**.
- etc.

For developing this guidance document, the information available mainly from the 'International Council on Systems Engineering – INCOSE' (see e.g., INCOSE, 2022b), but also from other literature is used.

2.1.4 Tools for requirements management

Requirements management is normally done with the help of tools that capture the full requirements management system (see chapter 2.6). The most primitive approach is to use tables (e.g. Word) that contain the information. As the information is interlinked, these links need to be captured; just with tables this gets cumbersome. Also the use of EXCEL is most likely not an adequate solution on the long run. Thus, the use of a **database software** is considered the best way to go. There exists a broad spectrum of software that can be used for requirements management. It may be advisable to get some support in the evaluation of the most useful software for the specific application at hand. However, for eliciting / extracting and compiling (and also for modifying/editing) information, Word and EXCEL can be useful tools, but the information collected in these tools should then be transferred into the database software – thus, it is advantageous if the database software allows both the import and export of information from standard software like EXCEL or Word.

The **database** has:

- to store the information,
- to be able to export the information,
- to use appropriate attributes for the later evaluation / visualisation of the information,
- to perform evaluations, and for that, create different views on the information stored,
- etc.

The database has also to be able to depict the **dependencies** of information, see chapter 2.5. This includes:

- the hierarchies used for the 'needs domain', the 'solution domain' and the 'functional architecture' as interface,
- the allocation of the requirements to the elements of the 'functional architecture' and the specifications developed for the elements in the 'solution domain',
- the links between different entities within the database,
- the attributes for the different entities in the database for different evaluations and analyses,
- etc.

2.1.5 Summary

The nature of requirements management can be summarized as follows:

- **Requirements management is a process** and **requirements management systems provide a platform** that supports this work process summarised as follows:
  - **elicit / extract the available information** related to requirements provided by 'external' stakeholders in a focussed manner, stores this information and decomposes them into more detailed requirements.
  - **analyse, organise and structure the information** related to requirements and ask for missing information and clarify unclear and negotiates conflicting requirements,
  - use the information to **develop a set of hierarchically organized requirements**,
  - define, refine and adapt the **elements of the waste management system** / sub-systems of the 'functional architecture' in a hierarchical structure as interface between the 'needs domain' and the 'solution domain',
  - **allocate the requirements** (the 'needs domain') to the corresponding elements of the waste management system captured by the 'functional architecture' and thus define which requirements each element of the waste management system has to fulfil; this defines the starting point of the design process,
  - based on this input, the **design process** develops **concepts** (in an early stage of the programme) or design **specifications** (later in the programme) - the 'solution domain'. The information available for defining the requirements and the design output (concepts, specifications) differ in their maturity (assumptions, ..., facts) and in the level of detail as a function of the status of the programme,
  - support the **implementation** and later **use of the waste management system** as soon as its specifications have reached the necessary level of maturity,
  - ensure for each element of the waste management system that meeting the requirements is **verified**,
  - ensure that meeting of the goals, needs and objectives of the waste management system or sub-system is **validated,**
  - provide **traceability** and **transparency** by referring to key documents and to (other) requirements and (other) system-elements,
  - and **support decision-making** and the management of **refinements** (incl. optimisation) **and changes** in a reliable manner,
  - provide a platform to analyse the importance of identified **uncertainties and risks**.
- Requirements management
  - involves a **broad spectrum of information providers** ('external' stakeholders, internal stakeholders with generalists & subject matter experts, supply chain) with different roles & responsibilities (see chapter 2.3),
  - affects (through requirements) the **whole programme of planning, implementing, using and decommission / management the 'end-of-life'** of the elements of waste management systems (all elements with their life cycle stages taking place at different times),
  - reflects the **evolutionary nature and stepwise approach** of a programme (early in the programme: assumptions / 'beliefs' at a high level; later in the programme: more and more

consolidated information & facts also at the detailed level); thus, the requirements management system grows and gets more mature with time,

  - is an **iterative process** and ensures a proper management of refinements and changes (all issues affected become visible and are addressed in traceable manner).

- Requirements management should **start early** in a programme and will evolve with progress of the programme (reflects the stepwise implementation). With progress of the programme, the level of detail and the maturity of the information will increase.
- The requirements management system can provide important input into the development and update of the **waste management programme** as response to EC's 'waste directive'.
- Requirements management is an **overarching activity** (if applied in the 'broad sense') and a key to success of a waste management programme.

2.2 The waste management system analysed and the management of its interfaces to other systems

2.2.1 Definitions

- The **waste management system** to be captured with the requirements management system should contain all the elements that are relevant for its **successful functioning when being used** and should contain the relevant **stages of the lifecycle** of these elements.
- The **boundaries** of the waste management system to be implemented delineate the system to be covered by the requirements management system from the 'outside world'. The requirements management system also includes a description of how the interfaces to other systems at the different boundaries are managed (e.g., through waste acceptance criteria).
- The involvement of **service providers** and the **supply chain** needs also to be managed as an 'external entity', as they are not part of the waste management system as long as their contributions are not ensured through contracts for the full time that they are needed.

2.2.2 Issues of importance for defining the boundaries of the waste management system and managing their interfaces

- Often, the waste management system and its boundaries are defined by **ownership** ('having direct and full control'). The system boundaries define the **interfaces** to the 'outside world' – other systems with whom the waste management system under development will most likely interact. Managing these interfaces is a very important issue; this can also lead to constraints (see chapter 2.5).
- If the ownership with having direct control gives not a clear answer, it is up to each programme / organisation to decide where to make the boundaries. The bigger the waste management system, the fewer interfaces one has (positive), but the bigger the system the more difficult and challenging it gets to manage it (negative). Thus, if the interfaces are easy to manage, there are good reasons to keep the waste management system small and easier to manage; if the interfaces are demanding, then there might be good reasons to enlarge the waste management system – at least until agreement has been reached on how to **manage the interfaces**.

Thus, for waste management programmes in an early stage, as a starting point the requirements management system should consider the **overall waste management programme**:

- to develop a rough overview on **where to introduce boundaries** and on how to manage the resulting interfaces, or
- to integrate the overall waste management system into one requirements management system that can be **divided up** into a number of requirements management systems for the different system elements **at a later stage**.

- If the overall waste management system is split up, **obvious boundaries** exist between:
  - **pre-disposal activities** (waste treatment / conditioning / packaging, transportation, interim storage, handling, …) with the corresponding pre-disposal infrastructure,
  - **on-going disposal activities** with the corresponding existing disposal infrastructure and
  - **planned disposal** infrastructure.

  As mentioned, these boundaries and interfaces can be managed e.g. by **waste acceptance criteria** that are imposed as constraints (requirements) on each respective system.

  With this, one has to ensure that the **waste** and the **systems** dealing with the waste are **compatible** with one another. To achieve this, it is important to develop already early in the programme **concepts** for all 'waste-related' facilities / processes (e.g. characterisation, treatment, packaging, handling/transportation, interim storage, disposal) that are sufficiently detailed to develop preliminary waste acceptance criteria to ensure the compatibility between the different wastes / waste types and the different processes / facilities of the waste management programme.

- Normally, the requirements management system should include all **stage of the life cycle** of the elements of the waste management system; this includes planning, building / construction, use / operation (including maintenance, renewal, modification), decommissioning / dismantling / 'closure' (managing the 'end-of-life').

  A special case exists when the requirements management is implemented at a time when **parts of the waste management system are already developed / implemented**, see also chapter 3.1.

- However, in some cases (e.g. in connection with updates of the requirements management system when moving from one phase to the next, see chapter 3.3) a stage of the life cycle may come to an end as **issues become reality** (e.g. site selected / basic concept of waste management system defined for its implementation) and are not anymore an internal part of the requirements management system but are covered by constraints in the requirements management system.

- For waste management, one should – besides pre-disposal and disposal – ideally also look at and **interact with the front end** (where the radioactive material enters the overall system) as it impacts predisposal and disposal with the aim to avoid unnecessary complications and to ensure optimised solutions.

- When discussing the boundaries of the waste management system and their management, one also has to acknowledge the importance of service providers, suppliers and the supply market (summarised as the **supply chain**) as outside of the system boundaries and not being under direct control, until binding contracts are made. Thus, the interface with and the management of the supply chain is of critical importance. In the broadest sense, this also includes shared solutions.

- Finally, when defining the system boundaries, the importance of **public support** should be evaluated – if it is a critical issue, measures to be taken to interact with the public should be included in the programme of developing waste management systems and thus become part of the requirements management system.

2.2.3 Summary

This chapter can be summarised as follows:

- The **boundaries of the waste management system** (for a system that covers only part of the overall waste management programme) have to be explicitly considered as boundary conditions, that are either fixed or that still need to be negotiated.
- The **boundary conditions** are an important issue that can have a big impact on the system looked at; thus, clarify the boundary conditions early enough (e.g., through waste acceptance criteria).
- The **supply chain** is often on the 'free market' and thus not directly under control and thus outside of the boundaries of the waste management system as long as no binding contracts are made for all the work done by the supply chain.

2.3 Stakeholders to be considered, their roles and their activities

2.3.1 Definition

A stakeholder is in this document defined as a person, a group or an organisation that **influences the requirements** to be met by a waste management system / programme and its implementation or that is **impacted by a waste management system / programme and its implementation**.

2.3.2 The different stakeholders to be considered

In this guidance document, stakeholders are divided into three groups:

- ‘**External’ stakeholders** are external of the operational work on the waste management system (no direct involvement in the development of the of the waste management system) but are decisive by providing the high-level overall goals of the waste management system under consideration. They have a strong interest in the success of the waste management system and are often involved in the initiation of the corresponding programme.
- The **'internal' stakeholders** are in charge of developing the waste management system under consideration and thus directly influence / control the development of the system-specific requirements, that have to fulfil the high-level goals of the ‘external’ stakeholders. These are then used by the internal stakeholders in the design of the waste management system and become fully effective after its implementation.
- Finally, there are a range of **stakeholders** that are **formally not directly involved in the development** of the waste management system but need to be informed and may be involved through consultation – this includes the public at large that is not directly affected by the waste management programme / system.

Below, the ‘external’ and ‘internal’ stakeholders are discussed in somewhat more detail.

'External' stakeholders include, e.g.:

- **Policy / policy makers and licensing body / decision makers**, issuing nuclear and other legislation that needs to be considered as requirements, and by using their power provided by legislation to impose requirements on the waste management system by their decision-making in the licensing process.
- **Regulator / regulatory support**, with requirements as documented in their regulations and with requirements according to their findings from reviews of the system of interest.

  Furthermore, most likely, the regulator will also review the requirements management system of the implementer and through his review comments influence the requirements management system of the implementer.
- **Local communities,** with requirements related to their needs and expectations. If the voluntary approach (or veto right) is used in site selection, then the views of host municipality must be included in the requirements management system.
- **Waste producers** not involved in the implementation of waste management systems (except for covering the cost due to their waste), sometimes also called ‘sponsors’.

'Internal' stakeholders include, e.g.:

- **Operator and developer** having the mandate (e.g. given by the state) to develop a solution (through coordination of the design and being involved in the design process and in the eventual implementation), in waste management often called 'waste management organisation' (WMO), relying on:
  - its own **in-house competencies**
  - **service providers**: design and support as system engineer or as designer for specific system elements (subject domain experts) with requirements related to their standards, codes, guidance that define 'good engineering practice' / state-of-the-art:
    - **internal** within the implementer organisation,
    - **external** to the implementer supporting the implementer.
  - **supply market** (system-elements / products) with requirements related to their standards, codes, guidance that define 'good engineering practice' / state-of-the-art.

or:

- **'Large' waste producers / consortium of waste producers** being the owners through their responsibility to find a solution – with the tasks and their organisation similar as the ‘operator and developer’ mentioned above.

It is of importance to be fully aware that the **implementer and regulator have different roles**. The requirements management system of the regulator (if available) should be independent of the requirements management system by the implementer; but the requirements management system of the implementer must include the regulatory requirements.

2.3.3 Requirements management – working as a team

Successful implementation of a waste management programme / waste management systems is a **team effort** by the 'internal' stakeholders (the waste management organisation) that relies upon both the technical development of the products needed and the project management supporting the technical development process:

- The **technical development** of the products is done by:
  - **Systems engineers**, responsible for the process of correctly populating the overall requirements management system with information (incl. design input requirements and design output specifications) and the correct use / application of the information. For this, the system engineers have to organise and oversee the design process and thus need to have a good understanding of the system to be developed, but they do not need to understand all the details about each product – they are 'generalists'.

    The system engineers are also responsible to **manage the requirements management process**. That includes the development of workflows and keeping them up-to-date as well as ensuring that they are applied whenever needed; thus, they ensure that the status of the information in the requirements management system is at all times clearly visible and that only 'cleared' information is being used for developing the projects.
  - **Subject matter experts**, responsible for the scientific-technological details of the different products, with also having a good understanding about the context of the products they are responsible for. They also have to be able to decompose the goals into functions / characteristics with their targets.

    Some of the subject matter experts **oversee the RDD** for the different products and provide the corresponding information, while the other subject matter experts are the **specialists for the design** and the development of the product specifications and production specifications and oversee implementation, use and 'end-of-life' of the product.

    Then, some subject matter experts **oversee** i**mplementation**, **use** and **'end-of-life'**, also to keep track of the detailed verification and validation.
- **Project management** for the work to be carried out **supports** the efficient technical development of the products and includes the management of the following issues:
  - activity lists, bar charts, network diagrams,
  - resources needed / available,
  - budget needed / available; status of cost,
  - organisational framework of the project,
  - etc.

Thus, there are **strong interdependencies between systems engineering, using and maintaining the scientific-technological basis and design, requirements management and project management** that must also be considered when setting up the requirement management system – what should be included and what not? At a high level, it is considered worthwhile to **also include** the project management issues. This also needs to be considered when organising the team; it is essential that the **team works as an integrated unit** well together without any administrative / organisational hurdles.

2.3.4 Summary

The importance of the **'external' and 'internal' stakeholders** and their roles and responsibilities can be summarized as follows:

- 'External' stakeholders are an **important source of information** related to requirements. Due to their role at the political / policy and at the scientific / technical level, their goals provide essential parts of the overall motivation for a waste management programme.
- Thus, it is very important to **identify all relevant 'external' stakeholders** and/or their information. If needed, the 'external' stakeholders should be involved in the extraction of relevant information related to their requirements to ensure that everything is correctly understood and nothing gets lost.
- Due to the long duration of waste management projects, **potential change** in the 'external' stakeholder 'landscape' must be carefully observed to ensure that the relevant 'external' stakeholders are known.
- As the nature of waste management projects changes from one phase to the next, the nature and the level of detail of the requirements needs to be adapted. This also has an **impact on the 'external' stakeholders to be involved**.
- The **public** needs to be informed and will be involved in the consultations conducted. In case of a voluntary approach for siting (or in case of having the veto-right), the **host municipality** with its needs and expectations must be included in requirement management as an **'external' stakeholder**.
- The 'external' stakeholders provide the **'raw information'** that may need interpretation, discussion and negotiation with proper documentation of the results and may include interaction with the 'external' stakeholders that provided the original information. This should ensure that their input is adequately reflected.
- The **different roles and responsibilities** of different (formal) 'external' stakeholders within each country must be acknowledged. In the elicitation / extraction of the input by the stakeholders it is important to keep in mind their specific role and responsibility in populating the requirements management system.
- The **'internal' stakeholders** are equally important as the 'external' stakeholders as they have the task to **develop and implement the waste management system**. For this, they have to decompose the high-level goals, needs and expectations of the 'external' stakeholders into more detailed, tangible requirements that are then the basis for developing designs that they will eventually implement and use.

2.4 Types and hierarchical structure of requirements and their definition

2.4.1 Introduction

- A **requirement** is a statement that **identifies** (i) a goal (needs / expectations) / principle by an 'external' stakeholder, (ii) a function / task, a characteristic / property / behaviour, (iii) the performance target of a function, the quality target of a characteristic (for both: to be met by an element of the waste management system) in order to meet the high-level goals, needs and expectations by the 'external' stakeholders. Requirements are important because, once the requirements are set, they are the basis for the work to follow: the development / design, the implementation, the testing (verification / validation), its use and – if applicable – its decommissioning / dismantling / closure / 'end-of-life'.
- Requirements apply to the **'means' (elements)** of the **'functional architecture'** at the interface between the 'needs domain' and the 'solution domain' for all stages of the life cycle of the different elements of the waste management system and thus cover all phases of implementation. With these 'means', all requirements of the 'needs-domain' must be fulfilled.

  The 'means' include **objects** (facilities, installations, equipment), other **products** such as documents (results from activities) and **decisions,** but the 'means' may also provide **'situations'** (e.g. safe situations).
- The following **categories of requirements** (as mentioned above) are distinguished:
  - **Goals, needs and expectations** on the overall waste management system or sub-system expressed by 'external' stakeholders; this may also include so-called principles,
  - **Functional requirements** and **(quality) characteristic requirements** that relate to an expected **performance or behaviour** to be provided by an element of the waste management system,
  - **Performance targets** are related to a function of an element that express the required performance of that function (to be met by an element of the waste management system),
  - **Quality targets** are related to a characteristic of an element that express the required quality / behaviour of an element (e.g., availability, reliability, testability, maintainability, repairability, etc.) of that characteristic (to be met by an element of the waste management system),
  - **Constraints** are (externally) imposed requirements that have an impact on specific requirements of the **'needs domain'** and/or **elements of the 'functional architecture'** that need to be considered in the design and affect the layout of waste management system ('solution domain').
- The **definition of requirements** is a very important task of requirements management. This is done for the high-level requirements through **interaction with the 'external' stakeholders** and/or through their documents that relate to the requirements they consider important and through **decomposition of the high-level requirements** into lower-level requirements by the 'internal' stakeholders.
- To fulfil its role, each individual requirement has to **fulfil certain criteria**, see chapter 2.5. Also the set of all requirements together has to fulfil certain criteria, see also chapter 2.5.

2.4.2 Types of requirements and their hierarchical structure

Below, the different types of requirements and their hierarchical structuring into **different levels** are briefly described. This hierarchical structure also recognises the different roles of the different stakeholders involved in defining the requirements for the development / design of the waste management system, see chapter 2.3.

At the **highest level** (called 'level 0' in this document):

- **Goals / needs / expectations**, sometimes also summarised as 'the **mission** of the undertaking' (as a broad title for the project)

  These very-high level requirements come from 'external' stakeholders (see discussion in chapter 2.3) that have goals, needs and expectation on the waste management system to be developed but are not directly involved in its development.

These external goals, needs and expectations ('level 0') are **complemented by lower-level goals** ('level 1') for the different stages of the life cycle either through input of the 'external' stakeholders or by the 'internal' stakeholders. The 'level 1' - requirements are then **decomposed into lower-level requirements (functions / characteristics** – 'level 2a / 2b' with **their targets** 'level 3a / 3b') that are then developed into element-specific **design input requirements** and **design output specifications** ('level 4a / 4b') and **production specifications** ('level 5'). The results from implementation are described in a document ('level 6').

Thus, the following **hierarchy** results:

- High-level (or system-level) requirements – the 'external' stakeholder **goals for the overall waste management system** ('level 0').
- Next, lower-level **goals** are defined **for sub-systems** and **for stages of the life cycle of the overall waste management system** ('level 1')
- **Functional requirements** – the functions / tasks specific elements of the waste management system have to fulfil. If needed, functions can be informed by sub-functions ('level 2a').
- **(Quality) characteristic requirements** – the characteristic or the behaviour a specific element of the waste management system has to fulfil ('level 2b').
- **Performance target** – a performance target (e.g., how fast? how much?) is directly related to a functional requirement to complement the function with a quantitative definition of its performance ('level 3a').
- **Quality target** – a quality target is directly related to a (quality) characteristic requirement to complement the characteristic with a measurable / assessable quantity ('level 3b').

  Thus, the **'level 2 / level 3' - requirements** are derived by **decomposition** of each of the **'level 1' - requirements**. The 'level 2 / level 3' - requirements have to be defined such, that if they are fulfilled, also the corresponding 'level 1'- requirement is fulfilled.

  The 'level 1 to 3' - requirements (based on the 'level 0' - requirements) form the so-called **'needs domain'**.

In a next step, by using the hierarchically organised **'functional architecture'** (see chapter 2.6) each of the **requirements** of the 'needs domain' is **allocated** to an **element of the waste management system** captured by the 'functional architecture'.

Through the **design process**, for each element of the waste management system, the requirements of the 'needs domain' are then developed into the 'level 4 and level 5' - requirements / specifications, see discussion below:

- First, the '**design input requirements'** ('level 4a') are developed where in a first step, the compatibility of the requirements allocated to the element are assessed – if needed, some corrections have to be made.

