tso

EUROPEAN COMMISSION

Community research

SecIGD2 Project

(Contract Number: 323260)

RD&D Planning Towards Geological Disposal of Radioactive Waste
DELIVERABLE (D-N°: 2.3)
Guidance for less-advanced Programmes

Author(s): **T. Beattie, R. Kowe, J. Delay, G. Buckau, D. Diaconu**

Reporting period: e.g. 01/07/2014 – 31/12/2015

Date of issue of this report: **30th June 2015**

Start date of project: **01/01/2013** Duration: 36 Months

Project co-funded by the European Commission under the Seventh Euratom Framework Programme for Nuclear Research &Training Activities (2007-2011)	
Dissemination Level	
PU	Public

EURATOM

History chart			
Type of revision	**Document name**	**Partner**	**Date**
DRAFT 0.1	Issued for review and input by PLANDIS organising committee members.	T. Beattie, R. Kowe	14 Oct 2014
DRAFT 0.2	Issued as DRAFT to IGD-TP Project Place for preview ahead of EF5	T. Beattie, R. Kowe	23 Oct 2014
DRAFT 0.3	Issued to IGD-TP Executive Group for Review	T. Beattie, R. Kowe	03 Nov 2014
DRAFT 0.4	Issued to IGD-TP Community and PLANDIS target distribution list for preliminary feedback	T. Beattie, G. Buckau, C. McCombie	27 Feb 2015
FINAL	Incorporating comments from feedback from PLANDIS workshop and further comments from EG members after EG17.	R. Kowe	30 Jun 2015

Reviewed by (Proposal below for review route in 2015)

IGD-TP Executive Group

Approved by (Proposal below for approval route in 2015)

Jon Martin (Head of Research, RWM) – approve for submission at EG 16
IGD-TP Executive Group – approve for dissemination at EG 16
Jacques Delay (SecIGD2 Coordinator) – approve for publication
IGD-TP Executive Group – approve for publication at EG 17

IGD-TP Report
RD&D Planning Towards Geological Disposal of Radioactive Waste:
Guidance for less-advanced Programmes

The research leading to these results has received funding from the European Union's European Atomic Energy Community's (Euratom) Seventh Framework programme FP7 (2007-2013) under grant agreements n°249396, SecIGD, and n°323260, SecIGD2.

Executive Summary

The SecIGD2 project of the Implementing Geological Disposal of Radioactive Waste Technology Platform (IGD-TP) has developed a Guide on RD&D programme planning towards geological disposal of radioactive waste. This Guide considers the essential elements of RD&D planning and provides instructional questions that should be addressed to respond to Council Directive 2011/70/EURATOM Articles 12 (1,F) and 12 (1,J). It considers the RD&D activities that are typically planned during early phases of disposal programme management. It also considers the management activities that need to be considered to successfully implement RD&D activities, 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.

This Guide is complementary to both: (i) NAPRO Guide (*Guidelines for the establishment and notification of National Programmes, 2011*); and (ii) IAEA Report on Planning and Design Considerations for Geological Repository Programmes (*IAEA Technical Report C-1755, 2014a*).

Users of this Guide are primarily programme owners and managers working within or on behalf of a waste management organisation (WMOs) responsible for implementation of geological disposal. As such, the contents of this Guide focus on the RD&D priorities and needs of WMOs. However, the rationale for organising the RD& D could be of use for Technical Support Organisations (TSOs – providing support to regulatory bodies when executing their regulatory function), representatives of civil society and experts knowledgeable in governance and involvement of civil society.

Table of contents

1. Introduction

1.1 Approach and background

This Guide has been developed by the SecIGD2 project of the Implementing Geological Disposal of Radioactive Waste Technology Platform (IGD-TP). It responds directly to the needs of less advanced programmes to '*set-out the research, development and demonstration (RD&D) activities that are needed in order to implement their national policies for the responsible and safe management of spent fuel and radioactive waste*' – Council Directive 2011/70/EURATOM Article 12, 1, F (Official Journal of the European Union 2.8, 2011).

The Guide has been co-developed by: (i) individuals experienced in RD&D planning for more advanced geological disposal programmes; (ii) individuals involved with the completion and delivery of RD&D on behalf of waste management organisations; and (iii) target end-users of the guide, represented by individuals working towards geological disposal from less-advanced waste management programmes. In addition to the co-authors mentioned, the guide builds on specific work recently undertaken by members of the IGD-TP Executive (see Zuidema and Johnson, 2013). The Guide has also been subject to wider engagement and preview during development, which has been obtained from:

- Target end-user input – Preview of the draft Guide to obtain constructive feedback on content and usability. Feedback has been used to update the Guide prior to publication;
- Peer review – Peers of RD&D planning from the IGD-TP Executive Group have provided review of the draft Guide. The IGD-TP Executive Group has provided endorsement of the Guide prior to publication; and
- Usability testing – Instructional questions and templates contained in the Guide on RD&D prioritisation scheme have been tested in a workshop attended by target end-users (PLANDIS, Romania, 2015). Feedback from this event has been used in the final revision of the document prior to publication.

The scope of the Guide is restricted to RD&D related to geological disposal of long-lived radioactive wastes and in general does not cover pre-disposal activities. The Guide is also particularly aimed at programmes making a first attempt to set-out at a national-level their RD&D needs towards geological disposal. It is complementary to: (i) ENEF *Guidelines for the establishment and notification of National Programmes* (ENEF, 2013); and (ii) IAEA Report on *Planning and Design Considerations for Geological Repository Programmes* (IAEA, 2014a).

In contrast to the IGD-TP *Strategic Research Agenda* (IGD-TP, 2011), the RD&D activities included herein are explicitly aimed at programmes with implementation schedules for working towards operational facilities well beyond 2025. It has been assumed that more

advanced programmes aiming for the IGD-TP Vision timescale of 2025 (IGD-TP, 2009), have already established programme plans for their remaining RD&D activities, and therefore are not considered as end-users of this document.

The Council Directive 2011/70/EURATOM (Official Journal of the European Union 2.8, 2011) establishes a broad Community framework for the responsible and safe management of spent fuel and radioactive waste. It covers in addition to RD&D planning requirements (i.e. Articles 12 (1,F)), many other national programme requirements that less-advanced programmes may likely consider of higher importance for their current needs[1]. Therefore, this Guide and its contents need to be used by individuals and entities with a sufficient understanding of their national policy towards geological disposal and the broader political dimension, including the other directive requirements which may merit higher prominence. The Guide is therefore primarily aimed at programme owners and managers working within or on behalf of a waste management organisation (WMO) responsible for implementation of geological disposal. As such, the contents of this Guide focus on the RD&D priorities and needs of WMOs. However, the rationale for organising the RD& D could be of use for Technical Support Organisations (TSOs – providing support to regulatory bodies when executing their regulatory function), representatives of civil society and experts knowledgeable in governance and involvement of civil society.

