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RD&D Planning for Radioactive Waste Management with focus on disposal

Work Package 12

Based on PLANDIS Guide 2015

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Executive Summary

The PLANMAN Guide is an update and an upgrade of the PLANDIS Guide on research, development and demonstration (RD&D) programme planning towards geological disposal of radioactive waste. The PLANDIS Guide considers the RD&D activities that are typically planned during early phases of disposal programme management, as well as the management activities necessary for their successful implementation such as competency management, civil society involvement, different contractual mechanisms for completing RD&D, and the potential benefits of technology transfer of RD&D knowledge from more advanced radioactive waste programmes.

While the PLANDIS Guide targets primarily Waste Management Organisations (WMOs) as potential end-users, as content is focused on the RD&D priorities and needs of WMOs, the PLANMAN Guide extends the scope of PLANDIS by including also the needs of other potential users like Technical Support Organisations (TSOs) and particularly by addressing specific RD&D needs of Early-Stage (ESP) and Small Inventory Programmes (SIP).

During the development of the PLANMAN Guide an important delivery of the EURAD programme – the EURAD Roadmap – representing a generic radioactive waste management programme and providing information on existing knowledge important for its implementation was developed and published (EURAD Roadmap, 2021; EURAD Roadmap Guide, 2021). Due to this action an additional objective to put the PLANMAN Guide in line with the EURAD Roadmap and to make its content consistent with the EURAD Roadmap was recognised and implemented.

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Glossary

CRA	Competent Regulatory Authority
EASAC	European Academies' Science Advisory Council
EC	European Commission
EDRAM	Environmentally Safe Disposal of RAdioactive Materials – (the International Association)
EIA	Environmental Impact Assessment
EMS	Environmental Management System
ENEF	European Nuclear Energy Forum
ESP	Early-stage Programme
EU	European Union
EURAD	European Joint Programme on Radioactive Waste Management
FEPs	Features, Events and Processes
FSC	Forum on Stakeholder Confidence
HLW	High Level Waste
IAEA	International Atomic Energy Agency
IGD-TP	Implementing Geological Disposal of radioactive waste Technology Platform
IGSC	NEA Integration Group for the Safety Case
ILW	Intermediate Level Waste
IMS	Integrated Management System
JRC	Joint Research Centre- European Commission
KM	Knowledge Management
LLW	Low Level Waste
KMS	Knowledge Management System
MS / MSs	Member State / Member States
NDA	Nuclear Decommissioning Authority (UK)

NEA	Nuclear Energy Agency (an intergovernmental agency for facilitating cooperation among OECD countries with advanced nuclear technology infrastructures)
NFRP	Nuclear Fission, Fusion and Radiation Protection Research
NPP / NPPs	Nuclear power plant / nuclear power plants
NRA	National Regulatory Authority
OECD	Organisation for Economic Co-operation and Development
OHSAS	Occupational Health System and Safety
PEBS	Performance of Engineered Barrier Systems
PLANDIS	RD&D Planning Towards Geological Disposal of Radioactive Waste, Guidance for less-advanced Programmes
PLANMAN	PLANMAN Guide – RD&D Planning for Radioactive Waste Management with focus on disposal
PMO	Programme Management Office
PU	Dissemination Level to Public
QA	Quality Assurance
QMS	Quality Management System
RD&D	Research, Development and Demonstration
RE / REs	Research Entity / Research Entities
RMS	Requirements Management System
ROUTES	Waste management routes in Europe from cradle to grave (WP9)
RW	Radioactive Waste
RWM	Radioactive Waste Management
RWMC	Radioactive Waste Management Committee
SEA	Strategic Environmental Assessment
SecIGD2	Secretariat for IGD-TP
SF	Spent nuclear fuel
SIP	Small Inventory´s Programme

SITEX	Sustainable network of Independent Technical EXpertise for radioactive waste disposal
SRA	Strategic Research Agenda
SRL	Scientific Readiness Levels
TSO / TSOs	Technical Support Organisation/-s (to National Regulatory Authority)
URF	Underground Research Facility
URL	Underground Research Laboratory
WAC	Waste Acceptance Criteria
WMO/WMOs	Waste Management Organisation / Organisations in frame of RWM
WP	Work Package

1. Introduction

All EU Member States (MSs) generate radioactive waste (RW), with inventories ranging from single producers and small inventories, up to large volumes of radioactive waste in MSs with nuclear programmes including also spent nuclear fuel (SF) or larger amounts of radioactive waste from reprocessing. Regardless of volume and type of radioactive waste, according to the Council Directive 2011/70/EURATOM (2011) all EU MSs have ultimate responsibility for managing their RW safely in the long term and during all relevant implementation phases depending on the type of RW. Taking over this responsibility requires also research and development activities, adjusted to the level of advancement and specific needs of national waste management programmes. MSs can get assistance through the EURAD – European Joint Research Programme on Radioactive Waste Management – which by intensive research-cooperation between MSs and more effective and efficient public RD&D) activities supports the implementation of the Council Directive 2011/70/EURATOM (2011) in EU Member States.

The IAEA (2022a) report on the Status and Trends project describes the waste management routes for different types of RW. Radioactive waste repositories are operated safely worldwide for very low-level waste (landfill type), short-lived low-level waste (mostly surface, near surface and sometimes intermediate depth disposal). Some of the underground, intermediate depth disposal can safely accommodate intermediate level waste with limited activity of long-lived radionuclides. Technical concepts are developed also for the disposal of disused sealed radiation sources in boreholes (IAEA, 2009b; IAEA, 2011) and are under development for the disposal of long-lived intermediate level wastes (Hicks et al., 2008; IAEA, 2009c; CARBOWASTE, 2008-2013).

For high level waste (HLW) and spent nuclear fuel the disposal in deep underground, a practice referred to as “geological disposal”, is generally adopted. Geological disposal[1] is recognised by participating Member countries of the NEA Radioactive Waste Management Committee (RWMC), as well as the European Commission (EC) and the IAEA, as the safest long-term solution for this type of wastes, even though some countries wish to postpone implementation of disposal or to evaluate other options in parallel, (which are mentioned below in some parts of the PLANMAN Guide). Significant progress has lately been achieved in Finland where the construction licence for geological disposal has been adopted and construction works are in progress. Several other Member States with advanced programmes like Sweden and France are also progressing with implementation of a geological repository.

[1] European Joint Programme on Radioactive Waste Management (EURAD) Founding Documents - Vision, SRA, Roadmap, Deployment Plan & Governance Scheme, Issue 1 September 2018; p. 5, first 10 lines of the Foreword.

Storage is an essential step of the back-end of the nuclear fuel cycle, (also for HLW generated in other nuclear applications), providing the time for the decrease of decay heat generated in SF or HLW, and allowing the safe implementation of further management steps. However, it also has to be noted, that due to a requirement of permanent institutional control, storage is only an interim solution useful for one or few generations and is not an alternative to disposal. Because of the long implementation timescales of a geological repository most of the EU MSs have to consider the extension of the storage period of SF or HLW. Extending the design lifetime of storage facilities requires also supporting RD&D activities related to stored waste packages and storage facilities.

For countries with small inventories and consequently small scale of the nuclear applications/industry it is challenging to provide necessary resources (human, technical, financial, etc.) for managing their radioactive waste and particularly for geological repository implementation. Some of these countries have organised themselves in the ERDO working group[2] and jointly develop shared solution for their radioactive waste (including shared disposal facilities) and following a ‘dual track’[3] policy. Such option has been recognised also by the Council Directive 2011/70/EURATOM (2011) which formulates in its preamble: “Some Member States consider that the sharing of facilities for spent fuel and radioactive waste management, including disposal facilities, is a potentially beneficial, safe and cost-effective option when based on an agreement between the Member States concerned”.

Efforts have also been taken to develop disposal solution for SF in deep boreholes (see e.g. SANDIA, 2011), which might be of interest for countries with small SF inventories. It shall be mentioned that the maturity of this concept is by far not at the same level as the technology of mined geological disposal (more on pros and cons in (SITEX, 2022)), the safety and technical feasibility of which has already been demonstrated.

Regardless of the amount of RW and SF, all EU MSs shall according to the Council Directive 2011/70/EURATOM (2011) “*develop the national programmes for the management of spent fuel and radioactive waste covering all types of spent fuel and radioactive waste under its jurisdiction and all stages of spent fuel and radioactive waste management from generation to disposal*”, which include also RD&D activities that are needed for implementation. These national programmes “*shall be regularly reviewed and updated, taking into account technical and scientific progress as appropriate as well as recommendations, lessons learned and good practices from peer reviews*”.

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[2] http://www.erdo-wg.com/index.html

[3] IAEA (2016): Framework and Challenges for Initiating Multinational Cooperation for the Development of a Radioactive Waste Repository: „dual track approach in which the options of a purely national approach and multinational sharing are both kept open“.

The NAPRO working group of the European Nuclear Energy Forum drafted a guide (NAPRO Guide (ENEF, 2013)) with the aim of assisting the MSs in the establishment of their National Programmes. The NAPRO Guide among others addresses guidance on how to develop a comprehensive programme for all waste streams and shows the management routes from the generation until the disposal in dedicated repositories (‘cradle to grave’ concept). The Council Directive 2011/70/EURATOM prescribes that, “*The National Programmes shall include (…) the research, development and demonstration activities that are needed in order to implement solutions for the management of spent fuel and radioactive waste*”. The National Programme has to be implemented and its supportive RD&D plan has to be carried out by taking into account (i) the requirements and goals of the National Policy and (ii) the national framework of a given MS as boundary conditions. These both items together define characteristics of the national solutions.

1.1 Approach and background

The present guide (hereinafter PLANMAN Guide) is built on the content of the PLANDIS guide 2015 (Beattie et al., 2015). The PLANDIS guide was developed in the frame of the SecIGD2 project initiated by the IGD-TP - Implementing Geological Disposal of Radioactive Waste Technology Platform and was prepared at the request of the EU Council in the context of the EURATOM coordination and support action SecIGD2 (Secretariat for IGD-TP). It is focused on the needs of less advanced programmes and aims at providing them with a framework of RD&D activities needed at different stages of implementing their national policies for SF and RW management. The scope of the PLANDIS guide is limited only to RD&D activities related to geological disposal of long-lived radioactive wastes from the perspective and needs of WMOs.

The PLANMAN Guide aims to enlarge the scope set in PLANDIS Guide to include also the views of the Technical Support Organisations (TSOs) as representatives of the national regulatory bodies on the planning of a RD&D programmes at different implementation stages. TSOs might have different views on RD&D programmes and in some cases establish their own RD&D programmes which complement implementer activities. The PLANMAN Guide gives special attention to Early-Stage and Small Inventory Programmes and their needs. Although the guide is still focused on geological disposal, with small adaptations it may be used also for any other type of radioactive waste disposal (near-surface disposal, deep borehole disposal).

This guide is targeting end-user from WMOs that are in the process to set up a plan for RD&D activities for managing their RW and SF, and TSOs that will review these plans and be involved in their implementation with assessment of licensing documentation for radiation and nuclear safety. It might be interesting and useful also for research organisations in RWM field, owners of research programmes at nuclear power plants or at ministries or representatives of civil society working in this area.

1.2 Objectives and Structure of this Guide

The main objectives of the PLANMAN Guide are:

- to take into consideration broader perspective of RD&D planning for managing SF and RW and in addition to the needs of the WMOs to include also the views and needs of other potential end-users, primarily the TSOs;
- to focus on Early-stage and Small Inventory Programmes and their specific needs in identifying necessary RD&D activities when developing their waste management programmes which may not be focused so much on geological and other disposal solutions but giving the priority to predisposal activities;
- to put the PLANMAN Guide in line with the EURAD Roadmap (2021) and
- to include relevant new developments in knowledge management on radioactive waste management, beyond RD&D planning, and give signposts to some guides that support ESP and SIP to implement their national waste management programme and meet articles of the Council Directive 2011/70/EURATOM (see Guidance on Cost Assessment and Financing Schemes of Radioactive Waste Management (EURAD D12.4, 2022) and guidance on requirements management in radioactive waste management (EURAD D12.6, 2024; EURAD D12.8, 2024; EURAD D12.9, 2024)).

The structure of the PLANMAN Guide follows the structure of the PLANDIS Guide (Beattie et al., 2015). It comprises three main sections. The first two sections are only slightly modified compared to the PLANDIS Guide primarily to provide short information on new aspects addressed in the PLANMAN Guide. The third section is organising and structuring typical RD&D activities according to the themes of the EURAD Roadmap and gives additional attention to the needs of ESP and SIP.

The PLANMAN Guide is a guide setting the context and providing the framework for national RD&D planning, recognising that no two national RWM programmes are the same and that each Member State might have its own particular challenges and opportunities relative to geological disposal of radioactive waste.

1.3 Definition of RD&D

Following the definition of Zuidema and Johnson (2013) research in this guide is considered as a systematic investigation of a subject or field of study of common interest oriented towards "understanding" and may lead to new (conceptual) models, data, etc. or confirmation/refinement of existing information. “Development” in this context is focused on the application of "understanding" for a specific purpose in waste management, whereas Demonstration intends to show/evaluate whether the issue under investigation is "under control", e.g. through full-scale Underground Research Laboratory (URL) experiments or technology development of prototypes.

RD&D provides input to system design and optimisation and makes essential contributions to siting, planning, construction and closure of repositories. It furthermore contributes to achieving a sufficient level of system understanding to allow an adequate evaluation of both operational and long-term safety. In addition, RD&D also addresses specific issues that are of concern to stakeholders.

Research of relevance for waste management is conducted by researchers and their teams either within WMO or TSO or in dedicated research entities (REs).

Planning of RD&D requires consideration of the programme needs over the sequence of steps and milestones with clearly defined goals at each of the milestones. The focus and level of detail of RD&D depends upon stage and size of programme.

2. Establishing an RD&D plan

This section sets out what needs to be considered when first establishing an RD&D plan. The Council Directive 2011/70/EURATOM (2011), Article 12 (1: a), f)) recalls: "*research, development and demonstration (RD&D) goals and activities needed in order to implement the national policies for the responsible and safe management of spent fuel and radioactive waste"* as obligatory part of the national programme for the management of spent fuel and radioactive waste (hereinafter "national programme"), covering all types of spent fuel and radioactive waste under jurisdiction of EU Member State and all stages of spent fuel and radioactive waste management from generation to disposal. Such RD&D plan is needed in order to implement national policies for the responsible and safe management of spent fuel and radioactive waste (Council Directive 2011/70/EURATOM, 2011).[4]

Member States have very different focus on SF and RW management activities, some are more advanced and are, for example, dealing with site characterisation and even construction activities for HLW and SF deep geological repository, while others at an early stage and are concentrating on activities related to establishment of surface and near-surface RW repositories. The size of the national programmes varies largely. Whatever the phase and size of activities, the approach to RD&D plans development has many similarities and is presented in this document. The themes which should be covered in the national programme, and RD&D plan, are linked with SF and RW production, and an interlinked management approach "from cradle to grave" involving:

- radioactive waste characterisation & processing (incl. separation, treatment, conditioning, packaging); storage of radioactive waste; and
- disposal.

The instructional questions developed herein (and the related templates contained in Appendix A) should be considered as purely illustrative. They should be used as a specialised guidance documents and therefore can be adapted to suit specific

[4] This should not be understood that by using this Guide, an EU Member State could be certain of meeting legal requirements of the Waste Directive, 2011 (Art. 12.1, f) when notifying the respective national programme to the Commission in accordance with Art. 13.

programme preferences and/or existing procedures and methods developed for RD&D planning on a national scale. The level of detail suggested is intentionally concise and brief, particularly in comparison to the comprehensive RD&D plans developed internationally for more advanced geological disposal programmes (AP). This should be sufficient to meet needs of ESP/SIP that may potentially have limited resources, or they have been only recently established (or are being working towards establishing) as mandated actors responsible for RD&D planning towards RW disposal on a national scale, respecting all needed steps from cradle to grave RWM.

There are also some differences related to RD&D activities between WMOs and TSOs, or broader regulatory function[5], as stressed in the SITEX-II report (2017). For instance, the TSOs RD&D is mostly intended to support safety function and to investigate safety issues with the objective to assess if the safety concept developed by the WMO fulfils the defined safety requirements. Meaning that, special attention is given to identification of questionable assumptions, knowledge gaps and incompleteness in the safety assessment performed by the WMO. These "challenging" activities are therefore more a "complement to" and "a verification of" rather than a "duplication of" the RD&D activities performed by the WMO[6].

2.1 Programme boundary conditions for waste disposal

Essential background to establishing and developing an RD&D plan is a clear description of the current national programme boundary conditions. That influences how implementation of disposal is anticipated, including the specification of the waste to be disposed of, who is involved (and respective responsibilities), timescales for key milestones in the stepwise implementation of the programme, and what other important factors need to be considered. Such conditions also identify needed other steps for safe RW and SF management. A common understanding of the programme boundary conditions needs to be established first as a basis for setting RD&D drivers, priorities and timescales (Andrei and Prisecaru, 2014).

The boundary conditions are specific to each national programme and may be set-out in quite some detail within government policy, or may be less formal commitments by different organisations to work towards a near-term objective that may lead e.g. to geological disposal. For those national programmes that have decided to take steps towards geological disposal, it is essential that the specific RD&D needs of the programme are framed in the national context. Likewise, for programmes that have yet to decide on geological disposal as the final solution for the safe management of their

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[5] Regulatory function is composed of regulatory authority which defines regulatory expectations and needs and is supported by TSOs with expertise function for regulatory decision.