  Next, the environmental conditions and loads the element (e.g. in case of objects) has to withstand are defined with some margins to take existing uncertainties in loads and conditions into account. The consolidated list of requirements (functions / characteristics with their targets), the environmental conditions and loads, etc. are the basis for a pre-design of the element (for objects, type of materials to be used, rough dimensions , etc.)
- The 'design input requirements' are the basis for developing the **design output specifications** ('level 4b') - the so-called product specifications – that contain the detailed design and document also the key input used for the design (besides the information of the 'design input requirements', e.g. the standards and codes used, etc.). The specifications have to show that the 'level 2 to 3' - requirements are met.
- Next, the **production specifications** ('level 5') are developed. Here, it may be useful to involve the service provider / supply chain to check the feasibility and cost-effectiveness of the proposed production process. These specifications also define all measures to be taken to demonstrate compliance with the 'level 2 to level 3' - requirements:
  - For each element of the waste management system this requires **verification**: the demonstration that the applicable lifecycle requirements imposed on a waste management system element have been correctly implemented.
  - For the overall waste management system or sub-system this requires **validation**: the demonstration that the correct system has been implemented that fulfils the requirements for the overall waste management system (or sub-system) that take the goals, needs and expectations of the 'external' stakeholder into account.
- Finally, there are also **constraints** that can in principle apply to all levels of requirements. Constraints are (externally) imposed restrictions for the 'solution' domain that must be respected, although they can in some cases be changed based on (mutual) agreement. The 'constraints' are considered in both the 'needs domain' and in the 'functional architecture'.

  There are several sources for such constraints:
  - **Factual constraints / restrictions**, e.g.:
    - Existing and expected / 'committed' types and volumes of waste to be managed,
    - Environmental conditions at the site selected (e.g. for interim storage facilities: unlikely external events),
    - Implemented facilities,
    - etc.
  - **Licensing, legal and political decisions**, e.g.:
    - Commitment to site selected (if no external reasons exist to abandon the site),
    - Licensed objects,
    - etc.

- **Agreements** related to constraints due to system boundaries, e.g.:
  - Agreed waste acceptance criteria.
  - etc.

2.4.3 Definition and development of requirements

For defining the requirements, the following activities are important:

- A list of **themes** for which requirements are needed must be defined; the themes often cover the **different stages of life cycle** and the interfaces with the public that need to be considered for the different elements of the waste management system of interest,
- The **sources of requirements** of the 'external' stakeholders for the different stages of the life cycle of the waste management system / themes must be identified,
- The **involvement** of the relevant 'external' stakeholders and/or the availability of the relevant information for each of the themes must be ensured,
- If deemed necessary, **structured interactions** with the 'external' stakeholders must take place that includes:
  - elicitation / extraction of information related to the requirements,
  - discussion and negotiation of information to derive the requirements,
  - documentation of the derived requirements,
  - review of the requirements with respect to the criteria discussed in chapter 2.5 (each requirement on its own and the set of all the requirements together).
- **Decomposition of the requirements** by the 'external' stakeholders ('level 0' - requirements and some of the 'level 1' - requirements) into more detailed requirements ('level 2a/b and level 3a/b' - requirements).

2.4.4 Documentation of requirements

- The documentation of requirements has to be comprehensive, complete and unambiguous.
- Especially **ambiguity** can be a **challenge** and is of concern. Therefore, different types of communication / writing of requirements exist for documentation:
  - **Natural language**-based products, with the following rules:
    - short and well-structured sentences
    - well-structured paragraphs
    - consistent use of uniform terminology
    - avoiding vague or ambiguous terms
  - **Template** based products, by using phrase templates for natural language (syntactic structure of phrases).
  - **Model**-based products.

Most likely, natural language-based products are sufficiently good to start. On the long run, it may be worthwhile to go to more complex approaches.

2.4.5 Summary

There are **different levels of requirements**; in this document, we use **seven levels**:

- The **higher levels** – the so-called 'needs domain' are in principle independent of detailed design.

  This includes:

  – ‘Level 0’: Highest level goals, needs and expectations (sometimes summarised as mission of the ‘undertaking’) are defined by **‘external’ stakeholders** not directly involved in the development and implementation of the waste management system.

  The next levels (‘level 1 to 3’) decompose the ‘level 0’ - requirements into system requirements by the **‘internal’ stakeholders** that are involved in the development and implementation of the waste management system (see chapter 2.3)

  – ‘Level 1’: **Goals and sub-goals** (or: principles)

  – ‘Level 2a’: **Functions and sub-functions** (or: behaviour / properties, tasks)

  – ‘Level 2b’: (Quality) **characteristics** or non-functional requirements

  – ‘Level 3a’: **Performance targets** for functions

  – ‘Level 3b’: **Quality targets** for (quality) characteristics or for non-functional requirements

  The development of the 'level 1 to 3' - requirements can be seen as a **decomposition process** that starts at the highest level, with decomposing the highest-level requirement (‘level 0’) into sub-requirements at the next level. The decomposition has to ensure that if all the requirements at the deeper level are fulfilled, then the requirement at the next higher level is also fulfilled.

- The ‘translation’ of the requirements of the 'need domain' by the **design process** into requirements / specifications for the elements of 'solution domain' results into additional system-specific requirement levels, ‘level 4a/b’ and ‘level 5’.

  Before this can be done, the ‘functional architecture’ with all elements needed to fulfil the ‘level 0 to level 3’ - requirements need to be defined. Then, each of the functions / characteristics (level 2a/b’ - requirements) with its target (‘level 3a/b’ - requirements) needs to be allocated to an element of the ‘functional architecture’.

  – ‘Level 4a’: **Design input requirements** consist of:

    – the consolidated ‘level 2a/b and level 3a/b’ - requirements allocated to an element (no conflicting requirements),

    – the design loads and conditions acting on that element (with some margins to take uncertainties into account) and

    – the results of a pre-design of the element.

    This is the basis for the detailed design (‘level 4b’).

  – ‘Level 4b’: **Design output specifications** (level 4b’) involve the detailed design of specific elements resulting in the product specifications, based on the input by the ‘level 4’ - requirements.

   - ‘Level 5’: **Prhhoduction specifications** define the requirements for the production process, including the description of the **verification** for each element of the waste management system and the **validation** of the overall system. It may be worthwhile to involve the supply chain in the development of the production specification to ensure the feasible and cost-effective production.

- ‘Level 6’: contains the **documentation** of the implemented waste management system element and of the overall waste management system, including the **results from verification** (elements) **and validation** (overall system).

2.5 Key properties of requirements

2.5.1 Introduction

- The set of **all the requirements together** has to ensure that – if all requirements are met – the waste management system is correctly implemented and the correct waste management system is implemented and thus fulfils the goals, needs and expectations of the ‘external’ stakeholders and respects existing constraints as well as the environmental loads and conditions and thus is technically feasible. This is checked by:

   - **verification** − checking that the elements of the waste management system are correctly implemented, and that the different elements of the waste management system correctly interact with each other and that they take the waste management system environmental loads and conditions (with some margins) correctly into account. This is done through measurements, tests and/or modelling.

   - **validation** – checking that the waste management system (or – in the case of very big waste management systems: each sub-system) fulfils the high-level ‘external’ stakeholder needs and expectation and thus, that the correct waste management system has been implemented. This is done through measurements, tests and/or modelling.

  The process of verification and validation is equivalent to the need to **demonstrate compliance** with all requirements.

- With this in mind, **criteria** for each of the **requirements individually** and for the s**et of all the requirements together** can be defined. Such criteria are reported in the literature and are described below.

2.5.2 Characteristics of and criteria for individual requirements

The text below is based on information from the literature, see e.g., INCOSE (2023). For individual requirements, the following criteria apply.

- **Necessary** – the requirement defines a function, a (quality) characteristic and/or a constraint. If it is not included in the set of requirements, a deficiency in function or characteristic will exist, which cannot be fulfilled by implementing one of the other requirements,

- **Appropriate** – the specific intent and amount of detail of the requirement is appropriate to the level of abstraction of the system element it refers to. This includes avoiding unnecessary restrictions on the system design to help ensure system design and implementation independence to the extent possible,

- **Unambiguous** – the requirement is stated in such a way so that it can be interpreted in only one way,

- **Complete** – the requirement sufficiently describes the necessary function (together with its performance target), (quality) characteristic (with its quality target) or constraint without needing other information to understand the requirement,
- **Singular** – the requirement should state a single function, characteristic or constraint,
- **Feasible** – the requirement can be realised within the existing constraints with acceptable risk,
- **Verifiable** – the requirement is structured and worded such that its compliance can be proven (verified) satisfactorily,
- **Correct** – the requirement must be an accurate representation of the parent requirement from which it was decomposed,
- **Conforming** – the individual requirements should conform to an approved standard style for writing requirements, when applicable.

2.5.3 Characteristics of and criteria for the full set of requirements

The text below is also based on information from the literature, see e.g., INCOSE (2023). For a set of requirements, the following criteria apply.

- **Complete** – the set of requirements on its own is sufficient to describe the necessary functions, (quality) characteristics or constraints of the overall system without needing other information.
- **Consistent** – the set of requirements contains individual requirements that are unique, do not conflict or overlap with other requirements in the set. The language used within the set of requirements is consistent, i.e., the same word is used throughout the set to mean the same thing.
- **Feasible** – the set of requirements can be realised within the existing constraints with acceptable risk.
- **Comprehensive** – the set of requirements must be written such that it is clear as to what is expected from the system elements and their relation to the overall system.
- **Able to be validated** – the set of requirements must we written and have a content such that it can be proven that the requirements of the 'external' stakeholders for the overall system are met.
- **Correct** – The set of needs must be an accurate representation of the sources from which it was derived, the set of requirements must be an accurate representation of the needs and higher-level requirements from which it was derived.

2.5.4 Summary

This chapter can be summarised as follows:

- The **correct formulation** of the **individual requirements** and of the **full set of requirements** is essential to ensure that the waste management system implemented (that is in accordance with these requirements) actually fulfil the external stakeholder goals, expectations and needs.
- Thus, it is essential to have **criteria** that allow to check the adequacy of the requirements specified each on its own and for the full set of requirements together.

2.6 Structure of requirements management systems and overall logics of how requirements management systems are used

2.6.1 Introduction and broad overview

The requirements management system has three domains that address different, but strongly interlinked, parts of the requirements management system, see Fig. 2 in chapter 2.1.2:

- *'why'* is *'what'* wanted by *'when'* (focus on the needs – the **'needs domain'**): the requirements related to what the relevant 'external' stakeholders expect from the waste management system implemented, considering the full life cycle of the different elements of the waste management system.

  The high-level goals of the 'external' stakeholders (the 'why') are supplemented by lower-level goals, and these are then decomposed into functions and characteristics with their targets (the 'what').

- '*who'* has to ensure that the *'what'* is achieved by *'when'* (focus on the elements needed – the **'functional architecture'**): the functional architecture captures the elements and their 'timing' needed to fulfil the goals, functions and characteristics and with allocating the goals, functions and characteristics to specific elements it is clearly defined 'who' has to fulfil 'what' by 'when'.
- *'how'* is *'what'* by *'who'* achieved (focus on meeting the needs – the **'solution domain'**): the design process leads to product specifications and production specifications for the elements of the waste management system as captured by the 'functional architecture'.

2.6.2 Description of the requirements management system and of the process of using it

The **'needs domain'** includes all levels of requirements needed for implementation ('level 0', and 'level 1 to level 3') as discussed in chapter 2.4.

The **'functional architecture'** has to capture all elements needed to fulfil the requirements defined in the 'needs domain'. These elements include objects / physical products, activities with their deliverables (documents, experimental results, results from studies, decisions, etc.) and other measures with their achievements (contracts, agreements, etc.). The 'functional architecture' also captures the interactions between the different elements of the waste management system and the 'timing' of their life cycle stages. The 'functional architecture' forms the **interface between the 'needs domain' and the 'solution domain'**. Each **requirement** of the 'needs domain' is then to be **allocated to an element** of the 'functional architecture'.

Within the **'solution domain'** the detailed design is developed. This includes for each element:

- The **'design input requirements'** (e.g. for objects) that summarize for each element the 'functions' and 'characteristics' and their 'targets' allocated to the element, the 'loads and conditions' acting on the element and the results of the pre-design with the types of materials envisaged and the broad dimensions of the object.
- The **'design output specifications'** are the result of the detailed design based on the 'design input requirements'. If appropriate, the suppliers are to some extent involved in this process to ensure that it is feasible to build / implement the envisaged product.

This results into **'product specifications'** and **'production specifications'**.

The 'needs domain', the 'functional architecture' and the 'solution domain' have to capture all relevant **stages of the life cycle** of each element the waste management system.

The first stage is related to **planning** and includes:

- planning, developing (incl. RDD, site investigations, etc.), design, etc. leading to **documents** as product of these activities for each element of waste management system.
- necessary licensing steps leading to **decisions for implementation** that are then constraints (requirements) for all future steps / activities.

With these elements of the life cycle providing the **basis for implementation** (e.g. waste treatment / packaging, interim storage, transportation and disposal solutions), the following stages of the life cycle cover then all issues of the physical (real) elements of the waste management system:

- construction / building,
- operation,
- decommissioning / dismantling / closure.

The different nature of the different stages of the life cycle of the elements of the waste management system must be explicitly acknowledged and made visible in the requirements management system.

The stages of the life cycle are connected to a timetable that consists of **specific phases**, with each phase:

- having clearly defined **goals**,
- being delineated by **milestones** (the start of the phase defined by the milestone of completion of the preceding phase and the end of the phase by the milestone of successful completion of all activities needed to reach the goals of the phase considered),
- with an anticipated **duration of the phase**

Thus, the structure of the requirements management system has to consider:

- The **'needs domain'**, the **'functional architecture'** and the **'solution domain'** that all have a hierarchical structure. These three domains have to address the different stages of the life cycle of each element of the waste management system of interest:
  - **planning** (planning of the planning, planning of implementation, planning of use, planning of the 'end-of-life'),
  - **implementing** (implementing the planning, implementing objects, etc.),
  - **using** (using the planning and their products, using the objects & installations, etc.),
  - managing the **end-of-life** (archiving of documents, decommissioning / dismantling of objects, etc.)
- As an additional dimension the **phases** have to be included:
  - the 'needs domain' has to identify the phase to which a **requirement** applies.
  - the 'functional architecture' has to identify for each **element** of the waste management system in which phase the element has reached what stage of its life cycle.
  - the 'solution domain' with the **specifications for each stage of the life cycle** of each element also applying to specific phases.

For **evaluating the correctness** of the information in the database, all the information (including attributes) that are needed to depict the relations must be included in the requirements management system and made visible in a suitable manner.

Finally, there is a need to **ensure traceability** to be able to properly manage refinements and changes. Traceability includes:

- Backward traceability: What was the origin of a certain requirement? Which sources (stakeholders, documents, other systems) were analysed during elicitation / extraction?
- Forward traceability: Where is this requirement used? The design / implementation / use /end-of-life of which elements of the waste management system are based on it?
- Traceability between requirements:
  - Do other requirements depend on this requirement or vice versa?
  - Is the requirement a refinement of a higher-level requirement?

2.6.3 Developing and using the requirements management system

The development process starts with the **elicitation and description** of the **goals, needs and expectations** of the high-level 'external' stakeholders and definition of the high-level **'external' constraints** (including constraints resulting from the interfaces to other systems) – the so-called **'level 0' - requirements**.

Next, the **'level 1'- requirements** are derived by decomposing the 'level 0' - requirements; if needed, this is done together with the relevant 'external' stakeholders. This results in more detailed **goals for the different life cycle stages** in the different phases of the waste management programme.

This followed by the decomposition of the 'level 1'- requirements into the **'level 2 and level 3' - requirements**, the **functions / characteristics with their targets**. The 'level 2 and level 3' - requirements must be developed such that if they are met, also the 'level 0' and 'level 1'- requirements are met.

The development process will as next take the **information and experience** in the respective programme into account to derive a hierarchically organized **'functional architecture'.** The 'functional architecture' contains all **objects**, activities with their **deliverables** and other measures with their **achievements** (the so-called 'means' of the waste management system) that are needed to fulfil the 'level 2 and level 3' - requirements. The 'functional architecture' also presents the **interactions / dependencies** between the different elements of the waste management system that are needed to make the waste management system work. It has also to take the different stages of the lifecycle of the elements of the waste management system and with this the stepwise approach and temporal dimension of the implementation process into account.

Here, also the **constraints** ('facts' such as existing and committed waste, geological options, sites chosen, existing facilities, etc) need to be included. The constraints need to be reflected in the **'needs domain'** at the appropriate levels but also as elements in the **'functional architecture'.**

Then each of the 'level 2 and level 3' - requirements is **allocated to a specific element** of the waste management system. This is done in an iterative manner to reach compatibility of the functions and characteristics allocated to a specific element. This may lead to modifications of the requirements (level 1 to 3) and/or to additional elements of the waste management system captured by the 'functional architecture'.

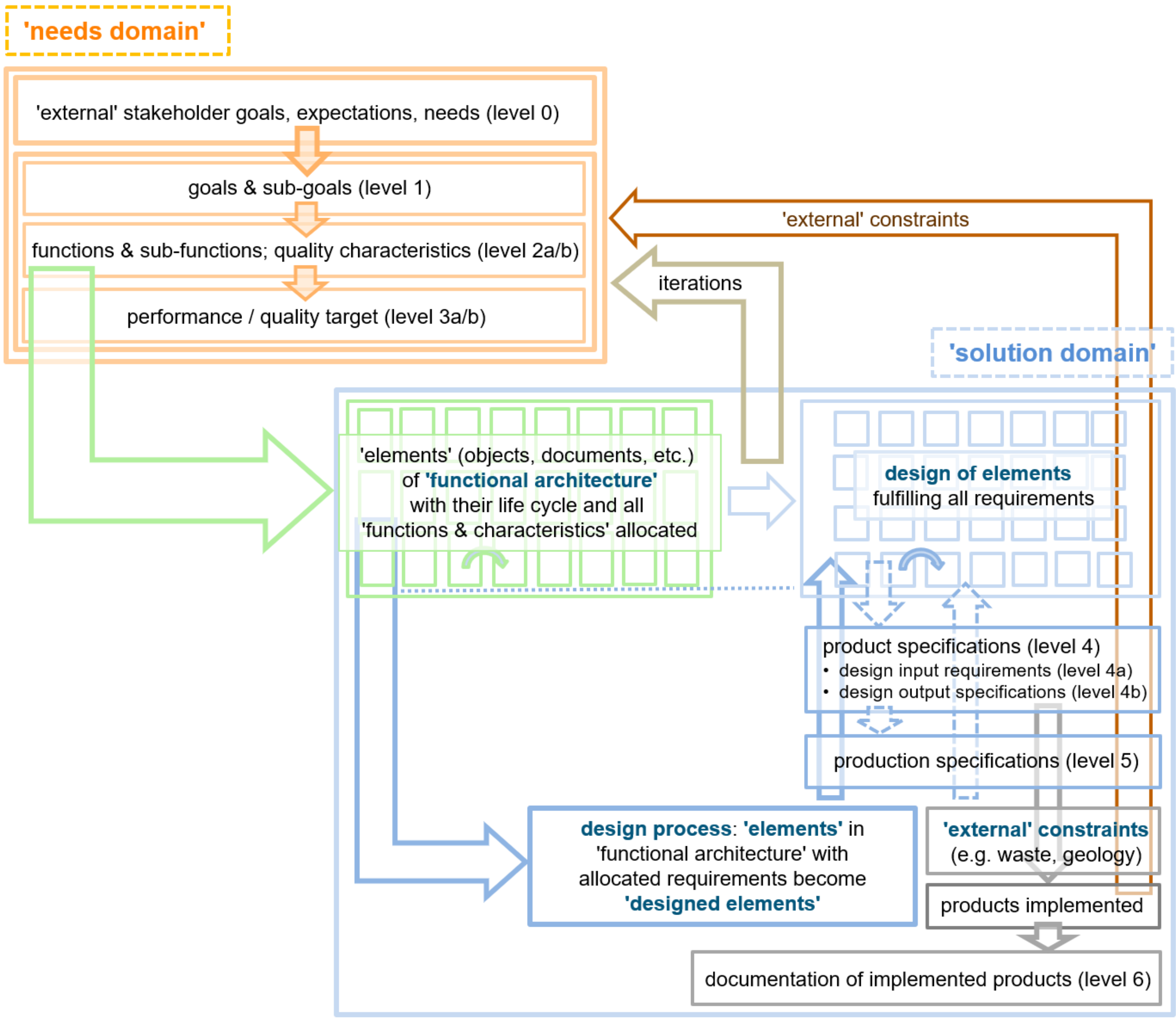


Figure 3 Scheme with the detailed structure of the requirements management system.as described in chapter 2.4 and 2.6.

The scheme shows the different domains and the different levels of requirements, with the arrows indicating the follow of information and the workflow.

Once this stage is reached, the **design process** can start that then leads to the 'level 4 / level 5' - requirements, as described earlier in chapter 2.6.2. This then provides the **basis for implementation** and using all the elements of the waste management system. When the 'use' has come to an end, the 'end-of-life measures as planned will be applied.

All these issues are described in somewhat more detail in chapter 3.1.

2.6.4 Summary

This chapter can be summarised as follows:

- The structure of the requirements management system consists of the **'needs domain'**, the **'functional architecture'** and the **'solution domain'** with all of them having a hierarchical structure.
- The requirements management system has to support and document the **allocation of the requirements** to the different elements of the waste management system captured by the 'functional architecture' also depicting the hierarchical nature of the waste management system.
- The requirements management system has to capture all **dependencies** (hierarchical and links).
- The requirements management system has to support the **workflows** of populating and managing the requirements management system (e.g. managing refinements and changes).

