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The NUMO Structured Approach to HLW Disposal in Japan

Staged Project Implementation at Volunteer Sites Utilising a Requirements Management System

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EXECUTIVE SUMMARY

The constraints set by the Japanese HLW disposal programme – particularly associated with the decision to initiate siting by an open call for volunteers to host a geological repository – pose particular challenges for repository project management. In order to maintain the flexibility required to respond to the conditions found at volunteer sites, NUMO has not published reference designs or site characterisation plans, as is normal for programmes progressing by site nomination. Instead, we have developed a methodology – the NUMO Structured Approach (NSA) described in this report – to allow such designs and plans to be tailored to particular sites in a flexible, open and efficient manner, with the aim of producing a site-specific process for design and operation of a demonstrably safe and practical facility. The NSA has similarities to the adaptive staging framework developed and applied in some other national waste management programmes. However, the specific Japanese boundary conditions and also the policies adopted by NUMO for its project work have led us to develop and document a formalised structure and to emphasise particular aspects such as flexibility, transparency and willingness to adapt concepts and to revise decisions in order to reflect the evolution of the project with time.

For a project involving stepwise implementation stretching until the end of the century, the flexibility provided by the NSA has great advantages; facilitating responses to the surprises that are almost inevitable in such projects and the changes in scientific and socio-political boundary conditions over this period. In addition, the emphasis on reversibility of decision-making has advantages for building dialogue with stakeholders – particularly local communities. This fits well within our policy of establishing NUMO's credibility as a competent and trustworthy partner for potential volunteers.

Although the NSA description is rather abstract, its practical applicability is illustrated by examples. It already forms the basis of tools that have been developed for selecting between different options for site characterisation or repository design for specific siting locations. While waiting for volunteers, these tools have been tested in a number of dry run exercises.

In order to implement the NSA in a clear and traceable manner, a special management tool is needed. We are thus currently developing a Requirements Management System (RMS), which will support – and help to document – the decision-making process at all hierarchical levels within NUMO. The RMS, together with its relationship to other supporting management infrastructure, is also outlined in this report.

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1 INTRODUCTION

1.1 NUMO and its role

The *Nuclear Waste Management Organization of Japan* (NUMO) was established in 2000 to prepare for and implement the geological disposal of "specified" waste – currently vitrified high-level radioactive waste (HLW) resulting from the reprocessing of spent fuel from commercial nuclear power plants. Legislation specifies particular constraints on such a repository in terms of depth and site geological stability. It also defines a stepwise siting process (Figure 1-1), which proceeds from literature survey to selection of preliminary investigation areas (PIAs), in which surface-based investigations will provide the basis for selection of detailed investigation areas (DIAs). Detailed investigations will include the construction of underground characterisation facilities and will then lead to the selection of a final disposal site.

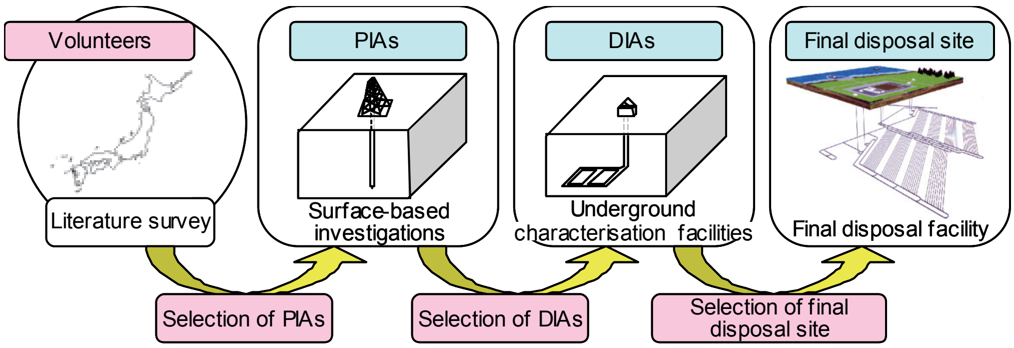

Figure 1-1: The stepwise siting process.

Based on experience in Japan and elsewhere, NUMO has identified public acceptance as a critical issue influencing the success of the repository project. We therefore decided to tackle this issue at the outset of our work by choosing to initiate siting by a call for volunteers, issued to all municipalities in Japan in 2002 (Kitayama, 2003). Due to the complex geology and active tectonic setting of the Japanese archipelago, we recognised that the assessment of the suitability of some volunteer siting areas could be complex and technically challenging. Nevertheless, given NUMO's commitment to openness and transparency, we will strive to ensure that the process is as understandable as possible to all stakeholders. Accordingly, we have already published the Siting factors that are used to exclude unsuitable sites and to compare sites in the case of multiple volunteers (NUMO, 2004a). The diversity of possible siting environments requires flexibility in terms of repository design and, instead of specifying a reference concept, we have therefore published a catalogue of options (NUMO, 2004b).

1.2 The need for special programme management approaches

The volunteering process presents unique challenges for programme planning. Reference concepts are needed to guide planning of site characterisation, repository design and safety assessment – and also, importantly, to enable NUMO to communicate effectively with the broad public in Japan. However, flexibility is essential to ensure that these concepts can be efficiently tailored to the specific environments presented by any volunteer. Fundamentally, NUMO has adopted a philosophy of emphasising an open decision-making process, which allows decisions at all hierarchical levels to be easily explained and, in particular, allows decisions to be revisited if particular boundary conditions change. We consider this last point to be particularly important in the light of experience from other national programmes, where implementing organisations have been reluctant to change early decisions with regard to siting or repository design due to concerns about confusing the general public.

The process of iterative refinement of site models and associated repository designs and safety cases is formalised as the NUMO Structured Approach (NSA). This recognises that, over the many decades until a repository is finally closed, science, technology and the socio-economic environment will evolve and the programme must be able to respond to the changes involved. Although such a concept is straightforward in principle, it is challenging to implement in practice because of the complex, multi-disciplinary network of requirements that influence key project decisions. Indeed, the challenge is even greater because of the long lifetime of the project and the corresponding need for clear and explicit documentation of the basis for all past decisions. Here NUMO has the distinct advantage of being a young organisation that does not face the task of retroactively documenting past decisions. On the other hand, NUMO staff members are currently rotated on relatively short-term secondment, so that an effective tool is needed to help guide and rigorously document technical decision-making. For this reason, we have placed high priority on developing a Requirements Management System (RMS), which will help with the day-to-day application of the NSA at all management levels.

The NSA has similarities to the adaptive staging framework developed and applied in various forms in some other national waste management programmes (e.g. NRC, 2003). However, the specific Japanese boundary conditions and also the policies adopted by NUMO for its project work have led us to develop and document a formalised structure for our iterative approach and to emphasise particular aspects that are especially important in the Japanese context. These include:

- Flexibility to cope with the diversity of siting conditions that may have to be considered;
- Transparency and traceability (as required by Japanese law), with specific focus on the decision-making processes;
- Recognition that not only gradual, evolutional changes must be anticipated, but also major surprises;
- Willingness to adapt concepts and to revise decisions in order to reflect the evolution of the

project with time and a readiness to accept stakeholder input.

1.3 Structure of this document

Chapter 2 expands on the boundary conditions on the NUMO programme, with particular emphasis on the need for NUMO to establish the credibility required to attract volunteers and on the very tight time schedule for the early stages of site selection. Chapter 3 describes the NSA, illustrating its initial application to repository concept development and then discussing its wider application throughout our programme. As such application is under development at present, specific examples are used to show how it may actually be implemented. Chapter 4 outlines the RMS, which is being tested in prototype form at present. This is planned to be a key management tool for NUMO and has a particular role in strengthening the interactions between the different technical groups involved in this complex project. Finally, in Chapter 5, this work is summarised from the perspective of practical implementation of our long-term programme.

2 BACKGROUND AND BOUNDARY CONDITIONS

2.1 Staged project implementation and the basic approach to confidence-building

NUMO was established in October 2000 as the implementing organisation responsible for the safe disposal of HLW, on the basis of the *Specified Radioactive Waste Final Disposal Act* (the "Final Disposal Act"). In accordance with the provisions of the Final Disposal Act, the Japanese government has issued ministerial ordinances on the *Basic Policy for Disposal of Specified Radioactive Waste* (MITI, 2000a) and the *Plan for Disposal of Specified Radioactive Waste* (MITI, 2000b). According to this disposal plan, the repository site is to be selected between 2023 and 2027 allowing the disposal facility to be commissioned around 2033-2037. The overall schedule for such staged implementation of the project is illustrated in Figure 2-1.

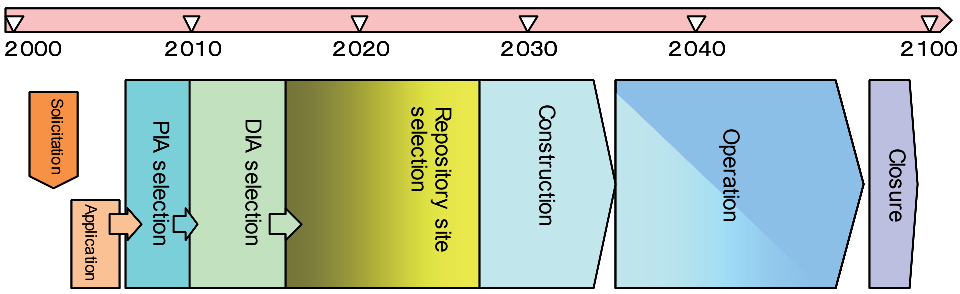

Figure 2-1: Planned schedule for project implementation (based on NUMO, 2004a).

As previously noted (see Figure 1-1), siting proceeds in three fundamental steps – but the first two are particularly short. After volunteers apply, we have to make very sensitive decisions about which potential siting areas will be carried forward as PIAs – and then which of these as DIAs – on the basis of only a few years of work. There are clear technical challenges here but, as public acceptance is seen to be a key factor, also challenges in the area of building confidence – in both the basic concept of geological disposal and in NUMO as a credible implementing organisation.

Our basic approach for building stakeholder confidence in the geological disposal project includes three components:

- Stepwise project development: Gradual focusing on a preferred site and associated repository design proceeds in distinct stages and we make the decision to move to the next stage only with the agreement of local communities;
- Engaging communities: Ensuring that local communities not only have access to all information that they need, but are also encouraged to develop dialogue, which we feel is essential to having them actively support the project;

- Focusing on transparency: Providing all relevant information, particularly that supporting key decisions, in an accurate and readily understandable manner.

Our decision to adopt an open solicitation procedure for the initiation of the siting process, based on inviting municipalities from all over Japan to volunteer for initiation of the first literature survey stage, is a result of NUMO's commitment to this approach. Although it is clearly difficult to attract volunteers, we consider the effort involved in finding and motivating potentially interested communities to be worthwhile in the context of a major, highly sensitive project extending in total over a period of a hundred years or more. Also in line with this approach, the call for volunteers was accompanied by a package of supporting documents[1], which provides interested municipalities with the background required for informed decision-making. These documents outline the repository implementation process, the criteria used to exclude unsuitable sites and the outreach scheme for providing technical and financial support to volunteers.

Although there have been no formal applications to date that could proceed to the literature survey stage (as of the end of June 2007), we have received inquiries from a number of interested municipalities. Efforts thus continue, at a national level, to raise awareness of the project in key stakeholder groups and, directly with interested communities, to enhance their understanding of the issues involved. The national efforts utilise mass media, but the local interactions focus on personal contacts, for example by organising briefing or study sessions with a view to establishing dialogue and raising local trust to the level needed for formal application as a volunteer PIA that could potentially become a repository host.