1.2 Structure of this Guide

The Guide comprises three main sections which are aimed at providing (i) an introduction to the broad disposal programme activities that affect how an RD&D plan is established; (ii) an illustration of the core RD&D activities that are typically prioritised during early phases of a disposal programme; (iii) instructional questions (contained in boxed text throughout) and example templates (in the Appendix) that can be used as a basis for a first attempt at developing a national RD&D planning document – specifically oriented towards geological disposal.

1.3 Definition of RD&D

Research is oriented towards "understanding" and may lead to new (conceptual) models, data, etc. or confirmation/refinement of existing information. Development is focused on the application of "understanding" for a specific purpose, whereas Demonstration evaluates whether the issue under investigation is "under control", e.g. through full scale URL experiments or development of prototypes (Zuidema and Johnson, 2013).

RD&D serves several purposes. It provides input to system design and optimisation and makes essential contributions to siting of repositories. It furthermore contributes to achieving

[1] A useful summary of the Council Directive is provided in Annex II of reference JRC, 2014.

a sufficient level of system understanding to allow an adequate evaluation of safety. In addition, RD&D may also address specific issues that are of concern to stakeholders.

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 of programme (Zuidema and Johnson, 2013).

2. Establishing an RD&D plan

This section sets out what needs to be considered when first establishing an RD&D plan. These are considered by the authors to reflect the minimum geological disposal related requirements of Council Directive 2011/70/EURATOM Article 12 (1,F) to *set-out the research, development and demonstration (RD&D) activities that are needed in order to implement their national policies for the responsible and safe management of spent fuel and radioactive waste'* (Official Journal of the European Union 2.8, 2011)[2]. 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 Guide and therefore can be adapted to suit specific 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. This is to meet the needs of programmes that may potentially have limited resources or have only recently established (or are working towards establishing) mandated actors responsible for RD&D planning towards geological disposal on a national scale.

2.1 Programme boundary conditions for waste disposal

Essential background to establishing an RD&D plan is a clear description of the current programme boundary conditions that influence how implementation of geological disposal is anticipated, including the specification of the waste to be disposed, 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. 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 to geological disposal. For 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 national inventory of radioactive waste, the national context may also be used to justify the current non-existence of a dedicated RD&D programme.

[2] This should not be understood to mean that by using this Guide, a WMO could be certain of meeting legal requirements of the Directive in establishing and implementing "*the research, development and demonstration activities that are needed in order to implement solutions for the management of spent fuel and radioactive waste;*" (Art. 12.1,f) when notifying the respective national programme to the Commission in accordance with Art. 13.

Figure 1 below 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, 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. The RD&D Plan should summarise the national programme context and provide a reference to where it is described more comprehensively in a '*Lead Document*', see Section 9 and Annex VI of the NAPRO Guide (ENEF, 2013).

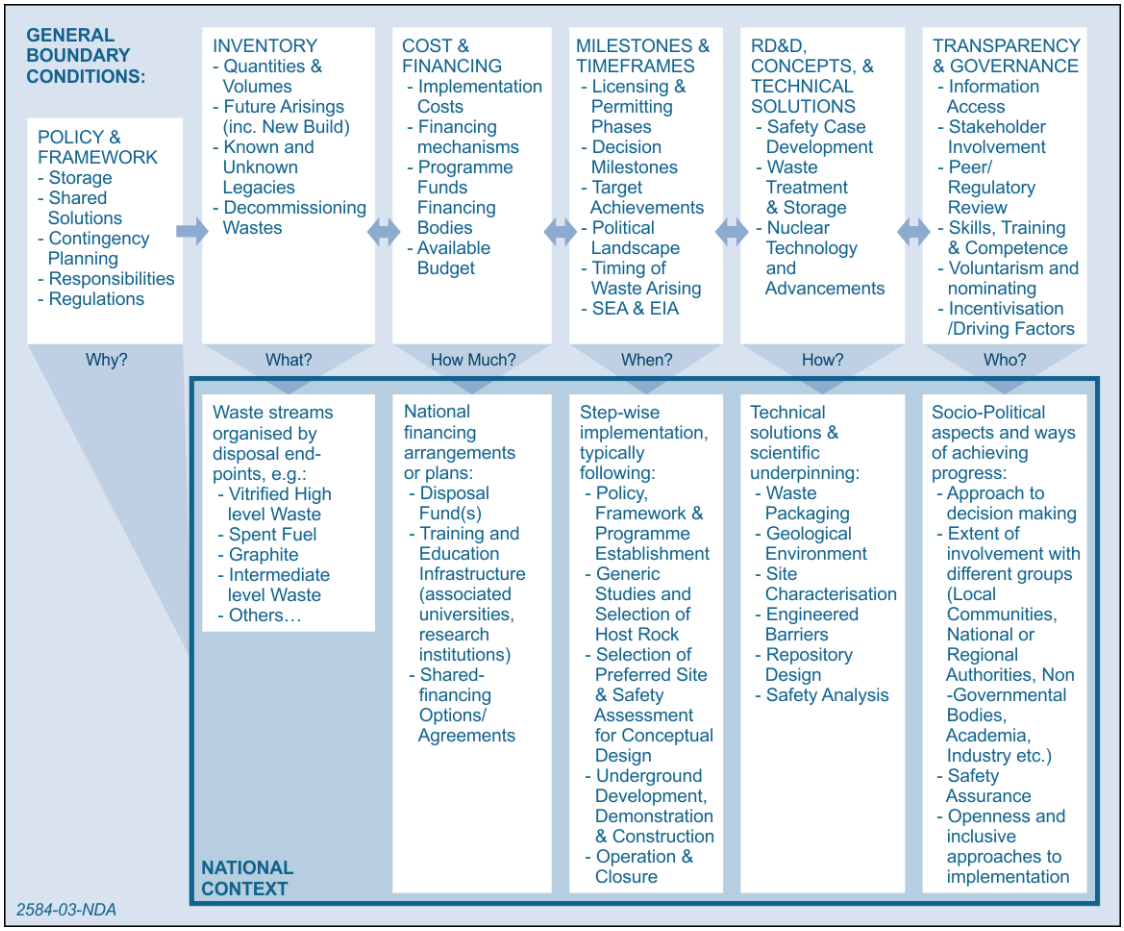

Figure 1 - 6 key questions to help summarise the national programme context: why, what, how much, when, how, who?