2.7 Evolution of the requirements management system and of the waste management system of interest in the stepwise approach of system implementation

2.7.1 Introduction and overview

The evolution of the requirements management system considers the typical phases of system development and implementation; the **stepwise approach** in and the **time schedule** for developing and implementing the waste management system must be reflected in the requirements management system.

In principle, **different approaches** exist in the development and exploitation of requirement management systems. The typical approaches are (see also Fig. 4):

- The **sequential approach**: Here, the requirements are all defined upfront before the start of implementation in 'one step'. Then, implementation starts, and this is also done in 'one step'. This approach is often called the 'V-model' (scheme A in Fig. 4).

  This approach is considered less suitable for systems that take a long time for implementation, such as waste management programmes or geological repositories because the requirements ('needs domain') and the detailed design and implementation ('solution domain') will change in the course of the project.
- The **incremental approach**: Here, the requirements are again all defined upfront before the start of implementation in 'one step'. Then, implementation starts, but this is done in several steps, taking experience and new information during implementation into account (scheme B in Fig. 4).

  Also this approach is considered less suitable for systems that take a long time for implementation, such as waste management programmes or geological repositories because the requirements ('needs domain') will change in the course of the project and can significantly change also implementation.

- The **evolutionary approach**: Here, both the requirements definition and the implementation is done in several steps that allows to take experience and new information during implementation into account (scheme C in Fig. 4).

  Therefore, this is the preferred option for systems that take a long time for implementation, such as waste management programmes or geological repositories. In this document, the evolutionary approach is discussed in more depth.

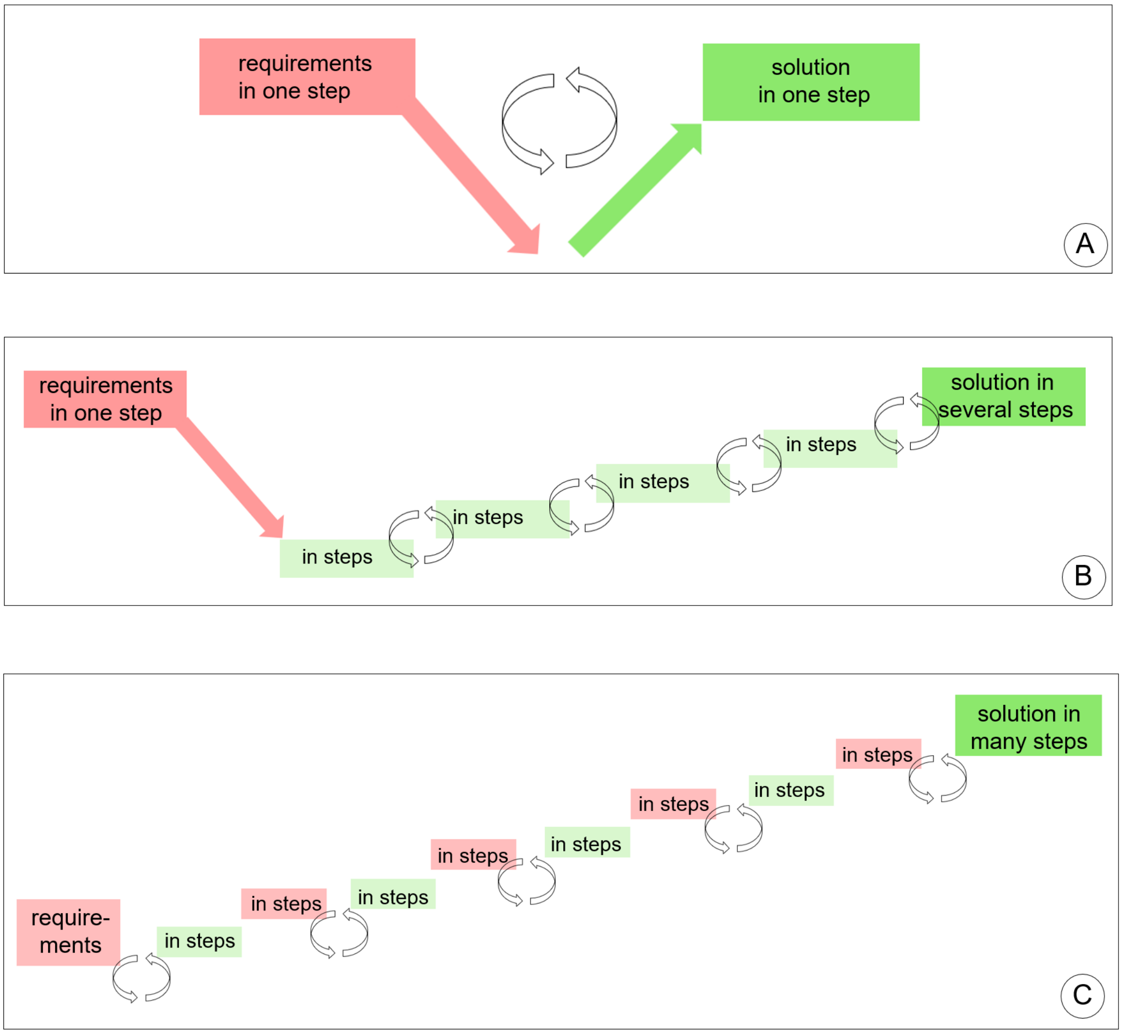


Figure 4 Scheme with different approaches for requirements management and for structuring the requirements management system, see text above.

The stepwise update of the requirements management system when **moving from one phase to the next** has to consider the 'needs domain', the ‘functional architecture’ and the 'solution domain'. It has to acknowledge that the **level of 'ambition' of requirements management changes** from one phase to the next.

- In the **early phase** of developing a waste management system, the requirements management system helps not to overlook something important (aim for **completeness, not for details**), as it provides a good framework and a suitable working process to check for completeness. This can be reasonably well done as the system in the early phases is still of limited complexity and size – see description of building up the requirements management system in chapter 3.1.
- In the **later phases** when moving from one phase to the next, it is in a way easier; one only has to look at those elements of the system where **progress** has been made and changes have occurred.
- With progress of the programme, things get more detailed: at the stage where some of the 'hardware' (site, facilities, …) gets **fixed** (licensed) or **implemented**, one has to assure the following issues:
  - The 'real data' from investigations, experiments, etc. that have been used in the design must be **'qualified' for use** to assess compliance with requirements.
  - If the 'real data' / new **results differ** from the original expectations, one has to check whether there is a need to initiate some changes in the waste management system / system design and/or in the requirements.
  - Then, there is also the need to assess the situation related to the availability of suppliers (planning, construction / building, using / production, …). If there are some 'limitations' in the **supply chain**, this may require some changes in the design of the waste management system and/or the requirements.

2.7.2 Issues to be considered

With respect to the content of the requirements management system, several issues must be considered when **moving from one phase to the next**:

- For the 'needs' domain:
  - The **level of detail** increases with progress of the project as plans, designs, etc. get more detailed. The level of detail in the requirements must be in balance with level of detail in planning. Thus, there may be a need to **decompose the available higher-level requirements** into more detailed lower-level requirements, if needed. This should be done in consultation with the corresponding stakeholders (if the information is not already available from their documents).
  - With progress of the programme, more and more **final (binding) decisions** are made (e.g. selection of site) and more elements of the waste management system are built / implemented and become constraints for the remainder of the programme, and this has to be reflected in the requirements management system.
- For the ‘functional architecture’
  - The level of detail in the waste management system increases when moving from the early phases with only very limited number of **high-level elements** of the system of interest towards later phases where at least some of the high-level elements of the waste management system are decomposed into **more detailed elements** / **sub-elements** or **components**.

This applies to all **stages of the lifecycle** of the different elements of the waste management system where the focus changes from assumptions / initial thoughts, to planning, producing / building, using the system / system element / product, decommissioning / dismantling / closing.

- For the 'solution' domain
  - The level of detail in the system increases when moving from the **early phases** with only '**conceptual thoughts'** towards later phases where at least some of the elements of the waste management system move towards a **detailed design** for construction / implementation (with binding decisions being taken) or are constructed / implemented (facilities).
  - In general, with progress of the programme, the solution domain changes as the **lifecycle stage** of the different waste management system-elements **change** (assumptions / initial thoughts, planning, producing / building, using the system / system element / product, decommission / dismantle / close).
- For all three domains
  - The **scientific-technological basis** for the requirements ('needs domain') and for the design of the waste management system and its elements ('solution domain') gets more mature – the requirements thus move from 'assumptions' in the early phases towards 'solid knowledge, supported by a sound 'scientific-technological basis', e.g., due to RDD and/or design work.
  - In this process, it is important to systematically check / assure the **quality of the 'scientific technological basis'** before moving from one phase / stage to the next to be sure that the planned path forward is still adequate.

To remember: Besides the update when moving from one phase to the next, also the iterative nature within each phase has to be considered, see the description in chapter 3.2 on using the requirements management system.

2.7.3 Summary

This chapter can be summarised as follows:

- Waste management systems are developed and implemented in a **stepwise approach** that delineates the implementation into a number of **different phases** that have different characteristics with respect to the information available (e.g. level of detail / level of sophistication) and the (irreversibility) of the decisions taken – this applies to the 'needs domain', the 'functional architecture' and the 'solution domain'.
- The **milestones** at the end of each phase are a **valuable 'check point'** to assess the quality of the available 'scientific-technological basis' and the adequacy of the path forward. As part of this assessment, it may be worthwhile to assess the importance of remaining **uncertainties and risks** (see also chapter 3.3).

3. Work processes related to the requirements management system

3.1 The steps for implementing the requirements management system

3.1.1 Introduction and overview

Implementing the requirements management system requires a **range of activities**. A brief summary of these activities is given below:

- The implementation requires good **preparation** to ensure:
  - that the waste management **system** looked at is defined correctly and in sufficient detail,
  - that the information is available to perform a **preliminary configuration** of your requirements management system (database),
  - that all **essential 'external' stakeholders** that need to be involved in the early phase of starting the project are identified and / or their documents relevant for requirements management are known and made available.
- The initialisation allows to perform the following issues in parallel:
  - analyse the documentation available related to **requirements**,
  - start the **elicitation process** with the 'external' stakeholders to collect their input related to defining the requirements.
  - analyse the documentation available related to the **'functional architecture'**,
  - start analysing the needs for **attributes** for the different applications (workflows, evaluations, ensuring traceability, etc.),
  - evaluate the **database software options** and acquire a suitable database software,
  - start with the **configuration** of the acquired database software.
- Populating the database with information can start as soon as the information mentioned above is available.
- During the **population of the database**, tests should be performed to continuously check consistency, completeness, etc.

The text below provides some more information on the issues mentioned above.

3.1.2 The steps when starting

The different steps to be made when starting with implementing a requirements management system are discussed below.

- Project initiation:
  - Define **waste management system** to be captured and define / manage the interfaces (e.g. by defining corresponding constraints).
  - Think about the **boundaries** of the waste management system – advantages / disadvantages when making the waste management system larger – advantages / disadvantages when making the system smaller, as discussed in chapter 2.2.
  - Based on the preliminary understanding, document **what is available** in the programme in relation to:
    - the **system concept**: the 'functional architecture' of the waste management system in the different stages of its life cycle, considering the different phases of system implementation,
    - the **life cycle concept**: the different broad types of measures needed in the different stages of the life cycle to arrive at the system in its final stage. The 'means' (objects, activities with their deliverables, other measures with their achievements) needed for implementation must be defined, see chapter 2.6.
  - Start with a list of **sources of requirements** (legislation, guidance, 'good practices', ….).
  - Start with the list of **'external' stakeholders** to be involved when defining the higher-level requirements.
  - Be clear about the **scientific-technological knowledge** available for the waste management system to be implemented and about the knowledge available in the organisation responsible for implementation for defining / developing of:
    - the waste management system to be worked on,
    - the interfaces at the system boundaries to other systems,
    - the environment in which the system is proposed to operate,

    Compensate significant weaknesses by focussed advice / support.
  - Be clear about the **methodological knowledge** and work experience in your organisation:
    - system analysis,
    - system engineering,
    - requirements management methodology / engineering.

    Compensate significant weaknesses by focussed advice / support.
  - Define the different **workflows needed** to implement and use the requirements management system, e.g.:
    - managing refinements / change management,
    - verification,
    - validation (e.g., supported by system modelling).

- Define the approach to **visualise dependencies** (e.g. to find mistakes, to achieve traceability, etc.).
- Based on the size, the complexity and the resources available, decide on the **software to be used** (if needed, with external support) and acquire it.

- Start the work:

  The **structure of the requirements management system**:

  - define the **domains** (needs, architecture, solution), **hierarchical levels**, links, attributes, etc.
  - ensure **bi-directional traceability** and **traceability between requirements** in general.
  - continuously assess **correctness, completeness, etc**.

  The **'needs domain'**:

  - identify the **sources for requirements**,
  - get the **documents** available that are of relevance for requirements,
  - if needed, get in touch with the **'external' stakeholders** to develop the requirements, taking the already available requirements into account – start at a high level, get more detailed by decomposing higher levels with progress of the project,
  - elicit, assess / discuss / negotiate, and document the requirements – one level after the other ('level 0' to 'level 3') by **decomposin**g the higher-level requirements to derive the lower-level requirements,
  - manage the interfaces with the (external) environment to derive the corresponding **'constraints'**,
  - ensure that each of the requirements fulfils the criteria defined in chapter 2.5.
  - ensure that the set of requirements fulfils the criteria defined in chapter 2.5.

  The **'functional architecture'**

  - develop a draft of the hierarchical 'functional architecture' based on your **system understanding**, using a reasonable level of detail.
  - identify **dependencies** and implement them in the 'functional architecture' (hierarchies, other links).
  - **allocate the requirements** developed in the 'needs domain' to the elements of the waste management system in the 'functional architecture'.
  - assess the **compatibility of allocated requirement**s for each element and make changes if needed.
  - etc.

  The **'solution domain'**:

  - start with developing the **'design input requirements'** for each element.
  - based on the 'design input requirements', perform the detailed design that results in the **'design output specifications'**, consisting of the **'product specifications'** and the **'production specifications'**.

- Perform tests to **check the functionality** of the requirements management system as implemented in the software tool.
- Review the set of all the **requirements** whether they fulfil the criteria defined in chapter 2.5.
- Finally, it may well be the case that requirements management is introduced when some **parts** of the waste management system have **already been implemented** (decision taken, facilitates implemented and already in use, etc.)

  Then, it is essential to **incorporate the existing elements** of the waste management system into the requirements management system as follows:

  - For the **existing elements** of the waste management system, (try to) **reconstruct** the corresponding requirements (goals, functions/characteristics and corresponding targets that match with the current use of the facility and that are compatible with the design of the facility)

    If this leads to a **satisfactory solution**, nothing else needs to be done. If things do not match and the design shows **some deficiencies**, these need to be analysed – either they can be tolerated, or otherwise corrective actions are needed.
  - For all other **elements still to be implemented**, the steps as described in this document can be followed.

3.1.3 The first iterations to check the feasibility of meeting the requirements with a reasonable design

Once the system has been initialised, first **'dry runs'** are needed to investigate the waste management system's functioning and feasibility. Such a dry run may show some problems that then need to be resolved.

3.1.4 Summary – some remarks

The following working principles (not discussed before) are considered to provide a good perspective on implementing a requirements management system:

- The requirements management system provides the combination of stating …
  - the **'problem'** (the goals, needs and expectations of the 'external' stakeholders),
  - the related **requirements**,
  - and the **resulting solution** that gives the answer to the problem and the underlying requirement by defining the path forward to the solution.
- Requirements management has to ensure that an answer to the 'problem' is given, that must be fulfilled by the waste management system – **requirements management systems without identifying the path towards a solution have no value**.
- Requirements management is about **satisfying the key goals, needs and expectations of the 'external' stakeholders**.
- The requirements management system must be designed and used in a manner that it supports the development of a **common basis of understanding** about the overall system analysed.
- The requirements management system provides a good platform for managing **uncertainties and risks** and also for **optimisation**.
- The requirements management system and the work process have to ensure that the **context is visible** and has been taken into account.

- **Verification and validation** are essential parts of requirements management.
- **Refinements and changes** in the requirements management system are not an accident, they are much more the rule and will improve the system.
- Planning of waste management system implementation requires **structured, systematic and disciplined work**.

3.2 The steps to use the requirements management system

3.2.1 Introduction and overview

After implementation of the requirements management system, the long period of use starts. In this chapter, the use within a phase is described – the steps to be taken when moving from one phase to the next, is addressed in chapter 3.3.

- Using a fully implemented requirements management system includes the following issues:
  - **Extracting the information** to be used by a person as input for his development / design work.

    When providing information, ensure that the **information is up to date**. This may need a defined workflow.
  - **Following up** the work done and progress made in using / applying the requirements and perform the needed 'checks' ('verification' and 'validation').
  - **Changing information** in the requirements management system because ongoing work shows that some changes are needed. The changes can involve:
    - **deleting** specific requirements because their use has become obsolete (e.g., an element of the waste management system has been implemented / built and changes its nature and becomes a constraint, a change has made in the requirements management system that makes the requirement superfluous),
    - **modifying** specific requirements,
    - **adding** new requirements. Here, it is important ‘not to get lost in all details’ – there is a danger that one adds too many not that relevant requirements (so-called ‘requirements creep’).
- There need to be **well-defined workflows** in place to be able to perform the different tasks mentioned above in a transparent and reliable manner (e.g. through independence of roles),e.g. for implementing refinements and for the change-management process, where the 'who', 'what', 'why', 'when', etc. of the process is adequately tracked.
- **Reasons for refinements and change** include:
  - Changes due to **progress made** in the programme (mode detailed knowledge, new insights, etc.),
  - **Changed needs / expectations** of the high-level stakeholders (e.g. change in legislation, regulation, etc.),
  - **Changes in the market** (new material suppliers with alternative materials of similar quality, new production methods, etc.),

  - Changes in **waste inventories** (changes in treatment / solidification / packaging, waste reduction, new sources of waste, etc.),
  - Changes in **technology** (design methods, construction / operational technologies, etc.),
  - **Feedback from system design** asking for new or changed features,
  - **Detection of errors** in requirements or detection of faulty domain assumptions,
  - **etc.**
- Using the requirements management system to **demonstrate compliance** with all relevant requirements. This involves **verification** (checking that each element fulfils its requirements) and **validation** (checking that the overall system fulfils the system-related requirements (the goals by 'the 'external' stakeholders)).
- Using the requirements management system for **assessing the importance and the impact of uncertainties and risk** (also to be used to identify mitigating actions if considered useful – e.g. through changes in system design or through focussed RDD).

3.2.2 Summary

This chapter can be summarised as follows:

- Using a requirements management system requires **clearly defined workflows**.
- Such workflows are needed in the development work and in the **iterations** taking place in the different phases of waste management system implementation – these workflows can be different from those used when moving from one phase to the next, with these workflows being connected with formal decisions.
- Although **assessing the importance of uncertainties and risks** is a key activity when moving from one phase to the next, it may be worthwhile to do such an assessment on specific topics also in the course of the development work within a phase.
- **Verification and validation** are central issues when using a requirements management system. At specific milestones verification and validation must take place according to well defined workflows.

3.3 The steps to manage the evolution of the requirements management system and of the waste management system analysed

3.3.1 Introduction and overview

In this chapter, the actions needed when **moving from one phase to the next** are briefly discussed.

- Development and implementation of waste management programmes / systems are often implemented in a **stepwise manner,** where the different phases are delineated by milestones with clearly defined deliverables and decisions.
- Thus, when moving from one phase to the next, the **adequacy of the information available** needs to be assessed and also an assessment of **uncertainties and risks** should be made to ensure that the movement to the next phase is justified.
- The final decision to move ahead is often coupled to a **formal decision** by an 'external' stakeholder (e.g. regulator or policy maker / government).

- If the decision has been taken to move into the next phase, as a first step the information in the requirements management system has to be **checked and updated carefully**, also to assess and ensure the scientific-technological correctness. For those issues that have changed their stage (e.g., going from planning to building / implementation), the information related to these issues have to be assessed and changed both in the 'needs domain' and in the 'solutions domain'.
- In connection with implementing the changes occurred, it may be worthwhile to review **progress in general** (within the programme but also world-wide) and then integrate all the new information in a formal change process.
- After this update, the new phase continues in a manner as described in chapter 3.2 until the next milestone is reached.

3.3.2 Summary

- In the stepwise approach, the **different phases** of implementation are **delineated by milestones** where progress is discussed, and remaining uncertainties and risks are assessed. Based on this, a **decision is** taken on the next steps, e.g. (i) to move ahead to the next phase, (ii) postpone the decision and clarify first the open issues that prevent the decision, (iii) revisit the overall plan and take the time to get a new plan.
- The most likely decision will be to continue. As a first step when starting the new phase, the **consequences of having passed the milestone** have to be implemented in the requirements management system – for the items changed by the decision to move ahead, the corresponding changes have to be made in the requirements management system.