2.2 Enhancing technical credibility as the project progresses

Attracting volunteers is clearly a major challenge for the NUMO's programme and a focus for communication efforts. Nevertheless, we consider it necessary to look beyond this point and plan for future stages of work (Kitayama, 2006). Figure 2-2 illustrates this process, noting particular work phases that overlap and extend beyond the strict stages of the site selection procedure. Planning ahead is important, especially for the short literature survey and preliminary investigation (PI) stages, in order to ensure that all technical infrastructure needed for the work is available as and when needed, in order to meet the tight deadlines. It is also important in terms of preparing the local communities for the politically sensitive decisions for selection of PIAs, DIAs and the final disposal site. For the local populace, a key factor will be the credibility of NUMO as an organisation. Such credibility is based on two components – our fundamental competence and our ability to communicate this to all relevant audiences. We plan to enhance both these components during these work phases.

[1] English translation of the documentation supporting the call for volunteers is available on the NUMO website www.numo.or.jp

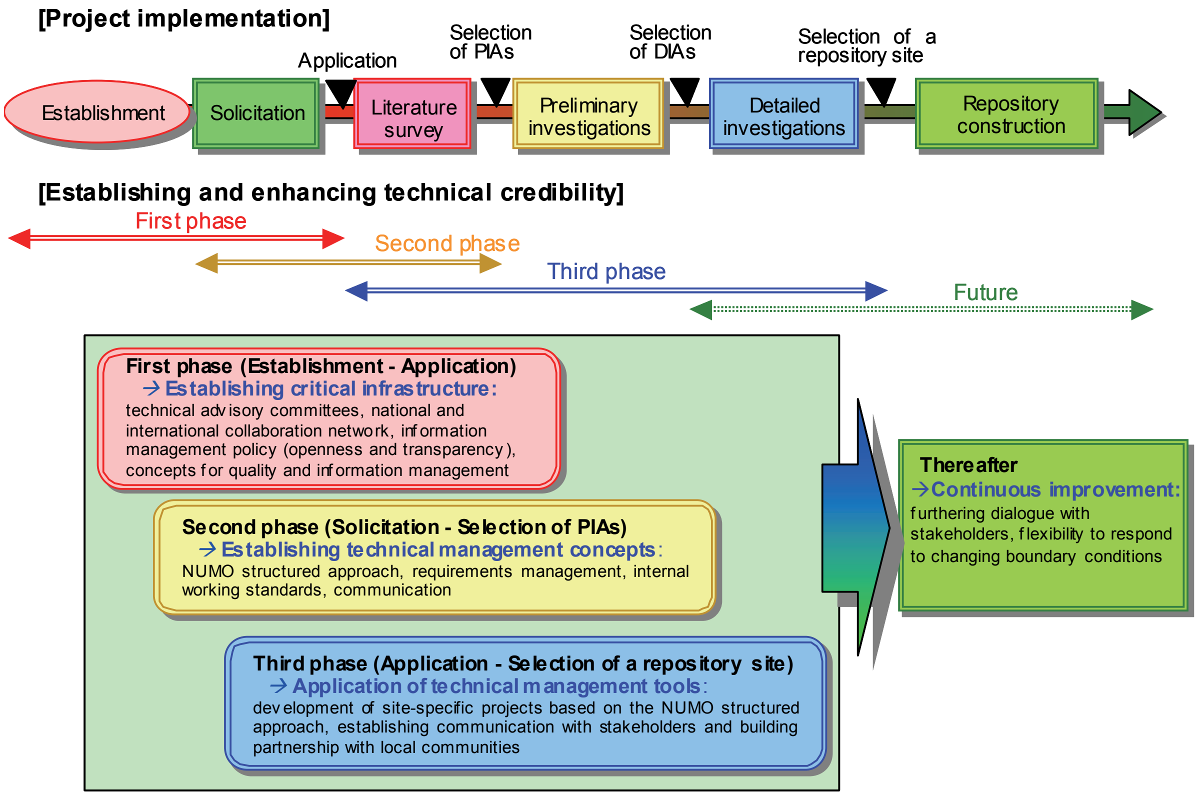

Figure 2-2: Establishing and enhancing technical credibility during staged implementation.

(1) First phase

In the first phase, covering the time period from establishment of NUMO up to receipt of an application from a volunteer community, our emphasis has been on building the critical infrastructure for demonstrating the competence of this new organisation. To begin with, a few competent and experienced project staff members were delegated to NUMO from Japanese nuclear organisations in order to take up the key management roles. Since then further staff positions have been filled by delegated personnel who, although inexperienced at the start, have rapidly learned the technical and project management approaches developed in NUMO. Unfortunately, the system of rotating external staff into short term delegate positions has also led to some of the acquired knowledge and experience being lost again. NUMO has now recognised the importance of building a permanent dedicated team. At an early stage, measures were taken to build experience rapidly. High profile *Domestic* and *International Technical Advisory Committees* (DTAC, ITAC) were formed to obtain expert reviews, for example of our technical activities and published documents (Kitayama et al., 2005a; DTAC, 2003). ITAC also helps to facilitate our access to the extensive international expertise in geological disposal[2]. In addition, NUMO has concluded technical cooperation agreements with other key domestic and international organisations active in this field and has worked with them in areas such as site selection

[2] Summary records of ITAC meetings are available in English on the NUMO website.

procedures, repository engineering technology, engineered barrier concepts and performance assessment methods (Kitayama et al., 2005a).

We have reported progress during this phase extensively in the technical literature, at national and international conferences and in technical reports (the NUMO-TR series). This has already been very successful in bringing NUMO to the fore in the international waste management community, and focused efforts continue to enhance awareness of the programme in Japanese technical, political and general public audiences (Kitayama, 2006). Local government officials and opinion-leaders (both individuals and non-governmental organisations (NGOs)) have been identified as playing an essential role here.

An important component of NUMO's infrastructure, even in this early phase, is a Quality Management System (QMS). This has already been used to ensure production of high-quality documents that are both readily understandable and accurate from a scientific and technical point of view. This QMS will be modified and expanded in further phases, so that it can be applied to all key tasks in the implementation programme.

(2) Second phase

In the second phase, running from open solicitation to selection of PIAs (ongoing at present), we will improve and expand our management toolkit in order to further enhance technical credibility. Because of the special boundary conditions imposed by the volunteering process, the NSA will play a key role in demonstrating our ability to respond to the challenges involved (Kitayama, 2005; Kitayama et al., 2005b and 2005c). Within only a few years, we must analyse literature information to determine the site conditions that are critical first for ensuring that the location meets the geological stability criteria required for qualification, and then for allowing evaluation of construction practicality and assessment of long-term safety. If, as expected, several volunteers come forward, such literature surveys may run in parallel for different sites and, additionally, we may need to rank these sites in terms of suitability, if there are more qualified volunteers than can be practically carried forward to the PIA stage.

The PIA selection decision is not only politically sensitive, but it also involves a major commitment of our limited resources. Clear and transparent documentation of this decision – and all the supporting argumentation behind it – should be facilitated by the NSA framework and the associated RMS tool (Kitayama, 2005; Sakabe et al., 2005). Key decisions need to be based on explicit guidelines and project goals. In the current absence of appropriate regulations, we are developing internal working standards that specify targets in terms of safety, environmental protection, etc. These complement the rather general PIA Siting factors, which we have already published (NUMO, 2004a).

In this phase, we wish to motivate volunteer municipalities to participate fully in the PIA selection decision. To encourage involvement, it is important to make our activities understandable, as far as possible, by the general public and local residents. To date, we have seen that traditional methods for establishing dialogue have often proved to be insufficient for communicating to non-technical audiences the rather complicated technical activities involved in geological disposal. Therefore, NUMO has initiated development of new techniques for promoting technical understanding, and is also investing in training to improve the communication and dialogue skills of key staff (Inatsugu et al., 2006).

(3) Third phase

In the third phase, from receipt of an application to selection of the final disposal site, the first intensive contacts between NUMO and the volunteer municipalities occur. Dedicated NUMO teams will develop projects for each site, with all activities being coordinated and integrated by the NSA. These teams will interact strongly with local communities, with the clear aim of establishing a partnership, so that residents identify with the project. In order to achieve this, it is clear that we cannot simply present a finalised, fixed programme, but must be prepared to take public concerns into account and modify the project as required. At the same time, we also have ethical responsibilities to ensure the safety of current and future generations and to develop a project with a reasonable use of resources. We expect that balancing potentially contradictory programme requirements in a clear and transparent manner will be helped by the envisaged development of the RMS, but will, nevertheless, function only if carried out by a competent and credible project team.

The requirement for flexibility with regard to these phases is illustrated for the case of Toyo-cho community, the first formal volunteer, which later withdrew its application. Clearly, withdrawal is part of the inherent reversibility of the solicitation process and responding to such unforeseen events in a way that reflects the values adopted by NUMO is a key role of the NSA.

(4) Future phases

After the selection of DIAs, there will be a long, intensive, period of fieldwork, with the ultimate aim of developing a repository implementation programme at the chosen site, should it prove suitable. We recognise that, even after the local community accepts the decision to be a DIA, continuous active dialogue is required to maintain commitment to the project and ensure that stakeholders buy into the decisions that will be made as the project becomes more concrete. We are aware that, even late in the programme, surprises in terms of site characteristics or changes in boundary conditions may occur. The NSA provides a framework for responding to such events, and for a structured decision-making process regarding the final site choice, but we feel it is important that the local communities understand the associated issues and also become involved in developing possible responses and deciding on which will be adopted.

3 THE NUMO STRUCTURED APPROACH

The particular value of the NSA is most apparent when the boundary conditions of the Japanese HLW programme are considered. To illustrate this, we describe the initial use of the NSA for planning repository concept development during the literature survey phase of characterising a volunteer site. It should be emphasised that NUMO uses a rather wide definition of *Repository concept* (RC), which includes not only a design but also specification of operational procedures and assessment of safety (Box 1). The initial illustration of the NSA is then extended to show how the iterative development of concepts at later stages of the programme utilises the NSA. Here "Structuring factors" are introduced to illustrate how the relative weighting of top-level programmatic issues can lead to changes in emphasis of the specific design and Siting factors that are used in lower level decision-making. From this basis, wider application of the NSA within the NUMO programme is considered.

Box 1
Repository concept: Definition (from NUMO, 2004b)

NUMO defines a "Repository concept" (RC) as a design of all surface and underground repository structures, along with a description of how the repository can be constructed, operated and sealed. This also includes an evaluation of operational and long-term safety and an assessment of costs and socio-political impacts. The concept is dynamic, evolving with our programme as it moves from early generic studies through to siting and, eventually, licensing for construction and operation. Indeed, continual evolution during the operational period is also possible, as experience is gained and technology develops.

3.1 Structuring the development of repository concepts during the literature survey stage

Soon after a volunteer comes forward, we will need to develop a site-specific repository concept, to serve as a focus for structuring our work programme and for discussions with stakeholders. As preparation for this, NUMO has reviewed the background provided by more than two decades of generic R&D on this topic in Japan. We concluded that the fundamental engineered barrier system components featured in the reference case of the H12 feasibility study (JNC, 2000) – vitrified waste in a thick steel overpack surrounded by a bentonite-based buffer – provided the basis for a robust safety case. However, we have examined many design variants that would allow options to be tailored to the particular characteristics of a wide range of volunteer sites (NUMO, 2004b). Furthermore, the catalogue of H12-based options is recognised as focusing on those technical areas where Japanese organisations have built up extensive experience and is thus not comprehensive; thus, even more variants would be possible based on experience gained in other national programmes.