[6] Whatever the role, all involved parties have to ensure "*to make arrangements for education and training for their staff, as well as research and development activities to cover the needs of the national programme for SF and RW management in order to obtain, maintain and to further develop necessary expertise and skills*" (Article 8, Directive, 2011) with sufficient financial resources (Article 9, Directive, 2011).

national inventory of radioactive waste, the national context may also be used to justify the current non-existence of a dedicated RD&D programme.

Figure 1 illustrates the context that is typically considered when developing an RD&D plan. The international content boxes (top of diagram) are common to all programmes and are based on six key questions to help summarise the national programme context: why, what, how much, when, how, who. The national content boxes (bottom of diagram) illustrate how aspects of each individual waste management programme may vary or how WMOs may need to consider issues specific to their national situation with respect to relevant TSO recommendations concerning of WMOs plans, funding, cost calculations or waste acceptance criteria (WAC) for given type of repository/disposal facility and release limits along the phases before relevant licensing procedure. The RD&D plan should summarise the national programme context and provide a reference to a document where it is described more comprehensively as, for example in a '*Lead Document'*, proposed as a generic structure for a programme with SF and all types of RW in the NAPRO Guide (ENEF, 2013, Section 9 and Annex VI, here appendix B). The Lead Document covers all elements of the article 12 (Contents of national programmes) from the Council Directive 2011/70/EURATOM (2011) including references and access to relevant supporting documentation.

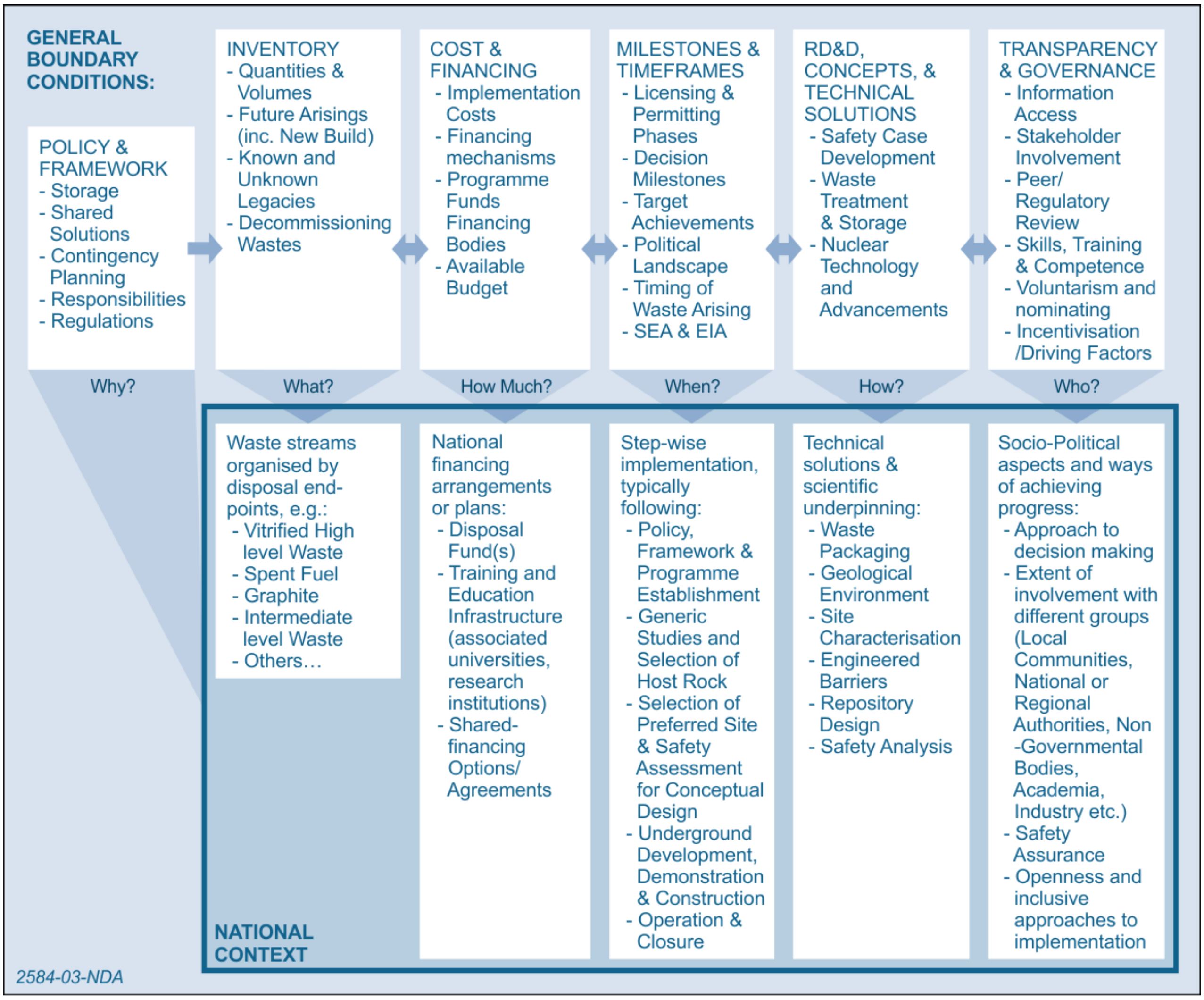

Figure 1 – 6 key questions to help summarise the national programme context: why, what, how much, when, how, who?[7]

European WMOs with relatively advanced programmes regularly update their national RD&D plans for geological disposal of radioactive waste (e.g., NDA, 2014; and Chapter 2 of IGD-TP, 2011) also with respect to TSO´s comments and recommendations on the WMO´s RD&D planning. In order to maintain the competence for performance of regulatory functions[8], also TSOs together with regulatory bodies develop their own RD&D, to address the issues/results presented by WMOs, but also issues identified by their own organisations. Such approach exemplifies good practice on how to

[7] Figure 1 from PLANDIS Guide (Beattie et al., 2015), p. 10.

[8] Performance of regulatory function is country specific and could be organised in different ways depending on the roles of involved parties. In some cases, the TSOs have to evaluate the safety related documentation from radiation and nuclear safety view, and the evaluation is part of submittal of implementer for obtaining the license, in other cases the regulatory authority organises all activities including the evaluation by TSOs. Some countries do not have TSOs, and regulatory function is performed by regulatory authorities.

contextualise an RD&D plan to the national programme boundary conditions (usually summarised at the beginning or introduction of the cited planning documents).

Typical questions addressed in a description of the programme boundary conditions are set-out below in Box 1. The Lead Document, as proposed in the NAPRO Guide (here Appendix B) would ideally complement a summary of programme boundary conditions used in an RD&D plan. For the purposes of the introduction of a RD&D plan, a high-level summary of a Lead Document would suffice to set-out the boundary conditions.

Appendix A provides a template (Template 1) to be used, together with the instructional questions in Box 1, to aid the development of a boundary conditions summary that may be used as part of the introduction to an RD&D plan.

BOX 1: Setting out **Programme boundary conditions** provides the requirements for how future progress in geological and other types of disposal, including all necessary steps in RWM, can be determined and provides the necessary context to allow RD&D needs to be identified and prioritised from different perspectives.

Example questions to address in a description of boundary conditions include:

<u>Government policy and framework</u>

- Has the national government set-out a commitment to support a geological disposal or other type of disposal?
- Has a process for implementation of a storage or RW disposal been agreed?
- Have commitments to timescales been made or key decision points agreed?
- Have mandated actors been established with clear roles and responsibilities for implementing the RW disposal? (E.g. Programme Owner, WMO, Regulatory authority, TSO/-s, REs and other key decision makers)
- Are other management options alongside geological or other disposals under consideration? (Long-term interim storage, take-back arrangements, shared repositories or other solutions)
- Is international collaboration in the field organised, and at which level?
- Is long term knowledge management organised?

<u>Wastes arising and current storage arrangements</u>

- Is there a developed inventory of the radioactive wastes (including future waste arising from ongoing and planned activities)?
- Are radioactive waste classifications/characterisation agreed upon?
- What are the current management arrangements for wastes?

<u>Costs and financing</u>

- Are adequate funding arrangements in place to implement geological disposal or another type of disposal?

- Is there a formal procedure to agree on cost estimation and financing mechanisms by key decision makers?
- Is the implementer a private company (e.g. nuclear power plant operator) or another entity (e.g., a state / a region -mandated agency)?
- How integrated are the waste management activities between waste generators (nuclear power plants), implementers and potential plans for new nuclear power plants – are there any important implications for the cost of the programme?
    - For NPP states: How integrated are the waste management activities between waste generators (nuclear power plants), implementers and potential plans for new nuclear power plants – are there any important implications for the cost of the programme?
    - For SIP states: How integrated are the waste management activities between waste producers (operational waste and waste from decommissioning of accelerators, research reactors, medical sources, irradiation sources (gamma, neutrons), spallation sources and orphan sources, including historical waste) and implementers– are there any important implications for the cost of the programme?

<u>Stepwise approach to implementation</u>

- Is there a process for identifying or agreeing the site of a geological disposal facility / any other type of disposal? For example, has a preferred geological rock type or near-surface geological formation been decided, is there an obvious site that could be subject to geological screening for suitability, has any site been identified and/or approved/rejected?

Have the siting criteria´s been specified? <u>Multi-barrier concept and technology solutions</u>

- What is the approach to developing a safety concept for geological disposal / any other type of disposal (intended safety function(s) of multiple barriers and your proposed design / technology solution)?
- What is the current status of safety case development (e.g. are there plans to produce a generic safety case or is there already a completed safety case)?

<u>Transparency and governance</u>

- Is there a process for co-working and/or maintaining public confidence on national level or with communities impacted by geological disposal / any other type of disposal? For example, how are local communities involved; are there financial incentives for a host or relevant local communities? Has a national communication plan or programme been formulated?
- How is the regulatory authority (through TSO´s) influencing the RWM decisions made by the implementer (WMO)?
- How are other authorities involved in the decisions? Is there any inter-governmental body established to coordinate the process?
- In order to build confidence in the current and planned RWM processes, has an IAEA IRRS (Integrated Regulatory Review Service) mission being asked for?

- Is there a process for how important decisions will be made? For example, national/local voting, regulations, appointed committee of experts, regional/local consensus?

2.2 Timeframes and milestones

For any disposal programme it is important to set-out timescales for implementing geological or other type of disposal which cover the main programme milestones. These should be realistically set during programme establishment, and they are often related to national regulatory requirements for demonstrating the required level of safety understanding at different phases of implementation (via the development of a safety case). Implementation of geological or other disposal types typically follows a stepwise approach with timescales for achieving publicly acceptable and regulatory approved operations in the order of tens to hundreds of years. Normally, the iterative process of documentation approval is established, in which during different phases of licencing process the WMO submits the safety documentation which is then assessed by TSO from radiation and nuclear safety aspect and approved by regulatory authority (licensing process). It is also indirectly shown in the Figure 2.

Across Europe, many repositories for low and intermediate level radioactive waste are already in operation and the first disposal facility for spent fuel (and HLW) is planned to be put into operation shortly. The timing of successive steps of implementation to achieve such milestones often varies between RWM programmes. However, the types of activities carried out within the successive phases are common to most programmes, enabling effective transfer of knowledge and ever-increasing coordination of RD&D activities. Enough flexibility should be kept in early phases of the programme. Therefore, a broader range of RD&D activities is necessary (e.g. consideration of alternative host rock formations and geological characteristics required, repository lay-out and engineered barrier systems).

Figure 2 illustrates the typical phases of implementing a RW disposal – with a focus on early licensing phases (there are different licensing procedures in particular countries: national programmes should be adopted accordingly) and on the development of a relevant safety case. It includes initiation of a programme, site selection, site characterisation, repository construction, operation and closure (EURAD Roadmap Guide, 2021). The post closure period is just indicated and not really addressed. Note that the timescales in Figure 2 are purely indicative and should be adapted to suit individual programme needs, and extended if programme decisions are likely to be postponed or interrupted. Specific timescales could be replaced by defining specific milestones and goals needed for progression to subsequent phases by decision makers. Also, the licensing process with different licences is just an illustration. In reality, the licensing process differs between MSs and depends on adopted licencing framework.

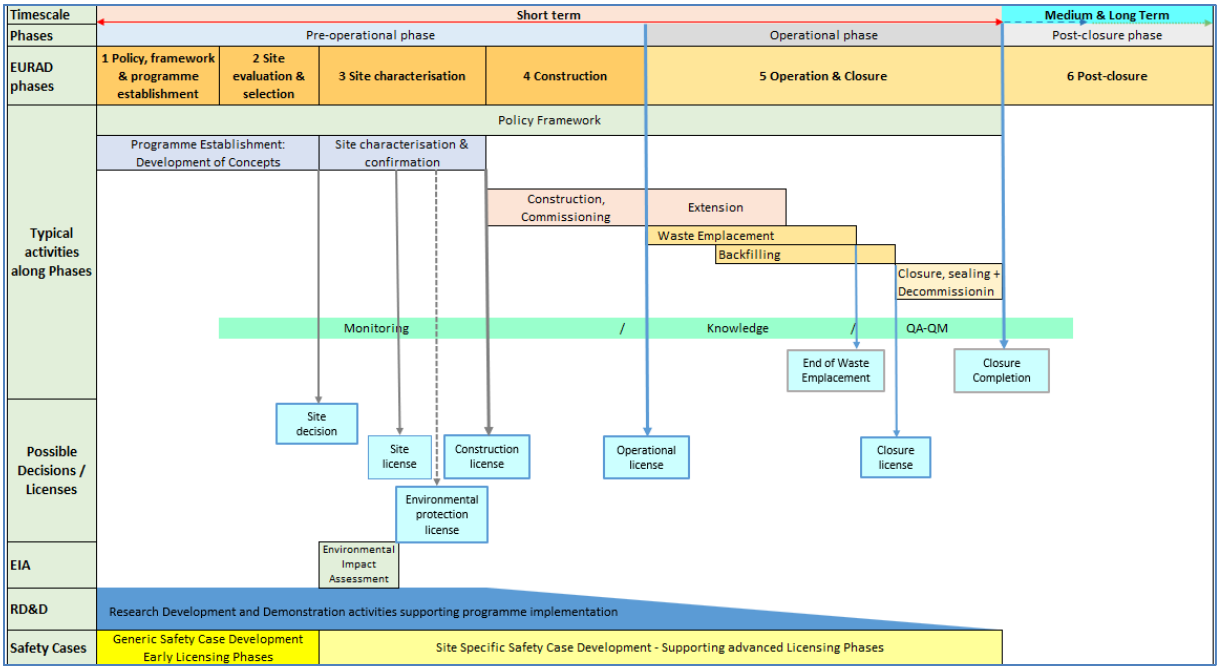

Figure 2[9] – Illustration of preparatory and implementation phases of RW disposal[10]

A safety case must be available at each licensing step in a prescribed format – usually the licences are issued for site, EIA consent, construction, trial operation, operation, and closure. It has to be stressed that the licencing process differs from country to country and some of licences could be merged or omitted. The scheme does not consider time needed for licensing decisions (period between submission of the application until the issue of a decision) as the relevant periods are different in MSs, depending on the national legal framework.

A licencing procedure (preparation and realisation) for any SF and RW management cycle should be performed as an interplay between WMO responsible for obtaining the

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[9] The breakdown (in Figure 2) has been developed by considering phases described or commented by

(i) IAEA Planning and Design Considerations for Geological Repository Programmes of Radioactive Waste (IAEA, 2014a), and also WENRA SRL.

(ii) EURAD Founding Documents (EURAD Vision, SRA, extended Roadmap (EURAD 2019), IGD-TP Strategic Research Agenda (IGD-TP, 2011) and IGD-TP Vision report (IGD-TP, 2009). We have added for the target audience to the PLANDIS Guide and consequently PLANMAN Guide, we have also intentionally added the preparatory phase: 'Policy, Framework and Programme Establishment' by drawing from indicative timescales included in (iv) JRC EASAC policy report no. 23 (JRC, 2014).

A full comparison of the above-cited references is included in Appendix C to show how we have interpreted the terminology and description of the phases described herein.

[10] Figure 2 is a composite of several figures: Figure 2 from the PLANDIS guide (Beattie et al., 2015) and similar Figures from NEA, and WENRA, modified to be in-line with the EURAD SRA and Roadmap. The licencing process is country dependent and scheme in Figure 2 is just an indication of possible situation.

license and regulatory authority (with TSOs) performing regulatory function[11] and responsible for license granting. How the licensing process is established differs from country to country.

Below typical RD&D activities relevant for different phases of disposal establishment are described in more details (based on the experience of advanced programmes), see the Roadmap Theme Overviews (EURAD Roadmap Guide, 2021).

1. Policy, framework and programme establishment

This phase covers a selection of RW disposal options at a national level in the frame a government policy / commitment by national government to pursue and support RW disposal. This often includes the creation of a waste management organisation (WMO) and establishing the appropriate regulatory oversight (paraphrase of IAEA, 2014), including relevant TSO to support the regulatory authority.

According to the Council Directive 2011/70/EURATOM (2011), Article 5, the regulatory framework shall be established and maintained with a national legislative, regulatory and organisational framework for SF and RW management that allocates responsibility and provides for coordination between relevant competent bodies. In this phase, also competent regulatory authority shall be established to ensure that together with support of TSO it is performing the regulatory function and is effectively independent.