European waste management organisations with relatively advanced programmes regularly update their national RD&D programme plans for geological disposal of radioactive waste (e.g., *NDA*, 2014, and Chapter 2 References of IGD-TP, 2011). These each exemplify good practice on how to appropriately 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 NAPRO Guide Annex VI also provides a proposal for a Lead Document which ideally would complement a summary of programme boundary conditions used in an RD&D plan. For the purposes of the introduction of an 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 which 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 disposal 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:

Government policy and framework

Has the national government set-out a commitment to support geological disposal?
Has a process for implementation of geological 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 geological disposal? For example, have regulators (and regulatory controls), implementers and key decision makers been established?
Are other management options under consideration alongside geological disposal?

Wastes arisings and current storage arrangements

Is there a developed inventory of the radioactive wastes (including future waste arising from ongoing generation)?
What are the current management arrangements for wastes?

Cost and financing

Are adequate funding arrangements in place to implement geological 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 separate entity (e.g. appointed government 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?

Stepwise approach to implementation

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

Multi-barrier concept and technology solutions

What is the approach to developing a safety concept for geological disposal (intended function of multiple barriers and how specified performance will be achieved by your proposed repository 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)?

Transparency and governance

Is there a process for working with communities impacted by geological disposal and/or maintaining public confidence? For example, how are local communities involved, are there financial incentives for a host or local community?
Is there a process for how important decisions will be made? For example, national voting, regulations, appointed committee of experts, regional/local consensus?

2.2 Milestones and timeframes

It is important for a geological disposal programme to set-out long-term timescales for implementing geological 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 disposal typically follows a stepwise approach with timescales for achieving publically acceptable and regulatory approved operations in the order of tens to hundreds of years. Across Europe, a few of the first disposal facilities for spent fuel are envisaged by 2025. The timing of successive steps of implementation to achieve such milestones often varies between 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, repository lay-out and engineered barrier systems).

Figure 2 below illustrates the typical phases[3] of implementing geological disposal – with a particular focus on early licensing phases and the development of a safety case. Note that the exact 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 (see Section 2.3) .

[3] The above breakdown has been developed by considering phases described by (i) *IAEA Planning and Design Considerations for Geological Repository Programmes of Radioactive Waste* (IAEA, 2014a), (ii) *IGD-TP Strategic Research Agenda* (IGD-TP, 2011), and (iii) *IGD-TP Vision report* (IGD-TP, 2009). For the target audience of this 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 B to show how we have interpreted the terminology and description of the phases developed herein.

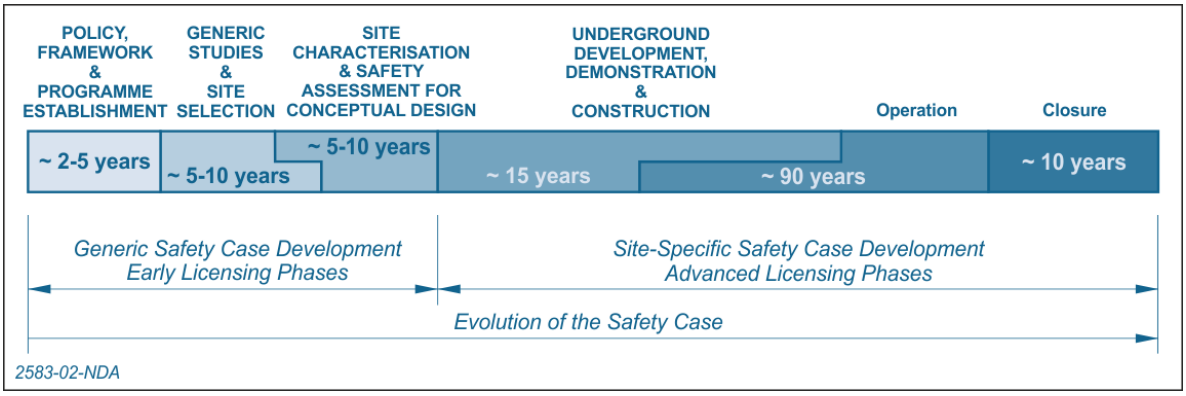

Figure 2 - Preparatory and implementation phases of geological disposal

1. Policy, framework and programme establishment

Selection of geological disposal at a national level as government policy / commitment by national government to pursue and support geological disposal. This often includes the creation of a waste management organisation (WMO) and establishing the appropriate regulatory oversight (IAEA, 2014a). Safety-documentation produced in this phase would 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 geological disposal. This phase may also consider the establishment of a regulated financing mechanism and a financing system to ensure that prioritised RD&D can be completed.

2. Generic studies and site selection

A broad range of RD&D studies to 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 relative safety of disposal for available geology and concept scenarios to support effective decision making in relation to siting. Consideration for societal aspects may begin in this phase, for example consulting and involving national stakeholders 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 a facility.

3. Site characterisation and safety assessment for conceptual design

Surface-based investigation of a potential site or sites (prior to going underground) including 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. This phase includes refinement of engineered barrier concepts, preliminary engineering design for constructability, 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 an underground facility.

4. Underground development, demonstration and construction

Detailed site characterisation and design testing (including site-specific underground testing). This will include the construction of access ways (shafts or ramp) to the host rock; underground characterisation of the host rock; 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 site (IAEA, 2013). Detailed design work, and further development of license-oriented operational and long-term safety cases will continue throughout construction of the facility. Via licensing, it is likely that national regulatory permits would be staged during construction, with a first step of in-situ testing of a non-active pilot facility. 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. Operations and closure

Includes the period of waste emplacement and any extended period of operation (open access ways and monitoring) beyond completion of emplacement. 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. Typically, RD&D Plans are developed with a 5 to 10 year forward horizon, and reviewed and updated periodically thereafter. Typical questions addressed in a description of the long-term and short-term description of timescales relevant to RD&D planning are set-out below.

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 organisations or in government policy for how safety should be demonstrated at specified milestones through successive phases of implementation. Example questions to address in deciding on timescales for safety case development (or other specified regulatory approval requirements) include:

Short-term Requirements

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 geological disposal?