Given this background, our challenge is to efficiently and transparently select a preferred option for a specific site. The approach developed is illustrated in Figure 3-1. The central part of the figure illustrates the progressive steps taken to develop a site-specific repository concept. The left hand part indicates the increasingly detailed site data that are needed for this, while the right hand blocks make clear that non-technical aspects (e.g. land ownership) and engineering constraints must be considered in parallel with the geotechnical issues. In both areas of development, the work may require specific R&D activities to be carried out, as illustrated by the outermost blocks.
Some particular points to be noted are:

- In the first step, the volunteer area is checked against the published exclusion factors; if it fails to qualify based on these site characteristics, it will be rejected;
- As Japanese volunteer municipalities may be rather small, with complex geological structures, existing data are used to identify the constraints on the potential location of the repository in terms of the footprint (area) and thickness (host formation and depth constraints set by rock mechanics or geothermal gradients);
- For any site with potentially suitable volumes of rock, available information on hydrogeology and geochemistry is used to evaluate constraints on operational practicality and repository design;
- After these simple checks, literature information is synthesised into a site conceptual model; the best understanding of the site is then integrated with an evaluation of design constraints to select one or more concepts appropriate to the siting option(s) in a volunteer area;
- A performance assessment (PA) is then carried out to check that the design shows promise in terms of meeting long-term safety goals; if it does so, the site can then be considered as a potential PIA;
- If there are problems in meeting safety goals with a particular design, there is the possibility to either modify the design to increase safety margins or to drop the site. If the problems appear insuperable, the site will be rejected. If it is considered that a safe repository at the site may be fundamentally feasible but would require development of further designs, then the site may be considered as a reserve option – to possibly be evaluated further depending upon what other siting options are available.

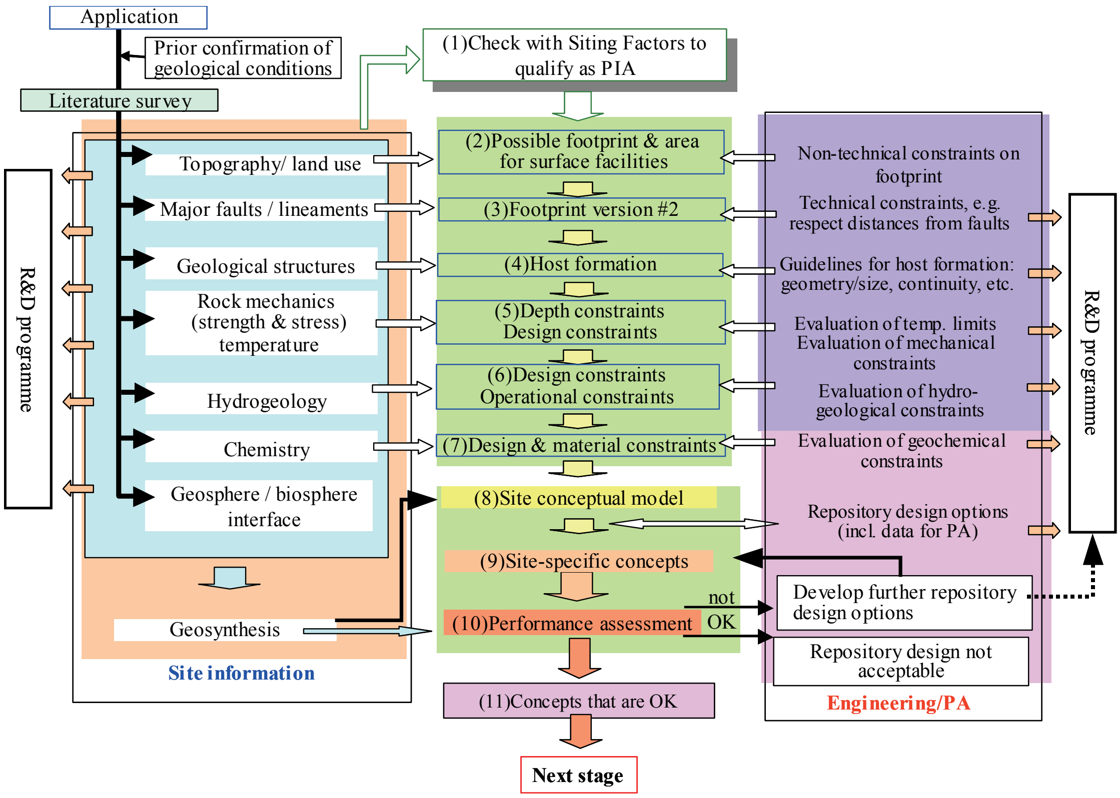

Figure 3-1: Illustration of the NUMO Structured Approach as applied to initial development of repository concepts during the literature survey stage (based on NUMO, 2004b).

The NSA provides a generalised methodology that we can apply to sites that have very different characteristics, which may result in diverse repository concepts. It thus serves as a basis for consistent treatment of volunteers and facilitates the comparison that may be needed if sites have to be ranked. It also helps us to document uncertainties and to prioritise R&D requirements in a structured manner. This is important because the residual levels of uncertainty and the requirements for additional R&D may both be used as attributes to be considered in ranking sites in a multi-criteria assessment procedure.

It is important to recognise that, during this early stage, site information will be very limited and there may be large uncertainties associated with key characteristics. The decisions we make at each of the individual steps shown in Figure 3-1 are thus provisional, based on a number of caveats. We thus emphasise to stakeholders that we will certainly modify concepts – possibly in a major way – as site understanding improves and as construction and operational aspects receive more consideration. Consistency is, however, provided by the NSA methodology which is used to identify and justify required changes – as discussed further below.

If there are only a limited number of volunteers, all sites with acceptable concepts may pass to the PIA characterisation phase; open issues and uncertainties identified during the process shown in Figure 3-1 will help focus the R&D included in the site characterisation programme and supporting engineering /

PA work programmes. In the case of a larger number of suitable volunteers, we need to rank them to allow the most favourable to be selected as PIAs and others to be either rejected or specified as reserves. To help this process, we have defined specific Siting factors ("Favourable factors") (NUMO, 2004a), which include many of the characteristics that have an influence on the entire repository project (e.g. land availability, transport infrastructure). Even then, strategic issues (e.g. balancing the regional distribution of sites or the pros / cons of selecting locations with similar characteristics) need to be included in the final decision process. Thus, this process will involve weighting of different project attributes; ideally both the attributes themselves and the weighting factors to be applied will be developed as a consensus with interested stakeholders.

It is emphasised that the ranking process above is not based on PA results alone and, indeed, at the level of analysis carried out at this time, PA results may be one of the attributes that show little discrimination between sites. A more useful concept in this regard may be the safety case. The term "safety case" as used by NUMO corresponds fairly well to that defined by the NEA (NEA, 2004); NUMO, however, emphasises that, at early stages, such a case is provisional and may involve much qualitative argumentation and be based on many assumptions that have to be validated as the project develops (Kitayama et al., 2007). Nevertheless, the ease of safety case development may be a feature that distinguishes between different sites.

3.2 Decision-making within the NSA

Within the process outlined in Figure 3-1, the selection of site-specific concepts (step 9) is particularly tricky, as the pros and cons of a number of different options need to be balanced against each other. To facilitate this process and aid decision transparency, we have also defined a specific set of attributes that we label as "Design factors" (Umeki et al., 2003; Ueda et al., 2004). These factors represent global characteristics of the repository concepts, which we consider when evaluating options, including: *long-term safety*, *operational safety*, *engineering feasibility/quality assurance*, *engineering reliability*, *site characterisation and monitoring*, *retrievability*, *environmental impact and socio-economic aspects*. Because of limited information during the literature survey stage, the extent of quantitative assessment of any concept is inherently limited; the achievable level at this stage may be similar to that in H12 (JNC, 2000) – i.e. idealised feasibility and post-closure safety assessment, with very limited evaluation of either practicality or operational safety.

We can use such Design factors in an absolute sense, to assess the fundamental acceptability of repository concepts for specific site conditions, or relatively, in order to compare alternative design options. We have previously described the procedures for using these factors, involving either a matrix presentation (bottom-up approach) or a multi-attribute analysis (top-down approach) (NUMO, 2004b). Indeed, both of these have been applied to a number of "dry run" test cases, to confirm their applicability. It has been seen that evaluating concepts in terms of their performance with regard to individual factors is predominantly a technical challenge: however, the weighting of different factors to produce an integrated evaluation requires top-level strategic input.

In addition to the technical Siting factors for site ranking and Design factors for repository concept ranking, we have defined a top-level set of programme "Structuring factors". Although the term used here is analogous to the siting and Design factors previously discussed, Structuring factors are of a rather different nature. They represent key aspects of the overall NUMO programme whose importance must be pragmatically weighted as the programme progresses in order to focus the overall effort, as illustrated below (see also Box 2). Unlike technical factors, the Structuring factors and their weightings are inherently subjective in nature and represent a strategic consensus of NUMO management – guided as much as possible by discussions with key stakeholders. Although a very rough indication of the way in which such factors may develop with time can be produced (e.g. Figure 3-2), this will certainly be sensitive to the type and number of volunteer sites, national and international political developments, advances in science and technology, etc.

Box 2
Transparent decision-making

When comparing different options for sites, designs, etc., it aids transparency when the factors to be used in assessing them are clearly defined in advance. NUMO has already published the *Design factors* used for evaluating RCs and the *Favourable factors* used to select PIAs. These attributes can be evaluated either quantitatively or using expert judgement. In order to rank options, "weightings" have to be established that indicate the relative importance of different factors. Such weightings will change as the programme develops; NUMO has attempted to provide some guidance for setting the weightings on Design and Siting factors by identifying overarching programme aspects, labelled *Structuring factors,* and by indicating how the importance of these varies during repository development. The specific Structuring factors used may be different at different programme stages. The relative and absolute importance attached to these key aspects will affect the weightings on siting and Design factors at any decision stage – but subjectively rather than in an objective, quantitative way.

The later stages of the project, as represented in Figure 3-2, should not be over interpreted, but some important messages to be communicated to stakeholders in early stages are indicated. Between the establishment of NUMO and the start of open solicitation, we place major weight on general risk communication: not consideration of a specific site, but rather the fundamental issues associated with the safety of deep geological disposal. Even at the stage of selection of PIAs, it is likely (but not known for certain until all volunteers come forward) that site information will be very limited and hence our focus will continue to be on general issues influencing risk (e.g. arguments for geological stability) rather than rigorous post-closure safety assessment. We also place significant weight on engineering practicality (on the basis of current technology) and associated operational safety, even though it is unlikely that these aspects can be quantitatively assessed with the information base available from the literature survey. This is because, in Japan, these topics are likely to be of concern to stakeholders and have not been examined much in the past (e.g. within the H12 project). Therefore, we assign relatively high weightings to siting and Design factors associated with these issues when comparing options, while R&D to support this work is given high priority. On the other hand, recognising that post-closure safety can be well quantified only after extensive site investigation leads to this factor having a very strong influence only later in the programme.