National safety criteria and arrangements for safety of SF and RW management and safety documentation should be elaborated in this phase and should be focused on meeting regulations for the safe storage and potentially conditioning/packaging of waste so that it is compatible with the options for the safe management of radioactive waste, including RW disposal (also geological disposal if needed). The licensing system with the interplay between WMO and competent regulatory authority should be defined with prescribed conditions for safe SF and RW management. The responsibilities of involved bodies in different steps of SF and RW management should be allocated and national requirements for public information and participation should be defined. This phase may also consider the establishment of a regulated financing mechanism[12] and a financing system to ensure that prioritised RD&D can be completed. The financial estimations of the RD&D activities as part of the national programme are evaluated also by authorities, sometimes also by the regulatory authority in line with the national legal framework.

2. Site evaluation and selection

A broad range of RD&D studies are required to support effective decision making on the approach to site selection, concept selection and site characterisation. Safety-documentation produced in this phase is typically aimed at demonstrating broadly the

[11] Regulatory function is a concept, developed in the SITEX.Network, https://www.sitex.network/, where regulatory authority with support of TSO is performing the functions required by licencing process.

[12] This mechanism has to be established and run during RW origination and or very soon after RW origination.

relative expected compliance to safety criteria of disposal for available geology and concept scenarios to support effective decision making in relation to siting. Sufficient safety related information should be provided to the competent regulatory authority to allow for the important decision in this licensing process. The established communication and supervision rules and practices between a regulatory authority (including TSO, if relevant) and WMO are in this phase implemented and refined. Preliminary safety analyses should support the site and concept decision and future characterisation needs. Consideration for societal aspects may begin in this phase, for example consulting and involving national stakeholders (local communities, local politicians, civil society organisations etc.) on the process for site selection. A Strategic Environmental Assessment (SEA) may be undertaken in this phase in order to assess the environmental impact of the planned facility.

3. Site characterisation

This phase includes surface-based investigation of a potential site or sites (prior to going underground) which may include geology-specific RD&D studies to aid final site-selection and concept-selection. Safety documentation produced in this phase is typically adapted to site-specific (or geology-specific) conditions and will address local community requirements (in addition to national stakeholders previously involved in phase 2) to support decision making on final site selection and concept selection. The safety case with Safety Analyses Report for site license and for construction license is in the licensing process thoroughly evaluated by competent regulatory authority from radiation and nuclear safety aspect and if all questions are successfully resolved, approved by the competent regulatory authority[13]. This phase includes refinement of engineered barrier concepts, preliminary engineering design for constructability and repository architecture, establishment of baseline site conditions, and regulatory approval of a continuation of the investigations from an underground facility at one or more sites (IAEA, 2013). The planning of this phase may integrate an Environmental Impact Assessment (EIA) procedure to assess the environmental impact(s) supporting the site(s) selected for building the facility.

4. Construction

This phase will use detailed site characterisation from previous step and extend a design testing (including site-specific underground testing if applicable). This will include the construction of disposal facility with support structures, access ways (shafts or ramp) to the host rock in case of geological disposal, testing of excavation and construction techniques, formulation of a detailed repository design, and the establishment of a detailed operational safety case. All this leads to seeking of regulatory approval to proceed to facility construction at the selected site (IAEA, 2013). Detailed design work, and further development of license-oriented operational and

[13] The license can be adopted by different authorities, depending on the national regulatory framework. For example, the construction license could be issued by regulatory authority, or by responsible ministry where regulatory authority is giving the consent.

long-term safety cases will continue throughout construction of the disposal facility. Via licensing process, where in an iterative procedure usually WMO submits the safety documentation to the regulatory authority, the documents are evaluated from radiation and nuclear safety aspect and approved (or providing the consent). It is likely that national regulatory licences would be staged during construction, with a first step of in-situ testing of a non-active pilot facility. In case of geological disposal, this process would be achieved by progressive excavation, construction and fitting out of emplacement areas, leading to the decision to begin emplacement of waste. The safety case at this phase is mature and is often used to support licensing of a site. This phase may consider an update of the EIA procedure supporting the decision for construction.

5. Operation & closure

These phases include the period of waste emplacement and any extended period of operation (open access ways and monitoring) beyond completion of emplacement. Emplacement of waste in a disposal facility may go in parallel with excavation of new disposal tunnels, assuring that mining activities and waste emplacement are physically and regulatory separated. Thereafter, the remaining works include sealing and closure operations leading to the post-closure phase and the decision to cease active control (IAEA, 2013).

Within these overall phases, disposal programmes must consider what the short-term and long-term requirements are with respect to RD&D needs. RD&D performed by regulatory authority and TSO shall also be planned in parallel to the RD&D programme of repository operator (usually WMO). Typically, RD&D plans are developed including medium term perspective and then they are reviewed and updated periodically, usually with a 5 to 10 year forward horizon. Typical questions to be addressed when deciding on the long-term and short-term timescales relevant to RD&D planning are set-out below in Box 2.

During this phase a safety case and supporting safety assessment is updated by the operator, as necessary during operation of a disposal facility and preparation for closure. During the operation the safety case and the supporting Safety Analyses Report have to be submitted to regulatory authority for approval periodically. The same is required whenever a significant change appears.

6. Post-closure

The post-closure state is out of scope of this guidance for RD&D planning. Despite this fact, institutional control measures, including post-closure monitoring, has to be considered by the EU MSs (Council Directive 2011/70/EURATOM, 2011; Art. 7(3)). However, the disposal is a passively safe solution, therefore a long-term institutional control is limited. Guidance can be found in (ENEF, 2013) on how to capture this topic in the national programme. If any monitoring would be required, it would need to be implemented during the operation and closure stage. The post-closure phase is a part of the licensing process, and the documents have to be approved by the regulatory authority.

BOX 2: A decision on **Timescales for RD&D planning** is often coupled to planned submission of safety case documentation relating to requirements for regulatory approval at different phases of implementation. These timescales provide a framework for near-term and long-term programme milestones that can be used to prioritise identified RD&D needs. Such requirements are typically set-out by national regulatory authority/-ies or in government policy for how safety should be demonstrated at specified milestones through successive phases of implementation. Typical questions to be addressed when deciding on timescales for safety case development (or other specified regulatory approval requirements) include:

<u>Short-term Requirements</u>

- What safety documentation is currently produced in relation to safe management of radioactive waste?
- Are there existing procedures/processes for demonstrating safety of radioactive waste? For example, demonstration of safe packaging and conditioning of radioactive waste so that it is both suitable for storage and for disposal?

<u>Long-term Requirements</u>

- What safety regulations exist (or are currently being established) at a national level in relation to geological disposal or any other disposal?
- Are there any (planned) or existing requirements to develop safety case documentation / submissions at key milestones of the programme? If, how often do they need to be updated?
- Are there any regulatory requirements for RW retrievability and/or recoverability?

Template 1 in Appendix A illustrates how to set-out key milestones of the programme to inform prioritisation of an RD&D plan.

2.3 Cost and financing

An important consideration throughout the RW disposal programme will be the ongoing management and funding for financing of the disposal programme and eventual construction and operation of a disposal facility (including the cost of the RD&D programme in support of the safety case that may run throughout all these phases). At the beginning of the programme, the focus will be on establishing a funding mechanism by which the necessary financial resources are set aside, most usefully in a segregated fund, to cover all future costs (IAEA, 2007a). The cost of a disposal programme is affected by many factors, including the type of wastes to be disposed of (e.g. the waste inventory), the timing of the waste production, the need for storage arrangements, and the timing and duration of different phases of repository implementation (IGD-TP, 2011). In the frame of EURAD WP12, the Guidance on Cost Assessment and Financing Schemes of Radioactive Waste Management Programmes (EURAD D12.4, 2022) has been developed describing the cost assessment process with methods for estimating the costs and possible financing schemes for disposal establishment. The guidance provides also several practical examples of cost estimations for different types of waste and different types of disposal facilities.

There are no specific RD&D tasks for prioritising of RWM programme relating to cost estimates and financing scheme. Ongoing development tasks that could be undertaken through involvement in international collaborative projects include:

- Cost benchmarking – advanced programmes often undertake or participate in benchmarking studies to compare cost assessment methodologies. EDRAM e.g. completed a study with the objectives of establishing a common list of cost items for disposal projects and of funding and planning the related accounting and financing mechanisms (EDRAM, 2014).[14]

2.4 Safety case as driver for RD&D

The most common approach for developing an RD&D plan is to use the safety case(s) and the supporting safety assessment as the drivers to determine the necessary tasks to prioritise.

This driver is particularly important for early-stage and small inventory Member States. A preliminary safety assessment or even disposal options feasibility study might be developed to understand what is possible and to identify the specific RD&D needs at a national level, compared to what can be used from the existing knowledge base. Such approach was successfully used in the Netherlands, where implementer COVRA develop the RD&D research plan (Verhoef, 2011) without a specific site and whilst also considering other solutions (share repository). A list of RD&D programmes in some countries is given in Appendix D.

The safety case is the collection of scientific, technical, administrative and managerial arguments and evidence in support of the safety of a disposal facility (IAEA, 2012; NEA, 2013). An initial safety case is recommended to be established early in the course of a disposal programme to support periodic development of the available knowledge base and document state-of-the-art underpinning of RW disposal. Such a preliminary safety case may cover a broad range of disposal options and siting scenarios considered by the programme (for example, a range of engineered barrier

[14] https://www.edram.info/joint-activities?tx_news_pi1%5Baction%5D=detail&tx_news_pi1%5Bcontroller%5D=News&tx_news_pi1%5Bnews%5D=6&cHash=6ec8fe89af97d2bb5fb94162e150a222

systems to suit inventory waste types and available host rock types or geological formations).

This can help to:

(i) identify issues significant for safety;

(ii) compare programme options and provide quantitative safety information to inform important disposal system development decisions; and

(iii) provide a basis for communicating and building broad confidence in the safety basis of disposal and competence of the WMO to implement the programme successfully.

Typically, generic safety case documentation would be developed during either the 'Policy, Framework and Programme Establishment' and/or 'Site evaluation and selection' phase. Thereafter the documentation should evolve with more detailed and site-specific information, continually working towards submission for key licensing phases (i.e. site-specific regulatory permits for site investigations, demonstration, construction and operations). Throughout this timeframe, the RD&D programme associated with the disposal programme will evolve, at each phase focused on addressing the significant issues and the generation of data and information required to support development of the safety case (Zuidema and Johnson, 2013). The identified RD&D needs in support of long-term safety (together with other important drivers) are documented within the safety case, including an explanation for how these needs will be addressed by the future programme. (IAEA, 2012; OECD/NEA, 2013). There must be an understanding, by all stakeholders, of what is to be broadly achieved at each phase (i.e. key milestones) in order to preserve credibility and confidence in the stepwise approach. in terms of information and confidence, to justify proceeding to the next phase of development (OECD/NEA 1999).

The safety case is often a key input to support the decision to move through successive phases of a disposal programme. As such, the RD&D needs identified at each phase predominantly reflect those prioritised by the waste management organisation and the regulators to achieve the safety requirements for implementing disposal. Different challenges will arise during different phases of implementation (for example, new information/data, changes in policy or implementation approach, education and training tasks, and specific concerns from the regulators and local communities) that change priorities and may not be entirely safety case driven. However, a large focus for most programmes is likely to be demonstrating safety of the disposal system during post-closure timescales (e.g. long-term durability of waste packages, evolution of the engineered and natural barriers and their contributions to long-term safety).

From the point of view of different end-users of the safety case documentation and importance from a WMOs perspective with respect to RD&D state-of-the-art and identified RD&D needs, there are a number of additional considerations that must be taken into account when preparing the safety case documentation (OECD/NEA 1999). These include:

- Transparency – a safety case and its underpinning references should be both clear and understandable to the intended audience(s);

- Traceability – for more technical audiences, it must be possible to trace all key assumptions, data and their bases;
- Openness – remaining uncertainties and open technical questions that may affect safety or confidence in safety should be discussed; and
- Peer review – both internal and external peer review are valuable tools for enhancing confidence in a safety case.

In this process the regulatory authority with support of a TSO is involved through the review of submitted documentation. The provided information has to be sufficiently detailed to allow for informative decision to be made in the licencing process. In this independent review of safety case and supporting safety assessment the regulatory authority with a support of a TSO has to provide additional requirements for RD&D if needed and if all questions accordingly resolved, issue the license. The regulatory authority with a supporting TSO has the obligation to communicate to different parties, including the general public, how the regulatory requirements have been fulfilled in this process.

It should be noted that a regulatory authority may decide or be required to develop its own RD&D strategy and conduct independent RD&D tasks where it considers that there is a need for additional studies beyond those prioritised or undertaken by the WMO. Either, this may involve RD&D tasks undertaken jointly by the regulatory authority and WMO, or there may be situations in which the regulatory authority needs to conduct independent RD&D work in order to perform a critical and objective review and assessment.

Typically, the broad categories of RD&D considered include the following (reproduced directly in-part from Zuidema and Johnson (2013)):

- Nuclear technology to develop and maintain a national waste inventory. This involves characterising the various waste types, developing waste acceptance criteria and developing model predictions about future waste arising.
- Geological science focusing on regional geology to understand long-term geological evolution, and on the detailed understanding of the relevant properties of potential host rocks. This also includes the demonstration that the important phenomena are sufficiently well understood, in some cases, like for geological disposal, through full-scale experiments in an underground research laboratory (URL).
- Site characterisation and characterisation of key rock properties through the use of geophysical techniques, hydraulic and geochemical measurements in boreholes and seismic investigations leading to the selection of the preferred site. As part of the full development of the selected site, construction of a URL will follow to allow detailed in-situ confirmation (and/or refinement) of some of the critical data on rock properties and state parameters for construction of the repository.
- Engineered barriers (overpack, backfill, seals, etc.), focusing on material properties and understanding of how different barriers can help prevent or limit the release of radionuclides and their migration to the undisturbed host rock. Emphasis is usually, through understanding and demonstrating specified safety

functions of each barrier as part of an integrated multi-barrier disposal concept. The long-term stability of the waste packages before emplacement in the disposal need to be understood, not to compromise the engineered barriers.

- Repository design (incl. construction, operation and closure) covering repository layout and development of practical and feasible procedures to repository implementation. Focus is often related to demonstrating technology readiness and performance to specified criteria, particularly full-scale testing in-situ once underground investigations commence. Scope often includes the design of the transport system and surface facilities, in addition to underground facilities and certain metrics of these designs such as the time and cost impacts.
- Safety analyses and performance analyses (methodology, tools, compiling all the information, drawing the conclusions). The focus is often on assessing safety to understand and illustrate the range of possible behaviours of the disposal system, to build confidence in this understanding, and to identify knowledge gaps and uncertainties. It is important to ensure that the timing and manner of the SEA and EIA procedures are correlated with the level of data and information documenting the safety case.

The above broad categories of RD&D should be structured and prioritised according to the specific needs and phase of the individual geological disposal programme of the ESP and or of the SIP. Terminology and exact RD&D task headings vary from programme to programme. Consistency with both NEA and IAEA guidelines provides adequate international consensus on the main elements of a safety case that should drive the majority of prioritised RD&D (NEA, 2013; NEA, 2020).

Figure 3 (reproduced from IAEA (2012)) illustrates the components of the safety case that should be considered.

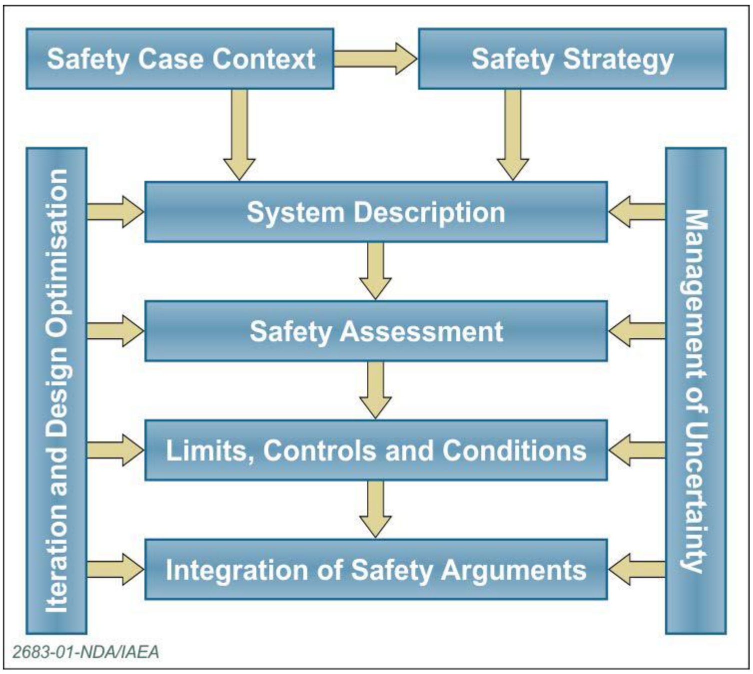

Figure 3 - Components of a safety case according to the IAEA (IAEA, 2012)

In order to conduct an RD&D programme for a safety case, it is essential to have adequate resources and expert competence of skill held by programme managers covering each of the main areas of the disposal system. In addition, the programme managers need to also hold a broad overview and understand the context of the RD&D in their areas within the entirety of the safety case and disposal system. This is particularly important to be able to conduct the 'Integration of Safety Arguments' as illustrated in Figure 3. Equally important is that the regulator (or mandated TSO) acquire adequately high-level competence to judge the validity of the safety case presented by the WMO.