Long-term Requirements

What safety regulations exist (or are currently being established) at a national level in relation to geological disposal?

Are there any (planned) or existing requirements to develop safety case documentation / submissions at key programme milestones?

Template 1 illustrates how to set-out key programme milestones to inform prioritisation of an RD&D Plan (see Appendix A).

2.3 Safety case as principal driver for RD&D

The most common approach to developing an RD&D plan is to use the safety case(s) as the main driver to determine the necessary tasks to prioritise[4]. The safety case is the collection of scientific, technical, administrative and managerial arguments and evidence in support of the safety of a disposal facility. 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 geological 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 systems to suit inventory waste types and available host rock types). This can help to: (i) identify safety

[4] The safety case is a main driver but it is not the only one. It is used in this document as a device to illustrate the different aspects of RD&D to consider at difference phases of implementation. It is likely that as a programme advances other RD&D considerations will become important such as those related to construction and operation. However, this would cover a lot more issues than could be covered in an overview document such as this Guide.

significant issues; (ii) compare programme options and provide quantitative information to inform important disposal system development decisions; and (iii) provide a basis for communicating and building broad confidence in the safety basis of geological 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 '*Generic Studies and Selection of Host Rock*' 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 underground 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). At each phase, 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). In order to preserve credibility, and confidence in the stepwise approach itself, there must be an understanding, by all stakeholders, of what is to be broadly achieved at each phase (i.e. key milestones) and what would be required, in terms of information and confidence, to justify proceeding to the next phase of development, or that the assessment basis should be modified and a new safety case compiled (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 geological 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).

Given the wide audience for 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.

It should be noted that a regulatory body may decide or be required itself 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 waste management organisation. This may involve RD&D tasks undertaken jointly by the regulatory body and WMO, or there may be situations in which the regulatory body needs to conduct independent RD&D work in order to perform a critical and objective review and assessment.

In support of long-term safety, RD&D programmes are often structured according to information or data needs associated with assessing different components of the disposal system. Available international state-of-the-art information from 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 this work enable an assessment of where there are high uncertainties associated with parts of the disposal system, which may be improved from further RD&D. 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 arisings.
- 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 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.
- 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 (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. 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 which should drive the majority of prioritised RD&D (NEA, 2013). Figure 3 (reproduced from IAEA, 2012) illustrates the components of the safety case that should be considered.

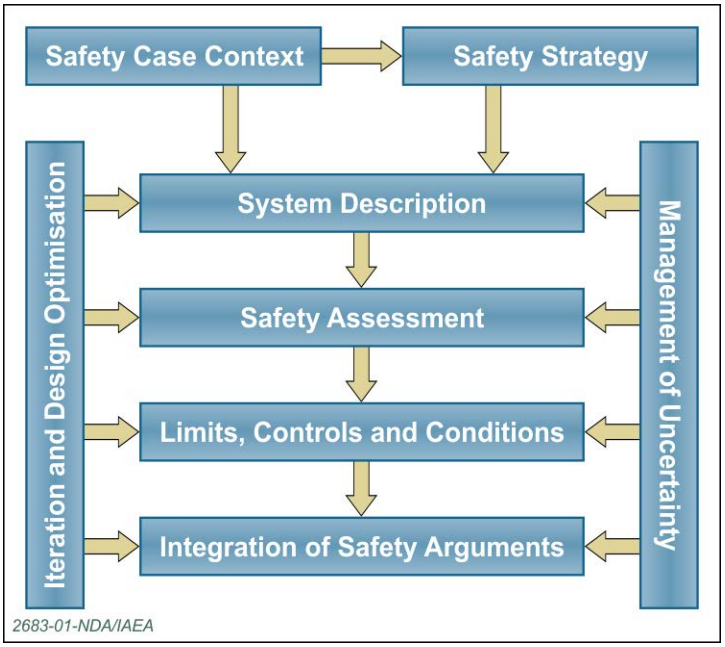

Figure 3 - Components of a safety case according to the IAEA (IAEA, 2012)

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.

2.4 Responsibilities and entities involved with RD&D

The development and management of an RD&D plan as part of a radioactive waste disposal programme is ultimately the responsibility of the mandated implementer, usually a waste management organisation. 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 waste management organisations with responsibility for waste management and / or implementing geological disposal. This includes responsibility for defining, financing or managing RD&D programmes (so-called "programme owners" and "programme managers") carried out at national or regional levels. So-called programme managers of RD&D are required who 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 and competency to act as the main points of contact for decision makers and being responsive to general stakeholders who may raise questions or 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. research sealed 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, 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 impacts 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 supporting strategic decisions for interim storage solutions.
- Regulators or Technical Support Organisations (TSOs) who can provide independent assurance or scrutiny of RD&D activities - it is usual for programmes to maintain a clear and responsive approach to engagement with regulators and/or TSOs and to establish external scrutiny (either by a committee of experts or selected and respected individuals) to maximise confidence in the programme.

- Research entities (research institutions, academics and learned societies) that are active in the broad RD&D categories of geological disposal - their role in a generic RD&D programme may range from complete day-to-day management of the programme to minimum conduct of one-off pieces of work, or providing influence and objective opinion to other stakeholders or decision makers on strategic aspects of the programme (e.g. forming part of an independent technical advisory role or assurance role); and
- Local communities / civil society – site-specific or local community requirements that may impact how geological 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 safe management of radioactive waste.

2.5 Methodology for prioritising RD&D

It is important that RD&D activities are appropriately prioritised to demonstrate that the right things are planned for the right time and that key outputs from RD&D are available for when they are needed at key programme milestones. The prioritisation scheme and relative importance of possible RD&D tasks will vary, depending on the perspective of each entity named above. However, from the perspective of the WMO, the prioritisation scheme will be dominated by the needs of the safety case (including safety cases in support of interim storage and waste conditioning). Therefore, 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 outlined above. Example questions to address when considering the drivers used for assessing priorities for planned RD&D activities are set-out below[5].

[5] 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 less mature alternative disposal concepts to bring them to an appropriate scientific readiness to facilitate future concept selection, i.e. to close the gap between the current SRL and that required to make a decision. Normally, RD&D leads to an increase in the TRL for a given task. SRL is a registered trademark of the National Nuclear Laboratory Ltd.

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 PRIORITIZING 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 or other)?
What do you need to know by when (focussing on information needed for programme implementation from WMO perspective)?
How important or significant is this activity?
What is the 'knowledge gap'?
What is needed to do to fill it?
How long will it take?
How urgent is the task?