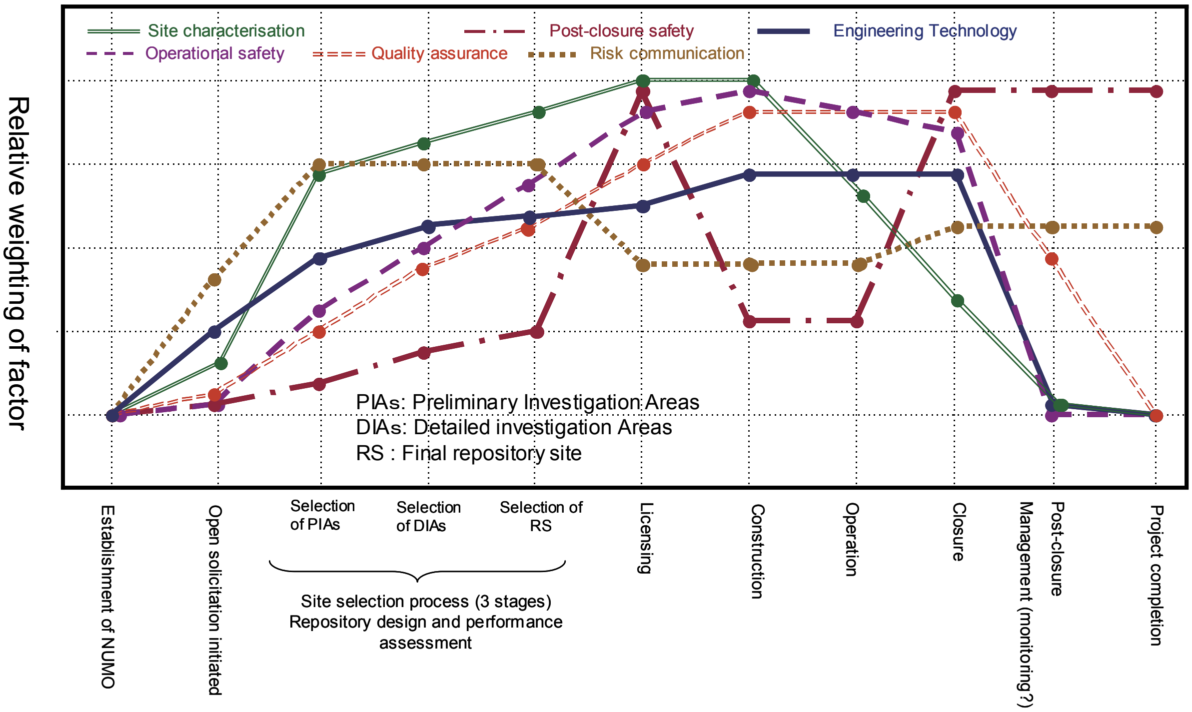

Figure 3-2: Illustration of potential changes in relative weighting of Structuring factors influencing the repository programme.

The figure includes quality assurance (QA) as a Structuring factor, which gradually increases in relative weight as the project develops. It must be emphasised that this does **not** mean that we do not consider quality to be important at early stages; rather it recognises the reality that, initially, the programme must utilise a lot of material that may not yet be fully quality assured. For example, the literature survey will simply have to make best use of whatever is available for a particular location. Nevertheless, even at this stage, QA measures will be applied to material identified as critical project input. At later stages, the QA programme will be more comprehensive but, even here, we recognise that we cannot aim for an "perfect" QA system that covers all possible system components, but have to define one that is sufficient for our purposes. This is especially the case if measures to assure QA compliance involve possible risks to operational staff; here a very careful balance has to be achieved.

For the specific case of comparison of sites and associated repository design options at the stage of PIA selection, the Structuring factors indicate the weighting we give to the different Design factors / Siting factors when used in multi-attribute analysis. This leads to a consistent assessment for this particular stage of the programme, while acknowledging that these will change in the future – with possible changes in relative ranking of sites and / or repository design options.

3.3 Structured planning of the entire repository project

3.3.1 Application of the NSA during staged implementation

Although Figure 3-1 focused on RC development during the literature survey phase, the NSA also serves to provide a structure for the planning and analysis of the field characterisation work. The figure can thus be generalised (Figure 3-3) to include all the technical decision-making associated with the staged siting process. Further, this process can actually be iterated at each of the implementation stages, taking into account the changes in the relative weighting of different issues as represented by the Structuring factors (Figure 3-2). In contrast to the approach in many other national programmes, the key feature here is that, during each iteration, we reassess the entire sequence of decisions (as indicated for RC development in Figure 3-1) in the light of improved knowledge, advances in science and technology and strategic weighting of Design factors and Siting factors.

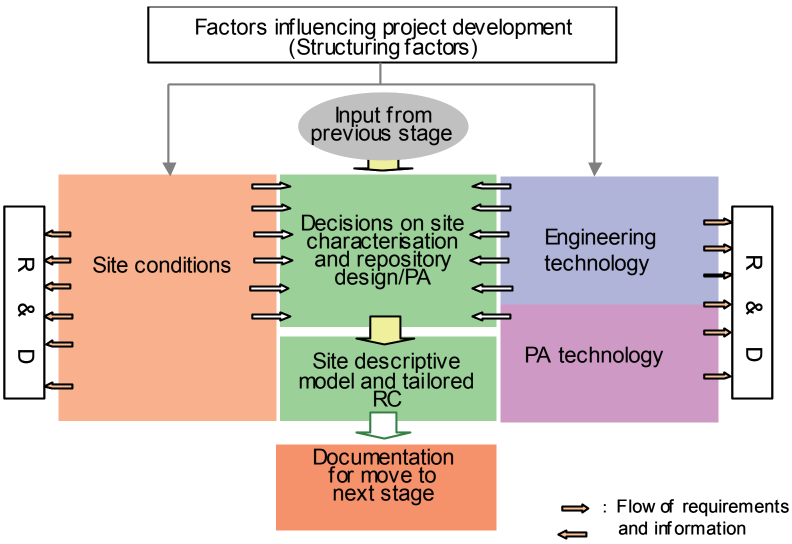

Figure 3-3: Generalised application of the NSA to guide site characterisation and repository design / PA at any siting stage.

The details vary somewhat, but we consider that the fundamental NSA is fully applicable to phases after site selection, including construction, operation and closure as indicated in Figure 3-4 (for simplicity and comparison with Figure 3-1, this illustration focuses on RC development). Between PIA selection and licensing of the chosen site, knowledge about the geological environment will have improved considerably and we will tailor the RC to the best available model of the site. The design will, however, also have to be optimised in terms of not only long-term safety, but also operational safety / practicality (especially in the light of remaining site uncertainties) and quality assurance procedures. We have thus decided that establishing the methodology for carrying out such optimisation is a priority for R&D in the intervening period. For example, the post-closure safety case will initially concentrate on near-field processes and a robust engineering barrier system, as a pragmatic response to the limited geological information at early stages. The basic PA modelling capability needs to be extended, however, to allow a more realistic assessment of total system performance, which will be needed to compare options. In addition, efforts are underway to rigorously assess operational phase safety and the practicality of assuring quality of the constructed engineered barriers. These are key components of the total safety case which are identified as being in need of particular attention now, as they may better discriminate between sites while information is still limited (Kitayama et al, 2007).

A basic principle of the NSA is that decisions are never frozen and can always be reassessed as required. Even after licensing, site understanding and technology will evolve further during the decades of construction and operation and hence further optimisation may be introduced. During construction and operation, operational safety and quality assurance are particularly important and experience gained from this “first-of-kind” project in Japan is expected to allow us to make continuous improvements.

Even at the final stage of licensing for closure, we will make use of the experience gained during all previous stages to optimise the final closure concept – which may well be very different to that envisaged in the original construction license. This step will certainly involve some discussion of post-closure monitoring. At present, there is no technology that could directly monitor safety-relevant performance of a repository without risking perturbation of the key safety barriers. This could, of course, be completely different at the end of the 21st century. On the other hand, either advanced safety assessment technology or growth in public confidence in repository safety might make such monitoring unnecessary. The NSA allows for such uncertain boundary conditions and provides a method for ensuring that we will find an optimum solution based on state-of-the-art understanding of the issues involved at the time when the decision finally has to be made.

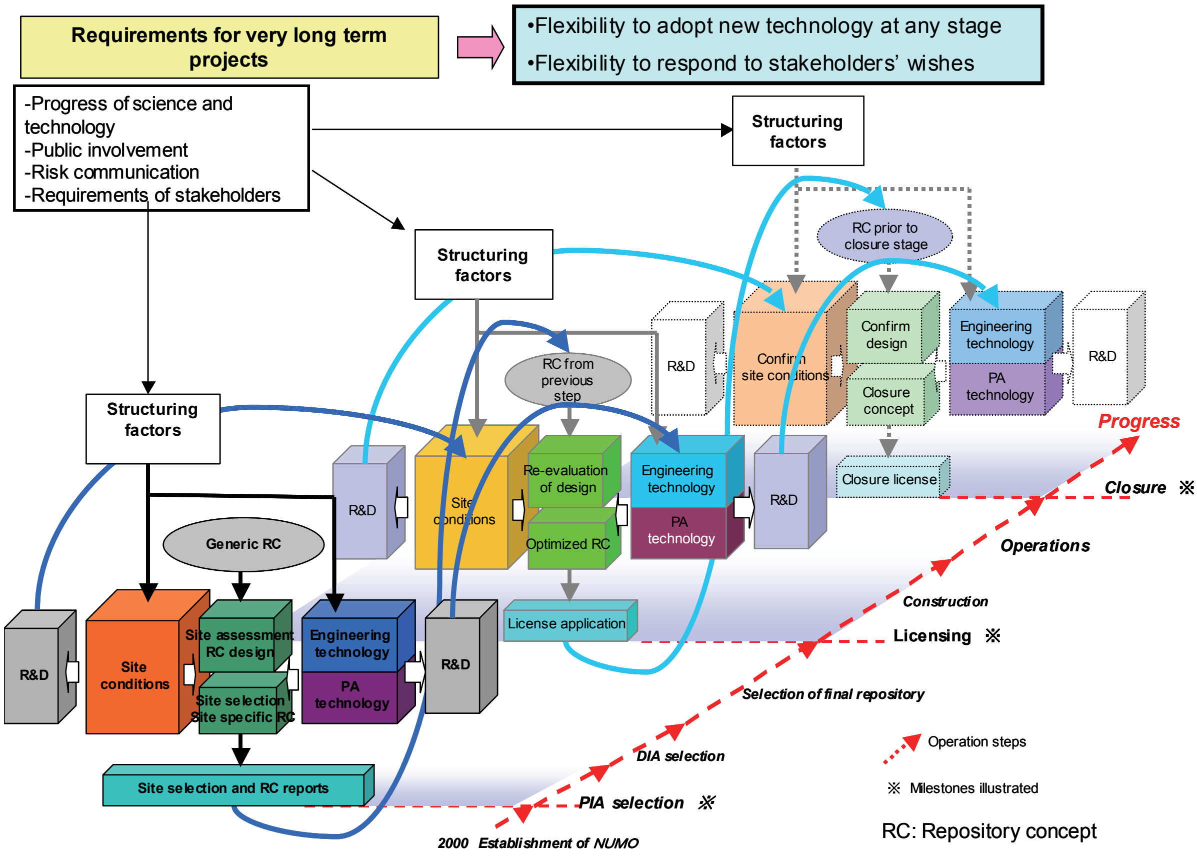

Figure 3-4: Illustration of potential changes in weighting within the NSA as the project develops.