2.5 Repository implementation as research driver

RD&D programmes are often structured according to the information or data needs associated with the assessment of different components of a disposal system. Available international state-of-the-art information from a completed RD&D is used at each phase to develop a description of the disposal system, its likely evolution, and to assess safety performance against specified criteria. The outputs of such approach enable an assessment of where there are high uncertainties associated with parts of the disposal system, which may be improved from further RD&D.

Research drivers include also optimisation of various steps in waste management programme, including repository siting, design, construction, operation, closure and post closure phases. Besides safety optimisation considers also economic and sustainability arguments.

2.6 Entities involved in RD&D and their responsibilities

The approach to the development of RD&D plan varies between countries. In some countries this is the responsibility of relevant ministries (based on technical inputs of WMO, other RW generators, and regulatory bodies with TSOs), in some others this is the responsibility of the mandated implementer, usually a WMO. The organisations and individuals who may be involved with planning, managing or conducting RD&D may vary beyond this and be very specific to the individual national programme. The roles and responsibilities may therefore need to be framed in the national context and clarified in the boundary conditions of the disposal programme. Entities involved in RD&D typically comprise:

- Mandated WMOs with responsibility for waste management and / or implementing RW disposal. This includes responsibility for defining, financing or managing RD&D programmes carried out at national or regional levels. Managers should have a good oversight of the broad categories of geological disposal, can appropriately prioritise and coordinate needed RD&D efforts, and can be responsible for maintaining the required skills. They must have a competency to act as the main points of contact for decision makers and being responsive to general stakeholders who may raise questions or have concerns about specific RD&D issues. Their critical work is usually associated with the integration of RD&D outputs through the development of safety cases related to progressive phases of implementation.

- Nuclear power plants (NPPs), either operating or in a state of decommissioning, or holders of nuclear material (e.g. sealed radiation sources) are all entities responsible for the safe management and interim storage of nuclear material. Responsibilities often include a contribution towards the financing of geological disposal or any other disposal, relative to their proportion of the waste inventory, which may include a contribution towards the RD&D programme. NPPs and holders of nuclear material are also responsible for understanding and accessing information about RD&D that affects their work on safe storage. This will typically be the provision of supporting development of accurate inventory information, developing understanding of current and future waste characteristics, timescales for when a repository may become available, conditioning and packaging advice (and waste treatment options), and support of interim storage strategic decisions.
- Regulatory bodies and/or their Technical Support Organisations (TSOs) who can provide independent assessment or checking of RD&D activities and assure that all related questions are appropriately addressed and thought off. Involvement of regulatory function assures to maintain a clear and responsive approach to engagement with regulators and/or theirs TSOs and to establish external assessment/checking (either by a committee of experts or selected and respected individuals) to maximise confidence in the programme.
- Research entities (REs – research institutions, academics and learned societies) that are active in the broad RD&D disciplines of geological disposal or any other disposal. Their role in a generic RD&D programme may range from complete day-to-day management of the programme to a minimum conduct of one-off pieces of work, or providing an influence and an objective opinion to other stakeholders or decision makers on scientific credibility and strategic aspects of the programme (e.g. forming part of an independent technical advisory role or assurance role); and
- Local communities / civil society, including civil society experts – addressing site-specific or local community requirements that may influence how geological disposal or other disposal is implemented.

Considering a broad range of entities and their individual involvement and influence on RD&D prioritisation helps to demonstrate the totality of work, identify upfront those that need to be involved with the outputs of the RD&D activities, and sets out clear responsibilities of various organisations in relation to the safety of radioactive waste management.

2.7 Methodology for prioritising RD&D

It is important that RD&D activities be appropriately prioritised to demonstrate that the right things are planned at the right time and that key outputs from RD&D are available when they are needed. The prioritisation scheme and relative importance of possible

RD&D tasks will vary, depending on the perspective of each entity named above and on programme current phase. From the perspective of the WMO, the prioritisation scheme will be dominated by implementation needs and the safety case (including safety cases in support of interim storage and waste conditioning), which is coupled to the step-by-step interaction process with the regulatory authority or mandated TSO. An important part of the prioritisation scheme will be to link identified priorities to the specific drivers for conducting RD&D, including those that originate from the perspectives of the organisations, such as regulatory authority or mandated TSO, research entities, NPP owners, non-NPP radioactive waste producers, local communities or civil society. Example questions to address when considering the drivers used for assessing priorities for planned RD&D activities are set-out below[15] (see Box 3 below).

BOX 3: To allow an RD&D plan to be robust to scrutiny and be 'needs driven' it is essential to set-out the ***METHODOLOGY FOR PRIORITISING RD&D*** that has been used (or is likely to be used / developed in the future). Example questions to address when considering how RD&D has been appropriately prioritised include:

Planning and prioritisation of RD&D activities

- What is the driver for the RD&D activity specified (e.g. safety case, implementation needs or other)?
- What do you need to know by when (focussing on information needed for programme implementation)?
- How important or significant is this activity?
- Is the knowledge available/are RD&D programmes ongoing in other countries/in your country with other actors?
- What is the 'knowledge gap'?
- What is needed to do to fill it?
- Is there any interest in some other countries to fill the gap together?
- Are there sufficient resources, infrastructures and competences?
- How long will it take?
- How urgent is the task?

Scales to judge or rank the significance of knowledge gap: The below matrix illustrates how a simple High-Medium-Low scale can be used to judge RD&D priorities.

[15] In prioritising RD&D tasks, the aim is to reduce the 'knowledge gaps', which are the gaps between our current knowledge and that which needs to be acquired. As a relative measure of the knowledge gap Scientific Readiness Levels (SRLs®) can be assigned to the tasks in the RD&D programme. SRLs are an indication of basic mechanistic understanding. They are used in the consistent assessment of scientific maturity and in the consistent comparison of maturity between different areas within a technical programme. In this way, appropriate effort can be channelled to the development of the science underpinning early stage alternative disposal concepts to bring them to an appropriate scientific readiness to facilitate future concept selection, i.e. to closing the gap between the current SRL and that required to make a decision. Normally, RD&D leads to an increase in the SRL for a given task.

	High	**Medium**	**Low**
Impact	Significant to that particular driver	Some significance, but unlikely to be determinant	Of little significance in the current phase
Knowledge Gap	Little relevant information exists	Information exists, but there would be benefit in carrying out further work in the current phase	There is a considerable body of relevant knowledge that is largely sufficient in the current phase
Urgency	The task should be progressed within the current phase	The task could be progressed in the current phase would be of benefit	The task need not be started during the current phase, or cannot be started (e.g. site-specific)

The above example questions (reproduced from (NDA, 2012) and (NDA, 2014)) are further illustrated in Template 2 of Appendix A.

2.8 RD&D competence management, contractual mechanisms and advisory support

An RD&D plan should include identification of the management activities (particularly competence management), types of contractual mechanisms envisaged to conduct RD&D, and advisory and review (and scrutiny) arrangements in place. As part of this overarching aspect of the RD&D plan, it is important to consider the following (see also Box 4 below):

- Competence management – Individuals involved with the specification, prioritisation, delivery and evaluation of RD&D activities need to be suitably qualified. During early programme phases (for example during 'Policy, framework and programme establishment' and 'Site evaluation and selection'), the organisation(s) responsible for conducting RD&D need to plan for appropriate development of a skilled and competent workforce. This activity may include considering over the short-term (immediate 5 to 10 year forward look) who is available to support RD&D activities and what training measures need to put in place to optimise their competence in a particular topic.

- Contractual mechanisms for completing RD&D – Organisational structures and mechanisms for contract work external to the WMO vary across programmes, ranging from completely open tendering of scopes of work to international suppliers, to programme alignment with a preferred technical and scientific organisation capable of completing the majority of RD&D tasks. It is important that the organisational structures between WMO and RE are long lasting and characterised by confidence to assure that RE operators have sufficient knowledge on the needs of the WMO.
- Advisory support and scrutiny / checking – In consideration of the overall management and wider endorsement of prioritised RD&D, it is common to establish roles (either internal or external to the implementing organisation / regulatory authority) to provide independent scrutiny and advice on RD&D activities (as prioritised from the perspective of the WMO). This activity may include establishing or formally appointing advisory panels or committees or may simply be the identification and networking with international experts to support or be involved with particular RD&D activities (as a form of peer review).

The regulatory bodies and/or their TSO´s also need to build-up an organisation that has the needed infrastructure, competencies, expert networks and budget resources to perform evaluation of the safety cases, ask for scientific results verification and perform independent research where necessary.

An essential part of programmes making a first attempt to set-out RD&D priorities should be to consider the potential for technology transfer and knowledge transfer from more advanced waste management programmes – which can be used to support all three of the overarching aspects above. With over 40 years of experience and completion of RD&D towards geological disposal internationally for the disposal of a range of waste types in different geological settings, there is a huge opportunity for ESPs or SIPs to benefit from this knowledge base. In an RD&D plan, international organisations and other national programmes should be identified who are best-placed to support cooperation and collaboration on RD&D (e.g. utilisation of memoranda of understanding, involvement in EC or international collaborative projects, or bilateral/multi-lateral alignment with programmes with similar boundary conditions).

BOX 4: It is essential that ***MANAGEMENT ACTIVITIES*** are included within a plan of RD&D activities to enhance confidence in the likelihood of its successful implementation. Example management questions to address when developing an RD&D plan include:

Competence management

- What training or specific development activities is in-place to develop or maintain a skilled and competent workforce to support your RD&D programme? It could be specified for both: WMO and TSO.

- Is there a mechanism to nationally support higher education (MSc and PhD programmes, vocational training) in RWM to support recruitment base for WMO and TSO organisations?
- What are the needs of regulatory function for review and licensing process?

Contractual mechanisms for completing RD&D

- Are there opportunities for collaboration in joint international programmes?
- Are there opportunities for technology transfer or knowledge transfer direct from other programmes that would save time and money?
- Is there an organisation or set of organisations that have the required competency and skill base to successfully conduct prioritised RD&D?

Advisory support and scrutiny

- Have you established internal assurance and governance arrangement for scrutiny of conducted RD&D activities?
- Have you established any advisory panels to support your RD&D plan, or sought input on your RD&D plan from experts or key organisations within the international radioactive waste management community?
- Do you participate to IAEA Integrated Review Service for Radioactive Waste and Spent Fuel Management, Decommissioning and Remediation (ARTEMIS) or IRRS (Integrated Regulatory Review Service) inspections?
- What is the approach of the regulatory function to the review of safety case? Are the result of safety assessment recalculated or is there another approach for review?

The above example questions can be used to guide responses, particularly stating if open international collaboration (technology transfer or knowledge transfer) is the potential source of information.

2.9 Quality Management System

Implementation of a Quality Management System (QMS) is recommended by the IAEA (IAEA 2006; IAEA, 2016b) and Council Directive 2011/70/EURATOM (2011) for the whole RWM programme. The WMO should design, establish, document, maintain, assess, store and continuously update a management system during all the activities to be carried out from site characterisation to closure of the disposal facility and, as required by the regulatory authority, post-closure activities. Independently of a kind of radioactive waste to be disposed of, such a system consists, in particular, of the organisational arrangements for the disposal project implementation, planning of significant activities to be taken during every step, development of operational and control procedures, including RD&D activities. The management system integrates different elements, including safety, health, environmental, security, quality, human and organisational factors, societal and economic elements, so that safety is not compromised. In doing so the graded approach should be used including criteria like safety significance and complexity of the organisation, potential associated impacts and consequences. The documentation of the management system shall be controlled, usable, readable, clearly identified and readily available at the point of use. Due to many interactions with vendors, contractors and suppliers, the management system shall include arrangements for specifications, monitoring and managing the supply of services that may influence safety.

The long timescale of the implementation process (i.e. several decades or centuries) requires confidence in the stability and knowledge management of the implementing organisation such that the safety strategy and safety relevant information will be preserved irrespective of potential future changes in organisations or responsibilities.

The Authorised institution of a Member State (e.g. WMO) should implement and develop a system (e. g. the Integrated Management System) in accordance also with the Council Directive 2011/70/EURATOM (2011) requirements as well as with relevant national legal framework and with principles of QM like:

- tiered approach;
- transparency;
- implementation the relevant QM/QA principles from the top to bottom;
- application of data management from the bottom up;
- implementation of requests of relevant regulatory bodies, and
- implementation of requests of relevant international standards[16].

3. Themes of RD&D and related programme implementation activities

A RW disposal programme contains a broad range of technical activities, which include a component, defined as RD&D. Planning of RD&D tasks must therefore be related to key programme activities or particular drivers. Table 1 illustrates the relations between these broader programme activities across programme phases with RD&D priorities indicated for each phase. Table 1 follows the themes and phases of EURAD Roadmap (2021). The text below summarises the highlighted programme activities (note that more detailed explanations are provided in (IAEA, 2014) and Theme overview documents produced within EURAD programme). It also indicates the types of RD&D activities that are typically prioritised in relation to these programme activities.

There is a vast amount of RD&D results on disposal of radioactive waste available internationally. In order to make best use of the available state-of-the-art knowledge, the RD&D prioritisation approach should be clear and should aim to quickly identify relevant topics.

The prioritisation is made by a MS taking into account the context, boundary conditions of its own National Framework, Policy and Programme. When EURAD programme was initiated a gap analyses and prioritisation of RD&D needs has been carried out and documented in EURAD Strategic Research Agenda (EURAD SRA, 2021). EURAD

[16] Like these: relevant IAEA Safety Standards and principles of: QMS (EN ISO 9000/2015), Quality of an organisation (EN ISO 9004:2018), EMS (EN ISO 14001), EMS (EN ISO 14001), and OHSAS (BS OHSAS 18001). Because it is probable that in future each of national WMO should be certified for Integrated Management System (IMS) by relevant national nuclear safety regulatory authority.

SRA describes the scientific and technical domains and sub-domains and knowledge management needs of common interest between EURAD participant organisations. RD&D needs and priorities of individual member state may be quite different than those identified by the EURAD SRA.

In this chapter the RD&D activities are structured according to the themes of EURAD Roadmap. The high-level RD&D and programme implementation priorities are summarised in Table 1.