Scales to judge or rank the significance or knowledge gap

The below matrix illustrates how a simple High-Medium-Low scale can be used to judge RD&D priorities:

	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 (see, Appendix A).

2.6 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:

- Competence management – Individuals involved with the specification, prioritisation, delivery and evaluation of RD&D activities need to be suitably qualified. During early licensing phases (for example during '*Programme Establishment*' and '*Generic Studies*'), 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 competing 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.
- Advisory support and scrutiny – 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).

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 30 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 less advanced programmes 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 (*from the WMO perspective*):

Competency management

What training or specific development activities are in-place to develop or maintain a skilled and competent workforce to support your RD&D programme?

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?

The above example questions can be used to guide responses to Section T2.5 of Template 2 (see Appendix A), particularly stating if open international collaboration (technology transfer or knowledge transfer) is the potential source of information.

3. Programme activities and RD&D tasks (up to construction)

A geological disposal programme will cover a broad range of technical activities which includes a component which can be defined as RD&D. Planning of RD&D tasks must therefore be related to key programme activities or particular drivers. Figure 4 below illustrates the relative importance between these broader programme activities across the early programme phases – with RD&D priorities indicated for each phase. The proceeding text summarises the highlighted programme activities (noting that more detailed explanations are provided in IAEA, 2014a). The proceeding text also indicates the types of RD&D activities that are typically prioritised in relation to these programme activities.

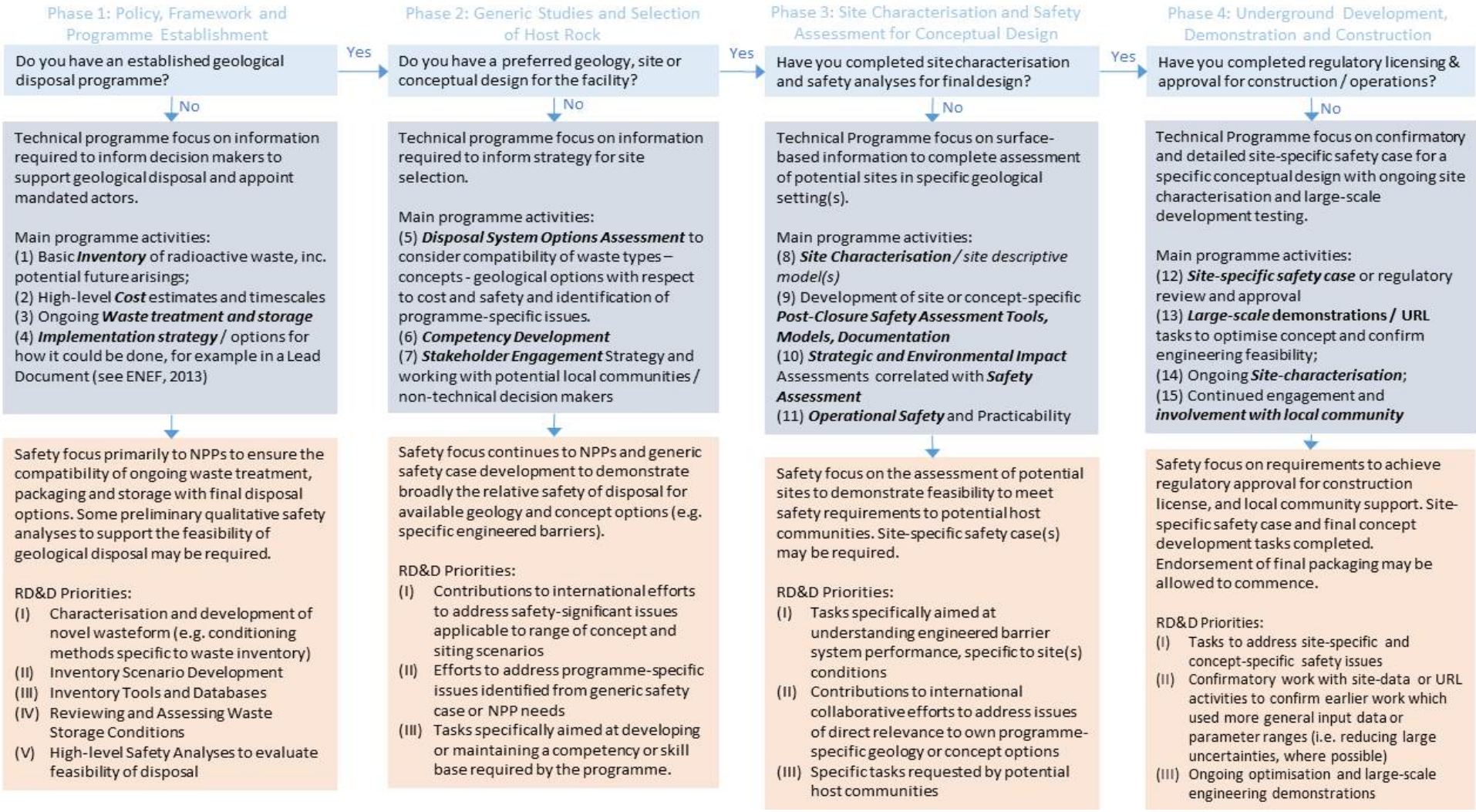

Figure 4 - Flow chart of typical programme activities and RD&D priorities (up to construction phase)

There is a vast amount of RD&D material available internationally on geological disposal of radioactive waste. 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 quickly to identify topics where either (i) information and approaches are already well-developed or adequate and can readily be imported and adapted to programme boundary conditions; (ii) significant new RD&D with potentially long lead times might be required to respond to specific programme factors; or (iii) significant new RD&D is expected internationally with which all programmes would need to keep abreast of such developments.

3.1 Inventory

The definition of waste sources and their classification is a key input to any disposal programme, see Section 8.3 (ENEF, 2013). Without a proper inventory of radioactive waste arisings, including their chemical, physical and radiological properties, it is not possible to design or assess the safety of a proposed facility for the handling, storage or disposal of these materials. Information on the quantities and types of radioactive waste and other materials (chemical) potentially destined for geological disposal should be periodically compiled to produce a formal waste inventory.