3.3.2 Response to surprises and unexpected changes in external conditions

Figure 3-4 emphasises the planned development of a project, where gradual changes in Structuring factors can be taken into account at project milestones or regular evaluation points within longer stages (e.g. every 5-10 years). We consider it very important, based on international experience, to also allow for surprises – which may either be technical (unpredicted geology, sudden technological breakthroughs) or socio-political (new concerns of local communities, social disruption). Such surprises, if significant, should result in a rapid response at an appropriate level, regardless of whether a reassessment milestone has been reached or not. Potentially the most disruptive would be events that influence the entire programme (Figure 3-5). Basically, however, any event can be reflected in a change in the Structuring factors, allowing the NSA to be directly applied.

For example, the scenario of a high profile accident in an underground construction project in Japan could be the trigger for a reassessment of the programme. Here, much higher weighting than previously used might be placed on site uncertainties (determining any similarities with the accident location) and operational safety. The output might involve both changes in the site characterisation plan (to improve assessment of similar risks under expected conditions) and the repository design (including both barrier features such as tunnel liners and operational procedures / infrastructure such as emplacement methodology, ventilation and drainage). The explicit consideration of such cases in the NSA allows responses to be implemented rapidly and readily communicated to stakeholders.

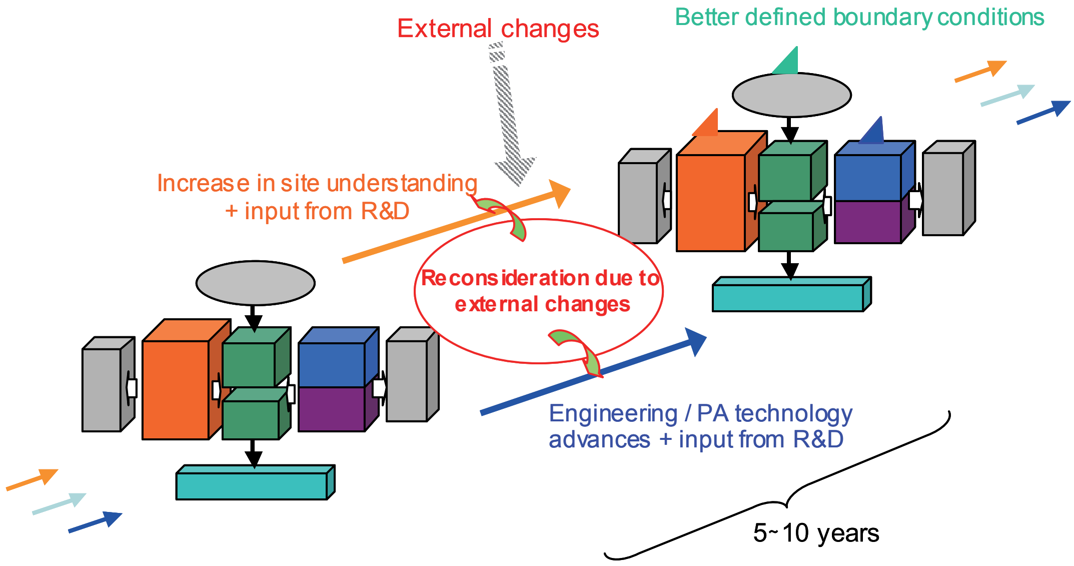

Figure 3-5: Application of the NSA between implementation stages.

Surprises may be categorised in terms of their impact. Some may clearly require an immediate and complete reassessment of the entire project; others may be more limited in scope and would primarily affect only a component of the technical programme – e.g. many types of unexpected geological findings. The latter are more probable and we can take them into account by applying the NSA to a reassessment of only the influenced components of the project. We can evaluate borderline cases between these two extremes qualitatively, by determining the extent to which “current” Structuring factors would be changed and assessing the impact of such changes on the programme.

For example (Figure 3-6), major advances in site characterisation technology could greatly reduce uncertainties – allowing improvement of the model of geological structures, including safety-relevant major faults and associated geochemistry – and could thus improve the assurance of performance of the natural barrier. Such improved understanding of the geosphere allows a change in the relative weighting of the Structuring factors, which might then allow us to optimise the engineered barriers, relaxing previous thermal, mechanical and chemical constraints. Again, this would be a structured response to a foreseeable development and should be able to be communicated as learning from experience, not to be confused with a simple “cost-cutting” measure, which might cause public concern.

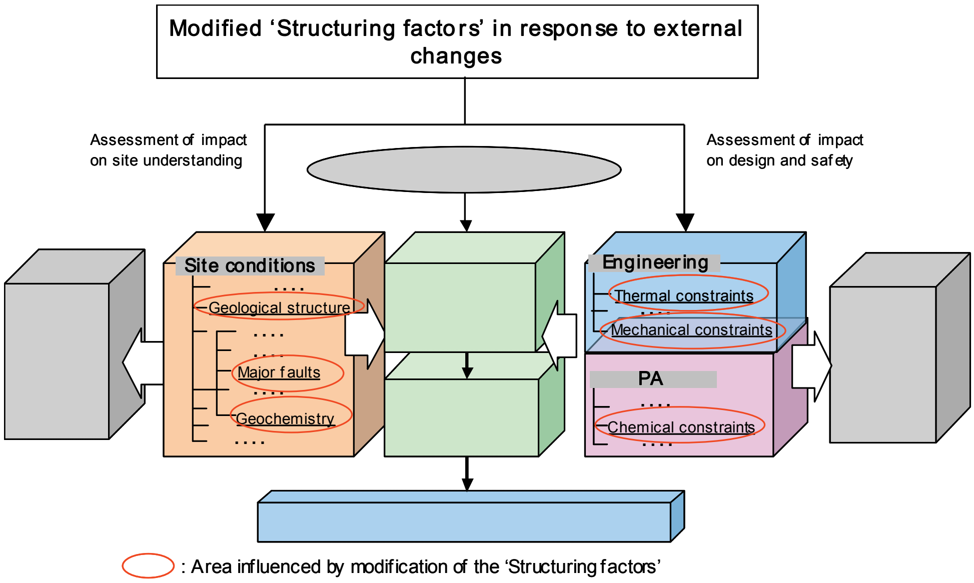

Figure 3-6: Example of the process of responding to external changes; modification of the Structuring factors leading to reassessment of assumptions and boundary conditions.

The optimisation process is indicated in Figure 3-7. The management decision that we have to make is whether the changes involved are so critical that an immediate re-focusing of the project is needed, or whether they can be accommodated by minor changes of component work packages – with complete reassessment postponed until the next planned project milestone. Whatever the case, the analysis involved and the resultant decisions are documented in a consistent manner that will be transparent to (or even include input from) local communities.

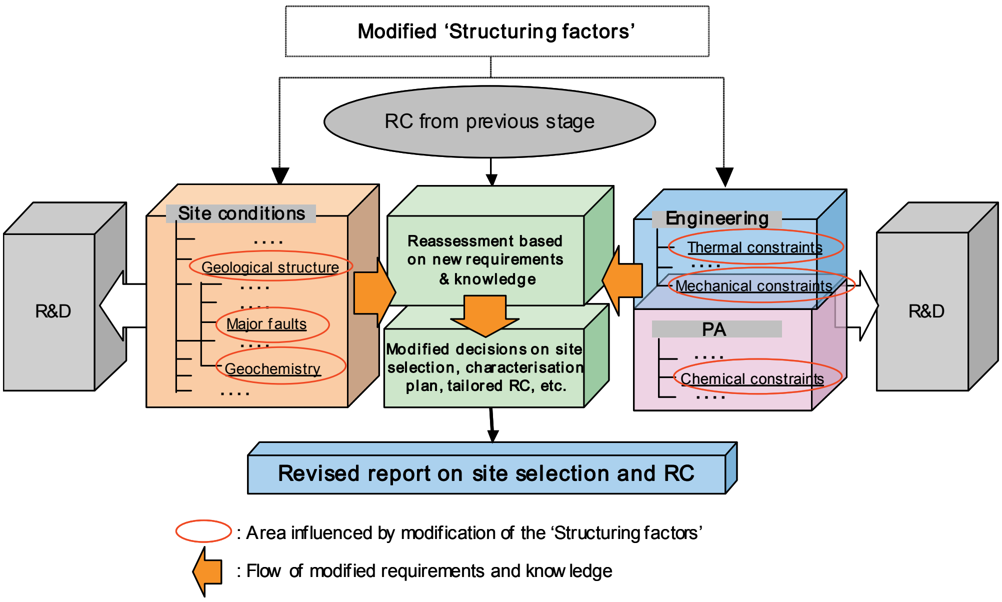

Figure 3-7: Example of the process of responding to external changes; project optimisation.

In overview, the development of a volunteer site might look quite different to the nomination of sites for a reference repository concept, as is the case in most other national programmes. For example, on the basis of the literature survey, three particular host rock / repository designs might be considered for a site. During PI, one option could be abandoned (e.g. if the host rock is not found at a depth accessible with existing technology) while another might be expanded into variants (e.g. if a potential host rock was stronger / more homogeneous than expected). By the detailed investigation (DI) stage, increased understanding and greater weight on operational safety may cause further reassessment of options – merging variants or postponing further consideration of options which appear more problematic. At any point, however, a change in external conditions (e.g. a social requirement for ease of retrievability) can cause modification of an option or, indeed, reconsideration of past decisions (e.g. mobilising reserve sites, revisiting abandoned designs which may become feasible on the basis of improved technology). The structure of the process described is illustrated in Figure 3-8. In effect, this emphasises both flexibility and the concept of the "reversibility" of decisions. These are features that are considered to be important in most national programmes that focus on staged implementation, but we consider them particularly critical for NUMO's special boundary conditions. Emphasis of this process from the beginning should show NUMO's preparedness to respond to changes and encourage the participation of interested parties in developing a consensus response.

The NSA provides a clear methodological framework for developing projects in a flexible manner, identifying the key decisions to be made and placing them in context. In itself, however, it provides little direct support for the various decisions that have to be made on a regular basis and at various hierarchical levels. Nevertheless, by identifying the factors that have to be considered and the weightings to be applied to them, the requirements to be considered when reaching and documenting decisions can be specified. This can assist our application of an appropriate management tool to guide complex, multi-disciplinary decision-making – the RMS described in the following chapter. Indeed, with the emphasis on flexible responses to changes and reversibility of decisions, the RMS is considered essential for practical implementation of the NSA – especially given the long duration of the repository project and the inevitable changes in personnel and boundary conditions that will occur over this period.

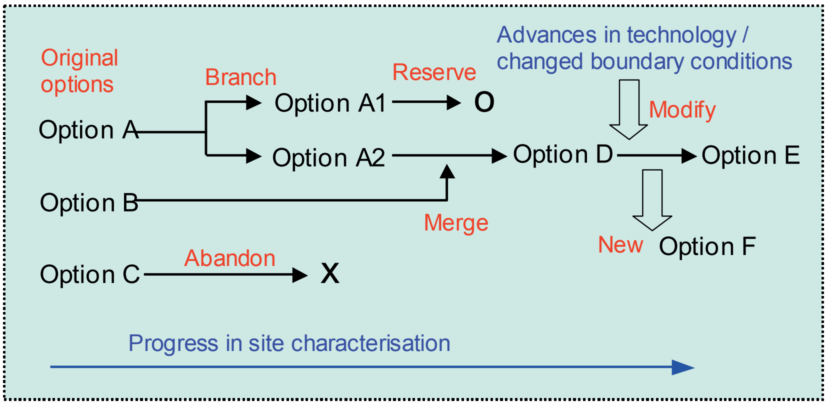

Figure 3-8: Process overview – maintaining flexibility and focus.