Phases* of the RWM programme	**Phase 1: Policy, Framework and Programme Establishment**	**Phase 2: Site Evaluation and Site Selection**	**Phase 3: Site Characterisation**	**Phase 4: Facility Construction**	**Phase 5: Facility Operation and Closure**
Main objective of the Phase:	*Establish radioactive waste management programme for a certain (or more than one waste stream) waste stream*	*Select a preferred locality and develop preliminary design for a radioactive waste facility*	*Complete characterisation for chosen site and safety analyses for final design*	*Obtain a licence for implemetation & construction from regulatory bodies*	*Obtain approval for facility operation*
Themes* of the RWM programme	**Main RD&D activities in Phase 1:**	**Main RD&D activities in Phase 2:**	**Main RD&D activities in Phase 3:**	**Main RD&D activities in Phase 4:**	**Main RD&D activities in Phase 5:**
1. Programme Management	(1.1) Define the waste stream under consideration, elaborate safety strategy, develop management system and methods for RD&D planning and oversight of RD&D activities, establish a knowledge management system and conduct societal and economical studies supporting the RWM programme, develop a requirements management system	(2.1) Update of the safety strategy (select disposal concept), compile an RD&D plan and perform work breakdown, competence development and maintenance to support RD&D activities, establish a data and information management system, societal and economical studies supporting site evaluation & selection, maintain a stakeholder engagement strategy, maintain requirements management system	(3.1) Finalise safety strategy (decide on disposal concept); iterative updates of RD&D plan, competence development and maintenance to support RD&D activities, operate and improve data and information management system and update societal and economical studies supporting site characterisation, utilise a stakeholder engagement system, maintain requirements management system	(4.1) Accomplish the safety strategy (implement facility), iterative updates of RD&D plan, maintain necessary competence to support facility construction and operation, maintain data and information management system and ensure long-term preservation of records, develop and maintain a stakeholder engagement system, maintain requirements management system	(5.1) Update safety strategy and optimise facility operation, iterative updates of RD&D plan, maintain necessary competence to support facility operation and closure, maintain data, information and knowledge management system and ensure long-term preservation of records, maintain a stakeholder engagement system, maintain requirements management system
2. Pre-disposal	(1.2) Develop a national radioactive waste inventory database inc. potential future arisings, collect available information on waste characteristics and conditioning methods, review and assess the existing and needed in the future storage capacities	(2.2) Specify inventory and charasteristics of the waste stream under consideration, perform laboratory investigations and modelling for waste form characterisation, review and evaluate treatment and packaging options, develop preliminary WAC for the selected disposal concept	(3.2) Update waste inventory of the facility, provide detailed source term understanding, elaborate WAC and develop waste package design for construction licence	(4.2) Finalise waste inventory and elaborate WAC for operational licence, adjust waste package detailed design	(5.2) Update waste inventory and ensure compliance with WAC, maintain detailed documentation on wastes emplaced in the facility, consider novel treatment, conditioning and packaging methods and modify WAC when appropriate for facility optimisation, a system for managing non-compliance packages should be developed
3. Engineered Barrier Systems	(1.3) Overview of possible EBS concepts for the considered disposal options, generic studies on EBS properties and long-term behaviour	(2.3) Develop and evaluate different EBS concepts consistent with preliminary facility design and safety assessment	(3.3) Finalise EBS concept and elaborate detailed design for construction licence, perform laboratory investigation and modelling to assess EBS properties and long-term performance, demonstrate feasibility of EBS construction and fulfilment of design targets	(4.3) Adjust EBS design for operation licence, demonstrate technical readiness, carry out (if necessary) demonstration experiments of EBS properties with long-term monitoring	(5.3) Implement EBS and monitor its behaviour (in a pilot phase if necessary), consider novel materials and technologies, modify EBS design when appropriate for facility optimisation
4. Geoscience	(1.4) Collect available information on properties of different host rock, generic studies on radionuclide transport and long-term geological evolution	(2.4) Perform some laboratory and field investigation to understand host rock properties and radionuclide transport, in order to support comparison of candidate sites	(3.4) Carry out detailed laboratory investigation to derive site specific data on relevant host rock properties and transport parameters, initiate underground in situ research in a rock laboratory (if necessary), assess long-term geological evolution of the selected site	(4.4) Update and consolidate knowledge on host rock properties, transport processes and parameters for operational licence	(5.4) Consider new knowledge (if any) on host rock properties, transport processes and parameters
5. Disposal Facility Design and Optimisation	(1.5) Overview of design requirements for possible facility concepts (disposal options), develop a generic design of facility layout – surface installations and underground excavations (if applicable)	(2.5) Develop preliminary facility design concepts for the sites evaluated/selected, consistent with site properties, evaluate possible transport routes in order to support comparison of candidate sites	(3.5) Perform final facility design for the selected site, develop construction methods and demonstrate feasibility of construction, initiate underground research of excavation and support methods in a rock laboratory (if necessary), develop preliminary design of facility equipment, instruments, installations and closure	(4.5) Construct facility – surface installations and underground excavations according to final design, optimise excavation and support methods, perform final design of facility equipment, instruments and installations, demonstrate their adequacy and efficiency (technical readiness)	(5.5) Operate facility, consider novel excavation and support methods for extension, modify layout when appropriate for facility optimisation, improve facility equipment, instruments and installations, develop detailed design for closure and decommissioning
6. Siting and Licensing	(1.6) Develop methodology for site selection, define evaluation criteria, collect available geological information and compile a preliminary list of perspective areas and/or host rock formations	(2.6) Perform evaluation, screening and ranking of perspective areas and/or host rock formations, carry out surface based geological and hydrogeological investigation (boreholes, geophysics), compile preliminary site descriptive models and assess external hazards for comparison of candidate sites	(3.6) Carry out detailed geological, geotechnical and hyrogeological investigation on selected site, compile detailed site descriptive model and perform numerical modelling (if necessary) to assess site suitability, install geological and environmental monitoring system and describe baseline conditions	(4.6) Perform geological, geotechnical and hyrogeological investigation during facility construction, continue with long-term geological and environmental monitoring, refine site descriptive model and assess external hazards for operational licence	(5.6) Continue with long-term geological and environmental monitoring
7. Safety case	(1.7) Compile a generic safety case to provide input for site selection and evaluation criteria and for generic design of facility layout	(2.7) Compile and update preliminary safety case(s) for comparison of candidate sites based on site evaluation data and information, support prioritisation of RD&D activities, provide input for preliminary facility design, evaluation of different EBS concepts and derive preliminary WAC, develop assessment methods and tools	(3.7) Compile and finalise safety case(s) for construction licence based on site characterisation data, demonstrate its safe operation and focusing on post-closure safety, support iterative update of the RD&D plan, provide input for final facility design, further development of EBS concept and update the WAC, develop assessment methods and tools	(4.7) Compile safety case for operational licence based on improved site specific data and information gained during construction, demonstrate operational and post-closure safety focusing on operational period (based on as-built state of the facility), further develop assessment methods and tools	(5.7) Periodic update of safety case to incorporate information and experience gained during operation, novel scientific and technical achievements, any advances in site understanding, support optimisation of facility operation, modification of WAC, EBS, closure concept etc.

*Phases and Themes according to EURAD Roadmap

Table 1. High level RD&D and related programme implementation priorities linked to the phases of implementation

3.1 National Programme Management

EURAD Roadmap goals breakdown structure (GBS) in Theme 1 provides a guide on the key activities needed to establish the RWM Programme. Table 2 lists out all the domains of Theme 1 with links to available Domain Insight documents. and specific guidance, including Requirements Management and Financing.

Table 2. EURAD Roadmap goals breakdown structure: Theme 1 (National Programme Management)

Sub-themes	Domain	EURAD docs
1.1 Programme Planning	1.1.1 National RWM Policy	
	1.1.2 Timetable for decision making	Domain Insight, June 2023
	1.1.3 Public information and participation	
	1.1.4 Safety, security, use of resources	
1.2 Programme Organisation	1.2.1 Licensing framework	
	1.2.2 Licensing criteria	
	1.2.3 Allocate responsibilities	
	1.2.4 Waste management System	
	1.2.5 RD&D Strategy	
	1.2.6 Requirements Management	Domain Insight, 28.02.2024 Specific guidance: EURAD D12.6, 2024 EURAD D12.8, 2024 EURAD D12.9, 2024
1.3 Programme Resources	1.3.1 Financing Scheme	Specific guidance, EURAD D12.4, (2022)
	1.3.2 Skills and Competence Management	
	1.3.3 International Cooperation	Domain Insight, 10.07.2023
	1.3.4 Procurement & Supply Chain Arrangements	
1.4 National inventory	1.4.1 National radioactive waste inventory	
1.5 Management Solutions	1.5.1 Integrated waste management routes and strategic options	
	1.5.2 Options and Concept selection	

RD&D Strategy

A strategy is required during the early phases of programme management to set out how implementation of a waste management and disposal system will be carried out.

This has been described previously in relation to programme boundary conditions in Section 2.1 and is synonymous with the Lead Document described by the NAPRO Guide (ENEF, 2013). There are no explicit RD&D needs required in order to prepare an implementation strategy, however, it should include a comprehensive description of programme management tasks required to successfully implement and support ongoing development of an RD&D plan. This may include how RD&D prioritisation will be undertaken and what needs and drivers are important for the RD&D plan. An important distinction to make here will be the approach to siting: whether the implementer will undertake geological screening to identify a preferred geology or will pursue a single siting strategy, or if a dual track approach in which the possibility of sharing a disposal facility with other national programmes is also considered (IAEA, 1994; IAEA, 2016a). The typical radioactive waste management activities that are required to successfully achieve generic goals in theme 1 on programme management are summarised in EURAD Roadmap Theme 1 Overview (2021).

Requirements management

Disposal 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 disposal systems have several life-cycle stages that need to be considered. The implementation of disposal systems is thus a process that covers a broad range of interrelated issues involving a range of disciplines; the corresponding disposal 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.

There is a broad agreement in systems engineering that requirements management is an important element to support the implementation process of complex (interrelated) systems such as disposal systems (EURAD D12.6, 2024).

The importance of the application of a proper Requirements Management System (RMS) to support the successful implementation of the National Programme was reflected in the topic selection of guidance documents in EURAD programme (EURAD D12.5, 2022). Three guides are developed within EURAD programme on:

- Developing, Using and Modifying a Requirements Management System for a Generic Waste Management System (EURAD D12.6, 2024),
- Developing, Using and Modifying a Requirements Management System for Implementing a Disposal System (EURAD D12.8, 2024),
- Developing, Using and Modifying a Requirements Management System for Waste Management Systems (EURAD D12.9, 2024).

The role of RMS in relation to RD&D activities are mentioned in these guides. As an example, the following statement from (EURAD D12.8, 2024) guide is worth mentioning: "*the preparation of repository implementation, including the necessary development work (studies (incl. RD&D), planning (incl. requirements management), design and licensing) and developing and using the safety case to guide* *implementation (by 'design for safety') is also included in the requirements management system for implementing a disposal system*".

Skills and competence development

Knowledge on RWM from cradle to grave has been accumulated since more than 40 years both internationally and nationally by the more advanced programmes. All disposal programmes need to ensure that the necessary core competence and skills required in RWM are built up and then maintained at the national level. This can be carried out most efficiently by creating an appropriate organisational structure with an independent waste agency and independent regulatory bodies (IAEA, 2009a) whose members are offered training and education opportunities and are subsequently fully integrated into the appropriate regional and global networks.

Participating in the IGD-TP itself gives a unique opportunity to closely follow (and to learn from) the development of more advanced programmes. However, there may still be a need to identify possible areas of technology transfer through specific agreements between more advanced programmes and early-stage programmes and to set up an official mechanism to facilitate this exchange.

With the aim to enhance and foster cooperation at the international level and achieve a high quality of expertise function in the field of RWM safety, the SITEX Network was established in 2018. This network is independent from organisations responsible for the implementation of waste management programmes and waste producers. The added value to other existing TSOs and regulator's networks is seen in bringing together different categories of expertise users, such as TSOs, REs, National Regulatory Authorities (NRAs) and Civil Society (CS). The main SITEX Network activities are providing trainings for new TSOs staff members, safety related activities, like the benchmarking of the approaches to the safety reviews processes and reviews of existed literature regarding new concepts (like Deep Borehole Repositories (SITEX, 2022)) and safety case review exercises.

Participation in international RD&D programmes like EURAD will also help to build the needed competencies, in particular since, within the EURAD programme high priority is devoted to knowledge management. A high-level document was drafted on knowledge management & networking, where strategic objectives were formulated for the enhancement and transfer of knowledge between generations, member states and organisations. EURAD Roadmap – with the linked Theme Overview documents – plays a central role in the organisation and coordination of knowledge management activities.

With respect to RD&D, an implementer responsible for managing a waste disposal programme needs to consider in-house technical programme management capabilities. If RD&D services are to be procured from external organisations or individuals, the implementer will also need to retain sufficient technical knowledge internally to competently specify requirements and manage delivery of the services undertaken externally. In particular, the capability of integrating RD&D results for planned safety case development will be essential.

Understanding the required skills and competences is considered as a necessary component of an RD&D plan. In particular, new programmes embarking on competence development focused RD&D tasks are encouraged to consider secondment opportunities with more advanced programmes and involvement of staff in international collaborative projects.

To contribute to building up the sustainable knowledge, competence and skills infrastructure in the field of RWM a diverse portfolio of tailored basic and specialised courses has been composed within EURAD project under the umbrella of the "School of radioactive waste management"[17]. These courses have been implemented for some R&D and Strategic Studies WPs. Despite possibilities to acquire knowledge through international collaborations, a successful RD&D programme implementation requires development of national competence to cover long-time implementation phases. Sparse national budget for small inventory programmes is a strong driver for a more intensive international collaboration.

Environmental impacts and socio-economic effects

In line with the requirements laid down in Directive 2011/92/EU (2011), before a disposal project starts environmental impacts of the planned RW repository must be assessed.

The environmental impact assessment (EIA) may be integrated into the existing procedures for consent to projects in the Member States.

Based on the requirements laid down in Directive 2001/42/EC (2001) on the assessment of the effects of certain plans and programmes on the environment and taking into account the national context of a MS strategical environmental assessment (SEA) has to be carried out for some programmes or projects.

The above-mentioned environmental assessments require the competence to evaluate environmental impacts not only for radiological, but also for non-radiological nature. The necessary activities to identify the initial environmental state of the site and monitoring activities to assess the environmental impacts of the project during implementation have to be addressed. It could be beneficial from public acceptance point of view if the socio-economic impacts of a repository implementation programme to the region of the site are assessed and documented in a transparent way.

Stakeholder engagement strategy and public involvement

A clear long-term strategy and commitment to involvement of stakeholders is essential for the decision-making process at all stages of a RW disposal programme. This shall include strategies on how stakeholders are involved and how the scientific basis of RW disposal is communicated to wide audiences. Large amounts of experience on how

[17] https://euradschool.eu/

effectively engage stakeholders on RD&D issues have been acquired across Europe through collaborative research projects. Also, in EURAD, interactions with civil society have been implemented in two strategic studies UMAN and ROUTES to "*facilitate the translation of scientific/technical results and create the conditions for Civil Society Organisations to express their expectations and views*" (EURAD vision, 2019). Although not considered an RD&D activity itself, a disposal programme needs to maintain up-to-date knowledge and adopt good practice into their implementation strategy with respect to stakeholder engagement and communications on the significance of RD&D. Owing to the importance of social and ethical considerations, alongside the safety of geological disposal, work continue internationally to consider methodological aspects of how to involve stakeholders.

Some earlier projects on stakeholder engagement include RISCOM II, (2000-2003), COWAM 2 (2004-2006), CIP (2007-2009), IPPA (2011-2013), FSC (2014) and InSoTEC (2011-2014).

Typical aspects considered include:

- Understanding and establishing dialogue with non-technical stakeholders who raise issues or concerns;
- Identifying and monitoring the potential societal and ethical impacts of implementing geological disposal;
- Reviewing international approaches to involve civil society in decision making processes and develop programme specific approaches (adapted to local and national boundary conditions); and
- Contributing to international efforts to improve the presentation of safety arguments during safety case development for non-technical audiences.

3.2 Pre-disposal

Detailed information on radioactive wastes and their classification is a key input to any disposal programme (see Section 8.3 in (ENEF, 2013)).

Waste inventory

For planning purposes, it is essential to have a sufficiently detailed understanding of the wastes that need to be managed and that eventually will be disposed of. For that purpose, it is useful to develop a waste inventory that contains not only the wastes that already exist but also those wastes that will only arise in future. Potential and limits for free release need to be considered. Any waste inventory has to be updated periodically to take into account new information. A proper inventory of radioactive waste arising, including their chemical, physical, biological, chemotoxic and radiological properties is necessary. The inventory is considered also a principal input to RD&D activities.

Waste acceptance

In addition to the waste inventory, it is essential also to implement a waste acceptance process already in the early phases of the programme. With such a process it is ensured that the information needed on the wastes is collected when this is still easy and the repository implementer has from the beginning a clear understanding of the details of the wastes that he needs to consider in his repository planning activities.

In the early phases of the programme, such a waste acceptance process has to have sufficient flexibility to allow for optimisation (e.g., changes in repository layout, modifications to waste packaging, the need for waste segregation).

Waste form design and characterisation

The waste form should contribute to the high-level objective of containment of a disposal facility by providing a number of safety functions. It does so by immobilising the radioactive content of the waste in a stable and durable solid. This is important during the phases preceding closure of a disposal facility and, for some waste forms (e.g., HLW, spent fuel), during the post-closure phase. The related R&D activities has to support the understanding of the long-term behaviour of the waste forms planned for disposal.

Packaging

Packages used for radioactive waste are designed to ensure their contents are confined and immobilised safely over long periods of time. Such periods cover all phases of disposal, including periods of storage as well as transport for ultimate disposal the operational phase of the facility and a period after closure.
The material of the packaging has to be designed so that, it is compatible with the waste form and also with the geochemical conditions of the host formation.
The supporting R&D activities has to be planned along the phases of repository implementation taking into account the availability of input data (e.g., preliminary information on the geochemical conditions of the host formation is available during site selection). Once geochemical conditions of potential disposal site(s) and the potential impact on these conditions by the interaction with the waste package are better defined, further research and development aimed at evaluating package evolution after closure will be carried out, as required.
Some basic information of the package (e.g., geometry, weight, chemical composition, mechanical strength) are essential inputs for the design activities. It can influence tunnel and gallery cross sections, mechanical loads and logistical processes, so in this respect careful optimisation is necessary and finally the disposal activities have to be demonstrated. Retrievability and reversibility can be an important factor in some programmes mainly during operational phase but in some cases (Germany) even in the post-closure phase. In that case retrievability of the packages has to be demonstrated.

Storage

In the early phases of a disposal programme initiation, it is essential to assess the waste inventory locations, the nature and quantities of the waste, and the storage facilities that are anticipated. The storage facility need (design) is determined by the materials that require storage, the anticipated duration, and the types of waste forms and containers to be stored.
The storage of radioactive waste packages and spent nuclear fuel can last several decades (e.g., because the lack of an operational repository or in order to reduce of the decay heat). The storage conditions (e.g., environmental conditions) has to be monitored with the aim to demonstrate, that the properties of the waste package or the spent fuel have not been degraded and those will meet the waste acceptance criteria for disposal.

Typical radioactive waste management activities completed in pre-disposal are summarised in EURAD Roadmap Theme 2 Overview (2021) linked to the phases of implementation.

3.3 Engineered Barrier Systems

The Engineered Barrier System (EBS) is the technical realisation of a safety strategy that has been developed based on a specific radioactive waste inventory and geological boundary conditions as well as a prognosis of future system evolution. Therefore, a broad spectrum of information is necessary to implement a disposal facility including the corresponding EBS.

The adequate understanding of the components of a repository system and their future evolution is fundamental for the development of a suitable safety concept and an adequate multi-barrier system.

The EBS is defined as a system of man-made components including the waste form, the waste packages, the buffer, the backfill, the repository plugs and seals and other engineered features. The components of EBS have to combine multiple safety functions and provide a high level of diversity and redundancy, so that safety is maintained even if one or more safety functions underperform.

The properties of EBS of a disposal facility shall be designed, to fulfil required safety functions with long-term performance to protect the biosphere from the impact of the facility. The time period for which safety functions have to be fulfilled in the post-closure phase, can be defined on the basis of the safety assessment. This time period could be significantly different for the different waste streams.

Requirement management is a key issue during EBS development for the different phases of the repository roadmap.