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Appendix A. Glossary

architecture	the (functional) architecture describes the system organization in terms of elements that perform functions and the interfaces between these elements and their decomposition into sub-elements performing sub-functions. As far as needed and possible, quality characteristics are allocated to these elements / sub-elements. The elements act as black boxes (no design defined yet).
(quality) characteristic	is related to a requirement ((quality) characteristic requirement); it includes characteristics such as reliability, availability, repairability, etc.
constraint	a requirement that limits the solution space beyond what is necessary for meeting the given functional requirements and (quality) characteristic requirements; constraints are often externally imposed.
element	element of the waste management system applies to all issues used to implement the system of interest. The elements provide the ‘means’ to implement the system of interest.
end-of-life	last stage of the life cycle after the stage of using a product has come to an end.
external entity	is outside of the system of interest but interacts with the system of interest.
function	a task, action, activity or behaviour that must be performed to achieve a desired outcome.
goal	instead of goal (for a high-level requirement) also the terms ‘objective’ or ‘principle’ are sometimes used.
level 0	needs, expectation and goals (high-level requirements) expressed by the external stakeholders to be fulfilled by the system of interest.
level 1	goals for the different phases / different stages of the life cycle derived by the internal stakeholders to fulfil the ‘level 0’ requirements.
level 2a	functional requirements derived from decomposing the ‘level 1’ requirements.
level 2b	(quality) characteristic requirements derived from decomposing the ‘level 1’ requirements.
level 3a	performance target related to specific functional requirement.
level 3b	(quality) target related to specific (quality) characteristic requirement.
level 4a	design input requirements.
level 4b	design output specifications.
level 5	production specifications.
level 6	documentation of implemented product.
living document	document to be updated when needed.
loads and conditions	acting on a system element; is considered in the development of both the design input requirements and design output specifications.
means	objects, activities with their deliverables / products / decisions, and other measures with their achievements / situations (e.g. stability) that form the elements of the functional architecture.

needs domain	defines the ‘why’, ‘what’, ‘when’. It contains all the ‘level 0 to level 3’ – requirements.
outside world	elements outside of the system of interest but potentially relevant for the system of interest.
problem	needs, expectations and goals of the 'external’ stakeholders.
product	can be an object (building, equipment, etc.), a document, a contract, a decision, etc.
requirements creep	danger of adding too many not that relevant (not needed) requirements.
service provider	supports the ‘internal stakeholder’ with implementing the system of interest. The (external) service provider is available on the market.
solution domain	contains all the system elements that make up the (total) system; the system elements make up the 'means' (with the objects, activities with their deliverables and other measures with their achievements) to achieve the ‘level 0’-goals of the ‘needs domain’ The ‘solutions domain’ defines the ‘who, ‘with whom’ (dependencies), ‘when, and ‘how’.
stakeholder	external stakeholder: is not involved in the development of the system of interest but has a strong interest in its implementation and has the corresponding needs, expectations and goals (sometimes summarized as the ‘problem’ statement). internal stakeholder: has the task to implement the system of interest.
stage	(or status) defines where in the life cycle an element of the waste management system is; the stage / status can be: ‘initial thoughts / planning’, ‘production / construction / building’,’ using the system / system element / product’, ‘decommission / dismantle / close’.
supply chain	supports the ‘internal stakeholder’ with implementing the system of interest by providing components for the system. The supply chain is available on the market.
system	items fulfilling the defined requirements, consists normally out of several elements.
the way of thinking	described by the methodology to be applied.
V-model	verification of ‘having done the things right’ and validation of ‘having done the right things’ are in the literature sometimes represented as the ‘V-model’, where each verification-step and each validation-step is linked to the corresponding requirement as defined at the outset of the implementation process.
validation	validation includes the evaluation whether ‘the right things have been done’; thus, it is evaluated whether the needs, expectations and goals of the (external) stakeholders are met; validation applies to the whole system of interest or to its sub-systems.
verification	verification includes the evaluation whether ‘the things have been done right’; thus, it is evaluated whether all requirements are fulfilled; verification applies to sub-systems, components, etc. (only part of the system of interest); however, all sub-systems, components must undergo verification.

voluntarism — describes an approach of site selection where municipalities must volunteer to be considered as a municipality that potentially will host a facility. The approach by providing a 'veto-right' to municipalities falls in the same category.

waste management programme:

contains all elements (processes, facilities) that are needed to manage the waste 'from cradle to grave'. It consists of several waste management systems related to collection of raw waste, waste characterisation, waste treatment / solidification / packaging, handling / transportation of waste, interim storage of waste, waste disposal.

why, what, when, who and how:

the cornerstones of the requirements management process – the 'why' captures the 'needs', 'expectations' and goals of the 'external stakeholders', the 'what' defines the functional requirements and the (quality) characteristic requirements and their targets, the 'when' defines the phase when then 'what' needs to be achieved, the 'who' defines the element (as part of the functional architecture) that has to fulfil the allocated requirements and the 'how' is defined by the 'design input requirements' and the 'design output specification' (together: the 'product specification') and the 'production specification'.

Appendix C Literature review on requirements management

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Executive Summary

Within Work Package 12 (Guidance) of EURAD, activities aim to develop a comprehensive suite of instructional guidance documents that can be used by EU Member States with radioactive waste management programmes, regardless of their phase or level of advancement with implementation of geological disposal.

This report summarizes the available key documents up to February 2024 on requirement management with focus on for radioactive waste disposal.

Several information sources have been analysed such as international organisations' publications and open websites.

Over the years, a wealth of information and experience has been accumulated on the principles and practices related to the successful application of requirement management. While all of this information is useful to the end-users in Member States, it is recognized that there is room for improvement in the way the information is organized and presented so that it becomes easier to use for specific needs in this area. The proposed guidance documents are willing to be a response to these requests and addresses the absence of technical guidance in this area.

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Key Acronyms

DGR	Deep Geological Disposal
DOORS	Dynamic Object-Oriented Requirements System, a requirements tool marketed by Telelogic Corporation
DSS	Disposal System Specification
EBS	Engineered Barrier System
G-RMS	Guidance document ‘Guidance on Developing, Using and Modifying a Generic Requirements Management System
GDF	Geological Disposal Facility
IAEA	International Atomic Energy Agency
IGSC	Integration Group for the Safety Case
INCOSE	International Council for System Engineering
IPAG	NEA Expert Group on Integrated Performance Assessment
JAEA	Japan Atomic Energy Agency
KM	Knowledge Management
KMS	Knowledge Management System
MESA	Methods for Safety Assessment for Geological Disposal Facilities for Radioactive Waste (NEA project)
MS	Member State
NDA	Nuclear Decommissioning Authority
NEA	Nuclear Energy Agency
NUMO	Nuclear Waste Management Organization of Japan
OECD	Organisation for Economic Co-operation and Development
R&D	Research and Development
REPMET	Radioactive Waste Repository Metadata Management Project (NEA)
RM	Requirements Management
RMS	Requirements Management System
RWM	Radioactive Waste Management
QA	Quality Assurance
QM	Quality Management
SE	Safety Envelope
TSO	Technical Support Organizations
WMO	Waste Management Organisation
VAHA	Vaatimusten Hallinta – Posiva Oy’s requirements management system
V&V	Validation and Verification
WP	Work package

1 Introduction

EURAD as a European Joint Programme in the field of RWM is managing three Knowledge Management (KM) work packages (WP11, WP12 and WP13) contributing to the expected KM goals. Within Work Package 12 (Guidance) of EURAD, activities aim to develop a comprehensive suite of instructional guidance documents that can be used by EU Member States with radioactive waste management programmes, regardless of their phase or level of advancement with implementation of geological disposal.

Cost Assessment and Financing Schemes of Radioactive Waste Management Programmes was the selected topic for the first guide (called pilot guide).

Aiming at selection of further guidance topics, a systematic and comprehensive literature survey was performed which could help in signposting and orienting users to what knowledge is needed and available when planning their geological disposal programme.

Based on the result of the literature screening and on the advice of the Roadmap Advisory Committee a preliminary list of topics for guidance was proposed, From the list, five topics – all related to requirements of the programme implementation – were selected and merged in a systematic way. The selected topic (requirements management) was to be developed as further guides within the first phase of EURAD.

Requirements management has been addressed in international fora as well as in national documents. The current review attempts to summarize – without claiming to be complete – the available documents and activities related to this subject.

Some key findings from these open literature sources of information are also given in this summary.

Please take note of the following:
The national examples may not be up-to-date. Some of the latest information were taken from recent presentations.
The document uses some schemes of INCOSE. These schemes are covered by copy right. As no use has yet been requested / given, please keep these schemes internal. If no solution can be found for the copy right, the schemes will be replaced by other schemes.

2 Requirements management methodology in general

Systems engineering

Systems engineering is defined as follows:
'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].

Systems engineering includes problem discovery and formulation, solution definition and realization, and operational use, sustainment, and disposal. It can be applied to single-problem situations or to the management of multiple interventions in commercial or public enterprises.

Systems engineering is the discipline that makes their success possible – their tools, techniques, methods, knowledge, standards, principles, and concepts. The launch of successful systems can invariably be traced to innovative and effective systems engineering.

Systems engineering is concerned with the development of systems as a whole including planning&design, hardware and operational processes. The logic of System Engineering is shown in Figure 1.

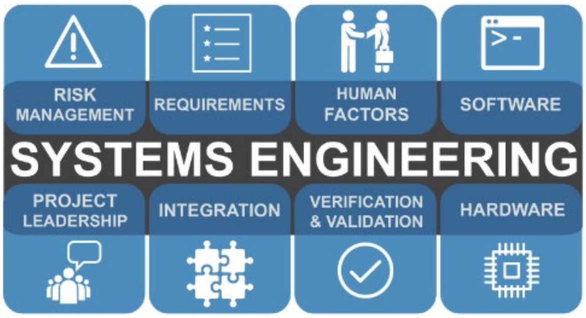

Figure 1 – The logic of System Engineering

The RMS needs to be designed for and to operate in a project context (Figure 2). The "customers" for the RMS therefore include project managers.

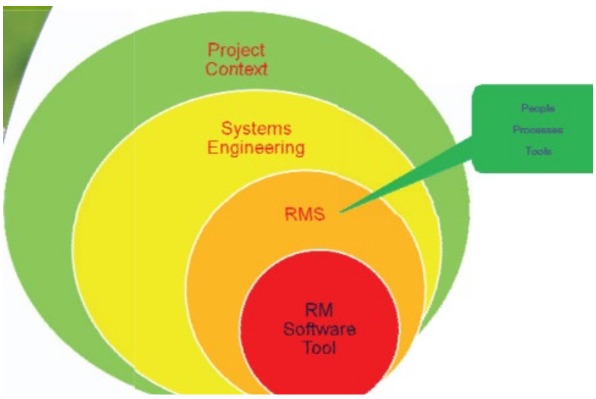

Figure 2 – Embedding of RMS in the project contents [2]

INCOSE

The International Council on Systems Engineering (INCOSE) is a not-for-profit membership organization founded to disseminate the practice of **systems engineering** and to develop and disseminate the interdisciplinary principles and practices that enable the realization of successful systems. Develops standards with relevant organisations. Its aim to connect System Engineering professionals.

The INCOSE Systems Engineering Handbook is a vital reference for systems engineering practitioners and engineers in other disciplines looking to perform or understand the discipline of systems engineering. The INCOSE Systems Engineering Handbook describes the state-of-the-good-practice of systems engineering [3].

The Guide to the Systems Engineering Body of Knowledge (SEBoK) provides a guide to the key knowledge sources and references of systems engineering organized and explained to assist a wide variety of individuals. The SEBoK is not a compendium but instead references existing literature [4].

INCOSE UK's 'Systems Engineering Education' series of books, 'Adventures in Systems Engineering' is an interactive fantasy-themed training course, designed to present Systems Engineering in an accessible, memorable, and even fun way for everyone. Participants work in teams to define, design and deliver an imaginary rescue system over a simulated full life cycle, all the while journeying across an enchanted valley. Throughout the course, teams encounter engaging characters and scenarios that prompt them to perform Systems Engineering activities [5] [6] [7].

Requirements management is an integral part of systems engineering with systems engineering being defined as follows (quote from INCOSE, 2015) [1]:
'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.'

Good practice in system engineering and requirements management requires to work systematically and structured with discipline according to the rules defined by the specific requirements methodology applied.

Several countries base the requirements management system on INCOSE standards.

From Systems engineering the Requirements engineering – the overall process to define the requirements – is derived. Requirements engineering is the process of defining, documenting, and maintaining requirements in the engineering design process. It is a common role in systems engineering and software engineering.

The requirements engineering process is the structured set of activities concerned with eliciting, analysing and documenting the system requirements. The output of this process are the system requirements documents [8] [9] [10].

Requirement
A requirement by the dictionary definition something demanded or imposed as an obligation; a thing desired or needed; expression describing desired function, capability, characteristic, property or quality.

L. Moren defined requirement as follows: requirements are a clear statement of objectives; requirements state the initial problem and the need that is to be satisfied; requirements define the characteristics of the set of acceptable solutions; requirements also provide guidance in the selection of the most appropriate solution [11].

Requirements describe what users want from a product or service. Requirements are the common thread that ties all the product development lifecycle phases together [12].

There are many types of requirements and forms of specification. Requirements may relate to cost, performance, reliability, acceptable failure modes, design life, service conditions, duty cycle, maintainability, equipment qualification, environmental limits or conditions, temperature, material properties, fabrication, inspection, shipping, storage, records keeping, human factors, security of supply, redundancy, and design simplicity.

Requirements can also be expressed in the form of assumptions, limits or constraints, uncertainties, targets, accuracy, or tolerances. Requirements can be attributes of the design, the design process, the design documentation, or the design verification process.

Requirements used for communication, definition of problem and scope, understanding the context, design, making the right things, optimization, change control, risk management, Quality assurance, testability, traceability [13].

Dependencies between requirements need to be taken into account. Capturing all the requirements depends on having a complete understanding of the system and achieving such an understanding is made difficult by the complexity of the interactions between individuals, technical systems and organizations in the totality of the entire system. Therefore, the way the systems works in practice may not be fully predictable. To guard against this problem, design requirements that limit the complexity in safety systems are identified to ensure the protection of the reactor under fault conditions. This is an area where ongoing research contributes to a better definition of requirements through structured or formalized methods to better express an understanding of the complex system and, thus, fulfill the necessary requirements [14].

A good requirement set should

- state the initial problem and the need that is to be satisfied;
- provide a clear statement of objectives;
- define the characteristics of the set of acceptable solutions;
- provide guidance in the selection of the most appropriate solution [3][4].

In order to be considered a “good”, a **requirement** should have certain characteristics, which include being [15].

- necessary: if the system can meet prioritized real needs without the requirement, it isn’t necessary;
- feasible: the requirement is doable and can be accomplished within budget and schedule;
- correct: the facts related to the requirement are accurate, and it is technically and legally possible;
- concise: the requirement is stated simply;
- unambiguous: the requirement can be interpreted in only one way;
- complete: all conditions under which the requirement applies are stated, and it expresses a whole idea or statement;
- consistent: it is not in conflict with other requirements;
- verifiable: implementation of the requirement in the system can be proved;
- traceable: the source of the requirement can be traced, and it can be tracked throughout the system (e.g., to the design, code, test, and documentation);
- allocated: the requirement is assigned to a component of the designed system;
- design independent: it does not pose a specific implementation solution;

- nonredundant: it is not a duplicate requirement;
- written using the standard construct: the requirement is stated as an imperative using “shall”;
- assigned a unique identifier: each requirement shall have a unique identifying number.

Requirements Management
“Requirements management” can be defined as a systematic approach to identifying, organising, communicating and responding to changing requirements during design, development, licensing and implementation. A critical task for all projects is to establish a solid set of baseline requirements and rigorously manage the changes in these as a project matures. Another key element of requirements management is the ability to define requirements at the correct level of detail for a specific application, taking into consideration both technical needs and external boundary conditions. The overall process of specifying and managing requirements is sometimes termed “requirements engineering” [15].

Requirements Management (RM) – being an integral part of systems engineering – is a systematic approach to identifying, organising, communicating and responding to changing external and internal requirements.

RM is a discipline that has been well established in various industries for over 25 years and is closely linked to systems engineering approaches.

Issues in requirements management are often cited as major causes of project failures. Having inadequately defined requirements can result in scope creep, project delays, cost overruns, and poor product quality that does not meet customer needs and safety requirements.

Requirements Management System
Requirements Management System (RMS) the combination of the people, the processes and the software tools used for the management of requirements. Having a RMS in place is critical to the success of any project because it enables engineering teams to control the scope and direct the product development lifecycle.

Requirements management system provides the structure (elements, relations, information flow, …) to store the information derived through requirements management (needs, architecture, solution) and manage this information (with the help of attributes, links, …), e.g. refinements ('evolution', change management, etc.

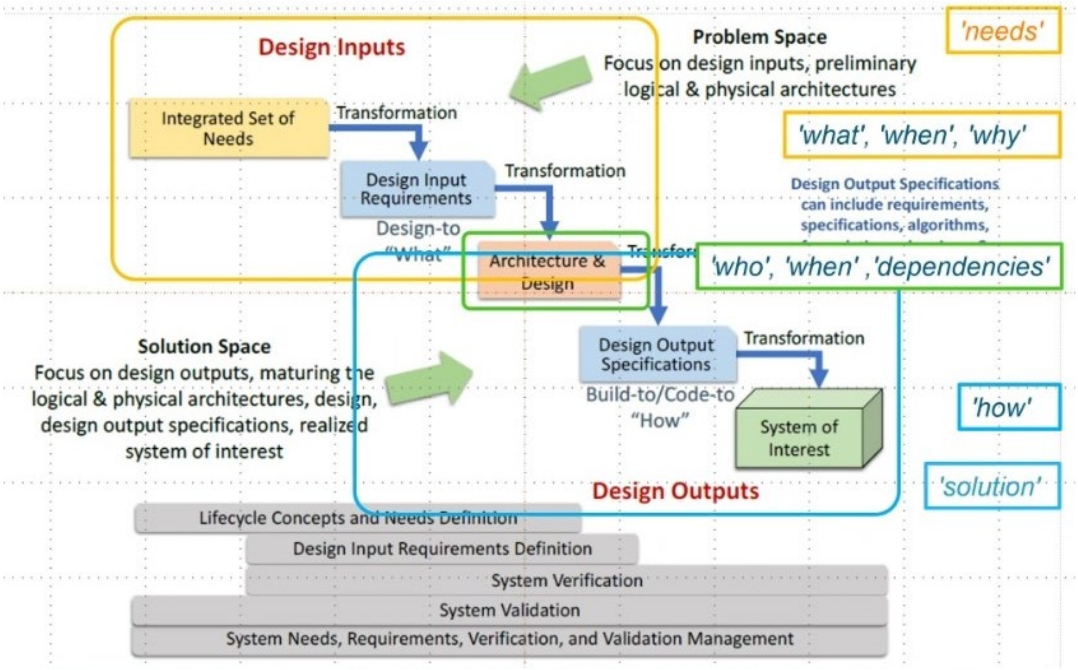

Figure 3 – Requirements Management System: design and implementation process [16]

Further useful information can be obtained about System Engineering and Requirements Engineering Management in [17]–[21].

The purpose of requirements management is to assure that an organisation clearly documents, verifies and meets the needs and expectations of its internal and external stakeholders. RM provides a way to avoid errors by keeping track of changes in requirements and fostering communication with stakeholders from the start of a project throughout the engineering lifecycle.

A requirements management plan helps explain how to receive, analyze, document and manage all of the requirements within a project. The plan usually covers everything from initial information gathering of the high-level project to more detailed product requirements that could be gathered throughout the lifecycle of a project. Key items to define in a RM plan are the project overview, requirements gathering process, roles and responsibilities, tools, and traceability.

Requirements management provides measures to meet the various requirements from the stakeholders involved. Furthermore, it aids confidence building. The purpose of RM is to assure that an organisation clearly documents, verifies and meets the needs and expectations of its internal and external stakeholders. RM should be a continuous process with a clear long-term scope.

Requirement management is a complex topic consisting of the right combination of people & mindsets, processes and tools, all interconnected with each other in a specific way.

A typical requirements management process complements the systems engineering V model through these steps [3]:

- collect initial requirements from stakeholders;
- analyze requirements;
- define and record requirements;
- prioritize requirements;
- agree on and approve requirements;
- trace requirements to work items;
- query stakeholders after implementation on needed changes to requirements;

- utilize test management to verify and validate system requirements;
- assess impact of changes;
- revise requirements;
- document changes.

By following these steps, engineering teams are able to harness the complexity inherent in developing smart connected products. Using a requirements management solution helps to streamline the process so you can optimize your speed to market and expand your opportunities while improving quality.

Some key findings

- Requirements should be established as early as possible in the life cycle of a programme or project, with a clear flow down into more detailed requirements as work progresses.
- A good requirement set should state the initial problem and the need that is to be satisfied; provide a clear statement of objectives; define the characteristics of the set of acceptable solutions and provide guidance in the selection of the most appropriate solution.
- Requirements can be generated by any stakeholder, including customers, partners, sales, support, management, engineering, operations and product team members. Constant communication is necessary to ensure the engineering team understands changing priorities.
- Terminology: the need for a single set of definitions to ensure good communication and reduce misunderstanding. This is especially true when people from different engineering disciplines meet and when more than one language is involved.
- Requirement management is a complex topic consisting of the right combination of people & mindsets, processes, tools all interconnected with each other in a specific way. The goal is to make the process look easy, where it isn't.
- Issues in requirements management are often cited as major causes of project failures.
- Having inadequately defined requirements can result in scope creep, project delays, cost overruns, and poor product quality that does not meet customer needs and safety requirements.
- Having a requirements management plan is critical to the success of a project because it enables engineering teams to control the scope and direct the product development lifecycle. Requirements management software provides the tools to execute the plan, helping to reduce costs, accelerate time to market and improve quality control.
- Requirements management may offer benefits such as:
  - lower cost of development across the lifecycle;
  - fewer defects;
  - minimized risk for safety-critical products;
  - faster delivery;
  - reusability;
  - traceability;
  - requirements being tied to test cases;
  - global configuration management.