4 CONCEPT OF REQUIREMENTS MANAGEMENT AND ITS APPLICATION WITHIN THE NSA

As any project grows in complexity, maintaining the overview needed for informed decision-making becomes more difficult. By the end of the 20th century, this was already acknowledged to be a particular problem in major, high-technology projects (a good example being the aerospace industry), especially when these might extend over decades and be subject to continuously changing regulatory and socio-economic boundary conditions and to steadily advancing science and technology. This has led to the evolution of the field of "requirements management" (see Box 3) and the development of many tools to assist implementation of various types of formal Requirements Management Systems (RMS).

Box 3
Requirements management

The term "requirement" as used here applies to any project constraint, i.e. to any quantitative or qualitative boundary condition or goal to be satisfied by the project. The challenge is to optimise the project with regard to such requirements – a task which increases in complexity as the number of requirements increases, as requirements change with time and as the project is defined in more technical detail.

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

The deep geological disposal of HLW might be regarded as a rather low-technology project in terms of practical implementation, but it is supported by state-of-the-art science in a wider diversity of technical disciplines than almost any other industry. Particularly when the long project duration is considered – around a century or more – repository implementation is clearly an appropriate field for the use of an RMS. The high priority we assign to development of such a system for the NUMO programme results, however, from the constraints set by the practical implementation of the NSA – requiring regular iterations of making (or reviewing) decisions at a range of hierarchical levels. In addition, our commitment to openness and transparency requires that such decisions should, wherever possible, include input from involved stakeholders and, in all cases, be clearly documented. The final consideration which gives urgency to this initiative is the current situation where many of our key staff members are only on relatively short attachments to NUMO; providing them with the background to be able to evaluate the basis for decisions and ensuring that all such decisions are comprehensively recorded is thus critical.

4.1 Hierarchical structure of decision-making within the NSA

As emphasised in the previous chapter, we make decisions in many different technical areas and at a range of hierarchical levels – from relatively frequent modifications of site characterisation plans or repository designs to the major site selection and licensing decisions made at project milestones. This situation is illustrated in Figure 4-1, which indicates also the important coupling between decisions. Thus, for example, a decision on the design of a waste overpack is coupled to decisions on the host rock chosen to be the focus of site characterisation and also on how compliance with regulatory guidance will be assured. Indeed, it can be even more complex as, even at a detailed technical level, decisions may interact with socio-economic issues such as public acceptance and cost. Coupling may extend not only horizontally, but may also directly link decisions at different hierarchical levels.

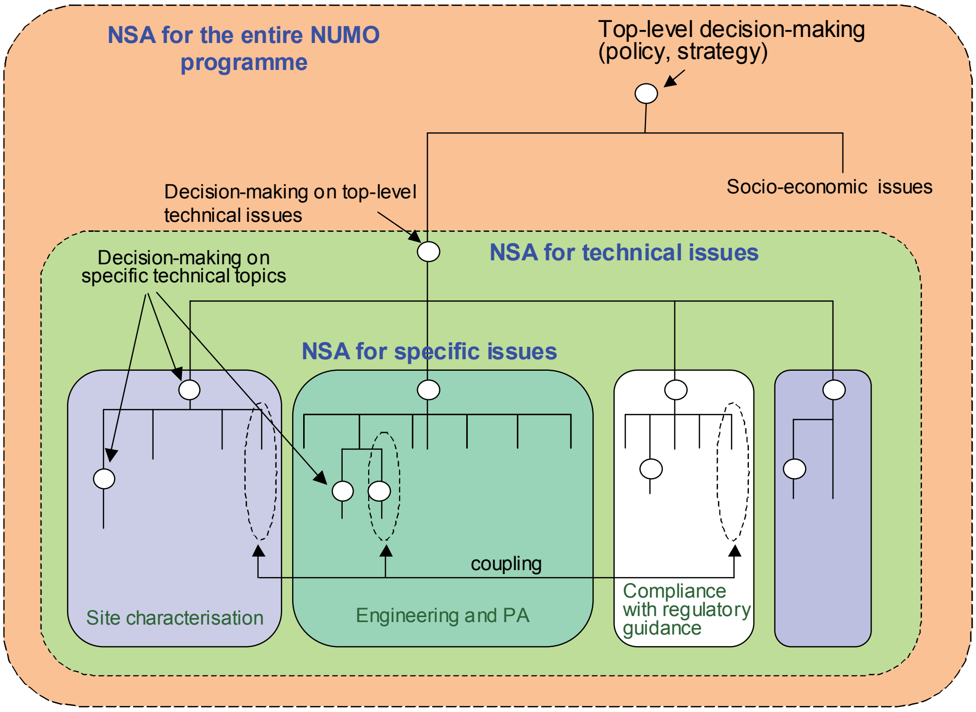

Figure 4-1: Hierarchical structure of decision-making within the NSA.

The need to make decisions influenced by a complex range of factors was recognised at an early stage by NUMO; this has also been well documented in other national programmes – particularly associated with site selection. To gain experience with practical support tools for making such decisions, we have been carrying out case studies using a fairly standard Multi-Attribute Analysis (MAA) approach (NUMO, 2004b; Tsuchi et al., 2007) and have also examined alternative methods such as Evidential Support Logic (ESL) (Tsuchi et al., 2003).

For decisions such as selection of preferred host rocks, sites or repository designs, we can base the attributes on the defined Siting factors / Design factors, while weightings of these would be based on the relative Structuring factor weightings appropriate to the particular stage of the programme (see Box 2). These methods can thus be useful for supporting major decisions at project milestones, but are of limited applicability to lower-level technical decisions of the type that are made on a regular basis. A further inherent limitation is that both these methods are passive – they do not provide any kind of active feedback to indicate when reassessment of the decision may be needed (a key component of the NSA) and they do not link different decisions. Such tools are thus necessary, but not sufficient, for our implementation of the NSA.

4.2 Decision-making within the RMS

Basically, the NSA provides a logical sequence for stepwise development of plans – leading to a network of decisions that, in general, become more technically detailed as they are traced to lower hierarchical levels. An example is indicated in Figure 4-2, which is a representation of the components of the decision hierarchy associated with repository design. Although appearing complex, this is actually a considerable simplification of the true situation, where the previously mentioned coupling between decisions is important – as indicated in Figure 4-3.

These figures also illustrate the common basis of any decision – which is reached from some kind of consideration of a number of different requirements that have to be met. Each requirement, in turn, is associated with certain arguments – or assumptions – that define its applicability. The requirements overlap between decisions and can be used to define the coupling between them. Thus, although interest is usually focused on decisions, requirements are more fundamental and hence form the basis for the RMS, which aids the decision-making process. It should also be noted that, although decisions may change over a short time period, in particular when knowledge about a site is increasing rapidly, the basic requirements change much more slowly and, indeed, some may alter little over the entire period of development of the project.

Examination of Figures 4-2 and 4-3 allows some of the key attributes that an RMS must have in order to support the NSA to be highlighted:

- The hierarchy of decisions must be established and these must be able to be followed (and evaluated) in both a top-down and bottom-up fashion;
- The considerations for decision-making (i.e. the specific basis on which the decision rests) must be fully recorded, particularly the weightings assigned to the different (potentially contradictory) requirements involved;
- The potential need to reassess any decision should be flagged automatically in the case of changes in either top-level considerations (e.g. due to a change in Structuring factors), the arguments supporting the requirements (e.g. due to a change in a lower-level decision) or the emergence of new requirements (e.g. due to a surprise external change).

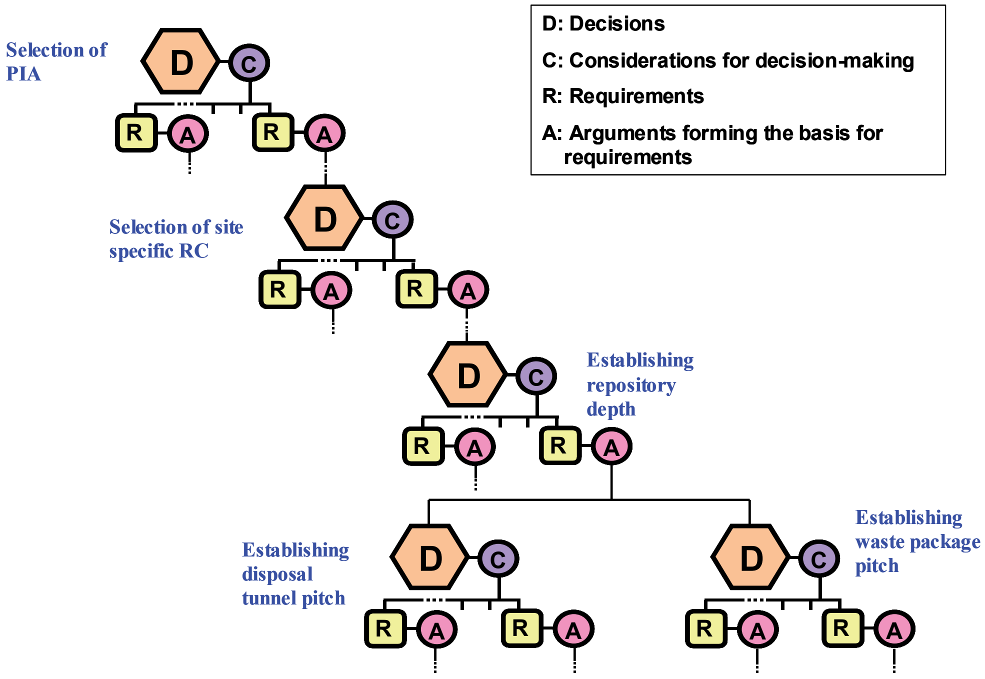

Figure 4-2: Example of the hierarchical structure of decision-making.