Starting point for developing an EBS-system is the identification of the safety goals from an analysis of the corresponding regulatory framework (incl. radiological and non-radiological requirements (mining, occupational safety, environmental protection etc.) and the development of corresponding safety strategies (host rock, EBS). The inventory to be accounted for forms another important basis. Safety functions for the different components of the barrier system and strategies to implement the barrier system through an adequate design concept have to be defined (compiled in a safety concept). R&D programmes should be initiated to develop a general understanding of the future evolution of a potential host rock type and its interaction with repository and waste components. At this time, a generic repository and EBS concepts will be developed. Investigations of the functionality and constructability of geotechnical barriers will be performed.

During the site evaluation and selection phase, based on rock type specific safety concepts, requirements for potential host rocks have to be identified, the compliance with the safety requirements has to be analysed and demonstrated through the results of exploration. After site selection, important boundary conditions for the safety concept can be specified by using site specific site data. The additional exploration data will be used to specify input data for the safety assessments and to reevaluate and possibly optimise the specified safety strategy. Furthermore, the generic repository design and the EBS concept have to be adapted to site-specific boundary conditions.

During site characterisation phase, a comprehensive set of rock data will be acquired to verify the compliance with the requirements for host rock properties and to get further data to optimise the safety concept and the corresponding EBS concept. The adaption of EBS design to the increasing knowledge on host rock properties is a persisting process during site characterisation, repository construction and operation. The host rock properties as well as important processes for the future repository evolution will be analysed by performing in-situ tests in the exploratory mines (focus on rock properties) or URLs (supplementary analysing the interaction between repository components and the host rock). The in-situ tests in URL will be performed to analyse the functionality and constructability of the EBS and to investigate the interactions between the host rock and the repository components. Results of the in-situ tests will be also used to evaluate, verify and optimise the safety concept, the repository design as well as the disposal and the barrier concept. The necessary R&D activities have to be carried out to provide an understanding on the long-term behaviour (e.g., degradation and corrosion properties, gas generation, thermal radiological, microbiological influences, other coupled processes) of EBS elements. The scope and extent of the R&D programme can be justified by a safety case reaching a tolerable level of uncertainty in the assessment which can be treated with realistic conservative assumptions. The requirements for the EBS elements have to be set. A procedure may also be needed for getting an industrial production for components required during construction. This procedure for industrialisation later could be further developed to cover also components that are needed for operation and closure.

During construction, further information will be acquired on the geosphere. Based on the in-situ results, the ‘as built state’ of the repository and the corresponding components will be captured and used for design verification. The properties of components and installations can be specified. During construction acquired data will be continuously compared with former assumptions and requirements and used for further optimisation of the repository design and disposal strategy as well as the closure concept. Preparation for long-term monitoring and/or demonstrations can also be considered. Increase of understanding of the system behaviour and optimisation of the system may continue where deemed necessary.

During operation and closure, the information on the geosphere will be continuously updated and confirmed. When the emplacement of the waste packages in a disposal area (borehole/drift/vault) has been completed, the local EBS will be installed; possible components are: the buffer (surrounding the waste package), the backfill and the borehole or drift-seals. After installation, the specific properties of each barrier have to be verified (as built state). In the course of repository operation use of novel materials and technologies can be considered. The facility optimisation may call for modification of the EBS design.

With increasing progress of RD&D work on EBS, operational aspects and feasibility assessments and demonstrations will become more important as complements to performance and safety assessments as well as for associated RD&D work.

Domain Insight on EBS was published in 2023 (EURAD EBS Domain Insight 3.4.1, 2023). A Theme 3 Overview in line with EURAD Roadmap for activities in relation to Engineered Barrier Systems is in publication.

3.4 Geoscience

The selected site and the host formation of the repository plays an important role in meeting the safety targets of a disposal system. In the case of high-level waste and/or spent nuclear fuel disposal, their contribution to fulfil the safety functions – due to the extremely long timescales considered after closure – could be prominent. Laboratory and field RD&D activities has to be carried out to gather information on the rock (or soil for near surface disposal) properties, to understand the radionuclide transport processes in the host (and also as necessary the surrounding) formations and to understand the long-term geological evolution of the site. For each phase of repository implementation, the scope, the methodology and the goals of geological investigations has to be specified such that the necessary information is provided to support the decisions (e.g., meeting site selection criteria, supporting a licensing step, confirmation of site suitability, providing input to a safety case) at the end of the phase.

During the site evaluation and selection phase usually desktop studies are carried out based on available geological data of a country to screen the potentially suitable formations for hosting the repository. It is essential to establish a clear framework for the decision-making process and set requirements for site selection. For a near surface repository more areas can fulfil the safety targets, while there can be limited potentially suitable formations to host a geological disposal facility for HLW and/or SF. The site investigation concept and methods have to be tailored to the type of potential host formation (e.g., clay, granitic fractured rock, salt). Some MSs follow the so-called dual track policy, when in parallel with searching for domestic locality for a geological disposal facility, shared solution could also be considered. In that case the necessary R&D activities can be coordinated between the MSs working on shared disposal options. At the end of the phase enough information has to be collected for the evaluation whether the site selection criteria are met.

For the site characterisation phase, it is important to have a clear vision on the disposal concept and in relation to that a goal-oriented site characterisation strategy. In the case of a geological disposal facility after the surface-based investigations usually a URL plays an important role to confirm the host rock properties based on the results gained from in-situ underground tests. There are different concepts for locating the URL: it can be a part of the future repository (meaning that the repository will be constructed as an extension of the URL) or it can be a separate facility. In the first case the URL has to be constructed such that the requirements applicable for the repository will able to be fulfilled once the extension to a repository will happen. In the latter case it has to be proved that the information gained from the URL is applicable and valid also for the area where the repository will be constructed (in simple way it requires the demonstration of the homogeneity of the host rock). In site characterisation phase the environmental initial state has to be defined and after that, environmental investigations have to be carried out to support environmental impact assessment. From post-closure point of view the prime interest is to understand those host rock properties, which plays important role in radionuclide transport. The other aspect, which has to be evaluated is the stability of the site. It is important not only from post-closure safety point of view, but also for proving safe operations (e.g., reception of the waste, buffer storage, encapsulation) in the surface facilities of the repository (assessment of external hazards and definition of the design basis). At the end of this phase the understanding of the site properties should be such that enables to carry out a safety case underpinning construction license application.

Before starting the construction of the facility, usually a monitoring programme is compiled, which can cover several areas (e.g., geotechnical, hydrogeological, environmental). The role of these monitoring activities is mainly to evaluate the different effects of construction (excavation of rocks, properties of the excavation disturbed zone around the cavities). Different models (e.g., geomechanical, hydrogeological, coupled THMC) can be used to provide predictions to these effects and by comparing the results of the monitoring investigations (URL experiments) with these predictions the models can be validated. Construction is a unique opportunity to continue host rock investigation underground. In this phase the uncertainty and sensitivity analyses performed as part of a safety assessment can be a good tool to prioritise the R&D activities. At the end of this phase the understanding of the site properties should be such that enables to carry out a safety case underpinning operation license application.

During operation the full-scale monitoring programme is carried out, some elements of this is focussed on geoscientific themes. As part of the periodic safety reviews a synthesis of the gathered information has to be carried out, which can provide feedback for the monitoring programme (review and update could be necessary). The repository is usually not constructed in one step, so the extension takes place in parallel with operation (note: and with the closure of some filled disposal rooms). For the repository extension some additional geological investigations could be necessary. During operation optimisation of the disposal system can happen. The optimisation of the disposal rooms (galleries, chambers, deposition holes) can be a part of that process, which has to be supported with some investigations and evaluations. In this phase those RD&D activities have also been carried out, which are necessary for the finalisation of the closure concept of the repository. At the end of this phase the understanding of the disposal system including the elements of the closure concept should be such that enables to carry out a safety case underpinning closure license application. As part of this application a programme for the post-closure monitoring in the active institutional phase has to be defined.

Typical actions completed for geoscience, based on the experience of advanced programmes, over different phases of implementation are summarised in EURAD Theme 4 Overview (2024).

3.5 Design and Optimisation

Disposal facility design covers early conceptual design during early programme phases, right through to detailed design for construction, operation and closure.

The first steps in designing a repository are the decisions upon suitable disposal options and the definition of design requirements related to the chosen disposal option. As the repository is part of the broader national programme on RWM the boundaries of the system (e.g., transportation routes, what is received raw waste or encapsulated waste) has to be defined. In early phases conceptual/generic and/or preliminary designs are carried out. This preliminary conceptual design can provide a rough estimate for the necessary area (footprint), which is required for the disposal of the given waste inventory. This information can be used during site selection.

The development and description of the design basis is an important aspect. This includes the definition of safety functions, performance targets and design specifications.

An important issue for the facility design is the role the engineered barrier system within the safety assessment. The facility design needs to be tailored to the corresponding disposal technology and thus to the necessary transport and handling equipment. The conceptual design is also an important input for preparing the preliminary cost estimates for the disposal programme.

During site characterisation phase the facility design has to be adapted to the site properties in compliance with proposed EBS and safety requirements. Compatibility of construction method and construction materials with EBS should be ensured. The feasibility of facility construction has to be demonstrated. In case of underground disposal, the excavation methods have to be investigated and selected in line with the properties of the host formation. To confirm the site suitability, during the site characterisation phase, in the case of a geological disposal facility the construction of a URL could be necessary. The URL provides the opportunity to carry out the necessary demonstration activities, which can prove the applicability of different elements of the design (e.g., logistical equipment, EBS elements).

During the construction phase it has to be demonstrated, that the facility has been built as planned, meeting the design targets defined by the safety case and in accordance with the terms of the construction licence. Towards the end of this phase the implementer presents the overall approach how the facility will be operated and develop a concept for closing the facility. In preparing for operation, the future operator will need to demonstrate safety during operation and radiation protection of workers and of the public and the environment. Final design of facility equipment, instruments and installations, demonstrate their adequacy and efficiency (technical readiness) is completed. During the construction activities conceptual models and computational models of the geosphere, biosphere, and engineered systems are to be updated and refined.

The design of the disposal system, including waste handling and emplacement continues to be refined and optimised during the operational phase. Barriers and seals for repository closure are to be checked continuously for potential optimisation needs. During the operational phase waste disposal activities, the extension of the facility (construction of new disposal capacity) and partial backfilling of some parts of the facility can take place in parallel. This work procedure has to be taken into account in the repository design. The operator may optimise a facility design based on progress in RD&D, and operational experience, during this phase. The operator also develops an application for closure (decommissioning) and sealing the facility, and further develops the plan for post-closure institutional controls, monitoring and surveillance. A demonstration programme can be developed to prove that the planned plugging, sealing and backfilling activities can be carried out and in the as-built-state the system elements meet the predefined requirements.

Typical actions completed in disposal facility design and optimisation, based on the experience of advanced programmes, over different phases of implementation are summarised in EURAD Roadmap Theme 5 Overview (2021).

3.6 Siting and Licensing

It is essential for successful RW repository implementation to establish a clear framework for site selection including the clear allocation of roles and responsibilities and a transparent decision-making mechanism including stakeholder involvement and participation.

Siting process usually relates to two main phases defined in EURAD Roadmap (2021). During the site evaluation and selection phase, several perspective areas and/or host rock formations are evaluated by screening, ranking, or compared using previously defined evaluation criteria. These criteria should reflect peculiarities of the adopted safety strategy or selected disposal option (near surface, deep geological, borehole disposal etc.). In addition to geo-scientific parameters, environmental, socio-economical and other aspects might also be considered. Good international examples show, that after reducing the potential host localities to a limited number, keeping at least one alternative formation next to the selected one can support successful implementation, among others from public acceptance point of view.

During the site characterisation phase, one or a few already selected (preferred) site/s are investigated in more detail, in order to collect necessary information for preliminary facility design and compilation of a preliminary safety case. At the beginning of the site evaluation and selection phase, typically the already available information is collected and evaluated, some surface-based geophysical survey and mapping is performed and only a limited number of boreholes are drilled, tested and sampled. Several documents provide detailed description of various siting methods and technics like The Management of Site Investigations for Radioactive Waste Disposal Facilities (IAEA preprint, 2023). This document provides a platform for initiating well-planned and tightly focussed site-specific investigations and relatively high-level information on a range of data acquisition and interpretation technologies and techniques that are currently potentially available to support site investigations.

However, the licensing process of a RW repository in any MS is based on international standards and directives, there could be some specificities, which are laid down in the national legislation or relates to other parts of the national framework. The roles and responsibilities of the licensee (implementer), the competent regulatory authorities and/or the government and the potential participation of the stakeholders in the licensing processes (e.g., through public hearings) has to be clearly defined for each licensing step. As an illustration Figure 2. of this document provides some usually applied licensing steps in RW repository implementation process.

The typical siting and licensing activities over different phases of implementation are summarised in EURAD Roadmap Theme 6 Overview (2021).

3.7 Safety case

The safety case is a critical tool for guiding programme development, integrating and synthesizing information to build understanding to inform decisions at each stage of the repository development programme and to guide and prioritise R&D activities.

Safety case with supporting safety assessment is an iterative process (see also chapter 2, Figure 3 and subchapter 2.4). The level of detail of safety cases increases with the advancement of implementation of a repository. Typical types of safety cases could be:

- generic safety case (before site selection);
- preliminary safety case (during site characterisation);
- safety case for construction license (after site characterisation and facility design);
- safety case for operational licence (after facility construction);
- safety case updates for operation; and
- safety case for closure licence.

In the early phases (Phase 1 and into Phase 2), the safety case will be generic. It may be based on illustrative concept designs and illustrative generic data or it may use example data from a specific site(s). The R&D programme may also be largely generic. The aim at these early stages is to establish the safety case framework, demonstrate the feasibility of disposal of the national waste inventory in available national geological settings and begin to identify the required information from the R&D programme and the uncertainties that will need to be reduced as the safety case develops. It is also important for the implementer to build up the necessary competences and skills to carry out or at least be able to coordinate the activities in relation to safety assessments.

In the conceptual planning stage, first the collection of information, data and knowledge relevant for the site selection process starts. At this point preliminary disposal concepts are also designed, and first preliminary safety assessments are performed in order to understand the behaviour of disposal concepts in a potential host environment (IAEA, 2009a). Preliminary safety case(s) can be used for comparison of candidate sites based on site evaluation data and information, support prioritisation of RD&D activities, provide input for preliminary facility design, evaluation of different EBS concepts and derive preliminary WAC.

Generic scenarios for the evolution of the disposal system can be developed by considering the safety functions and the features, events and processes (FEPs) that may affect them over time. International database on FEPs is published in (OECD/NEA, 2019). The safety assessment strategy should also consider the timescale to be addressed in the safety case, in relation to the properties of the disposal inventory (by reference to half-lives) and by reference to appropriate safety arguments. At early stage, it is important to maintain flexibility in the safety assessment strategy, allowing for continual developments and refinements in subsequent phases as the disposal concept is developed into a more detailed system design.

The preliminary safety analysis used as the basis for site selection will guide the safety strategy for site characterisation by identifying the significant uncertainties that need to be resolved during site characterisation (Phase 4). Once site-specific data become available (Phase 3 onwards), these enable the safety case to become increasingly representative of the site(s) under consideration. The facility design may also be updated to reflect site conditions. In an iterative process, the safety case is used to inform the ongoing R&D and siting programmes, such that identified uncertainties are resolved or mitigated as the safety case is developed.

As site characterisation progresses there will be iterative developments and refinements to the site descriptive model as more site data are gathered. All data should be accessible through the relevant databases and enhancements to these databases may be required.

The safety case will also be used in communication with stakeholders, including competent regulatory authorities and local communities and will underpin decision-making throughout the disposal facility development programme.

The safety case supporting construction licence application is based on site characterisation data. Usually, this safety case is focusing on post-closure safety, but safe operation should also be demonstrated. Additional role of the safety case in that phase is to support iterative update of the RD&D plan, to provide input for final facility design, to assist further development of EBS concept and to update the WAC.

Before operation, safety case supporting operational licence application is compiled based on improved site-specific data and information gained during construction. This safety case demonstrates operational and post-closure safety focusing on operational period (based on as-built state of the facility). Detailed safety assessment of the reference scenario for the agreed disposal inventory is performed and robustness of the disposal system to all credible alternative scenarios is demonstrated. Clear safety strategy should explain how repository operations, including any simultaneous construction and waste emplacement activities will be conducted. The safety strategy should include monitoring requirements and the requirements and appropriate procedures and actions for incident reporting. The safety strategy for repository closure must explain how the facility will remain passively safe without reliance on further human intervention or control. Once closed and sealed it is likely that the disposal facility will enter a period of institutional control, where the site is still licensed and site access is controlled (thus preventing any human intrusion, for example).

During operation of the facility, periodic update of the safety case is performed aiming to incorporate information and experience gained, utilise of novel scientific and technical achievements, as well as any advances in site understanding, support optimisation of facility operation, modification of WAC, EBS, closure concept etc.

The past experience shows that assessment tools and safety case methodologies are continuously being developed and improved to demonstrate long-term safety. Methodologies and tools developed can be adopted and with minimum application of RD&D tailored to specific programmes (e.g., adapting input data to national waste inventories and site-specific characteristics).

Assessments as part of a generic safety case development may involve making simple presentations of the disposal system using representative or bounding parameters / input data (in the absence of specific site data) to demonstrate safety and assess options. The level of detail built into the safety assessment model is increasing when more site information is available and decision on the concept is made. Good practices are shared and published in many guidance and technical documents. The long-established OECD/NEA Integration Group for the Safety Case (IGSC) has organised several events and produced several documents on the Safety Cases (OECD/NEA IGSC, 2022). Relevant international guidance related to safety case production can be found in IAEA safety standards developed for all particular phases of the waste/spent fuel life cycle (IAEA, 2012). These should be used, together with national regulations to guide RD&D in support of demonstrating disposal safety.