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3 Requirements management for radioactive waste disposal

The implementation of a disposal programme requires the hierarchical consideration of a wide variety of requirements. These include technical requirements for ensuring the safety of a repository and requirements for quality management, as well as requirements from laws, regulations and policies defined by the national government, regulatory bodies, or requested by various stakeholders. In order to manage this, a Requirements Management System (RMS) needs to be developed, aimed at systematically identifying the wide variety of requirements and managing them in an effective and transparent manner.

Such requirements and associated decisions need to be consistent in each phase of the programme, and also throughout the diverse range of technical work carried out by managers and technical teams. The RMS ensures completeness of the requirements and provides a mechanism for change management, with transparency and traceability, as requirements evolve with time associated with the stepwise progress of the programme, impacting decisions made based on these requirements (e.g. design specifications). This is complemented by structured management of associated knowledge), allowing appropriate responses for any case where significant changes in boundary conditions occur, with reference to the basis of the recorded background to past decisions or judgments.

The requirements management is one of the key components to ensure the safety in the disposal program. The requirements management provides effective measures to meet the various requirements from stakeholders in perspective. It helps to build their confidence in the program.

The evolution of the programme from inception/generic studies over siting, licensing, construction, operation, to closure and transition to post-closure, during which requirements may be specifically needed.

The purposes of the RMS with regard to a disposal implementation project:

- Facilitate decision making; RMS will allow the justifications, supporting arguments and knowledge base used for every decision to be clearly recorded and will highlight when such decisions may need to be revisited, for example due to changing boundary conditions or technical advances. Integration of information and knowledge coming from the different fields of the programme can be performed through the RMS.
- Facilitate system understanding and put details in the design;
- Provide correct and complete design premises for the planned repository;
- Ensure that the repository facility conforms to the design premises;
- Make the basis for the design of the repository facility traceable;
- Facilitate development and management;

An RMS would help at various licensing stages to show how the regulatory requirements are fulfilled. This provides a rigorous, traceable method of translating safety principles and the safety concept to a set of safety functions, performance requirements, design requirements and design specifications for the various barriers, i.e. a specification for enactment of the disposal concept.

There are essentially three major international organisations that provide comprehensive documents on radioactive waste and spent fuel management, IAEA, OECD/NEA and the European Union (through the Euratom treaty). There is a range of other international bodies. Especially the ICRP has a very prominent standing.

A large and detailed international knowledgebase exists, but the application, interpretation and expansion of this international knowledge to national boundary conditions (policy, inventory, geological setting and paired disposal concept) remains the role of the national implementer.

3.1 IAEA

The IAEA publishes the safety standards series comprises three levels of documents: Safety Fundamentals, Safety Requirements and Safety Guides.

3.1.1 Safety requirements

IAEA Safety Requirements publications establish international consensus requirements that apply the fundamental safety objective and fundamental safety principles established in the Safety Fundamentals [1].

Based on IAEA safety principles the management system for a repository,
"para 3.12…. Safety has to be achieved and maintained by means of an effective management system. This system has to integrate all elements of management so that requirements for safety are established and applied coherently with other requirements, including those for human performance, quality and security, and so that safety is not compromised by other requirements or demands…"[1].

The Specific Safety Requirements publication establishes requirements for all the important areas of safety in all stages of the lifetime of a nuclear fuel cycle facility, including design and operation and all activities performed to achieve the purpose for which the facility was constructed.

In this publication, nuclear fuel cycle facilities are nuclear installations, other than nuclear power plants, research reactors and critical assemblies, in which nuclear material and radioactive material are processed, handled, stored and prepared for disposal, in quantities or concentrations that pose potential hazards to personnel, the public and the environment [2].

The GSR Part 1 publication establishes requirements for [3]:

- governmental responsibilities and functions for safety,
- liaison within the global safety regime, and
- the regulatory body.

The GSR Part 2 publication sets out requirements for management systems that can be used as the basis for the management system of the regulatory body [4].

Safety assessments are to be undertaken as a means of evaluating compliance with safety requirements (and thereby the application of the fundamental safety principles) for all facilities and activities and to determine the measures that need to be taken to ensure safety. The safety assessments are to be carried out and documented by the organization responsible for operating the facility or conducting the activity, are to be independently verified and are to be submitted to the regulatory body as part of the licensing or authorization process.

Safety requirements publication on safety assessment for facilities and activities is to establish the generally applicable requirements to be fulfilled in safety assessment for facilities and activities, with special attention paid to defence in depth, quantitative analyses and the application of a graded approach to the ranges of facilities and of activities that are addressed. This publication also addresses the independent verification of the safety assessment that needs to be carried out by the originators and users of the safety assessment [5].

The SSR-5 has defined a series of 26 specific safety requirements for operators/ implementers, to provide assurance of the radiation safety of the disposal of radioactive waste, in the operation of a disposal facility and especially after its closure. The requirements related to the management system of this publication can also be applied for the regulatory body's activities [6].

These safety requirements are often incorporated into the guidance provided to the implementers by the Regulators within the particular country where repository development is located.

3.1.2 Safety guides

IAEA Safety Guides provide also recommendations on satisfying the requirements concerning particular responsibilities and functions of the regulatory body in the regulation of nuclear facilities [7].

The objective of this Safety Guide is to provide recommendations on meeting the requirements of GSR Part 1 (Rev. 1) on the regulatory body's core functions and the associated processes to implement those functions. These supporting functions and the associated processes are described in GSG-12 [8].

The General Safety Guide on Leadership, Management and Culture for Safety in Radioactive Waste Management provide recommendations on developing and implementing management systems for safety during all steps of radioactive waste management including disposal [9].

3.1.3 Technical reports

The IAEA-TECDOC-1933 aiming to provide guidance for an efficient RM programme created a set of principles that describes the important considerations and attributes necessary for a high-quality RM for nuclear facilities. These are as follows [10]:

Principle 1: The capturing of requirements is a task that needs knowledge and experience in the technology, engineering, and scientific discipline being analysed and familiarity with the source documents being considered.
Principle 2: The quantity and completeness of the specifications of the requirements increases and improves as a nuclear facility moves through different facility life cycle phases and as such it has to be maintained as a "living entity" throughout.
Principle 3: Ownership of a requirement is clearly defined, assigned and managed for each facility life cycle phase and is transferrable between life cycle phases.
Principle 4: Requirements are decomposed to the lowest possible level to ensure that only one requirement is covered per unique identification created.
Principle 5: Once a requirement is established, it undergoes revision control over the entire life cycle to ensure traceability.
Principle 6: The owner of the requirement needs to manage the interfaces necessary to ensure that stakeholder perspectives are addressed to ensure the correct development, commitment and implementation of the requirement.
Principle 7: The RM process needs to be a part of the integrated management system of the owner-operator and are appropriately interfaced with other management processes (e.g. configuration management, modification process, etc.).
Principle 8: In setting up the RM programme, the properties required for control and management need to be defined and their usage explained.

The requirements related to a nuclear facility go beyond the design elements of the facility. For example, there are technical requirements that have environmental, legal and financial aspects amongst others. All of the above-mentioned principles are applicable for radioactive waste disposal programs.

IAEA-TECDOC-1755 covers the planning and design considerations for geological repository programmes of radioactive waste [11].

The long periods involved in any repository development programme mean that a provision and commitment need to be made to long term data gathering, the wide transmission of knowledge and sustained expertise. This also requires the development of a quality management system and knowledge management that cover all aspects of repository development.

This publication is aimed at providing the collective experience of some Member States (MSs) with more advanced repository programmes on the manner a geological repository programme may be defined and planned, for the benefit of MSs contemplating or initiating their own programmes as well as MSs interested in improving their own programmes at different development stages.

Nuclear Energy Series No. NW-T-1.27 addresses design principles and approaches for radioactive waste repositories. The publication provides an overview of design principles and approaches that have either already been fully implemented, or are in the implementation phase, in several MSs [12].

The approach presented is based on fundamental safety principles and uses a systems engineering, requirements driven design approach that can be considered a primer for the design of radioactive waste disposal facilities.

Section 3 presents the guiding principles and framework for an iterative, requirements driven, systems engineering design process, which moves from a conceptual stage, through optioneering to a final design and eventual siting, licensing, construction and, ultimately, closure.

Technical specifications comprising the design basis for a repository are commonly articulated as a set of requirements, assumptions and constraints that are developed and managed throughout the design process. The process of 'requirements management' is used to:
- Clearly define the requirements and assumptions pertaining to the disposal system and its individual components (e.g. EBs);
- 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.

It is recommended practice in developing and implementing a DGR to adopt a system engineering approach based on a hierarchical requirements management system. Such systems link high level goals and objectives to functions of the system and its parts, measures of expected performance and consequent specifications for component design and properties

A requirements hierarchy typical of an advanced geological disposal programme could include numerous levels.
High-level requirements: These can also be termed 'stakeholder' requirements. High level requirements can be mandatory (e.g. imposed by legislation, regulations and local and national authorities responsible for licensing the repository) or by agreement, (e.g. with local and regional communities and with agencies responsible for funding the repository). They also include requirements from waste producers responsible for packaging. These entities will vary according to country regulatory regimes and the extant stage of repository implementation.

Repository System requirements: Qualitative and quantitative requirements that define how the total system satisfies the High-level External Requirements. These are functional (i.e. the function of a system) and non-functional (e.g. safety functional) requirements that define the total repository system and its management. These can include site specific constraints and characteristics, waste inventory, waste package types and numbers, the mode of transport for waste and construction materials to the repository, etc. Controlled assumptions (verifiable or not) are also often included.

Sub-system requirements: At this level the safety concept is specified as requirements for each of the major components, engineered (and geological) barriers and activities of the repository, where appropriate, expressed as ‘safety functions’.

Component specification requirements: Detailed requirements for each component, barrier and associated safety function, which cover the design, construction and manufacturing.

Nuclear Energy Series No. NW-T-1.43
This document provides a roadmap for developing and implementing a geological disposal programme based on current international experience. It lists the activities that are commonly planned and executed for each of these phases in a clear and systematic manner [13].

Section 3.1.2 entitled in programme requirements management concludes as follows:
Requirements management can be defined as three distinct activities:

- Requirement identification: The requirements are decomposed, classified, grouped, ranked, and prioritized during this stage. It is important that stakeholders ensure the requirements are correctly defined, captured and interpreted. This activity is concluded with the agreement and approval of all stakeholders that a valid and applicable requirement has been identified.

- Requirement commitment: The commitments needed to meet requirements are identified, documented, and approved by stakeholders.

- Requirement implementation: These activities are focused on implementing requirements and associated commitment(s).

The WMO may elect to manage project requirements in a series of separated systems (e.g., requirements from the regulator might be tracked in a database dedicated to regulatory commitments, whereas financial commitments would be managed by the finance department) or in an integrated manner using a centralized method.

3.1.4 GEOSAF project

In 2008, the IAEA launched the GEOSAF project harmonizing the demonstration of safety of geological disposal facilities during and after their operation. GEOSAF I, II, III focuses on the demonstration of the safety of geological disposal with the safety case as the main tool for this demonstration [14][15][16][17].

The third part of the project, in place from 2017, focuses on the practical applications of the safety approach developed in the previous parts of the project. Member States with mature safety programmes in this area contribute with their inputs to the third project phase.

GEOSAF concept is illustrated in Figure 4.

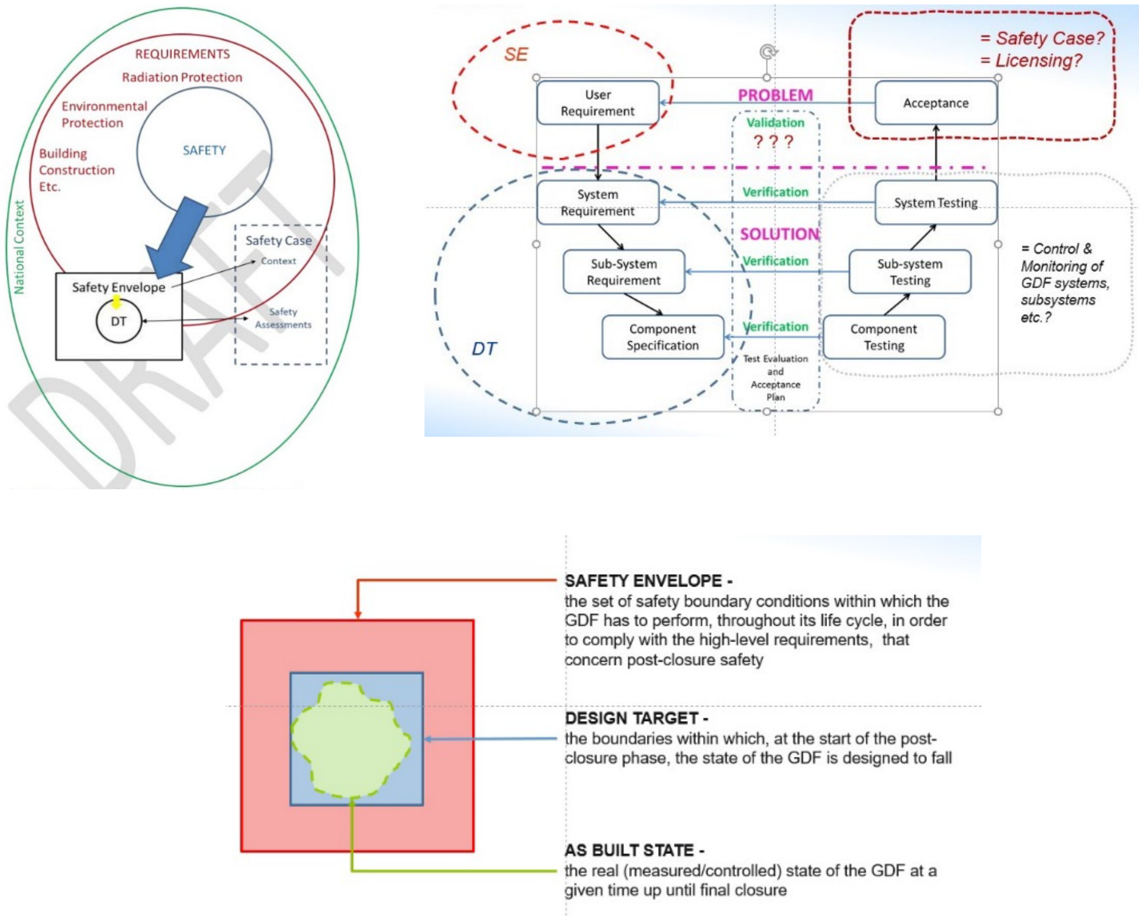

Figure 4 – GEOSAF concept [18] [19]

The Safety Envelope (SE) is the set of safety boundary conditions within which the geological disposal facility shall perform, in order to comply with the high-level requirements, that concern post-closure safety. The SE needs to be identified by the operating organization by taking into consideration applicable regulatory requirements in safety case context, and in consultation with the regulator(s) and other interested parties to ensure that there is full understanding of the requirements.

Requirements could come from international safety requirements, such as IAEA's SSR-5 (e.g., containment, isolation, defence in depth, passive protection, robustness, quantitative acceptance criteria like dose and risk) and specific national requirements (e.g., retrievability, minimum containment rock zone, etc.).

The SE can be affected in time by e.g. changes in the legal and regulatory framework (i.e. regulatory authority/stakeholders' requirements) that can be considered as factors external to the GDF itself and cannot be affected by any reasons arising from development of GDF project or internal factors.

The Safety Case is evaluated against the SE. If the Safety Case provides sufficient confidence that the SE will be met, the GDF is considered to have an acceptable level of post-closure safety.

In order to fall within the SE, a high-level conceptual design of the GDF is developed and constitutes the basis for an initial safety assessment at the beginning of such projects.

The high-level conceptual design is iterated until the safety assessment provides sufficient confidence that the SE can be met, at which point the high-level conceptual design of the GDF forms the basis for defining safety functions of the overall GDF and its individual barriers. The set of safety functions of the overall GDF, and of the individual barriers corresponds to the DT in the GEOSAF concept.

3.1.5 Some key findings

- Requirements management – identification, commitment, approval and implementation of requirements – should be a continuous process over the repository program implementation It is an essential part of the management of all repository developments, irrespective of the scale of the repository,

- Requirements management is the process by which the programme team defines what repository development is intended to achieve. Some of the requirements may be defined externally, for example by law, by the regulators, by national and international standards, and so on. Other requirements may be generated internally within the implementer on the basis of the understanding of what features the repository must possess in order to be suitable for disposal of the defined wastes within the particular geological environment at the selected site. The number of requirements identified may grow to tens of thousands in numbers over a facility's lifetime.

- The level of detail and resolution of the RMS depends on the stage of the programme. All cannot be resolved at the first instance.

- Requirement development should be an iterative process which includes assessment, integration, feedback, interfaces management, updates. Iteration is essential and it must be allowable – and easy (but also traceable) – to change decisions and requirements.

- It is recognised that all RWM programmes adopt slightly different systems engineering language and hierarchy. Each programme must develop its own approach and requirements, to suit national boundary conditions (national regulations, different waste types, different concept options, different host rock environment, etc.).

- A requirements driven approach enables the holistic integration of requirements, constraints and assumptions from a relatively early stage, thus ensuring that mandatory drivers for safety, physical protection, environmental protection and nuclear safeguards are integrated into the design basis.

- A functional description of the repository as a holistic system helps develop system requirements. This functional description is used to develop operational and safety requirements.

- Satisfaction or achievement of each requirement can be measured by a prespecified verification activity.

- Repository development necessitates the meeting of a wide range of diverse requirements through the implementation of a large number of different activities over a period that will certainly extend for many years, and most probably for decades. The nuclear industry operates in a complex stakeholder environment where multiple sets of requirements require a structured approach to delivery to ensure a robust, holistic product is produced that satisfies the varied needs of the stakeholder community. Therefore, a formal requirement management programme needs to be put in place at disposal facility. This will allow auditing and traceability of the requirements identified.

- The RMS should be suitable for the stepwise approach of the disposal facility, include all elements of the life cycle of facilities (planning, construction, use, maintenance & renewal, modification, dismantling, closure) and need to consider the overall waste management strategy (either as input or to be integrated into RMS).

- Developing a useful RMS is not a computer software issue but rather a matter of defining and structuring its content to ensure that its application is practical, efficient and consistent; transparency is essential. Interfaces between different users – e.g. R&D programme, design, site characterisation – need to be established, with a shared vision and shared responsibility.

- There are many other requirements than long-term safety requirements to be managed, for example operational safety requirements and "functional" requirements.

- The RMS ensure that the repository facility conforms to the design premises and make the basis for the design of the repository facility traceable. It also facilitates system understanding and put details in the design and design work in their context. Furthermore, RMS enables an easy review of compliance between separate specifications and requirements; and a systematic review and documentation of influence derived from alterations in requirements.

- RMS should allow the justifications, supporting arguments and knowledge base used for every decision to be clearly recorded and highlight when such decisions may need to be revisited, for example due to changing boundary conditions or technical advances. Integration of information and knowledge coming from the different fields of the programme can be performed through the requirements management.

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3.2 OECD NEA

3.2.1 Technical reports

The International Experiences in Safety Cases for Geological Repositories (INTESC) project analysed existing safety cases, and their elements, to provide an overview of progress during the last decade, to identify key concepts and to give insight into regulatory expectations on the contents and review of safety cases [1].

The chapter 3.3.2.2 covers the Requirement management systems.
Formulating, managing and integrating the various requirements on the design are key tasks that, experience suggests, are best started at an early stage. For this purpose, many organisations have implemented computer-based requirement management systems (RMS). based on the use of RMS thus far in national programmes, some observations are:

- An RMS typically sets out from top-level requirements (i.e. design principles) and traces down into sub-system and detailed-level requirements. Such a structure is suitable for documenting and tracking decisions, as well as for identifying the bases for requirements and detecting potential conflicts between fundamental requirements.
- However, a top-down RMS does not always capture effectively how knowledge is derived or how designs develop in reality. Safety functions are not always readily interpreted into design requirements that are feasible to implement. Also, detailed investigation of relevant processes may not develop until there are specific engineering solutions to consider. This means that design and associated requirements need to be developed iteratively – using both bottom-up and top-down approaches.
- Developing a useful RMS is not a computer software issue but rather a matter of defining and structuring its content to ensure that its application is practical, efficient and consistent; transparency is essential. Interfaces between different users – e.g. R&D programme, design, site characterisation – need to be established, with a shared vision and shared responsibility.
- The level of detail and resolution of the RMS depends on the stage of the programme. All cannot be resolved at the first instance. Iteration is essential and it must be allowable – and easy (but also traceable) – to change decisions and requirements.