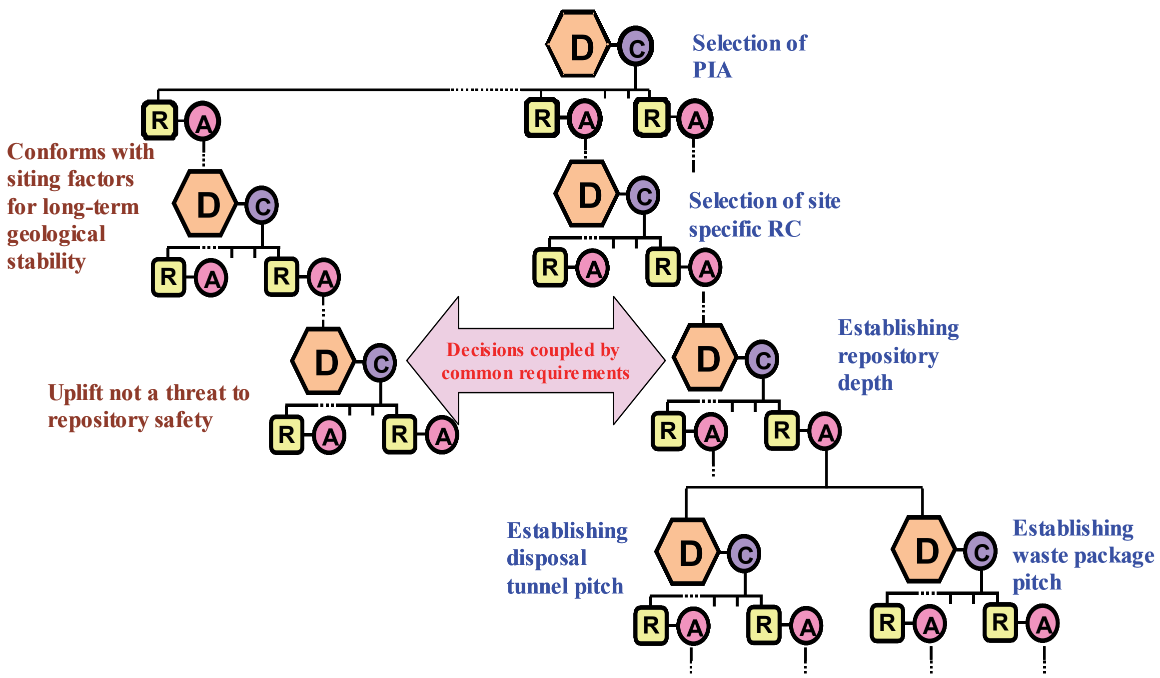

Figure 4-3: Example of coupling of decisions.

4.3 Requirements management in the decision-making process

4.3.1 Terminology

To avoid confusion, it must be emphasised that the term "requirement" as used in the RMS field is a general term applied to any project constraint (see Box 3) and not a hard "necessity" as implied by colloquial English. For a geological disposal project, requirements may be quantitative (40,000 waste package inventory for repository) or qualitative (desire for a simple geological setting), externally imposed (e.g. 300 m minimum depth) or NUMO decisions (volunteering approach), well-defined (exclusion distance from Quaternary volcanoes) or provisional assumptions (maximum acceptable uplift rate). Requirements can also be structured hierarchically, the top-level set by legislation and policy leading to lower-level, derived requirements – leading eventually to detailed work or product specifications. This is formalised within an RMS; in principle, however, the process is similar to the traditional use of hierarchies of reports to describe a project and, indeed, some RMS software utilises such documentation to structure the implementation of a practical system for the management of requirements.

The decisions illustrated in Figures 4-1 and 4-2 involve assessment of information, which may be used to determine the extent to which requirements are met. As emphasised before, such information may be very uncertain in the early stages of the project and an improvement in understanding may be a trigger for us to reassess a decision. Alternatively, lack of knowledge of key system characteristics may require us to make a provisional assumption, with resolution of specific issues identified as priority topics for R&D. As the amount of information – which can generally be classed as "knowledge" – expands in a project, its management also becomes a challenge. This has been recognised by the Japan Atomic Energy Agency (JAEA), which is currently developing advanced concepts for a Knowledge Management System (JNC, 2005) that could, in principle, provide support for the NUMO's RMS. Such developments are being actively followed by NUMO but, at present, are less critical than establishing the basic RMS infrastructure and putting a QMS in place for the key knowledge that will be generated by NUMO as soon as the siting process commences.

4.3.2 Outline of the NUMO's RMS

(1) Hierarchy of requirements

At a top hierarchical level, it is clear that NUMO has to develop a repository project that conforms to the requirements specified in laws and regulations. To date, the main law of relevance is the Final Disposal Act, which is complemented by outlines of policies and implementation plans produced by the Atomic Energy Commission (AEC) and the Nuclear Safety Commission (NSC). These will be expanded on at a national level as the repository project moves towards implementation and will, as siting progresses, also include regulations or guidelines that may be specified at a more local level by the prefecture or the municipality.

Although it is only intended to be illustrative (the actual hierarchical structure to be used in the RMS is currently under development), the appendix indicates how the top-level legal requirement can be broken down into sub-requirements – which can be separated pragmatically into those relating to the site and those focused on the repository concept. At an even lower level, design requirements can be split into those that are related to operational safety, those more relevant to post-closure safety and those associated with environmental impact. It should be emphasised, however, that there are clear links between such requirements and that this process can be continued to several lower, more detailed hierarchical levels.

In addition to legal requirements, there are also technical constraints on the NUMO programme and practical requirements associated with credibility – not only of the programme, but also of NUMO as the implementing organisation (as highlighted in Chapter 2). Again, such top-level requirements can be broken down in increasing detail. It is interesting to note that the NSA, and the RMS itself, arise naturally as important components of NUMO's programme to respond to these requirements.

(2) NUMO's technical basis for implementing the RMS

The appendix not only lists examples of requirements, but also provides comments that indicate the particular approaches, infrastructure, tools or focused R&D that NUMO will use to satisfy them. Although the RMS development is ongoing at present, significant progress has already been made in ensuring that the technical basis for implementing the RMS will be available as and when needed. The management structures associated with the NSA have already been discussed, and the overarching QMS has been mentioned. This section thus summarises progress in technical areas - broken down into site selection / site evaluation, repository concept development and compliance with regulatory guidance (Figure 4-4).

With regard to siting, we have already published Siting factors for the selection of PIAs (NUMO, 2004a), which include the legal requirements for site selection as laid down in, for example, the Final Disposal Act. Similar, more detailed Siting factors are scheduled to be published in advance of the subsequent selection phases and these will reflect the changes in weightings in the programme and advances in site understanding as indicated by the structured approach. We have developed methods for technical evaluation of factors associated with site suitability and have also prepared associated databases. These include, for example, a geographic information system (NUMO-GIS) and a geological environment data management system. We are also examining an "information flow diagram" approach for the literature survey, which effectively provides a method for defining the links between required assessment information and the investigation methods used (Noda et al., 2007). We will update these databases and the associated information flow diagram on the basis of increasing information as the project advances, or, as emphasised by the NSA, in response to surprises or changes in boundary conditions.

We will establish appropriate, tailored repository concepts by iterating repository design and performance assessment on the basis of site conditions; initially, comparison of various options will be aided by Design factors, which we have already published (Umeki et al., 2003; Ueda et al., 2004). The selection of site-specific reference concepts will also be guided by the NSA and reassessed at project milestones and in the event of any changes in boundary conditions. To assist re-evaluation, we have been looking at a computer-assisted repository concept development system (NUMO, 2004b), which allows repository design and performance assessment to be conducted systematically and efficiently for specifically defined site conditions.

Overlapping these two technical areas, we have, as previously mentioned, examined the applicability of comparison and evaluation methods based on MAA and ESL to allow ranking of sites and / or repository concepts.

Due to the absence of regulatory guidelines to date, we have placed a high priority on establishing internal working standards. These will effectively define our goals and code of conduct for early project phases, until the official safety regulations for geological disposal and any other relevant legislation (e.g. on environmental protection) are established in the future. In line with the NSA, these standards will evolve with the progress of the project and will be key requirements to be applied in site selection, establishment of repository concepts and construction, operation and closure of the repository.

Given the importance we assign to involvement of stakeholders in the entire process, efforts towards developing improved methods of risk communication has wide applicability. This is complemented by technical work to establish methods, using relational databases, for communicating and archiving key knowledge and information that support our evolving safety case.

We expect that such a comprehensive toolkit, utilised in combination with the RMS, will facilitate our implementation of practical and efficient projects within the overall framework set by the NSA.

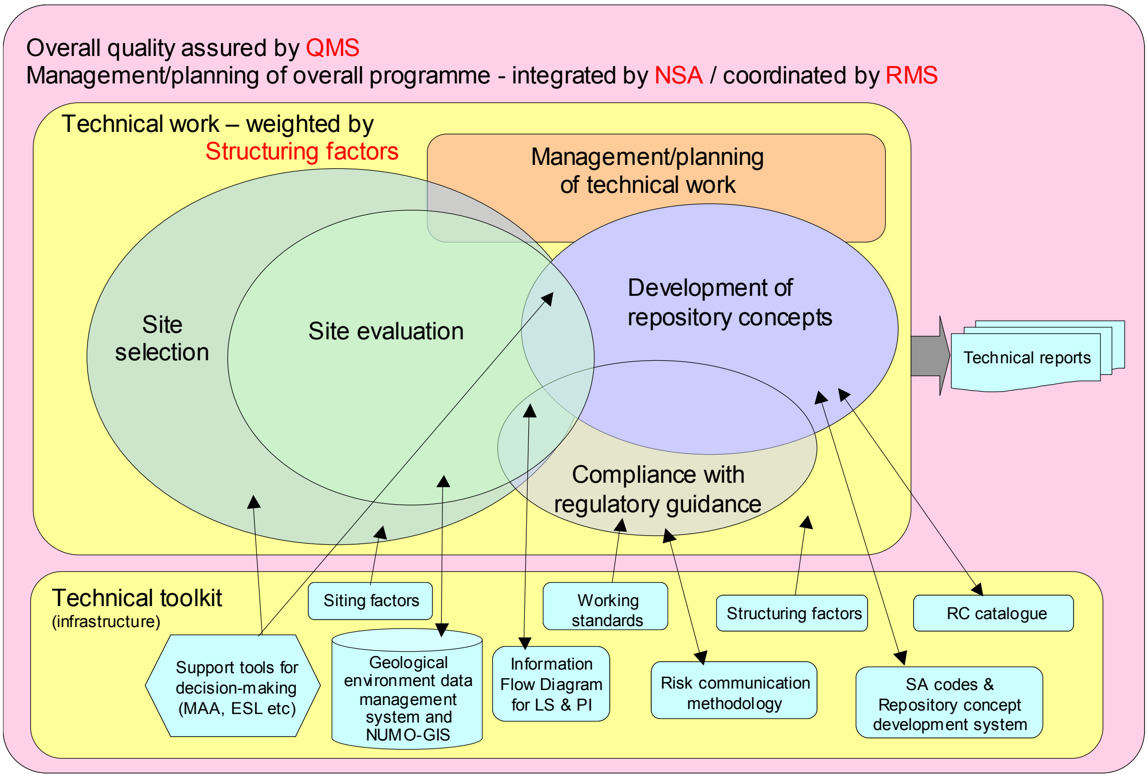

Figure 4-4: Overall perspective of NUMO's technical programme.

(3) Practical constraints on development of the RMS

We intend the RMS to be a practical tool that will assist in the implementation of decision-making within the NSA – both for day-to-day technical decisions and major project reassessments, either at planned milestones or in the case of surprises. Indeed, as previously noted, ideally the RMS should actively identify links between decisions and flag cases where past decisions might need to be re-evaluated.

The major objectives behind developing an advanced software RMS tool include (Sakabe et al., 2005):

- Ensuring transparency and traceability in decision-making processes;
- Recording project decisions, considerations that influenced them and requirements and arguments behind these decisions;
- Anticipation and support of future decision-making;
- Identifying the consequences of changes in decisions or boundary conditions;
- Supporting R&D planning by establishing needs and setting priorities.