During various phases of the repository development, special attention is given to the identification of uncertainties, knowledge gaps and incompleteness in the safety assessment.

Typical sub-topics of prioritised RD&D (being examined today by advanced programmes) relating to the disposal system include:

- Waste form evolution and dissolution rate data;
- Waste package evolution and ongoing developments to improve understanding of waste package contributions to long-term safety in a range of concepts and evolution scenarios;

- Understanding of buffers and backfill contributions to long-term safety and demonstrating how their emplacement helps to meet specified performance requirements;
- Demonstrating that seals and plugs are meet specified performance requirements and confirm feasibility of conceptual designs;
- Improved understanding of the excavation disturbed zone (and other major engineered barrier interface zones, particularly with respect to the role of temperature and microbes during early post-closure) and its potential impact on post-closure safety;
- Improved site-specific data collection and modelling for understanding of the host rock environment, geological or near-surface formations and groundwater transport modes through the geosphere / natural barrier;
- Improved biosphere data collection, modelling and scenario development;
- Improved modelling and understanding of potential gas transport pathways in the EBS and geosphere;
- Continued demonstration of engineering feasibility to emplace and manufacture facility components to meet their specified requirements to satisfy long-term safety; and
- Continued demonstration of the retrievability and modes of reversibility – specifically considering possibility of waste package retrieval after buffer / backfill emplacement and reversibility of the decision-making processes.

Typical sub-topics of prioritised RD&D related to safety case methodology include:

- Features, Events and Processes (FEPs) of the disposal system and scenario analysis – comprehensive list of FEPs and disposal system evolution descriptions tailored to programme boundary conditions;
- Building confidence in safety – natural analogues and structured lines of evidence to demonstrate performance of the system (aligned with developing a requirements management system for disposal system components);
- Mathematical model development – modelling tools to undertake high-level performance assessment and more detailed process (e.g., coupled processes) and component-level models for specific aspects of the system that needs enhanced understanding; and
- Treatment of uncertainty – methods or developed approach for treating and assessing uncertainty in different components of the disposal system.

Typical actions completed in relation to safety case development over different phases of implementation are summarised in EURAD Roadmap Theme 7 Overview (2021).

Information, Data, and Knowledge management

The implementation period of a disposal programme may last several decades. Therefore, data management and preservation of records and knowledge collected and developed during this period should be an integral part of RD&D planning.

National radioactive waste repository programmes are collecting large amounts of data to support the long-term management of their radioactive wastes. The data and related records increase in number, type and quality as programmes proceed through the successive stages of repository development: pre-siting, siting, characterisation, construction, operation and finally closure. Metadata allows context to be stored with data and information so that it can be located, understood, used, updated and maintained. Metadata helps WMOs to better utilise their data in carrying out their statutory tasks and can help verify and demonstrate that their programmes are appropriately driven. There is therefore a need for better understanding of the identification and administration of metadata. This is a key aspect of data management, to support national programmes in managing their radioactive waste repository data, information and records in a way that is both harmonised internationally and suitable for long-term management and use (OECD/NEA, 2014).

Long-term projects such as geological disposal are vulnerable to loss of records, knowledge and memory. There is a strong interest in that appropriate provisions exist for preserving detailed information about the repository and the waste it contains for as long as possible. This may be driven by national legislation and regulations (e.g., aimed at preventing human intrusion, assessing retrievability of the waste, allow future generations to make their own informed decisions about the waste) and interest from host communities and regions (OECD/NEA, 2011).

It is also recommended to take into account results of the previous activities of the NEA/OECD RWMC, in particular the Radioactive Waste Repository Metadata Management (RepMet, OECD/NEA, 2014) initiative (2014–2018); the “Preservation of Records, Knowledge and Memory (RK&M) across Generations” initiative (Phase I: 2011-14, Phase II: 2014–2018); and the Expert Group on Inventorying Reporting Methodology (EGIRM) (Phase I: 2014–2016, Phase II: 2017–2018). The outcomes of the activities of Working Party on Information, Data and Knowledge Management (WP-IDKM) could also be considered. Since 2019, the WP-IDKM has brought together experts from 26 organisations representing 11 OECD/NEA member countries and the European Union. Subjects for the working party include safety issues, knowledge management, archiving and preservation of data and information (OECD/NEA, 2023).

4. Conclusions

The PLANMAN Guide is an update of the PLANDIS guide (Beattie et al., 2015), which besides the needs of WMOs addresses also the complementary views of regulators and their mandated TSOs. It is focused on providing essential background for early-stage and small inventory programmes, making a first attempt to set-out at a national-level their RD&D needs towards disposal of radioactive waste. Development of any

RD&D plan is an iterative process in which with increased knowledge also additional tasks might be recognised and planed.

The content of the PLANMAN Guide provide key references to the vast quantity of information and knowledge sources that exist in relation to RD&D towards implementation of disposal of all types of radioactive waste. The two core sections aim to provide basic information on how to develop and what to address in national RD&D programme. Important aspects of any programme development are national boundary conditions for waste disposal establishment with timeframes, important milestones, estimation of costs and financing. Safety case development is foreseen as a principal driver to define RD&D activities in which involved entities has the agreed responsibilities. An important aspect is the implementation of a quality management system. The guide is consistent with the adopted EURAD documents like EURAD Roadmap (2021) and includes also the approaches and activities and corresponding themes of RWM programme relevant for different phases of radioactive waste disposal implementation.

Appendix A. Templates to develop an RD&D plan

In accordance with PLANDIS Guide 2015 Appendix A, modified to include also TSOs views.

Template 1 Boundary conditions

T1.1 Government Policy and Regulatory framework

T1.2 Role and Responsibilities of Waste Management Organisation

T1.3 Role and Responsibility of Technical Support Organisation/-s

T1.4 Waste Arising and Current Storage Arrangements

Inventory Summary (use this table format or alternative inventory table):

which

Waste Types / Classification	Volumes / Quantities	Disposal Route / Date of Disposal
Exempt Waste (exemption/clearance)		
Very Short Lived Waste (decay storage)		
Very Low Level Waste (landfill disposal)		
Low Level Waste (near surface disposal)		
Intermediate Level Waste (intermediate depth disposal)		
High Level Waste (deep geologic disposal)		
Spent Nuclear Fuel (deep geologic disposal)		

T1.5 Adaptive Phased Management

Estimated Timescales for Key Programme Milestones (use this table format or alternative figure/ table):

Key Date	Milestone	Required Documentation / Decision
	Policy & Programme Establishment	
	Site evaluation and selection	
	Surface-based Studies	
	Operations	
	Construction & Underground-based Investigations	
	Operations	
	Closure / Post-closure	

T1.6 Disposal Concept / Geological Settings

T1.7 Summary of Current RD&D Programme Planning
T1.8 Key References:

Template 2 RD&D task description
T2.1 Description of the Main Driver for 'X' RD&D Task in Current Phase of Programme
T2.2 List Urgency for 'X' RD&D Task by summarising what you need to know by when: - is it needed immediately (up to 1 year), 1-3 years, 3-5 years, or 5-10 years? - is it a site-specific tasks that should be delayed to future programme phase? - is it needed to underpin next safety case document(s) or next programme phase activity? - is it needed to maintain skills, expertise and capability in an important topic? - is it needed for strategic decisions at Nuclear Power Plants (e.g. packaging of waste)?
T2.3 What is the Knowledge gap for 'X' Task (i.e. what is the gap between current understanding and the knowledge that you need to improve, high/medium/low)? This should consider: - High: little relevant information exists - Medium: Information exists, but there would be benefit in carrying out further work during the current phase of the programmes - Low: there is a considerable body of relevant knowledge, which is largely sufficient for current phase of the programme
T2.4 Assess the Impact of each RD&D Task (suggest to use high/medium/low with respect to safety significance for current safety case and important towards moving the disposal programme forward). Consider: - High: indicates an area that is significant to a particular driver - Medium: indicates that the topic are is of some significant, but unlikely to be a detriment to progress of the overall programme - Low: expected to be of little overall significance at this phase of the programme, although recognised as a topic area of interest
T2.5 Decide what you need to do to fill the knowledge gap (review activity, international project opportunity to access existing data/knowledge, conduct experiment, other task).
T2.6 Other information that you need to capture to communicate 'X' RD&D Task

Appendix B. Proposed generic structure of Lead Document

Proposed Generic Structure from NAPRO Guide (ENEF, 2013):

1. Introduction - Background - Purpose of the report

2. Overall principles and objectives of the national policy and existing legislation
    a. Main principles
    b. Legal and regulatory framework
    c. Responsibilities for the implementation of the National Programme and organisations involved
    d. Transparency policy and public involvement processes
    e. Agreements with other countries
    f. Waste classification system. Inventory of all spent fuel and radioactive waste and estimation of future arising including supporting assumptions for future estimations.

3. SF & waste management
    a. Existing management methods implemented internationally and used as reference [by the concerned country]
    b. Existing and planned SF & RW management according to existing or planned waste streams from generation to disposal routes, with reference to

        b.1 Existing technical solutions up to disposal (according to the national waste classification)

        b.2 Solutions to be developed up to disposal and post closure (according to the national waste classification)

        - Time schedules - significant milestones and time frames up to closure

        - Plans for post-closure period

4. RD&D Plans and activities

5. Economical and financial issues
    a. Assessment of costs
    b. Financing schemes, needs and estimations

6. Key performance indicators for monitoring progress

7. Glossary

8. References and access to relevant supporting documentation

Appendix C. Terminology and comparison of phase descriptions

<table>
<tr><th rowspan="2">Phase descriptions used in PLANMAN Guide:</th><th rowspan="2">Phase descriptions used in PLANDIS Guide (IGD-TP, 2015):</th><th colspan="3">Cited International References Considered and Compared</th></tr>
<tr><th>Council Directive 2011/70 EURATOM (OJEU, 2011)</th><th>IAEA Doc Planning and Design Considerations for Repository Programmes (IAEA, 2014a)</th><th>IGD-TP Strategic Research Agenda (IGD-TP, 2011)</th></tr>
<tr><td rowspan="3">Policy, Framework and Programme Establishment</td><td rowspan="3">Policy, Framework and Programme Establishment</td><td>Establishing the Policy</td><td rowspan="3">Establishing Waste Management Organisation and Regulatory Body</td><td rowspan="4">Generic Studies</td></tr>
<tr><td>Establishing the National Framework</td></tr>
<tr><td>Establishing the National Programme</td></tr>
<tr><td rowspan="4">Site evaluation and selection</td><td rowspan="3">Generic Studies and Site Selection</td><td>Concepts and Plans</td><td rowspan="4">Site Evaluation and Site Selection</td></tr>
<tr><td>Selection of Host rock type(s) and Site (s)</td><td rowspan="2">Site Selection</td></tr>
<tr><td>Select Preferred Site</td></tr>
<tr><td rowspan="2">Site Characterisation and Safety Assessment for Conceptual Design</td><td>Safety Assessment for conceptual design</td><td rowspan="2">Development/ Repository Design</td></tr>
<tr><td>Site characterisation</td><td>Site Characterisation</td><td>Site Characterisation</td></tr>
<tr><td>Construction</td><td>Underground Development, Demonstration and Construction</td><td>Construction</td><td>Facility Construction</td><td>Demonstration</td></tr>
<tr><td rowspan="2">Operation and Closure</td><td>Operation</td><td>Operation</td><td rowspan="3">Operation, Closure & Post-Closure</td><td rowspan="2">Application/ Operation</td></tr>
<tr><td>Closure</td><td>Closure</td></tr>
<tr><td>Post-Closure</td><td></td><td>Post-Closure</td><td></td></tr>
</table>

Appendix D. Research, development and demonstration plans for the radioactive waste disposal

European countries

Sweden	RD&D Programme for Research, Development and Demonstration of Methods for the Management and Disposal of Nuclear Waste	SKB Technical Report, TR-10-63 2010
	RD&D Programme 2013. Programme for research development and demonstration of methods for the management and disposal of nuclear waste	SKB Technical Report, TR-13-18. 2013 http://www.skb.com/publication/2670359/TR-13-18.pdf
	RD&D Programme 2016 Programme for research, development and demonstration of methods for the management and disposal of nuclear waste	SKB Technical Report TR-16-15 Sept. 2016 https://skb.se/publikation/2485289/
	RD&D Programme 2019 Programme for research, development and demonstration of methods for the management and disposal of nuclear waste	Technical Report TR-19-24 Dec. 2019 https://igdtp.eu/skbs-rdd-programme-2019-published/
	RD&D Programme 2022 RD&D Programme for research, development and demonstration of methods for the management and disposal of nuclear waste	SKB TR-22-11, Dec. 2022 https://www.skb.com/publication/2506485/TR-22-11.pdf
Finland	Safety functions, performance targets and technical design requirements for a KBS-3V repository	Posiva SKB Report 01 January 2017
	Finnish Research Programme on Nuclear Waste Management 2011–2014, Final Report	MEE. (2015b). KYT2014 https://julkaisut.valtioneuvosto.fi/bitstream/handle/10024/74994/TEMjul_60_2015_web_19112015.pdf?sequence=1&isAllowed=y
France	Evaluation of the feasibility of a geological repository in an argillaceous formation Meuse/Haute-Marne site	ANDRA.Dossier 2005 Argile, Dec. 2005 http://www.andra.fr/download/andra-internationalen/document/editions/266va.pdf

	Programme de R&D 2013-2016. Executive Summary. ANDRA, Chatenay-Malabry (in French)	Andra Report 2014 http://www.andra.fr/download/site-principal/document/editions/542.pdf
Switzerland	The Nagra Research, Development and Demonstration (RD&D), Plan for the Disposal of Radioactive Waste in Switzerland	Technical Report 09-06, Nov. 2009
	The Nagra Research, Development and Demonstration (RD&D) Plan for the Disposal of Radioactive Waste in Switzerland	Nagra Technical Report NTB 16-02 2016
	The Nagra Research, Development and Demonstration (RD&D) Plan for the Disposal of Radioactive Waste in Switzerland	Technical Report NTB 21-02 Nov. 2021 https://nagra.ch/wp-content/uploads/2022/08/NTB-21-02.pdf
Belgium	Technical Overview of the SAFIR 2 report	ONDRAF/NIRAS, NIROND 2001-05 E Dec. 2001
	SAFIR2: Belgian R&D Programme on the Deep Disposal of High-Level and Long-Lived Radioactive Waste	OECD/NEA (2003) https://www.oecd-nea.org/jcms/pl_13794/safir-2-belgian-r-d-programme-on-the-deep-disposal-of-high-level-and-long-lived-radioactive-waste?details=true
	Geological disposal: R&D for the geological disposal of medium and high-level waste in the Boom Clay.	SCK-CEN report Febr.4, 2011 http://www.sckcen.be/en/Our-Research/Research-projects/NIRAS-ONDRAF
	ONDRAF/NIRAS, Waste Plan for the long-term management of conditioned high-level and/or long-lived radioactive waste and overview of related issues	NIROND 2011-02 E, 2011 https://www.niras.be/sites/default/files/2023-02/A4-E%20Waste_Plan_BC_2011-02E_1.pdf
UK	A Research and Development Strategy for the Disposal of High-Level Radioactive Waste and Spent Nuclear Fuel	DETR Report DETR/RAS/99.016 1999
	R&D Programme overview: Research and development needs in the preparatory studies phase 2012 Revision (with Changes)	NDA/RWMD/073 Version 2 2012

Czech	Priorities of the 2021 Research, Development and demonstration activities plan of the Bukov Underground Research facility	Technical report No. 550/2021 2021
Hungary	The Boda Claystone Formation site research framework program (in Hungarian)	Manuscript, RHK Kft., Paks, RHK-N-005/18. 2018
	Geological research program of the Bodai Clay Formation (in Hungarian)	RHK Kft. (PURAM) Report, SMI-019/17 2018
Slovenia and Croatia	Spent nuclear fuel and high-level waste Disposal in Slovenia or Croatia Reference scenario for geological disposal facility In hard rock with cost estimation for its implementation	IBE, Consulting Engineers; NRVR--0X/02B Feb. 2019
Netherlands	OPERA Research Plan Verhoef, E, and T Schröder	OPERA-PG-COV004, COVRA, 21 June 2011
	Long-Term Research Programme for Geological Disposal of Radioactive Waste. Overall research program and work program for 2020–2025.	Nieuwdorp: COVRA and Technopolis 2020 https://www.researchgate.net/publication/347836713_long-term_research_programme_for_geological_disposal_of_radioactive_waste
Norway	Concept Description for Norwegian National Disposal Facility for Radioactive Waste	AINS Group Technical report June, 2020

+ZIRA: zone of interest for the future site characterisation (la Zone d'intérêt pour la recherche approfondie

Non-European countries

Japan	Guideline on Research and Development related to Geological Disposal of High-level Radioactive Waste in Japan, Advisory Committee on Nuclear Fuel Cycle Backend Policy (in Japanese)	AEC (Atomic Energy Commission of Japan) Report 1997
	Project to Establish the Scientific and Technical Basis for High-Level Radioactive Waste Disposal in Japan: Second Progress Report on Research and Development for the Geological Disposal of HLW in Japan	JNC (Japan Nuclear Cycle Development Institute) 2000
	H12: Second progress report on R&D for the geological disposal of HLW in Japan	JNC TN1410 2000-001. JAEA, Tokai 2000