It concludes that further development of some aspects and tools, such as Quality Assurance programmes and requirements management systems, can be expected as safety cases are further refined to support programmes moving toward implementation of geological disposal.

Sourcebook of International Activities Related to the Development of Safety Cases for Deep Geological Repositories

This document summarizes the activities undertaken by the NEA, the European Commission (EC) and the International Atomic Energy Agency (IAEA) relating to safety cases for the operational and post-closure phases of geological repositories for radioactive waste, ranging from low-level waste to high-level waste and spent fuel [2].

Managing Information and Requirements in Geological Disposal Programmes

The document covers the following topics [3]:

- Main principles underlying information and requirements management;
- Structuring of information and requirements;
- Software tools and formal procedures to support information and requirements management;
- Interaction between information and requirements management, safety assessment and design development;
- Key challenges of evolving requirements and information

The key conclusions are as follows:

Since geological disposal is a first-of-a-kind project, there is a lack of information on requirements setting and management process. Important challenges include the following:

- The amount of information and data that must be managed by disposal programmes increases over time as the programmes proceed.
- The information and data that must be managed is highly diverse. Some raw data are difficult to collect in databases. Also, they might require a large amount of specifications and metadata to understand them.
- The information and data is used and managed by a variety of different actors over several generations.
- The data changes must be properly managed, including by recording and maintaining the history of such changes.

Information management and requirements management are closely related. Requirement management systems in particular have been identified as essential tools in the development of geological disposal systems and their safety cases. Such systems may be used to:

- Ensure all relevant requirements are addressed;
- Structure safety cases in such a way as to show how requirements are met and to highlight any remaining open issues;
- Prioritise future work to address such issues;
- Facilitate the optimisation of disposal systems, taking all relevant requirements into account; and
- Guide the development of monitoring programmes e.g. to identify any non-conformities or deviation of a measurable parameter with respect to pre-established requirements.

Requirements management is likely to become a prominent feature in future safety cases. Recently, many advanced programmes, such as those in the Nordic countries, have been carrying out important work on the topic.

It is recommended that, perhaps in a few years' time, the IGSC should consider making a synthesis of these developments, bringing together material from future safety cases and from international fora. In this respect, requirements management relevant to the construction and operation phase may deserve particular focus.

Data management systems and records management

Maintaining evidence of how and why decisions have been made, that is traceable and searchable. See guidance on archiving and metadata requirements to allow improved searchability developed by REPMET [4].

E*ngineered Barrier Systems (EBS): Design Requirements and Constraints*
The IGSC is co-sponsored a project to develop a greater understanding of how to achieve the necessary integration for the successful design, construction, testing, modelling and performance assessment of engineered barrier systems 5].

The following principal conclusions were drawn:

- Designing, constructing and operating a radioactive waste disposal system is a complex project that has to take account of the many requirements that the disposal system has to fulfil. Requirements management systems and tools can assist in the successful completion of such complex projects. Key advantages of requirements management systems are that they formalise the repository design process; ensure that the design takes adequate account of the various requirements and constraints placed on the disposal system; and help to achieve the goals of clear communication and traceable, justified decision making.

- Requirements management systems and tools are complementary to safety and performance assessment techniques and tools. Requirements management and performance assessment share some common inputs (e.g. site characterisation information, regulations), methods (iteration, change control), goals (transparency), and needs (quality assurance, traceability, successful integration of project teams, stakeholder dialogue), but each provides important and distinct outputs (e.g. detailed specifications that would allow the construction of an engineered barrier, estimates of potential dose). Thus, while the perspectives of requirements management systems and performance assessment are slightly different, both form logical parts of the overall safety case for the disposal facility.

- Active stakeholder dialogue is a key element contributing to the success of processes for selecting waste management options and developing design solutions. Ensuring clear communication between project teams is also of high importance.

3.2.2 Expert groups activities

All national radioactive waste management programmes today recognise that a robust safety case is essential in developing disposal facilities for radioactive waste. The modern concept of “safety case” was first introduced by the NEA Expert Group on Integrated Performance Assessment (IPAG) and has since been adopted internationally. the NEA Integration Group for the Safety Case (IGSC) conducted a thorough review of the recent/ongoing safety case activities performed at the international level.

The IGSC is the main technical advisory body to the Radioactive Waste Management Committee (RWMC) on deep geological disposal, especially for long-lived and high-level radioactive waste.

Integration Group for the Safety Case (IGSC) has taken a leading role in identifying, documenting and evaluating emerging issues and trends, and in establishing consensus on good practices in the development of the safety case.

IGSC Expert Group on Operational Safety (EGOS) focus on operational safety or design requirements.

IGSC ad-hoc group on Transfer and Return of Gained Experiences on Safety Cases for Disposal Facilities (TARGES).

IGSC organised a project examining and documenting Methods for Safety Assessment for Geological Disposal Facilities for Radioactive Waste (MeSA) [6]. This activity of the IGSC aims to expand the description of the interaction between the safety case and the development of the design basis for a radioactive waste repository. In particular, the group considers lessons learned and methodologies related to requirements management that have been gained and developed in advanced programmes approaching construction and operation of a DGR.

The outcome should be a report in which the derivation of technical requirements and their interplay with assessment activities is described in a systematic way. Issues to be considered are technical feasibility, long-term safety and operational safety as well as compliance with the regulatory framework.

Based on a review of approaches to safety assessment followed by various national and international organisations, a generic safety case and safety assessment flowchart was developed within MeSA. See. Figure 5.

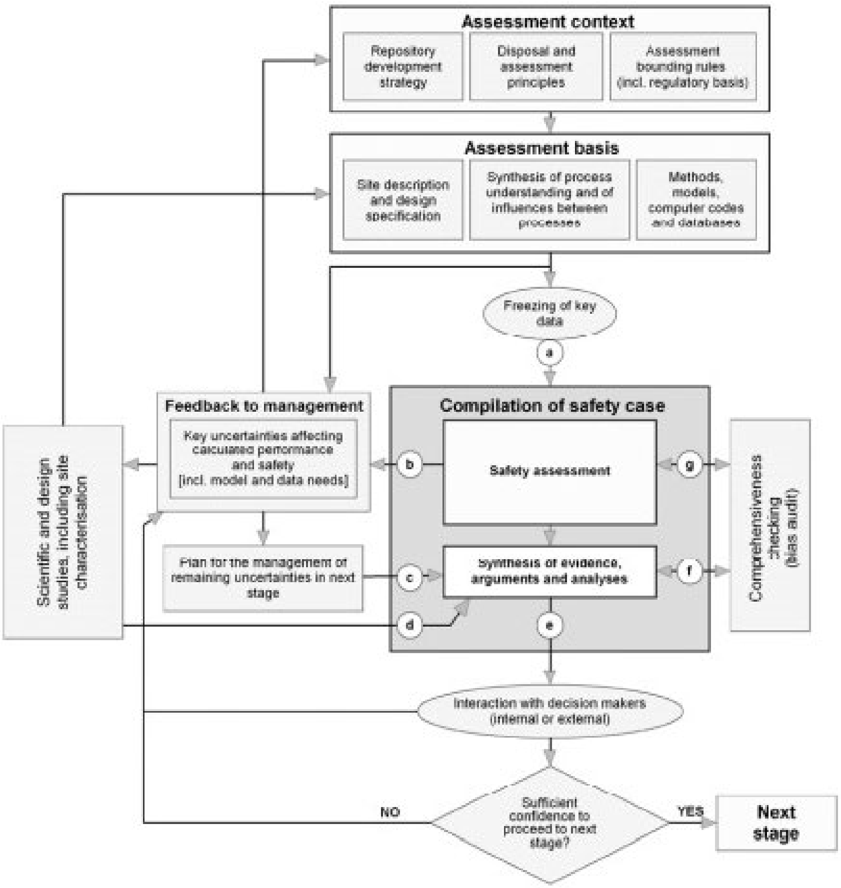

Figure 5 – MeSA flowchart [6]

IGSC's "MeSA 2" project addresses the derivation of technical requirements and their interplay with assessment activities in a systematic way. MeSA 2. is limited to safety assessment, but there are many interfaces: SA provides input to the development and assessment of requirements.

MeSA extension was proposed by TARGES which aims at extending the description of the interaction between the safety case and the development of the design basis in the MeSA framework addresses the derivation of technical requirements and their interplay with assessment activities in a systematic way.

3.2.2 Some key findings

- RM is a central part of ensuring safety as part of the disposal programme.
- It is important for the early programmes to get information to learn from advanced programmes.
- Experience gained by advanced programmes indicates that requirement management should be planned in a holistic way from the start of a geological disposal programme. In accordance with the holistic planning, it is important that all types of requirements are represented in RMS throughout the course of a programme, even if some types of requirements are initially only high-level and general in nature, so as not to lose sight of the importance of each type.
- Requirement formulation and management for geological disposal programmes require effective co-operation between long-term safety, design and production/construction in order to achieve the desired level of specificity, clarity and effectiveness of requirements.
- It is important to reach common understanding of the interpretation of requirements.
- Regulations should be as stable as possible since establishing a design with a “moving target” presents an obvious challenge. Even with a stable regulatory framework and requirements, an increasing level of detail in the design as well as in the interpretation of regulatory requirements can be expected as programmes progress towards implementation.
- Because of the iterative nature of the disposal system development cycle (design, safety assessment, RD&D), it is often hard to maintain effectively complete consistency across teams and publications. Smarter IT systems, improved knowledge management behaviours (and culture) and digitization of safety cases is helping to address this.
- One of the biggest challenges of RMS in radioactive waste disposal area is the proper definition of the system boundaries i.e. what is the system and what is not in it. It is easy to expand the scope of the project indefinitely, particularly when stakeholders evolve their needs. A well-defined system boundary will permit the project funding and resources to be planned will also allow interfaces with external organizations to be defined. Conversely, a poorly defined system boundary makes it hard to decide what to design, makes it hard to predict funding and resources and makes it impossible to agree external interfaces. All this can increase the project risk significantly.
- Staff and organisation will change over the long process repository implementation.
- Technical specialists and project managers may have different views on RMS.
- The implementer RMS must include regulatory requirements.
- There is a need for integration with customer and contractor RMS.
- Abstraction of information coming from various specialist groups to the succinct requirements that are needed.
- The transfer of knowledge and experience between generations should be taken into account and should over time be the subject of continuous attention.

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3.3 EU- EURAD

The documents worth mentioning in connection with requirements management are as follows:

EURAD Roadmap Guide, Issue 2, 2021
https://www.ejp-eurad.eu/roadmap

EURAD Roadmap Theme 1 Overview, Programme Management, 2021
https://www.ejp-eurad.eu/publications/theme-overview-ndeg1-programme-management

EURAD Roadmap Theme 5 Overview, Facility Design and Optimisation, 2021
https://www.ejp-eurad.eu/publications/theme-overview-ndeg5-disposal-facility-design-and-optimisation

EURAD Roadmap Theme 7 Overview, Safety Case, 2021
Theme Overview n°7 : Safety Case (DOI 10.5281/zenodo.7024678) | Eurad (ejp-eurad.eu)

EURAD 7.2.2 Information, Data and Knowledge Management, Domain Insight Version: 1.0, 17.11.2023
https://www.ejp-eurad.eu/sites/default/files/2023-12/EURAD%20Domain%20Insight%207.2.2%20-%20IDKM.pdf

There is international consensus that it is good practice to introduce a requirements management system. An RMS supports organisations in developing safety cases that evolve but preserve traceability over the long project implementation period, ensuring that decisions are made in an open and transparent manner. An RMS integrates constraints based on environmental protection, societal acceptance and economic factors along with the fundamental principles, regulations and guidelines for geological disposal.

There is a clear relationship between the RMS, which defines the decisions to be made and the KMS, which provides the knowledge to make sound decisions.

The RMS is also associated with the quality management (QM). The need for QA is great for a geological disposal programme where the duration of a project will span several generations of workers. It is essential to assure the usability and traceability of information relied on through time.
Quality management arrangements that allow all types of information to be traced back to their source are particularly important. We shall require access to the original data and shall want to know how they were gathered, so that we can examine the provenance and interpretation of the data.

3.4 ISO documents

ISO document sets requirements and provides guidelines for establishing, implementing, maintaining, reviewing and improving an effective management system for knowledge management in organizations. All the requirements of this document are applicable to any organization, regardless of its type or size, or the products and services it provides [1].

[1] ISO 30401:2018 Knowledge management systems Requirements, 2018-11
https://www.iso.org/standard/68683.html

4 Selected topics on requirements management

4.1 Stakeholders involvement in the requirements management process

"Developing requirements is not an exercise in writing, but is an exercise in engineering. Every requirement represents an engineering decision as to what the system needs do or a quality the system needs to have in order to meet stakeholder needs " [1].

The stakeholders of a disposal facility such as the regulatory body, designers, vendors, suppliers, technical support organizations (TSO), and research and development (R&D) organizations play different roles and functions for each facility life cycle phase.

The responsibilities of requirements management stakeholders, as well as the resources needed, change over the facility's life cycle.

Figure 6 – Transforming stakeholder needs into requirements [1]

the IAEA project GEOSAF final report indicates that "early definition of requirements provides security in that the stakeholders know the "rules of the game" from the beginning".

It is important to reach consensus among all stakeholders involved regarding the interpretation of requirements as displayed in Figure 7. [2].

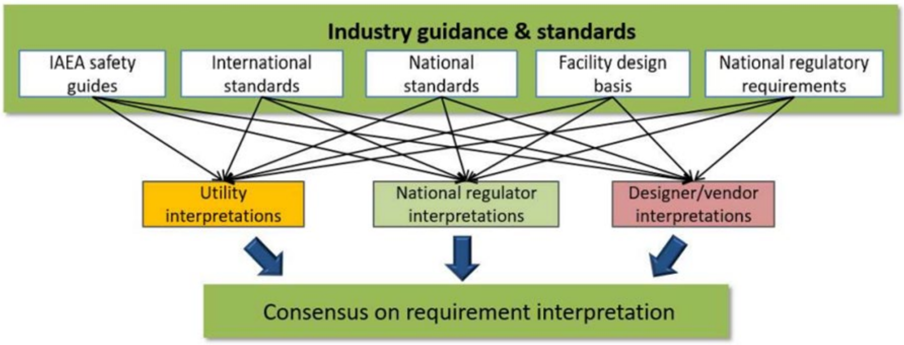

Figure 7 – Typical relationship between stakeholders needed to reach consensus on requirements interpretation [2]

Some key findings:

- The stakeholder needs should be clearly communicated the design team. Stakeholder needs are not requirements. From the stakeholder needs technical requirements should be developed.
- Requirements management provides measures to meet the various requirements from the stakeholders involved.
- Requirements management aids confidence building.
- RMS should be an important tool to discussion with all stakeholders and demonstrate how these are met.
- Many people involved whereby all come with their own mindset, which occasionally does not facilitate an expedient decision making.
- The political and social context of the development of geological disposal projects also has its own requirements and dynamics that must be taken into account.
- Stakeholders and regulators don't behave ideally.
- The responsibilities of stakeholders, as well as the resources needed, change over the facility's life cycle.
- Communication of the requirements is of high importance. A short document to communicate high-level requirements to a range of stakeholders and a longer document for technical audience that provides justification of requirements can facilitate this interaction.
- RM provides measures to meet the various requirements from the stakeholders involved. Furthermore, it aids confidence building, ¬ As the disposal programme continues over a period of more than 100 years and the constraints and premises are likely to change within this timeframe, RM should be a continuous process with a clear long-term scope.

4.2 Verification and validation

A question we are often asked is "What is difference between verification and validation?"
While these terms are commonly used, the true meaning of the concepts represented in each are often misunderstood and the terms are often used interchangeably without making clear the context in which they are used – resulting in ambiguity [3].

Using the terms interchangeably with the assumed or implied meaning and context leads to confusion and misunderstanding. When referring to IV&V, the ambiguity in the general use of the terms verification and validation creates even greater difficulties, especially if an organization is being contracted to perform "IV&V". First, the 'I' in IV&V is often used to mean 'independent' V&V in which an outside organization is called in to undertake 'V&V' as an activity.

Verification of what? Validation of what? Without a qualifying adjective, context is assumed and it is therefore not clear what 'V&V' refers to: requirements, design, or the system that has already been designed and built in accordance with the requirements.

Sometimes, however, the 'I' means 'integration' when referring to the right-hand side of the systems engineering 'Vee' model that depicts the processes of integration, verification, and validation. Clearly, by not being precise in the use of the terms and not indicating the context intended, confusion can result.

To avoid this ambiguity, each term needs to be preceded by a modifier (i.e., the subject) which clearly denotes the proper context in which the term is being used, specifically requirement verification or requirement validation; design verification or design validation; system verification or system validation. The concepts of verification and validation are very different depending on the modifier. When using these terms, it should be clear as to which concept is intended.

A requirement set results from a formal transformation of stakeholder needs and expectations. Correspondingly, design is a result of formal transformation of the requirement set in to an agree-to design, and a system is a formal transformation of the design into that system.

The process of creating a requirement set involves:

- analyzing stakeholder needs and expectations to obtain the necessary elements to be included in the requirement set;
- selecting a format for the requirement expression and an organization of the requirement set;
- identifying the characteristics of the desired result against the organizational guidelines and rules by which the requirement statements and requirement set is to be written, and
- transforming the stakeholder needs and expectations into a set of requirements that unambiguously communicates these stakeholder needs and expectations to the design organization.

In this context, **Requirement verification** confirms, by inspection, that the requirements contain the necessary elements and possess the characteristics of a well-formed requirement, and that the requirement set conforms to the rules set forth in the organization's requirement development guidelines.

Requirement validation confirms, by inspection and analysis, that the resulting requirement set meets the intent of the stakeholder needs from which the requirements and requirement set was decomposed or derived. Thus, the requirement statements and the requirement set are confirmed by both verification and validation activities.

Based on this discussion, to help remove the ambiguity in the use of the terms "verification" and "validation", the following definitions of these terms are included in terms of a product life cycle context:

– *Requirement verification:* the process of ensuring the requirement meets the rules and characteristics defined for writing a good requirement. The focus is on the wording and structure of the requirement. "Is the requirement worded or structured correctly in accordance with the organization's standards, guidelines, rules, and checklists?".

– *Requirement validation:* confirmation that the requirements and requirement set is an agreed-to transformation that clearly communicates the stakeholder needs and expectations in a language understood by the developers. The focus is on the message the requirements and requirement set is communicating. "Does the requirements and requirements set clearly and correctly communicate the stakeholder expectations and needs?" "Are we doing the right things?" or "Are we building the right thing [as defined by the requirement set]?"

Requirement verification and requirement validation activities should be done continuously as one develops the requirements at each level and as part of baseline activities of the requirement set performed during the System Requirements Review (SRR) or similar type of gate review at each level.

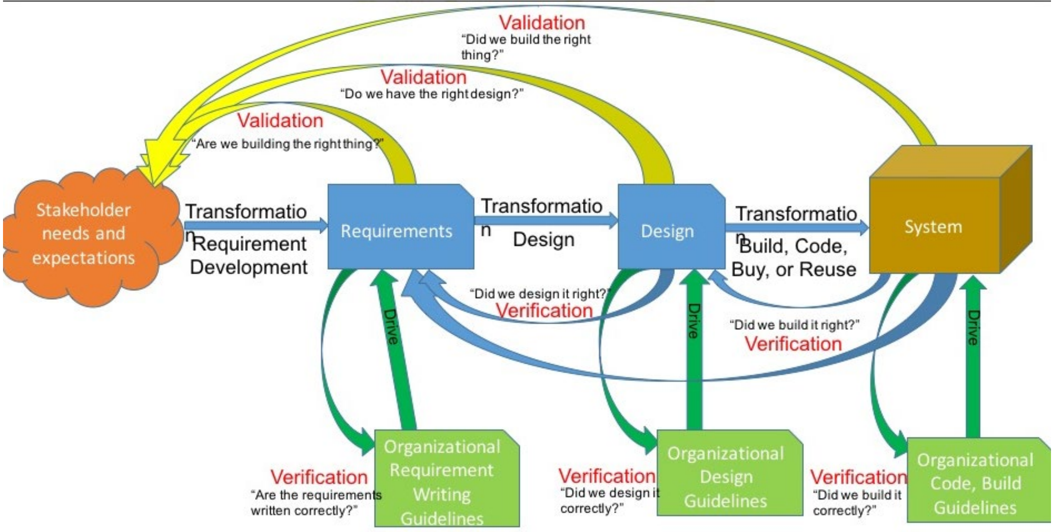

Figure 8 – Verification and validation are the processes of confirming that artifacts generated during the transformation processes are acceptable [4]

4.3 Requirements change management

As requirements are analysed and implemented, errors and inconsistencies emerge and must be corrected. These may be discovered during requirements analysis and validation or later in the development process [5].

Requirements change factors

- Changing stakeholders's priorities: may change during system development as a result of a changing business environment, the emergence of new competitors, staff changes, etc.
- Environmental changes
- The environment in which the system is to be installed may change so that the system requirements have to change to maintain compatibility
- Organisational changes
- The organisation which intends to use the system may change its structure and processes resulting in new system requirements

Change management is concerned with the procedures, processes and standards which are used to manage changes to system requirements.