With the above objectives in mind, the resulting RMS tool should have functions that include (Sakabe et al., 2005):

- Taking full account of the interconnected nature, hierarchy and cross-relationships between decisions and requirements;
- Being flexible enough to allow for the changing nature of requirements and the possibility of revising or reversing decisions as the project progresses;
- Accepting and recording changes in a controlled, orderly and well structured manner, supervised by a system administrator;
- Incorporating the concept of " ownership" - each user is authorised to propose modifications to a limited subset of requirements and decisions;
- Actively providing input to, and accepting feedback from, users (NUMO staff) affected by any decision/information changes;
- User-friendliness: simple, self-evident commands and operations incorporated into an interface allowing ease of use by even non-technical staff;
- Providing adequate security - allowing only limited access to sensitive information and assuring a robust system of archive backups;
- Being centrally hosted so that only the current version is always running.

It must be emphasised that such a system does not make decisions – it merely ensures that decision-makers have ready access to all of the information relating to any issue and are fully aware of the consequences of different available options. Together with the support tools for evaluating complex decisions (MAA, ESL), this will aid openness and transparency and, ideally, also involvement of stakeholders in developing a consensus on key issues.

Practical implementation within an evolving project is illustrated in Figure 4-5. The RMS represents any decision in a standardised manner. In the case of any change in an external decision / requirement / argument linked to this decision, the influences are clearly highlighted and their effect on the considerations behind it are noted. This allows the decision-making process to be modified and the justification for the new decision to be documented. In fact, as the entire process is recorded, the evolution of a project can be readily traced. Termed "change management", this has been identified as a key function of our RMS.

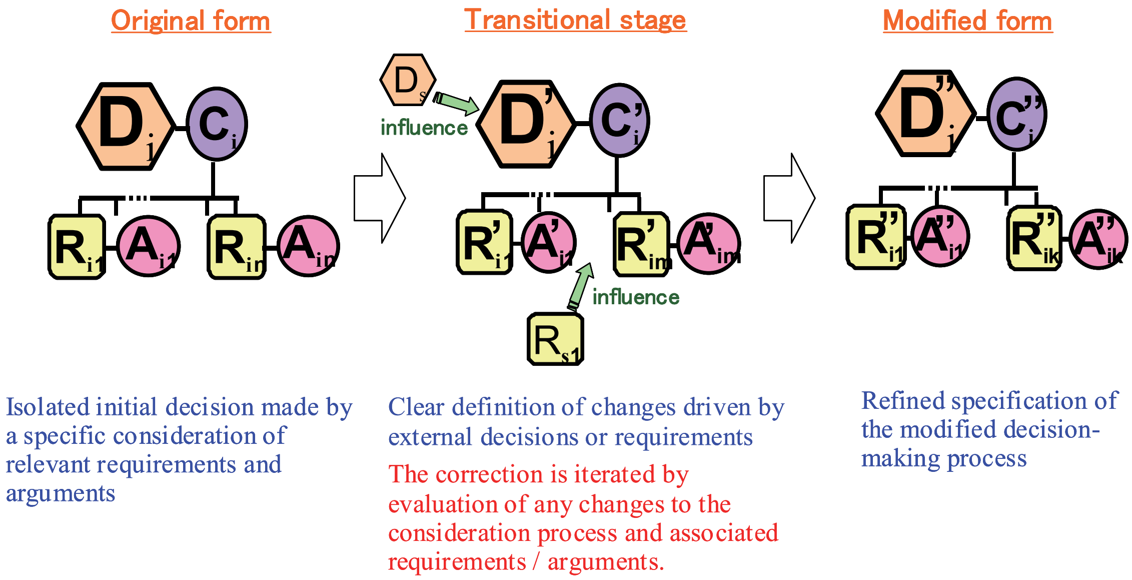

Figure 4-5: An example of record preservation for the modification of a decision in response to changing knowledge or requirements.

The RMS thus identifies gaps in knowledge or uncertainties which make a decision provisional, depending on particular assumptions. These assumptions can serve to focus and prioritise R&D and, based on the results of improved understanding, either lead to confirmation of the decision or else flag it for reconsideration as described above. In the future, it may be that this latter function can be implemented by a supporting Knowledge Management System; although this does not currently seem practical on the basis of existing technology, developments in this area will be followed with interest.

4.4 Further development and implementation

The rather detailed description of the fundamentals of the decision-making process, as we intend to implement it within our RMS, highlights the logical structure involved. It is presented in such detail not only to show its flexibility in terms of application to all parts of our programme, but also to emphasise the role of change management, which – as is clear from the earlier NSA discussion – is a critical issue in our programme. From this basis we need to develop dialogue with key stakeholders so that they can see how decisions are made and how such decisions might change in the future – particularly as a result of surprises. Ideally, stakeholders will actively participate in this process.

In the interim, the main role of the RMS will be within NUMO, helping our staff to prepare for volunteers and to move forward efficiently as soon as potential sites appear. Here, it is essential that the theoretical structure presented above works in practice. Thus, development of a prototype RMS tool proceeds iteratively with checks of practicality for specific test cases. Such a procedure is, of course, in line with the NSA concept; we accept that our RMS may need to be modified in the light of experience to ensure that it is tailored to our particular needs.

5 CONCLUSIONS AND A LOOK TO THE FUTURE

This report has outlined the special boundary conditions on the NUMO programme. These result predominantly from the flexibility needed to implement geological disposal of HLW based on the NUMO volunteer approach to siting and on the strict Japanese requirements for transparency and traceability, but due also to the inherent constraints set by a complex, highly sensitive project that will develop over a period of a century or more. Rather than the conventional emphasis on a reference repository design and host rock – as is typical of most national programmes – we have concentrated on the process of optimally tailoring a technical project to the particular conditions encountered, as formulated in the NSA. The use of the NSA has been illustrated by its application to the development of site-specific repository concepts during the literature survey phase, but it will be applied to our entire programme. To assist in its application, we are in the process of developing a formal RMS.

The NSA places particular emphasis on the provisional nature of decisions made when uncertainties are large, particularly at early stages of site characterisation. The system allows for ease of reassessment or, indeed, reversal of decisions – a key attribute of adaptive staging. Further, within the RMS, the evolution of system understanding and boundary conditions can be followed automatically and decisions that may need such re-evaluation can be identified. The NSA applies to the expected development of the project, allowing for changes in the weighting of particular issues at different stages – as indicated by Structuring factors. This flexibility also allows the consequences of technical surprises or unexpected changes in boundary conditions to be readily incorporated into the NSA process.

Apart from practical advantages, the application of the NSA and the supporting RMS are a deliberate part of our strategy to develop technical credibility. This area is one where we feel a need to be at the forefront of the state-of-the-art, demonstrating an ability to respond to the complex challenges in the Japanese HLW programme and illustrating our commitment to open and transparent decision-making. In addition to the RMS, we are developing a range of supporting management tools that will assist with compiling and assessing the large volume of information that will accumulate during this project – and refining it into a form suitable to support the decision-making process. Of particular importance here is the overarching Quality Management System; although this is clearly essential and urgent, our development of this system is proceeding in a stepwise manner to ensure that it is properly tailored to NUMO's particular requirements.

For the immediate future, the main challenge is clearly to motivate and support volunteer communities. The investment in improving communication tools and efforts to develop dialogue with interested communities and key opinion-formers is expected to bear fruit only if NUMO can be seen to be a technically credible, honest partner. The NSA may be difficult to implement, but it shows a commitment to flexibility and preparedness to change plans to meet the desires of stakeholders, which we think would be difficult to demonstrate using conventional approaches. Implementing and operating the formal RMS may also be expected to result in challenges but, from the perspective of the entire project duration, an intensive effort now may yield benefits at later stages of the programme – particularly when work pressure and deadlines might be more critical than at present.

With the advantage of being a young organisation, NUMO has been able to incorporate the NSA as a keystone of our corporate culture. This is apparent in the way that flexibility and reversibility are being emphasised in all our planning documents, in marked contrast to the rather rigid planning approaches formerly used in the nuclear field and common still in other industrial areas. It is one of the first successes of our work in this area that, even prior to implementation of the RMS, our staff members are effectively applying the principles of the NSA in their daily work – even if do not always make explicit reference to the formalised structures involved.

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APPENDIX ILLUSTRATION OF HIERARCHICAL RANKING OF REQUIREMENTS

The table below illustrates the way in which top-level (1) requirements can be refined to produce lower-level (2, 3) requirements. This process can be continued further to derive technical specifications for individual processes or repository components. This is only a small subset of the set of requirements that is currently being assembled for our prototype RMS. The challenge is to ensure that the complete set of requirements is comprehensive, is specified at the appropriate hierarchical levels for specific applications and is kept up to date, with any changes being properly recorded. As discussed in Chapter 4, such requirements are the basis for decisions made within the programme. As many requirements may influence a specific decision, explicitly representing this in the RMS allows more open, transparent and consistent decision-making.

Requirement Level	Requirement title	Comment
1	Project meets legal requirements	Requirements defined in existing and future laws and regulatory guidance
2	Site meets legal requirements	Current law reflected in "Evaluation factors for qualification"; future requirements anticipated in Siting factors and working standards
2	Repository design meets legal requirements	No current legislation; assumed to be covered by operational and long-term safety requirements
3	Site-specific design meets post-closure safety guidelines	Anticipated requirements included in working standards
3	Site-specific design meets operational safety guidelines	Includes exploration, construction and operation: anticipated requirements included in working standards
3	Site-specific design meets environmental protection guidelines	Includes exploration, construction and operation: anticipated requirements included in working standards
1	Repository project is technically credible	The entire programme corresponds to the technical state-of-the-art
2	Post-closure safety is assured by a passive system of robust barriers	The safety case is built on a well-understood EBS tailored to a well-characterised host rock
2	Construction and operation of the repository is practical and safe	Efficient, robust and fail-safe procedures tailored to site characteristics
2	The site and design minimise the risk of disruptive scenarios	Siting and Design factors reduce both the probability of disruptive processes and events and the consequences of any perturbations that might occur

3	The EBS provides complete containment for the period of highest waste toxicity	The fundamental components of the EBS are based on H12 (JNC, 2000), tailored to assure 1000 years containment at any site
3	After complete containment, RN releases from the EBS are very low	Set by constraints on release from glass matrix, solubility limits, retardation processes, etc.
3	Releases from the EBS are reduced and delayed by the NBS	The natural geological barrier reduces releases by retardation (decay), dilution and dispersion
3	Performance of the repository is assured by rigorous QA	Both operational and post-closure safety are assured by QA procedures which ensure that materials and operations conform to tightly defined specifications
3	The repository can be developed with acceptable use of resources	Manpower and financial resources needed should be appropriate to the national significance of the project
1	NUMO is credible as an implementing organisation	Active establishment of national and international reputation and rigorous plans for developing internal competence in key areas
2	Staged project implementation	Stepwise site selection and licensing with full reversibility of decisions and evolving programme focus as specified by Structuring factors
2	Active support of host communities	Active and comprehensive programme developing dialogue to encourage full participation in key decision-making processes
2	Well-structured and transparent programme	Incorporated in the NSA and overviewed in this report
3	Criteria for decision-making are open and transparent	Publication of Siting factors, Design factors, etc. in advance of key milestones
3	Clear ranking of options	Use of established MAA and ESL methodology
3	Open decision-making process	NUMO's RMS allows efficient and open documentation of decision-making
3	Clear procedure for responding to surprises	Key advantage explicitly provided by the NSA

EBS – engineered barrier system
MAA – Multi-Attribute Analysis
NSA –NUMO structured approach
RMS – requirement management system
ESL – Evidential Support Logic
NBS – natural barrier system
QA – quality assurance
RN – radionuclide