The inventory is considered a principal input to RD&D activities, and therefore not usually included within the scope of the RD&D programme itself. However, owing to the coupled relationship of the inventory as source input data to models and performance assessment calculations, there are development tasks ongoing internationally that may need to be considered:

- Inventory scenarios – these needs to be tailored to the national boundary conditions;
- Inventory development tools and databases – remaining challenges include: (i) the integration and expansion of existing codes and databases to provide a comprehensive overview of all existing and expected wastes; (ii) setting such tools within a structure which allows feedback from performance assessment of the disposal system in order to optimise waste conditioning and packaging; and (iii) establishing suitable quality management / data management system to ensure all inventories will be rigorous enough for licensing purposes.

3.2 Cost

An important consideration throughout the geological disposal programme will be the ongoing management and funding for financing of the disposal programme and eventual construction and operational facility cost (including the cost of the RD&D programme in support of the safety case which may run throughout all these phases). At the beginning of the programme, the focus will be to establish 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 (e.g. the waste inventory), the timing of the waste production, the need for interim storage arrangements, and the timing and duration of the different phases of implementation (IGD-TP, 2011).

There are no specific RD&D tasks expected to be prioritised relating to cost estimates and financing schemes. Ongoing development tasks that could be undertaken through involvement in international collaborative projects include:

- Cost bench-marking – advanced programmes often undertake or participate in benchmarking studies to compare cost assessment methodologies. EDRAM e.g. is currently completing 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, and NEA, 2014).

3.3 Waste treatment and storage

Supporting the ongoing development of an integrated waste management approach[6] of radioactive waste requires coordination and consideration of all activities relating to waste treatment, packaging, storage and final disposal. During the early phases of '*Programme Establishment*' and '*Generic Studies*', a large effort is typically directed towards supporting effective waste storage strategies and ensuing waste treatment and packaging options are compatible with final disposal options, even if this is many decades into the future (IAEA, 2007b). Prior to siting, the main focuses of the tasks are typically prioritised towards:

- Wasteform characterisation – review of programme specific waste types and the provision of technical support and advice on waste conditioning methods compatible with disposal options should be explored. Scope of RD&D tasks will likely relate to understanding long-term behaviour of new or novel wasteforms and fuels (e.g. higher burn-up fuels), and in particular the generation of source term data specific to the national inventory of wastes and fuels in preparation for future safety assessments.
- Packaging assessments – where there is a need to commence packaging of wastes, work should be undertaken to understand the likely performance of such packaging options with respect to long-term safety (i.e. how they are likely to evolve in a geological disposal facility during post-closure and contributions to longer-term safety), their compatibility with disposal concept options, and whether any specific requirements are placed on the geological disposal system or interim waste storage facilities by the proposed packaging options.
- Storage conditions – development of a knowledge base for existing wastes' storage conditions (e.g. environmental conditions) to support long-term estimates of wasteform or waste package integrity.

[6] 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.

3.4 Implementation strategy

An implementation strategy will be required during the early phases of programme management to set-out how implementation of a geological disposal 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 communicate the important needs and drivers for the RD&D plan. An important distinction to make here will be the approach to siting (and whether the implementer will undertake geological screening to identify a preferred geology) and whether the implementer 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).

3.5 Generic safety case development

Once the disposal programme has been established, the main technical activities will be to review engineered barrier system options for use in the disposal system and the development of assessment methodologies and tools to consider and evaluate available options. This is commonly undertaken first by considering potential disposal system options for the most challenging waste types – i.e. those that are more toxic and longer-lived, requiring greater robustness of the engineered and / or natural barriers. Studies carried out over the last couple of decades have shown that, under programme-specific boundary conditions, many different combinations of waste type / engineered structures and geological settings can provide high levels of safety. Approaches to concept development / selection typically fall into two categories:

- Given a site or preferred geological setting (e.g. in the vicinity of waste production) tailor a reference engineered barrier system / concept to it; or
- Assuming a reference engineered barrier system / concept, select a suitable site that will make its implementation easier.

The main technical activity during early phase programme development and prior to siting will be to develop a disposal concept (or range of potential concepts) for the national waste inventory (IAEA, 2009). There are many state-of-the art reviews available of engineered barrier system / concept options considered internationally for different waste types. Supporting such strategic options assessment (and potential related safety assessments) are usually prioritised RD&D tasks associated with different aspects of the disposal system under consideration (see also broad categories of RD&D described by Zuidema and Johnson, 2013). The existing knowledge base for different disposal system options is extensive, and the key challenge for early phase programmes is the appropriate use of this information (and underpinning data) when applied specifically to one's own national boundary conditions and programme-specific waste types. In the absence of site-specific data, generic safety case

production can be pursued to aid identification of programme specific issues that would subsequently be the focus of prioritised RD&D tasks. This also aids the implementer to periodically assimilate international state-of-the-art knowledge and gather data in preparation for future programme phases. Typical sub-topics of prioritised RD&D (being examined today[7] by advanced programmes) relating to the disposal system include:

- Wasteform 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 for their emplacement to meet specified performance requirements;
- Demonstrating of sealing and plugs to meet specified performance requirements and confirm feasibility of conceptual designs;
- Improved understanding of the engineered disturbed zone and (other major engineered barrier interface zones, particularly with respect to the role of microbes during early post-closure) and their potential impact on post-closure safety;
- Improved site-specific data collection and modelling for understanding of the host rock environment 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 engineered barrier system 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 and of the ease of retrievability and modes of reversibility– specifically considering ease of waste package retrieval after buffer / backfill emplacement and reversibility of the decision making processes.

3.6 Competence development

All disposal programmes need to ensure that the necessary core competence and skills required in waste management is 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 whose members are offered training and education opportunities and are subsequently fully integrated into the appropriate regional and global networks and independent regulatory bodies (IAEA, 2009). Across Europe there are several initiatives operating to enhance knowledge transfer between disposal programmes and aid national competency development, in particular the IGD-TP operate a working group on competence

[7] For less advanced programmes that will move towards implementation of geological disposal some decades from now, it expected that for many of these RD&D topics, a sufficiently large knowledge base of information will be available of direct relevance from the advanced programmes that have achieved operating status.

maintenance, education and training (CMET) which is represented in the PETRUS II project (IGD-TP, 2012).

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

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 national skills and competence development is considered necessary background to an RD&D plan. However, an RD&D plan may include some tasks with a principal driver to develop a particular competence (e.g. expert specialism and knowledge of specific RD&D topics of high significance). In particular, new programmes embarking on competency development focused RD&D tasks are encouraged to consider secondment opportunities with more advanced programmes and involvement of staff with international collaborative projects.