Change management policies may cover:

- The change request process and the information required to process each change request.
- The process used to analyse the impact and costs of change and the associated traceability information.
- The membership of the body which formally considers change requests.
- The software support (if any) for the change control process.

When requirements changes are proposed, first check how many requirements (and, if necessary, system components) are affected by the change and roughly how much it would cost, in both time and money, to make the change.

When change is implemented, a set of amendments to the requirements document or a new document version is produced. This should, of course, be validated using whatever normal quality checking procedures are used.

Change analysis consists of the following steps:

- The change request is checked for validity. Stakeholders can misunderstand requirements and suggest unnecessary changes.
- The requirements which are directly affected by the change need to be discovered.
- Traceability information is used to find dependent requirements affected by the change.
- The actual changes which must be made to the requirements are proposed.
- The costs of making the changes are estimated.
- Negotiations with stakeholders should be held to check if the costs of the proposed changes are acceptable.

During change processing, proposed changes are usually recorded on a change request form which is then passed to all of the people involved in the analysis of the change.

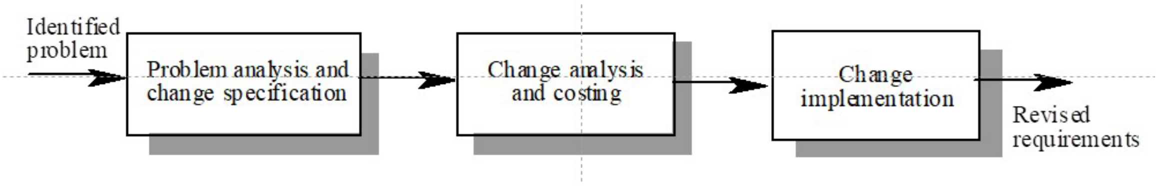

Figure 9 – Change management stages [5]

The number of requirements identified may grow to tens of thousands in numbers over a facility's lifetime. In addition, there may be changes to plant SSC, procedures and other processes as part of the continuous improvement and they, by their very nature, necessitate changes to requirement specifications. It is, therefore, essential to have suitable control mechanisms to assess, change and approve requirements [6].

Within a facility life cycle, as work progresses, there will be a need to include new or modified requirements. For this purpose, a formal requirement change management process needs to be put in place. Also, as a facility moves through life cycle phases, new requirements may be identified, and existing requirements may acquire different significance.

All such new or modified requirements will need careful review. Sometimes new or additional requirements have an impact on existing requirements, safety cases and compliance commitments; in which case such existing requirements need to be evaluated (impact assessment) and updated to meet the potential new requirement (depending on the impact). Therefore, in order to effectively review and monitor the whole process of RM, suitable control mechanisms are essential. The control mechanism needs to have suitable revision control mechanisms in order to help track the revisions/changes [7].

It is necessary to collect requirements for each stage of the facility life cycle. Source data for requirements that are relevant can be requirements from any other stages (predecessor as well as successor life cycle phases) as well as requirements specific to the life cycle phase.

4.4 Software tools to support information and requirements management

Data must be available over lifetime of the disposal project and beyond. It is crucial to maintain evidence of how and why decisions have been made, that is traceable and searchable [8] [9].

Requirements Management is an essential part of the management of all repository developments, irrespective of the scale of the repository. For small-scale repositories, it is likely that requirements will be documented and managed using a paper-based system and documented in reports. As the scale and the complexity of the repository development increases, the effective management of requirements will most probably necessitate the use of commercially available requirements management software.

Requirements management is normally done with the help of tools that capture the full requirements management system. The most primitive approach is to use tables (e.g, Word) that contains the information. As the information is interlinked, these links need to be captured; just with tables this gets cumbersome. Also, the use of EXCEL is most likely not an adequate solution on the long run. Thus, database software is considered the best way to go.

There are a number of commercially available software packages to facilitate the assembly and collation of requirements and of tracking that requirements have been met. There is no specific RM software aiming for nuclear waste management, most are aiming at pharma, aero, automotive, industry, or software development

Most of the available software solutions will be able to support the users' approach and offer sufficient functionality or even offer much more than they need. In that case they'll be paying for functionality they'll never use.

It may be advisable to get some support in the evaluation of the most useful software for any specific application. However, for eliciting and compiling (and also modifying/editing) information, Word and EXCEL can be useful tools but the information collected in these tools should then be transferred into the database software – thus, it is advantageous if the database software allows both the import and export of information from standard software like EXCEL or Word.

A number of software tools and formal procedures have been developed to support information and requirements management.

Digital requirements management is a beneficial way to capture, trace, analyze and manage requirements changes. Digital management ensures changes are tracked in a secure, central location, and it allows for strengthened collaboration between team members. Increased transparency minimizes duplicate work and enhances agility while helping to ensure requirements adhere to standards and compliance [10].

Requirements management software provides the tools to execute that plan, helping to reduce costs, accelerate time to market and improve quality control.

Requirements management is normally done with the help of tools that capture the full requirements management system. There exists a broad spectrum of software that can be used for requirements management. It may be advisable to get some support in the evaluation of the most useful software for your specific application.

A good software choice allows to cover other areas such as stakeholder management, variants, risk management, knowledge management, traceability, consistency (interface clarification) and compliance.

State of the art Requirements Management Systems: IBM® DOORS, JIRA, R4J - Requirements Management for JIRA, Atlassian, Polarion, JAMA, Orcanos DOORS.

IBM® Engineering Requirements Management DOORS (DOORS) is a leading requirements management tool that makes it easy to capture, trace, analyze, and manage changes to information. DOORS is an acronym for Dynamic Object-Oriented Requirements System. Using the DOORS family of products, you can optimize requirements communication, collaboration, and verification throughout your organization and across your supply chain [11].

IBM Engineering Requirements Management DOORS (DOORS) is a requirements management tool that is used for capturing, tracking, analyzing, and managing user requirements.

DOORS makes it easy for everyone in the organization and beyond to participate in and contribute to the requirements management process:

- Using a web browser, you can access your requirements database through IBM Engineering Requirements Management DOORS - Web Access.
- You can manage changes to requirements with either a simple predefined change proposal system or a more thorough, customizable change control workflow through integration to Rational® change management solutions.
- With the Requirements Interchange Format, you can directly involve suppliers and development partners in the development process.
- You can link requirements to design items, test plans, test cases, and other requirements for easy and powerful traceability.
- Business users, marketing, suppliers, systems engineers, and business analysts can collaborate directly through requirements discussions.
- Your testers can link requirements to test cases using the Test Tracking Toolkit for manual test environments.
- You can use the Open Services for Lifecycle Collaboration specifications for requirements management, change management, and quality management to integrate with systems and software lifecycle tools.

Jira Software is a work management tool for software teams that need to organize and track their work. Jira is incredibly flexible and can be customized to work with your team's unique workflow, meaning teams of all kinds can enjoy increased productivity and visibility as they march toward releasing amazing software.

JIRA supports a lot of different plug-ins extending its functionality. It is highly customizable.
With time very powerful plug-ins have been developed. An example is R4J (Requirements for JIRA).

Some key findings

- Larger systems usually need a database which is designed to manage a very large volume of data running on a specialised database server.

- If a database for software engineering support is already in use, this should be used for requirements management.

- Data migration to future software tools will be necessary in the longer term.

- Data formats will become obsolete

- RMS is linked with an information system/database and supports decision making (it is however not a decision-making system).

- If the requirements are developed by a distributed team of people, perhaps from different organisations, you need a database which provides for remote, multi-site access.

- Maintain a record of decisions (for newcomers, for revisiting old decisions).

- Various software codes are in use by the different implementers. First the needs should be defined, then appropriate software can be selected.

- See the software as a tool, which is replacing a paper document or Excel sheet (and saving a lot of time to maintain these), therefore first you have to define everything around the tool (strategy, team, workflows, interfaces) and then pick one software and set it up.
- Based on size, complexity and resources available, decide on the software to be used.
- A good team will define the requirements for the software matching your use case.
- Good software solutions offer not just requirements, but also configuration & change management (and more).
- Start with the configuration of the database software. During the population of the database, tests should be performed to continuously check consistency, completeness.
- Check the functionality of the requirements management system as implemented in the software tool.
- Most software suites deliver at least 80% of all needed features, some deliver much more than you need (and cost more than you should pay).

4.5 Early stage disposal programme challenges

Some lessons learnt

- Since geologic disposal in many countries is a first-of-a-kind project there is lack of operational experience in general and also in requirements setting and management process. A further challenge is that quality standards for requirements verification are often missing or have to be modified from other applications (e.g. nuclear power plants);
- Each RWM programme must develop its own approach and requirements, to suit national boundary conditions (national regulations, different waste types, different concept options, different host rock environment, etc.).
- The lack of experience in requirements formulation, verification and requirements management in general can pose challenges (e.g. the initial formulation of requirement is unclear, more than one requirement is lumped together and the requirement hierarchy is not sufficiently established;
- It is useful to start early with identifying (and tracking) the upper level requirements;
- Historical requirements to be integrated in RMS often not well documented, have different purposes, do not have any clear rationale, may be poorly formulated, variable in level of detail.
- At the early stages of repository planning when information on such issues as the disposal concept, waste inventory, site location or site characteristics, safety criteria, design criteria etc. is not known, it is often necessary for an implementer to make a series of assumptions about these issues in order to progress the repository studies; a particular challenge faced by implementers is to clearly differentiate between assumptions and requirements; requirements and preferences are not to be confused;
- Unless, clear records are maintained about what these assumptions are, as time progresses these assumptions can become regarded as requirements;
- At the early stages of project development, the repository design and corresponding safety case tend to focus on long-term safety as the driving issue and often the most challenging to define;
- The requirements are themselves evolving along the development of the repository programme and this introduces additional hurdles to requirements management and design development work;

- For the implementer, RMS arises from the need to document and integrate requirements from a range of sources, driven by a range of considerations (long-term safety, operational safety, engineering practicality);

- Laws and regulations cannot easily be used directly to define the detailed requirements necessary to be demonstrated by the disposal system and its various parts. Consequently, the implementer (WMO) must translate regulatory requirements into functional system requirements, to be demonstrated by the repository and its surrounding environment.

- Get the documents available that are of relevance for defining the requirements needed.

- Many documents do not present requirements in a structured way (text, diagrams, pictures, etc.). It may not be possible to capture the requirements by simply going through relevant documents as they may not be explicitly mentioned in them. Therefore, it is important that requirement information in a document is captured regardless of how the information is presented.

- It is crucial that all essential stakeholders that need to be involved in the early phase of starting the project are identified and/or their documents relevant for requirements management are known and available.

- 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, if using illustrative designs (designs borrowed from advanced programmes) that requirements are specified as illustrative so that changes can be easily made to adopt different solutions once there is less uncertainty of key boundary conditions.

- In programmes that are still in an early (i.e. pre-site selection) stage, it may be deemed more important to show adherence to some requirements more than others, with the focus generally being on long-term safety requirements.

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5. National examples on information and requirements management

In 2010, NUMO published a document on Requirements Management Systems: Status and Recent Developments [1]. In this Meeting Report, information was given on the application of RMS in different national radioactive waste disposal programmes including

- Japan (NUMO)
- Sweden (SKB)
- Belgium (ONDRAF/NIRAS)
- Finland (Posiva)
- Switzerland (Nagra)

In 2018, the OECD NEA issued a document on Managing Information and Requirements in Geological Disposal Programmes which provided several national examples about RMSs [2].

The countries contributed to the compilation are indicated in the table below.

Organisation	Country	Role
ONDRAF/NIRAS	Belgium	Implementer
Nuclear Waste Management Organization (NWMO)	Canada	Implementer
Radioactive waste repository authority (SÚRAO)	Czech Republic	Implementer
Posiva	Finland	Implementer
Andra	France	Implementer
Federal Office for Radiation Protection (BfS)	Germany	Implementer
Radioactive Waste Management Limited (RWM)	UK	Implementer
Department of Energy (DOE)	US	Implementer
Institute for Radiological Protection and Nuclear Safety (IRSN)	France	TSO
Japan Atomic Energy Agency (JAEA)	Japan	RD&D
Swedish Radiation Safety Authority (SSM)	Sweden	Regulator

note: Compiled in 2015 and reflect the situation at this date.

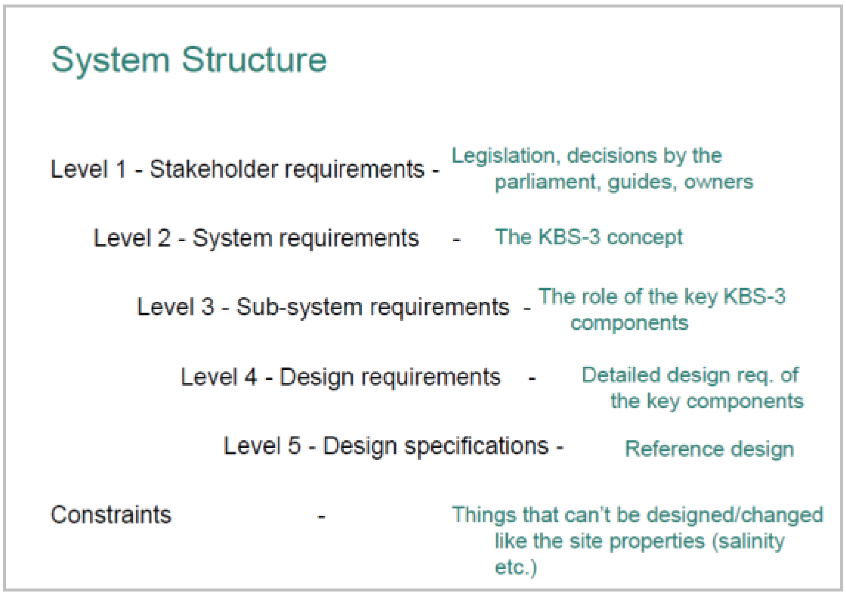
5.1 Finnish Requirements Management System

Posiva has already over 40 years of site investigations and site selection behind it.
The objective of the RM project has been to design, implement and introduce a systematic process and an information system to manage the requirements related to the geological disposal of spent nuclear fuel in Finland. Before the start of the project the site was already selected [1].

The desired result of the project is an information system with a database which

- Includes all the significant requirements, the reasoning underlying them, and the existing specifications to fulfil them,
- Enables an easy review of compliance between separate specifications and requirements,
- Contains information of dependencies between requirements,
- Enables a systematic review and documentation of influence derived from alterations in requirements,
- Enables implementation of RM as part of day-to-day operations within organization.

The DOORS software was chosen as the preferred software. The structure and contents of the RMS were developed in 2007.
The system structure:



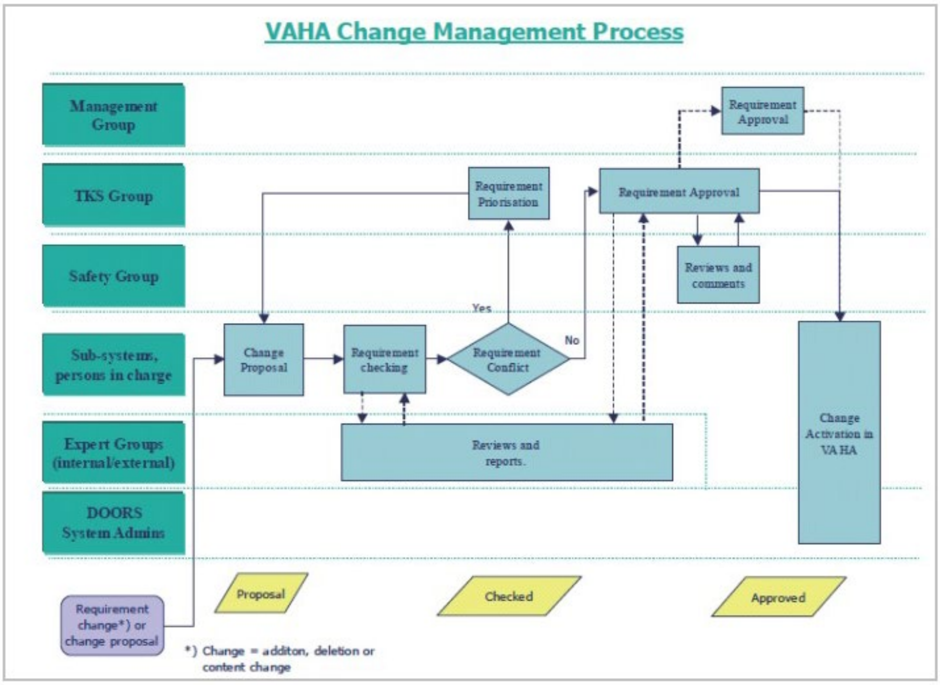


Figure 10 – The change management process as proposed for the POSIVA requirement management system

Posiva Oy's requirements management system VAHA is an information system designed by Posiva to manage the requirements related to the geological disposal of spent nuclear fuel. The main scope of the system is in the safety of disposal. VAHA was planned to include requirements and their references. The requirements are cross-checked against the technical solutions to comply with them. The idea of VAHA was to show the relation between high-level safety concepts and the actual technical design specifications [2][3][4][5].

The VAHA database is organised into five levels:

- Level 1 consists of stakeholder requirements. These are the requirements arising from laws, regulatory requirements, decisions-in-principle and from other stakeholders, such as Posiva's owners.
- Level 2 consists of system requirements as defined by Posiva based on requirements listed at Level 1. Level 2 requirements define the engineered barrier system (EBS) components and the safety functions of the EBS and host rock.
- Level 3 consists of subsystem requirements, which are specific requirements for the individual barriers. Level 3 includes the performance targets for the EBS and the host rock, applying to the long-term performance of the barriers.
- Level 4 consists of design requirements, which further clarify and provide more details of the requirements specified at Level 3, with the focus on those properties of the barriers that can be verified during the operational phase.
- Level 5 consists of design specifications. These are the detailed specifications to be used in design, construction and manufacturing.

In terms of the disposal site (in Posiva's case, Olkiluoto), Level 1 includes regulations applying to site selection and the properties of the disposal site in general, as well as some regulations on the properties of the host rock volumes to be selected for disposal.

At Level 2 (L2), Posiva has defined host rock as the natural barrier.

Level 3 presents the performance targets for the host rock, also termed target properties. These were initially presented in Posiva and have been updated based on the collaboration between Posiva and SKB [19] . Performance targets apply to the long-term performance of the barriers (in this case, the host rock), and the evaluation of their fulfilment requires modelling, which, however, considers present-day measurement results as the starting point for evolution modelling.

Levels 4 and 5 apply to the state of the barriers at the time of manufacture or installation, and, in the case of the host rock, this refers to the design and as-built state of the underground openings.

The L4 requirements and L5 specifications are rather detailed and both site-specific and design-specific, and they do not apply as such to a generic disposal site.

The five levels of requirements provide a practical means to relate all types of requirements with each other in a logical system. The highest-level regulations and the general safety functions can be used to derive lower-level, detailed requirements and specifications to consider in the design and construction phase. The requirements at higher levels can be used to guide the site investigation work.

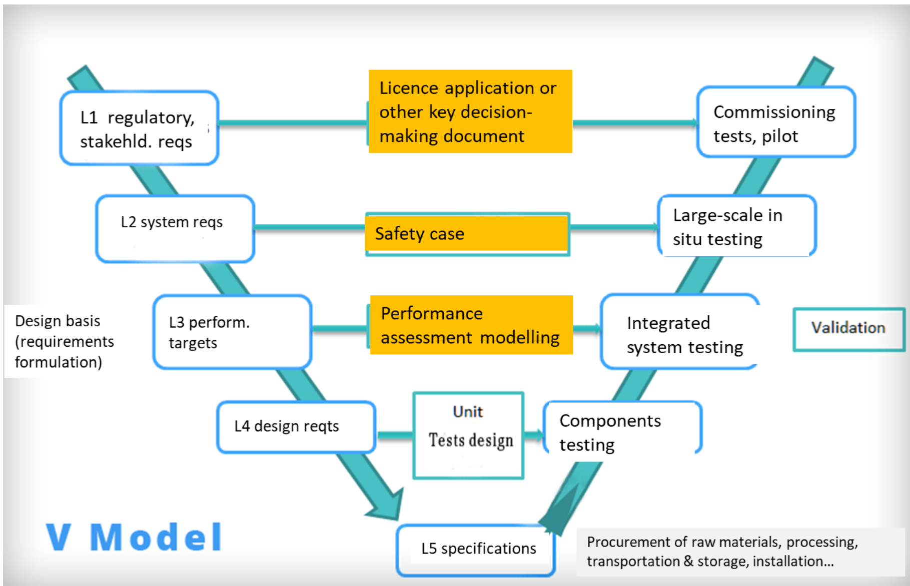


Figure 11 – VAHA system [6]

Defining the requirements:
The project team gathered the Stakeholder requirements (L1) and the System requirements (L2). During 2007, gathering existing requirements for levels 3-5 in each sub-system group was done Specifying the structure and the contents and defining dependencies for the requirements management system was also carried out.

Up to 2007 appr. 1500 requirements and specifications were gathered.

As far as RMS tool is concerned, the requirements management software was tested/piloted around 2006-2007. Doors was officially implemented in 2010. Posiva uses DOORS "Classic" v.9.6.
It is unclear why DOORS was selected. A possible reason was that this was the most advanced RMS tool available at that time; another possible reason was to harmonize requirements management with SKB.