	R&D Needs for Geological Disposal Project - for the Selection of Detailed Investigation Areas. (in Japanese)	NUMO-TR-10-02 2010
USA	Used Fuel Disposition Campaign Disposal Research and Development Roadmap	Prepared for U.S. Department of Energy Used Fuel Disposition Campaign FCR&D-USED-2011-000065 REV 1 Sept. 2012

Appendix E. List of definitions

Definition	Description of definition	Note
beneficiary	Organisation having received a mandate by its national programme owner(s) (usually Ministry/regional authority) to participate in the EURAD implementation phase and that is willing to share the EURAD Vision/SRA/Roadmap.	EURAD Founding Documents
Early-stage Programmes	Radioactive waste management programmes that are at an early stage of development with respect to implementing disposal. This typically includes programmes in establishment or undertaking preliminary site evaluation and selection, or programmes yet to develop demonstrable competence for producing comprehensive safety cases (and their supporting evidence base) for detailed conceptual designs.	EURAD Founding Documents
competent regulatory authority	CRA means an authority, or a system of authorities designated in a Member State in the field of regulation of the safety of spent fuel or radioactive waste management as referred to in Article 6 of Council Directive (2011/70/EURATOM).	Council Directive 2011/70/EURATOM
information	Data that has been organised within a context and translated into a form, which has structure and meaning.	IAEA-TECDOC-1586
knowledge	A mix of experiences, values, contextual information and expert insight for acquiring, understanding and interpreting information. Together with attitudes and skills, it forms a capacity for effective actions. Acquiring, understanding and interpreting of information. Knowledge is often used to refer to a body of facts and principles accumulated by humankind over the course of time. Explicit knowledge is knowledge that can be easily expressed in documents. *Implicit knowledge* and *tacit knowledge* represent knowledge or know-how that people carry in their heads. *Comment*: Knowledge is distinct from information, as knowledge is information that has a purpose or use. Data leads to information and information leads to knowledge. Knowledge confers a capacity for effective action. Knowledge is information that has a purpose or use.	EURAD ROADMAP USER GUIDE IAEA-TECDOC-1586
management system	A set of interrelated or interacting elements (*system*) for establishing policies and objectives and enabling the objectives to be achieved in an efficient and effective manner. • ***integrated management system:*** A single coherent *management system* for *facilities and activities* in which all the	IAEA Glossary, 2022

Definition	Description of definition	Note
	component parts of an organisation are integrated to enable the organisation's objectives to be achieved. • ***knowledge management system*** (KMS) as a logical and technological part of IMS effectively supported all activities inside and outside of relevant institution	Paraphrase of team experiences
near surface disposal facility	A *facility* for *radioactive waste disposal* located at or within a few tens of metres of the Earth's surface. *practice* of disposal of *waste* in a *near surface disposal facility* with an engineered cover is also referred to as 'shallow land burial' of waste.	IAEA Glossary, 2022
integrated management system	A single coherent management system for facilities and activities in which all the component parts of an organisation are integrated to enable the organisation's objectives to be achieved *processes*.	IAEA Glossary, 2022
isolation (of radioactive waste in a disposal facility)	The physical separation and retention of *radioactive waste* away from people and from the *environment*.	IAEA Glossary, 2022
knowledge management	An integrated, systematic approach to identifying, managing and sharing an organisation's knowledge and enabling groups of people to create new knowledge collectively to help in achieving the organisation's objectives.	IAEA Glossary, 2022
minimisation (of radioactive waste)	The *process* of reducing the amount and *activity* of *radioactive waste* to a level as low as reasonably achievable, at all stages. (from the *design* of a *facility or activity* to *decommissioning*, by reducing the amount of *waste* generated and by means such as *recycling* and *reuse*, and *treatment* to reduce its *activity*, with due consideration for *secondary waste* as well as primary *waste*.) • *Minimisation of waste* is not to be confused with *volume reduction*.	IAEA Glossary, 2022 See below.
quality assurance	The function of a management system that provides confidence that specified requirements will be fulfilled. ! The IAEA revised the *requirements* and guidance in the subject area of *quality assurance* for its *safety standards* on *management systems* for the *safety* of *facilities and activities* involving the use of *ionizing radiation*. **!** The terms quality management and *management system* were adopted in the revised standards in place of the terms *quality assurance* and *quality assurance* programme.	IAEA Glossary, 2022

Definition	Description of definition	Note
	quality assurance (all those planned and systematic actions necessary to provide confidence that a *structure, system or component* will perform satisfactorily in service) and definitions of related terms can be found in the International Organisation for Standardisation's publication ISO 9000:2015	
quality control	Part of quality management intended to verify that *structures, systems and components* correspond to predetermined *requirements*. *quality control* and definitions of related terms can be found in ISO 9000:2015.	IAEA Glossary, 2022
radioactive waste	1. For legal and regulatory purposes, material for which no further use is foreseen that contains, or is contaminated with, radionuclides at activity concentrations greater than clearance levels as established by the regulatory body. ! It should be recognised that this definition is purely for regulatory purposes, and that material with activity concentrations equal to or less than clearance levels is radioactive from a physical viewpoint, although the associated radiological hazards are considered negligible. Practical use of phrases like: high level waste / low level waste used by experts according with IAEA Glossary may be misinterpreted by laymen and or robotic translator such as: high quality waste / low quality waste and not as high radioactive waste / low radioactive waste. 2. [*Radioactive material* in gaseous, liquid or solid form for which no further use is foreseen by the Contracting Party or by a natural or *legal person* whose decision is accepted by the Contracting Party, and which is controlled as *radioactive waste* by a *regulatory body* under the legislative and regulatory framework of the Contracting Party.]	IAEA Glossary, 2022 Paraphrase of team experiences
radioactive waste management (RWM)	1. All administrative and operational activities involved in the handling, pre-treatment, treatment, conditioning, transport, storage and disposal of radioactive waste. 2. [All activities, including decommissioning activities that relate to the handling, pre-treatment, treatment, conditioning, storage or disposal of radioactive waste, excluding off-site transportation. It may also involve discharges.]	IAEA Glossary, 2022 IAEA Glossary, 2022
RWM – *Conditioning*	Those *operations* that produce a *waste package* suitable for handling, *transport*, *storage* and/or *disposal*. • Conditioning may include the conversion of the waste to a solid waste form, enclosure of the waste in containers and, if necessary, provision of an overpack.	IAEA Glossary, 2022

Definition	Description of definition	Note
RWM – *Immobilisation*	Conversion of *waste* into a *waste form* by solidification, embedding or encapsulation. *Immobilisation* reduces the potential for *migration* or *dispersion* of radionuclides during handling, *transport*, *storage* and/or *disposal*.	IAEA Glossary, 2022
RWM *Integrated waste management*	Integrated waste management in the context of this Guide means considering geological disposal in coordination with other relevant waste management activities, such as decommissioning, waste treatment and storage as part of the broader nuclear life cycle (Integrated management system. A single coherent management system for facilities and activities in which all the component parts of an organisation are integrated to enable the organisation's objectives to be achieved.	Paraphrase of Integrated management system, IAEA Glossary, 2022
RWM – *overpack*	A secondary (or additional) outer container for one or more *waste packages*, used for handling, *transport*, *storage* and/or *disposal*.	IAEA Glossary, 2022
RWM – *packaging*	Preparation of *radioactive waste* for safe handling, *transport*, *storage* and/or *disposal* by means of enclosing it in a suitable *container*.	IAEA Glossary, 2022
RWM – *predisposal management*	Any waste management steps carried out prior to disposal, such as pre-treatment, treatment, conditioning, storage and transport activities. Predisposal is not a form of *disposal*: predisposal is used as a contraction of '*pre-disposal management* of *radioactive waste*'.	IAEA Glossary, 2022
RWM – *pre-treatment*	Any or all of the *operations* prior to *waste treatment*, such as collection, *segregation*, chemical adjustment and *decontamination*.	IAEA Glossary, 2022
RWM – *processing*	Any operation that changes the characteristics of waste, including pre-treatment, treatment and conditioning.	IAEA Glossary, 2022
RWM – *segregation*	An activity where types of waste or material (radioactive or exempt) are separated or are kept separate on the basis of radiological, chemical and/or physical properties, to facilitate waste handling and/or processing.	IAEA Glossary, 2022
RWM – *treatment*	*Operations* intended to benefit *safety* and/or economy by changing the characteristics of the *waste*. Three basic *treatment* objectives are: (a) *Volume reduction*; (b) Removal of radionuclides from the *waste*; (c) Change of composition.	IAEA Glossary, 2022

Definition	Description of definition	Note
RWM – ***volume reduction***	A *treatment* method that decreases the physical volume of a *waste*. • Typical *volume reduction* methods are mechanical compaction, incineration and evaporation. • Should not be confused with *waste minimisation*.	IAEA Glossary, 2022 See also *minimisation of waste* above.
reprocessing	A *process* or *operation*, the purpose of which is to extract *radioactive* isotopes from *spent fuel* for further use.	IAEA Glossary, 2022
Research Entity (RE)	Nationally founded entity working to different degrees on the challenges of RWM (and sometimes in direct support to implementers) under the responsibility of the Member State.	EURAD Founding Documents
Regulatory function	Regulatory function is composed of regulatory body which defines regulatory expectations and needs and is supported by TSOs with expertise function for regulatory decision	SITEX-II, Deliverable 1.1,
safety case	A collection of arguments and evidence in support of the *safety* of a *facility or activity*. • This will normally include the findings of a safety assessment and a statement of confidence in these findings. • For a *disposal facility*, the *safety case* may relate to a given stage of development. In such cases, the *safety case* should acknowledge the existence of any unresolved issues and should provide guidance for work to resolve these issues in future development stages. According to OECD/NEA a safety case is a formal compilation of evidence, analyses and arguments that quantify and substantiate a claim that the repository will be safe.	IAEA Glossary, 2022, OECD/NEA 2013
site confirmation (in the siting process for a disposal facility)	The final stage of the *siting process* for a *disposal facility*, based on detailed investigations on the preferred site, which provide site-specific information needed for *safety assessment*. • This stage includes the finalisation of the *design* for the *disposal facility* and the preparation and submission of a *licence* application to the *regulatory body*. • *Site confirmation* follows *site characterisation* for a disposal facility.	IAEA Glossary, 2022
site evaluation	*Analysis* of those factors at a site that could affect the *safety* of a *facility or activity* on that site. This includes *site characterisation*, consideration of factors that could affect *safety features* of the *facility* or *activity* to result in a *release* of	IAEA Glossary, 2022

<table>
<tr><th>Definition</th><th>Description of definition</th><th>Note</th></tr>
<tr><td></td><td> radioactive material and/or could affect the dispersion of such material in the environment, as well as population and access issues relevant to safety (e.g. feasibility of evacuation, location of people and resources). The analysis for a site of the origins of external events that could give rise to hazards with potential consequences for the safety of a nuclear power plant constructed on that site. facility, site evaluation typically involves the following stages: (a) Site selection stage. One or more preferred candidate sites are selected after the investigation of a large region, the rejection of unsuitable sites, and screening and comparison of the remaining sites. (b) Site characterisation stage. This stage is further subdivided into: Site verification, in which the suitability of the site to host a nuclear facility is verified mainly according to predefined site exclusion criteria;
Site confirmation, in which the characteristics of the site necessary for the purposes of analysis and detailed design are determined. (c) Pre-operational stage. Studies and investigations begun in the previous stages are continued after the start of construction and before the start of operation of the facility, to complete and refine the assessment of site characteristics. The site data obtained allow a final assessment of the simulation models used in the final design. (d) Operational stage. Appropriate safety related site evaluation activities are carried out throughout the lifetime of the facility, mainly by means of monitoring and periodic safety review. </td><td>Paraphrase of IAEA Glossary definition.</td></tr>
<tr><td>site (seismic) response</td><td>The behaviour of a rock column or soil column at a site under a prescribed ground motion load.</td><td>IAEA Glossary, 2022</td></tr>
<tr><td>siting</td><td> The process of selecting a suitable site for a facility, including appropriate assessment and definition of the related design bases. The siting process for a nuclear installation generally consists of site survey and site selection.
site survey: The process of identifying candidate sites for a nuclear installation after the investigation of a large region and the rejection of unsuitable sites.
site selection: The process of assessing the remaining sites by screening and comparing them on the basis of safety and other considerations to select one or more preferred sites.</td><td> IAEA Glossary, 2022 Paraphrase of IAEA Glossary definition. See also site evaluation above. </td></tr>
</table>

Definition	Description of definition	Note
	• The *siting process* for a *disposal facility* is particularly crucial to its long term *safety*; it may therefore be a particularly extensive *process*, and is divided into the following stages: ○ Concept and planning; ○ Area survey; ○ Site characterisation; ○ Confirmation of selected site for waste disposal. • The terms siting, design, construction, commissioning, operation and decommissioning are normally used to delineate the six major stages of the lifetime of an authorised facility and of the associated licensing process. In the special case of disposal facilities for radioactive waste, decommissioning is replaced in this sequence by closure.	
Small Inventory´s Programme	Radioactive waste management programmes that have a small inventory typically containing medical waste, disused and sealed radioactive sources and possibly a small amount of spent nuclear fuel from research reactors. Such programmes typically consider the construction of a dedicated national geological repository unfeasible and work in pursuit of economical ways for disposing of small amounts of radioactive waste, either through the possibility of shared regional facilities, borehole disposal or through a focus on long-term storage.	EURAD Founding Documents
spent fuel	1. Irradiated *Nuclear fuel* removed from a reactor that is no longer usable in its present form because of depletion of *fissile material*, *poison* build-up or *radiation* damage. The participle ‘spent’ suggests that *spent fuel* cannot be used as *fuel* in its present form (e.g. as in *spent source*). In practice, however (as in (2) below), *spent fuel* is commonly used to refer to *fuel* that has been used as *fuel* but will no longer be used, whether or not it could be used (and that might more accurately be termed ‘disused *fuel*’). 2. [*Nuclear fuel* that was irradiated and permanently removed from a reactor core.]	IAEA Glossary, 2022 Paraphrase of IAEA Glossary definition.
spent fuel management	All activities that relate to the handling or storage of spent fuel, excluding off-site transport. It may also involve refuelling.	IAEA Glossary, 2022 Paraphrase of IAEA Glossary definition.
storage	The holding of radioactive sources, radioactive material, spent fuel or radioactive waste in a facility that provides for their/its containment, with the intention of retrieval/access.	IAEA Glossary, 2022

Definition	Description of definition	Note
	According with: the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, the Code of Conduct on the Safety and Security of Radioactive Sources, etc.: **The storage** is by definition an interim measure, and the term "interim storage" would therefore be appropriate only to refer to short-term temporary storage when contrasting this with the longer-term fate of the radioactive waste. **The storage** as defined above should not be described as interim storage and it is quite different from the term "a disposal facility". There is in many cases, the only one important element of this definition "the difference" between disposal facility (with no intent to access) and storage (with intent to access). • In such cases, a definition is not necessary; the distinction can be made in the form of a footnote at the first use of the term disposal or storage (e.g. “Use of the term disposal indicates that there is no intention to retrieve the waste. If retrieval of the waste at any time in the future is intended, the term storage is used.”). • For storage with both: storage and disposal facility, for which a decision may be made at the time of its closure whether to remove the waste stored during the operation of the storage facility or to dispose of it by encasing it in concrete, the question of intention of retrieval may be left open until the time of closure of the facility. • Contrasted with disposal.	Paraphrase of IAEA Glossary definition.
structures, systems and components	A general term encompassing all of the elements (items) of a facility or activity that contribute to protection and safety, except human factors. • Human factors may be reflected in structures, systems and components in so far as ergonomics — the study of people’s efficiency in their work setting — is an element in their design. • ***Component:*** One of the parts that make up a system. ○ A *component* may be a hardware *component* (e.g. wires, transistors, integrated circuits, motors, relays, solenoids, pipes, fittings, pumps, tanks, valves) or a software *component* (e.g. modules, routines, programmes, software functions). ○ A *component* may be made up of other *components*.	IAEA Glossary, 2022 Paraphrase of IAEA Glossary definition. See also *active comp.*, *passive comp.* and *core components* at IAEA Glossary

Definition	Description of definition	Note
	• ***Structure:*** A passive element (e.g. building, vessel, shielding). • ***System:*** A set of components, which interact according to a design to perform a specific (active) function, in which an element of the system can be another system, called a subsystem.	
survey	• ***Area survey:*** An early stage of the *siting process* for a *disposal facility*, during which a broad region is examined to eliminate unsuitable areas and to identify other areas, which may contain suitable sites. ○ *Area survey* is followed by *site characterisation*. ○ *Area survey* may also refer to the *siting process* for any other *authorised facility*. ○ See also *site evaluation*, which includes *site characterisation* and is not specific to a *disposal facility* site. • ***Habit survey.*** An evaluation of those aspects of the behaviour of *members of the public* that might influence their *exposure* — such as diet, *food* consumption rates or occupancy of different areas — usually aimed at characterising the *representative person*.	IAEA Glossary, 2022 Paraphrase of IAEA Glossary definition.
Technical Support Organisation	Beneficiary carrying out activities aimed at providing the technical and scientific basis for notably supporting the decisions made by a national regulatory body.	EURAD Founding Documents
Waste Management Organisation	Beneficiary whose mission covers the management and disposal of radioactive waste.	EURAD Founding Documents

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