3.7 Stakeholder engagement strategy

A clear strategy and commitment to involvement of stakeholders is essential to the decision-making process at all stages of a geological disposal programme. This will include how stakeholders with interest in RD&D will be involved and ways of communicating the scientific basis of geological disposal for a range of audiences. Large amounts of research have been completed and are continuing across Europe through collaborative research projects to learn from good practice for stakeholder engagement on RD&D issues. Of particular importance is the accessibility of RD&D results through open publications and the provision of technical communications that are accessible and understandable to non-technical audiences. 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 proactive stakeholder engagement and communications on the results of RD&D. Owing to the importance of social and ethical considerations, alongside the safety of geological disposal, tasks continue internationally to consider methodological aspects of how to involve stakeholders (FSC, 2014 and InSoTEC, 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.

3.8 Site characterisation

Site characterisation generally comprises detailed airborne surveys, non-intrusive and intrusive-based surface exploration and underground investigations that are required to acquire and interpret information on the geo-scientific, environmental and socio-economic conditions at one or more sites. Before sites are identified, there is a need to plan the approach to site investigations, and to consider where available techniques can be used for a specific programme. Site characterisation programmes can be costly and need to be planned so that they are implemented in a timely and efficient manner. This is also the phase of the programme when stakeholders will require open and transparent feedback on new and developing data acquisition, interpretation and modelling techniques, so improving and developing data management systems often feature highly as a priority topic at this phase of implementation.

Typical sub-topics of prioritised RD&D relating to site characterisation include:

- Reviewing state-of-the-art site characterisation technologies;
- Researching and understanding lessons-learned from other waste management programmes and keeping informed about latest developments;
- Developing an approach to sealing deep investigation boreholes in a manner which avoids unnecessary impacts on long-term safety; and
- Developing a geoscientific conceptual understanding of the host geology and/or model of the site to allow comparison and assess suitability of candidate areas or sites.

3.9 Post-closure safety assessment tools / models / methodology

Demonstrating post-closure safety of a geological disposal facility, potentially for hundreds of thousands or even millions of years, poses one of the greatest challenges in radioactive waste management. Assessment tools and safety case methodologies are continuously being developed and improved internationally to demonstrate long-term safety. Methodologies and tools developed can be adopted and tailored for use by developing programmes, with minimum RD&D efforts to adapt input data to national waste inventories and site-specific characteristics (where data exists or generated by site characterisation activities).

Assessment methodologies and tools usually adopt a range of disposal system evolution scenarios and analyses for long-term safety. These are supported by underpinning knowledge or data, and where possible, by multiple lines of evidence that are adequate in their treatment

of uncertainty. Assessments as part of a generic safety case development may involve making simple representations of the disposal system using representative or bounding parameter / input data (in the absence of actual site date) to demonstrate safety and assess options. The level of detail built into the safety assessment model would typically become more detailed as site information and decisions about the concept are made. Good practice is shared and published in many guidance and state-of-the-art documentation produced by the long-established NEA Radioactive Waste Management Integration Group for the Safety Case (IGSC, 2014). Relevant international safety requirements relating to safety case production can be found in IAEA safety standards developed for all particular phases of the waste–spent fuel life cycle (IAEA, 2014). These should be used, together with national regulations to guide RD&D in support of demonstrating long-term safety. Typical sub-topics of prioritised RD&D relating 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 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.

3.10 Environmental impacts and socio-economic effects

Alongside long-term safety considerations the disposal programme will also need to prepare for sustainability and environmental impact assessments to communicate the potential environmental and socio-economic effects of a disposal facility (SEA, EIA). Recent developments in relation to this programme activity include the increasing priority being given internationally to reduce carbon emissions, typically managed by optimisation studies to minimise the facility footprint. The main RD&D ongoing works in relation to sustainability and environmental impact assessments include:

- Generation of environmental baseline data to consider the existing situation for radioactive waste management in absence of a disposal facility[8]. Importantly this will consider other proposal waste management routes (other than geological disposal) and likely future changes to the environment with and round potential sites for the facility.
- Methodology development for establishing the socio-economic baseline data for all the planned implementation phases and the (short-term) post-closure phases.

[8] For example, see Strategic Environmental Assessments (SEA) legally required by the EC Directive 2001/42/EC.

3.11 Operational safety and practicability

Most attention in disposal programmes during early phases is typically directed towards the assessment of long-term safety. As concepts from programmes in advanced phases (i.e. underground demonstration) continue to be optimised and move towards site-specific safety case development, the importance of assuring construction and operational safety and practicability to implement the final facility designs grows. This is particularly important to local communities who may be the providers of the workforce employed during the construction and operations phase.

RD&D challenges remain for advanced disposal programmes with respect to operational safety which are being addressed through large-scale international demonstration projects (see for example, the PEBS project (PEBS, 2014) which included specific tasks on the design and construction of engineered barriers). Programmes in early phases do not need to embark on programme-specific RD&D in relation to demonstration, but should actively maintain an awareness of international demonstration work programmes and would benefit from involvement in ongoing international efforts by making best use of the opportunities for technology transfer and competency development. Ongoing RD&D challenges that are being addressed by more advanced programmes include:

- Operational safety considerations – treatment of fault sequencing for range of scenarios during operations of the facility. This includes the assessment of the risks and consequences of various incident, accidents and possible perturbations (e.g. a major earthquake) that may occur during construction and operations;
- Operational environmental safety assessment – understanding potential gaseous discharges and impact or consequences of delayed closure of delayed backfilling on disposal areas;
- Assuring institutional control throughout the disposal programme timescales; and
- Safety performance and practicability of conceptual designs - feasibility assessments and large-scale demonstration tests on existing technology to move from conceptual designs to a design that is possible to implement and one that is truly practical under the boundary condition in an underground or site-specific environment.

3.12 Data management and preservation of records

There is a significant time lag between advanced and less advanced programmes, and the life time of a facility also lasts over decades. Therefore data management and preservation of records and knowledge should be an integrated part of the RD&D planning.

National radioactive waste repository programmes are collecting large amounts of data to support the long-term management of their nations' 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 waste management

organisations better utilise their data in carrying out their statutory tasks and can also 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 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 regulation (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).

4. Conclusions

The contents of the Guide so far have provided essential background aimed at programmes making a first attempt to set-out at a national-level their RD&D needs towards geological disposal. The contents provide key links and references to the vast quantity of information and knowledge sources that exist in relation to RD&D and Technical Programme Management towards implementation of geological disposal of radioactive waste.