The Finnish lessons learned has been that DOORS is not intuitive for a novice user, however, it becomes user friendly "enough" if the user practices a bit [6].

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5.2 Swedish Requirements Management System

TR-00-12 Technical Report gives an account of what requirements are made on the rock, what conditions in the rock are advantageous (preferences) and how the fulfilment of requirements and preferences (criteria) is to be judged prior to the selection of sites for a site investigation and during a site investigation. The work was initiated in 1997 and an interim report was submitted in conjunction with RD&D-Programme 98 /SKB, 1998/. The work is an important part of SKB's preparations for execution of the site investigations [1].

The knowledge gained during SKB's safety assessment, SR 97, is particularly drawn on. The reported requirements, preferences and criteria will be used in SKB's continued work with site selection and site investigations.

The results, and particularly the stipulated criteria, apply to a repository for spent fuel of the KBS-3 type, i.e. a repository where the fuel is contained in copper canisters embedded in bentonite clay at a depth of 400–700 m in the Swedish crystalline basement. If the repository concept is changed or if new technical/ scientific advances are made, certain requirements, preferences or criteria may need to be adjusted. Therefore, it should be emphasized that the work cannot be used as a basis for siting of other types of repositories or in other geological settings.

The formulations of requirements are governed by Swedish laws and regulations.
To achieve a safe final repository, SKB has developed a final repository concept (KBS-3) based on the fundamental safety functions of isolation and retardation.

These functions are influenced by the design and construction of the facility and the engineered barriers, and by the site-specific conditions on the repository site. A number of general requirements and preferences can also be formulated for facility construction.

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5.3 UK Requirements Management System

The UK approach is not as advanced as the Finnish VAHA system but shares many of the basic principles. The UK approach adopts a hierarchical structure as shown in the following Figure, leading to a characteristic "V diagram". Figure 12 (original: Figure I-2) illustrates that requirements management is a tool that is not only used to record requirements but also to record verification and compliance checks. Like the Finnish VAHA system, the UK approach is structured in a number of tiers with the level 1 defining the "user requirement" which is defined as regulatory and stakeholder requirements. At this level the UK defines what is the 'need' that the geological disposal facility is designed to meet. The subsequent lower order tiers are developed based on the 'solution' and lead to the definition of system requirements, sub-system requirements and ultimately to component specifications. Having specified the various requirements, the system provides a systematic way of recording and demonstrating that the specified requirements have been delivered [1].

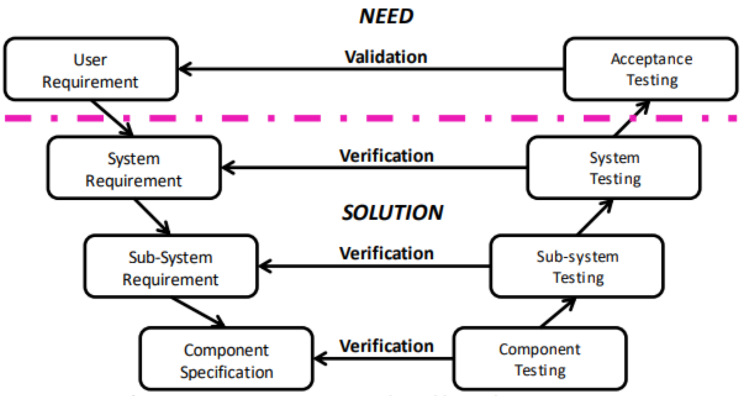

FIG. I-2. Basis for requirements management adopted by Radioactive Waste Management in the UK (Reproduced courtesy of Nuclear Decommissioning Authority © (2016) Ref Radioactive Waste Management UK).

Figure 12 – Basis for requirements management (UK approach)

Radioactive Waste Management Limited (RWM), a wholly owned subsidiary of the Nuclear Decommissioning Authority (NDA), is responsible for implementing the UK Government's policy on geological disposal of higher activity waste. RWM is being developed into a Site Licence Company responsible for the construction and operation of a geological disposal facility (GDF). RWM has developed a generic Disposal System Specification (DSS) to describe the requirements on the disposal system which form the basis of RWM's design and assessment work. The DSS comprises two documents [2] [3].

- Disposal System Specification Part A: High Level Requirements
- Disposal System Specification Part B: Technical Specification

Part A purpose is to document the high level requirements on the disposal system which derive from:

- inventory of waste for disposal
- legislative and regulatory requirements
- stakeholder requirements

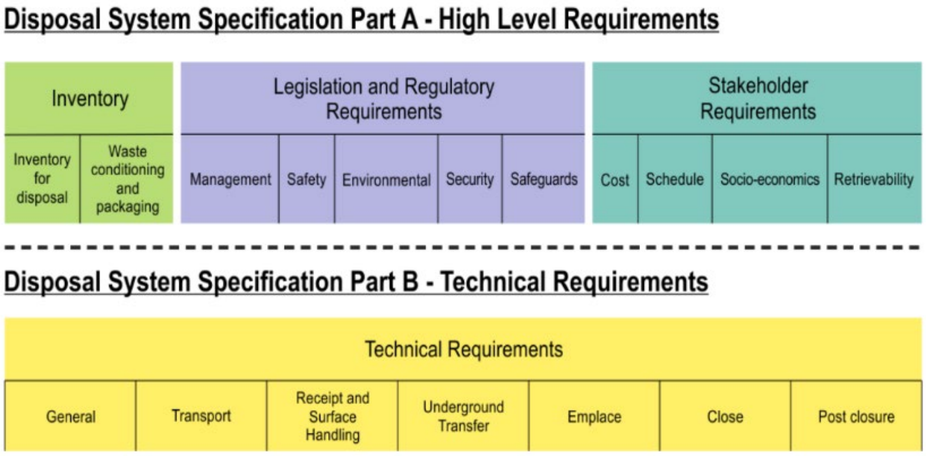

Figure 13 – Structure of the disposal system specification

More up to date information was shared by S. Bryson, during the EURAD Training Course on application of requirements management systemsin Budapest, 16 – 18 January 2024 [4].

According to the requirements management, UK currently in the needs domain. The main functions of a GDF but without a site UK can only produce the highest level of functions and the requirements associated with those functions associated with the geology don't know.

Currently the stakeholder goals are determined and those have used to then break these down to the system level requirements in the solution domain that start to answer these stakeholder requirements.

At the moment assumptions form a large part of what will become requirements.

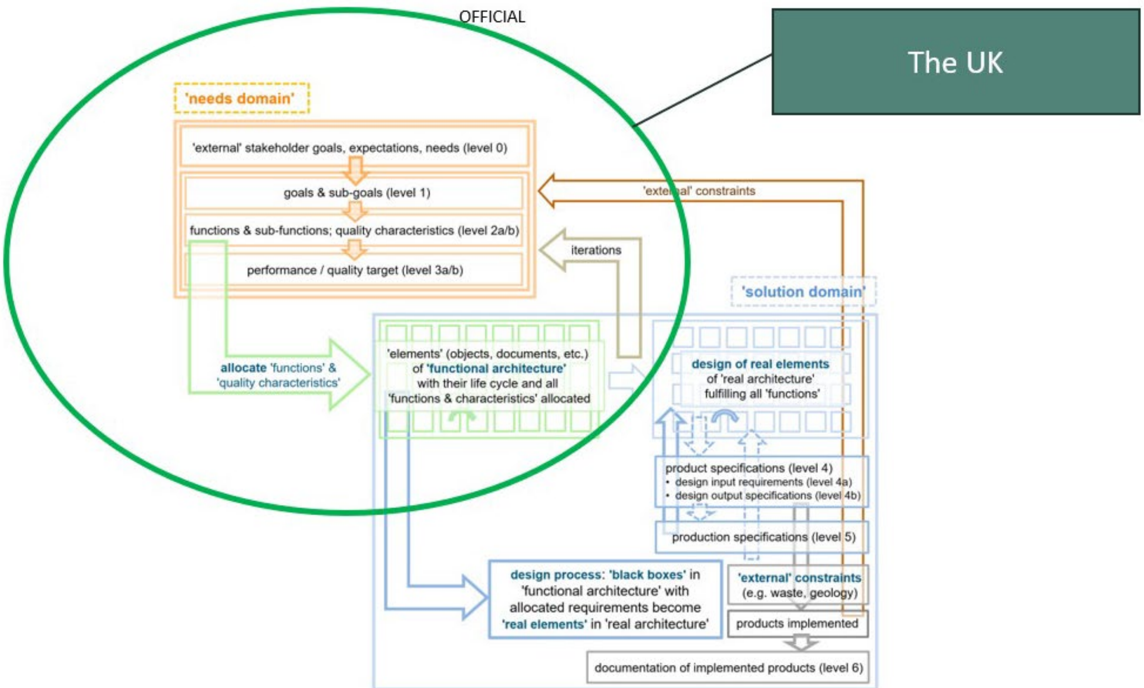

Figure 14 – Current status of the UK RMS [4]

At the moment assumptions form a large part of what will become requirements.

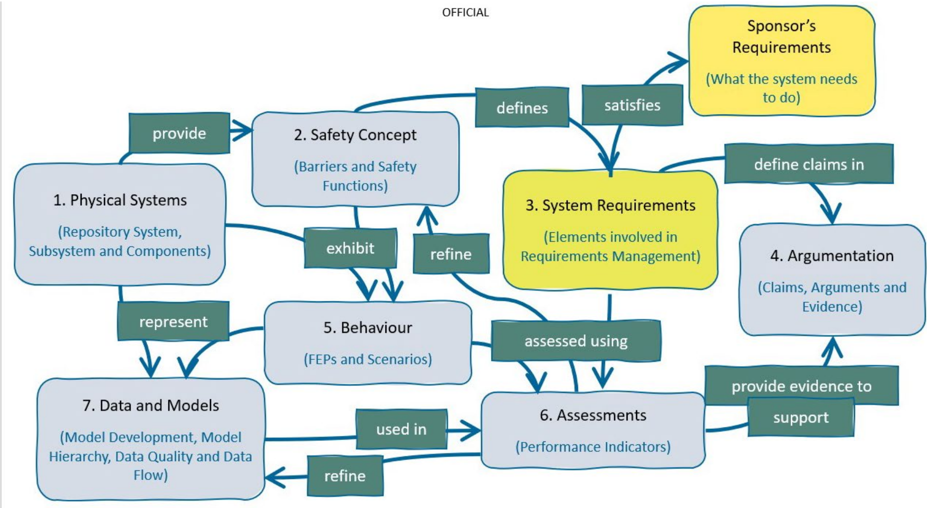

Figure 15 – Integration of Post closure safety and System requirements [4]

As specialists have started to introduce requirements, all were trying to work out how they work with requirements. They are all the most important discipline and their needs outweigh others. This is linked to quality characteristics.

Radioactive Waste Management Limited document provides useful insight to legal and other requirements, land use planning requirements and siting process requirements to be applied during site evaluation [5].

Many useful information can be found on various aspects of requirements relative to geological waste disposal [6][7][8][9].

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[5] Site Evaluation: How we will evaluate sites in Wales, Radioactive Waste Management Limited, 2020
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5.4 Swiss Requirements Management System

The short summary below is based on an early (2010) information [1].

Requirements Management has been used in several key projects such: Wellenberg site investigation (1997-2000), waste management programme (2006-2008) and site selection process: proposal of siting regions (2003-2008, continuing).

Major goals for Nagra's requirements management system:

- To have a complete overview on all relevant requirements (compilation of requirements).
- For each of the issues at hand, ensure that all relevant requirements are considered (specification of requirements).
- Operational goals.
- Facilitate repository development (incl. transparency for communication with stakeholders)
- Facilitate decision making (clarify objectives).
- Ensure traceability of decisions (motivation for decisions).
- Ensures continuously updated basis (and helps keeping track of changes).

Thus, the requirements management system has to contribute to ensuring safe repositories and should provide confidence to the stakeholders involved.

Requirements Management is part of Nagra's (quality) management system. It Is part of strategic planning (formal process) with periodic check-points. Also, it has direct links to projects (input to development of project specifications / boundary conditions for project). Requirements Management is also part of (formal) interaction with authorities.

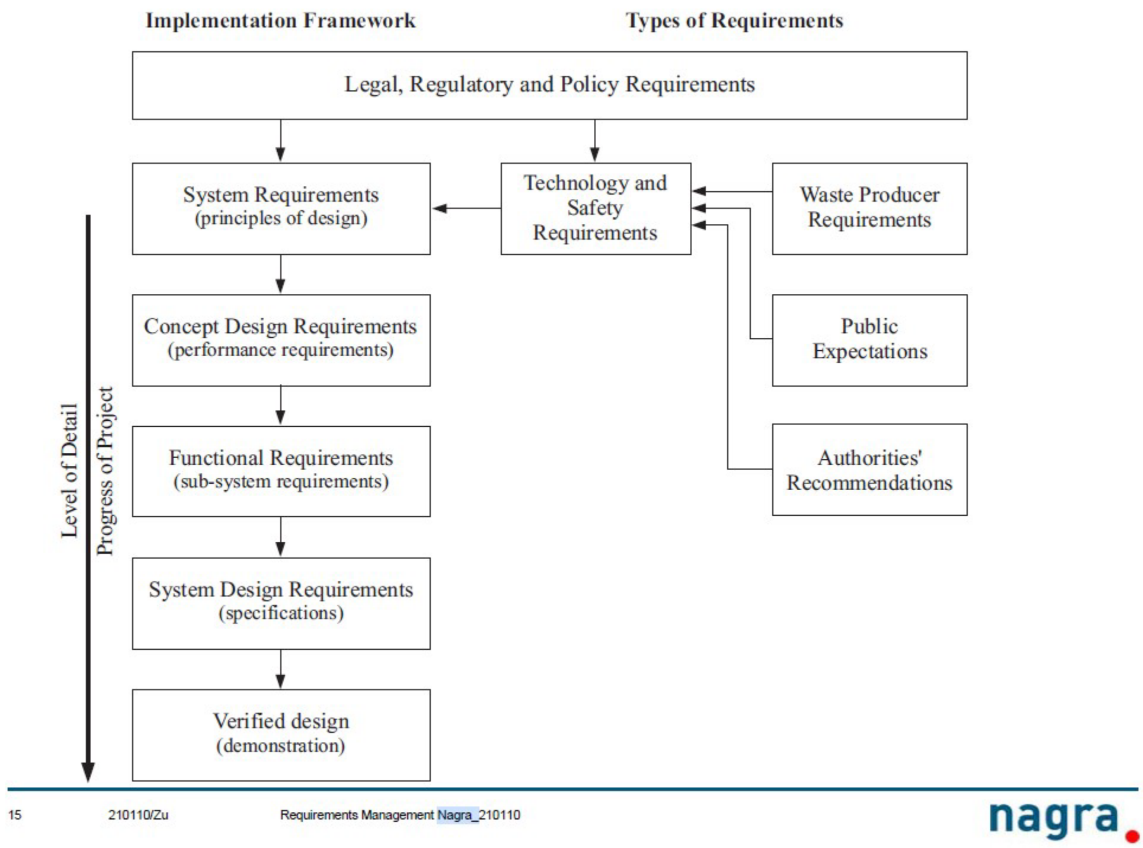

Figure 16 – Information flow in Nagra's RMS

Basic structure of Nagra's RMS addresses the following issues:
for which reason, what requirement, for which element, when, for which (alternative) system?

Structure & process of requirements management has developed (evolutionary process, still changing); development will continue.

In the case of Nagra there is no need to develop all requirements to the lowest level in this stage of their project as the focus is on the site selection. However, one should make sure that there are no show stoppers at this lower level in the future. One should avoid making decisions too early in the process.

Some lessons learnt:

- The major difficulty encountered up to now is related to the documentation of requirements.
- The requirements are stored in more than one database –while their underlying scientific basis is documented in several formal reports.

More up to date information was shared by B. Sosnik, during the EURAD workshop and training course [2][3].

Nagra wants to combine requirement management with configuration and change management in one system (integrated management approach). Bringing configuration and change management to the requirement management allows Nagra to develop a system without haste and the need to be correct & complete right from the start. It allows to improve and complement the knowledge we have already in a graded approach.

Figure 17 – Integrated management approach

Good software solutions offer not just requirements but also configuration & change management (and more).

Nagra redefined the scope and were looking for a solution integrating requirements, configurations & changes A good software choice allows to cover other areas:

- Stakeholder management
- Variants
- Risk management
- Knowledge management
- Traceability
- Consistency (Interface clarification)
- V&V
- Compliance

Nagra plans to go 100% digital since this gives more possibilities than a paper or electronic document approach. The envisaged advantages include (i) integration with other systems, automation (ii), active notification of all involved participants, (iii) traceability and active communication to stakeholders.

References

[1] (NUMO 2010), Requirements Management Systems: Status and Recent Developments. Meeting Report, NUMO-TR-10-07
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[2] B. Sosnik, How to run a RMS software matching your needs, EURAD Training Course on application of requirements management systems, Budapest, 16 – 18 January 2024

[3] B. Sosnik, Requirements in motion, EURAD WP12 Requirement Management Systems, Workshop #3 on Requirements Management 30.05.2023

5.5 Japan Requirements Management System

The early history development of the NUMO-RMS [1].
2005: Research on RMS initiated using DOORS®: Organization and description of requirements considered for engineering requirements
2006-07: Development of NUMO-RMS with basic functions for trial use
2008-09: Development of NUMO-RMS with fundamental functions for practical use

NUMO has developed a Requirements Management System aimed at systematically identifying the wide variety of requirements and managing them in an effective and transparent manner. Such requirements and associated decisions need to be consistent in each phase of the programme, and also throughout the diverse range of technical work carried out by NUMO managers and technical teams.

Basic functions of the RMS tool:

- Record-keeping: the RMS tool records the requirements, constraints, premises, arguments and related information in a well-organized structure;
- Support of decision-making: ensures no critical requirements are overlooked;
  Change management: if any changes in requirements and decisions occur, the RMS tool identifies the related requirements and decisions and alerts the responsible persons;
- Schedule management: RMS identifies what decisions will be made in future stages and when/how/by whom the requirements should be fulfilled.

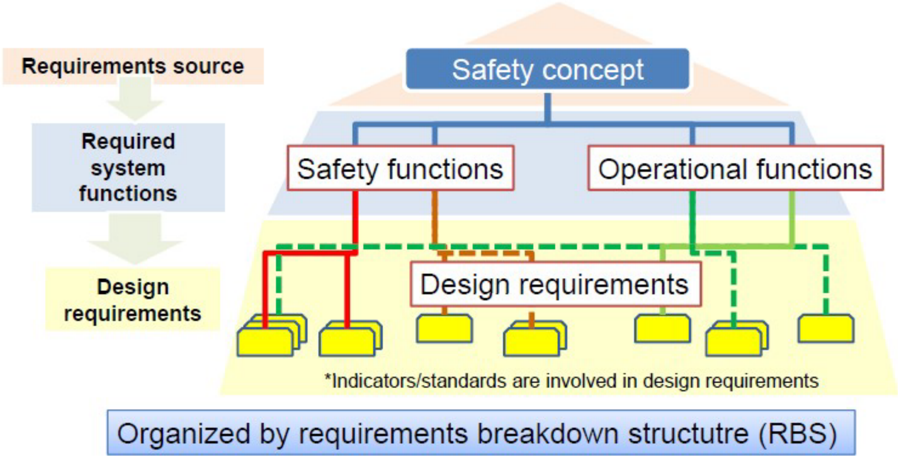

Figure 18 – Requirements breakdown structure

NUMO was to develop a Requirements Management System to help implement the NUMO Structured Approach. This RMS can allow the justifications, supporting arguments and knowledge base used for every decision to be clearly recorded and can highlight when such decisions may need to be revisited, for example due to changing boundary conditions or technical advances. Integration of information and knowledge coming from the different fields of the programme will be performed through the RMS in NUMO.

As a step forward, NUMO planned to RMS link with Knowledge management system (KMS) and application of R&D results.

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Appendix B. Abbreviations

DGR	Deep Geological Repository. Normally used for the disposal of SF, HLW and LL-ILW
DS-RMS	Document 'Developing, Using and Modifying a Requirements Management System for Implementing a Disposal System' (EURAD document)
EURAD	European Joint Programme on Radioactive Waste Management
G-RMS	Guidance document 'Guidance on Developing, Using and Modifying a Generic Requirements Management System' (this document)
HLW	High-level radioactive waste
INCOSE	International Council for System Engineering
LL-L/ILW	Long-Lived Low-/Intermediate-Level Waste disposed in mined repositories at greater depth,
L/ILW	Low-/Intermediate-Level Waste disposed in near surface disposal facilities or in mined repositories at limited or greater depth,
LLW	Low-Level Waste disposed in (near) surface disposal facilities or in mined repositories at limited depth
OAM	Object (O), activity (A), other measure (M)
QA	Quality assurance
RDD	Research, development, demonstration
RMS	Requirements management system
SF	Spent Fuel
VLLW	Very Low-Level Waste often disposed in surface disposal facilities
WAC	Waste acceptance criteria
WMP-RMS	Guidance document 'Guidance on Developing, Using and Modifying a Requirements Management System for Waste Management Programmes with their Different Systems' (EURAD document)

Appendix C. Literature review on requirements management