This Guide is a deliverable produced by the SecIGD2 project of the IGD-TP. It is highly encouraged that individuals or organisations attempting to use the Guide as a basis for responding to the Council Directive 2011/70/EURATOM Article 12.1(f), also embark on active involvement within the IGD-TP and related collaborative RD&D projects and/or joint activities. This is considered to be of benefit to less-advanced programmes, particularly with respect to networking opportunities and direct access to a vast knowledge resource. The templates contained in Appendix A illustrate how to use the content described in Sections 2 and 3, to develop a first RD&D Plan towards implementing geological disposal for a less-advanced programme.

References

Andrei., V and Prisecaru., I, *How Important is the National Content in Planning Romania Geological Disposal*, 7th Annual International Conference on Sustainable Development through Nuclear Research and Education, Nuclear 2014 Conference, Pitesti-Mioveni, Romania, May 2014.

EDRAM (2014), *International Association for Environmentally Safe Disposal of Radioactive Waste*, webpage: http://www.edram.info./.

ENEF (2013), *Guidelines for the establishment and notification of National Programmes, European Nuclear Energy Forum, ENEF Working Group Risk*, Working Group on National Programmes NAPRO, January 2013.

FSC (year), *Forum for Stakeholder Confidence (FSC)*, webpage: https://www.oecd-nea.org/rwm/fsc/.

IAEA (1994), *Siting of Geological Disposal Facilities*, Safety Series No. 111-G-4.1, IAEA, Vienna, 1994.

IAEA (2007a), *Cost Considerations and Financing Mechanisms for the Disposal of Low*

IAEA (2007b), *Selection of Away-from-Reactor Facilities for Spent Fuel Storage*,

IAEA (2009), *The types and quantities of waste expected to arise, Policies and Strategies for Radioactive Waste Management*, IAEA Nuclear Energy Series No. NW-G-1.1, IAEA, Vienna, 2009.

IAEA (2009), *Responsibilities and Capabilities of a Nuclear Energy Programme and Intermediate Level Radioactive Waste*, IAEA-TECDOC 1552, IAEA, Vienna, 2007.

IAEA (2012), *The Safety Case and Safety Assessment for the Disposal of Radioactive Waste - Safety Specific Guide, IAEA Safety Standard Series*, No. SSG-23, IAEA, Vienna, Austria.

IAEA (2013), *Options for Management of Spent Fuel and Radioactive Waste for Countries Developing New Nuclear Power Programmes*, IAEA Nuclear Energy Series No. NW-T-1-24, 2013.

IAEA (2014a), *Planning and Design Considerations for Geological Repository Programmes of Radioactive Waste*, IAEA TECDOC No. 1755, 2014.

IAEA (2014b), *IAEA Safety Standards Series*, IAEA, Vienna, Website Access: www-ns.iaea.org/standards/default.asp?s=11&l=90.

IGD-TP (2009), *Vision Report - Appendix 2: Organizations endorsing the Vision Document*, Implementing Geological Disposal of Radioactive Waste Technology Platform, 2009.

IGD-TP (2011), *Strategic Research Agenda, Implementing Geological Disposal of Radioactive Waste Technology Platform*, 2011.

IGD-TP (2012), *Master Deployment Plan*, Implementing Geological Disposal of Radioactive Waste Technology Platform, 2012.

IGSC (2014), *NEA Radioactive Waste Management Integration Group for the Safety Case*, (http://www.oecd-nea.org/rwm/igsc/).

InSoTEC (2014), *Addressing the long-term Management of High-level and Long-lived Nuclear Wastes as a Socio-Technical Problem*, Insights from InSOTEC D4.1, 2014.

JRC (2014), *Management of spent nuclear fuel and its waste*, EASAC policy report no. 23, JRC Reference Report, July 2014.

NEA (2013), *The Safety Case for Deep Geological Disposal of Radioactive Waste: 2013 State of the Art*, Symposium Proceedings, 7-9 October 2013, Nuclear Energy Agency, Radioactive Waste Management Committee, NEA/RWM/R(2013)9, 12 March 2014.

NDA (2012), *R&D Programme overview: Research and development needs in the preparatory studies phase 2012 Revision (with Changes)*, NDA/RWMD/073 Version 2, 2012.

NDA (2014), *Geological Disposal: Science and Technology Plan*, NDA/RWM/121, 2014.

OECD/NEA (1999), *Confidence in the Long-Term Safety of Deep Geological Repositories - Its Development and Communication*, OECD/NEA, Paris.

OECD/NEA (2011), *Vision for the RWMC Project on "Preservation of RK&M Across Generations"*, NEA/RWM(2011)6/REV2, OECD/NEA, Paris.

OECD/NEA (2014), *Vision Document for the Radioactive Waste Repository Metadata Management (RepMet) Project*, NEA/RWM(2014)2, OECD/NEA, Paris.

OECD/NEA (2013), *The Nature and Purpose of the Post-Closure Safety Cases for Geological Repositories*, NEA/RWM/R(2013)1, OECD/NEA, Paris.

OJEU (2011), *The Council Directive 2011/70/EURATOM, establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste* ("Waste Directive"), Official Journal of the European Union 2 August 2011.

PEBS (2014), *International Conference on the Performance of Engineered Barriers: Physical and Chemical Properties, Behavior and Evolution*, I. Gaus, K. Wieczorek, A. Schafers, S.Fahland, February 6-7, 2014, BGR, Hannover, Germany.

Zuidema., P, and Johnson., L. (2013), *Challenges in establishing a national programme for research, development and demonstration*, 8th EC Conference on the Management of Radioactive Waste Euradwaste'13 - 14-16 October 2013, Vilnius/Lithuania.

Appendix A: Templates to develop an RD&D plan

Template 1 Boundary conditions

T1.1 Government Policy

T1.2 Role and Responsibilities of Waste Management Organisation

T1.3 Waste Arisings and Current Storage Arrangements
Inventory Summary (use this table format or alternative inventory table):

Waste Types / Classification	Volumes / Quantities	Disposal Route / Date of Disposal
LILW-SL		
Long-lived Wastes		
Spent Fuel		
Other (if applicable)		

T1.4 Adaptive Phased Management

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

Key Date	Milestone	Documentation / Decision Required
	Policy and Programme Establishment	
	Generic Studies	
	Surface-based Studies	
	Operations	
	Construction and Underground – based Investigations -	
	Operations	

T1.5 Disposal Concept / Geological Settings

T1.6 Summary of Current RD&D Programme Planning

T1.7 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: Terminology and comparison of phase descriptions

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