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# **A Challenge on Development of an Advanced Knowledge Management System (KMS) for Radioactive Waste Disposal: Moving from Theory to Practice**

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## **1. Introduction**

In recent years there has been much discussion on the topic of knowledge management in many areas of nuclear science, particularly associated with the nuclear renaissance and the evident shortage of skilled manpower (e.g. Yanev, 2008). More generally, however, the exponentially expanding capacity of computer systems parallels an explosion in the documentation and databases supporting nuclear projects. This is nowhere more evident than in the field of radioactive waste management, characterised, as it is, by the extremely wide range of disciplines involved and very long project timescales (e.g. Kawata et al., 2006; Umeki et al., 2008; Umeki et al., 2009).

Although this may not yet be universally accepted, there is increasing evidence that the rapid rate of growth of material supporting complex technical projects – which we will term ‘knowledge’ – is rapidly reaching, if not passing, the point where conventional management systems show signs of collapse. Although tried and tested over millennia, the type of Knowledge Management System (KMS) developed to handle written documents is proving inherently incapable of being simply modified to cope with the present flood of electronic material. Although Moore’s Law of expansion of data transfer speeds and storage capacity means that some of the simpler tasks involving document collation and archiving can be handled, there has been little progress in addressing the more difficult problems of how the huge volumes of documentation being produced can be critically reviewed/quality assured, synthesised, integrated and communicated to all the interested stakeholders in a form that they can understand.

A common blockage to progress is that, while many of the component problems (symptoms) may be acknowledged, it is not easy for organisations to perceive the magnitude of the approaching catastrophic system collapse and hence to implement the paradigm shift needed to introduce effective solutions. Indeed, it is a classic Catch-22 situation: the breakdown of conventional approaches means that those involved lack the overview required to see that their KMS is becoming increasingly dysfunctional.

The exponential growth in the knowledge base for radioactive waste management is a cause for concern in many national programmes. In the Japanese radioactive waste disposal field,

the problems of information overload were recognised during a comprehensive assessment of High-Level Waste (HLW) disposal feasibility at the turn of the century (JNC, 2000). This problem is exacerbated by a Japanese volunteering approach to siting of a deep geological repository, which requires particular flexibility in the tailoring of site characterization plans, repository concepts and associated Performance Assessments (PAs). Recognition of this situation led, in 2005, to initiation by Japan Atomic Energy Agency (JAEA) of an ambitious project to develop an advanced KMS aimed to facilitate its role as the supplier of background R&D support to both regulators and implementers of geological disposal.

The chapter introduces the background to this initiative and the basic approach selected, and then review progress to date in this work, with emphasis on tailoring of existing Knowledge Engineering tools and methods to radioactive waste management requirements, and outline future developments and challenges (Umeki et al., 2009; Osawa et al., 2009b; Semba et al., 2009; Makino et al., 2009a; Makino et al., 2011).

## 2. Approach and features of the JAEA KMS

Recognition of the importance of knowledge management by JAEA led to establishment of a new Knowledge Office with the remit to develop and implement an advanced KMS tailored to the requirements of the Japanese geological disposal programme. This programme is coordinated with initiatives led by the responsible Government department 'ANRE' (Agency of Natural Resources and Energy) of METI (Ministry of Economy, Trade and Industry) and will, eventually, be formally linked to other relevant organisations in Japan that may be either producers or users of knowledge. Within JAEA, the Knowledge Office not only develops the new tools and organisational structures required to implement the KMS, but also provides executive support for synthetic analysis and evaluation of knowledge (including meta-analysis and top-level quality management).

It is important to emphasise here the particular boundary conditions for this KMS. At the most fundamental level, JAEA is charged with providing scientific and technical support to both implementing and regulatory organisations and also interested stakeholders – including the general public. This requires that all parties recognise JAEA to be a competent and unbiased organisation and that the KMS incorporates a rigorous Quality Management System (QMS) that is accepted by all.

For geological disposal in Japan, the implementer 'NUMO' (Nuclear Waste Management Organisation of Japan) has selected a volunteering approach for initiation of the siting process, which introduces technical challenges in terms of assuring flexibility of site characterisation planning, repository concept development and associated PA (e.g. Kitayama et al., 2005). Additionally, attracting volunteers and developing dialogue with local communities involve challenges in public communication.

On the regulatory side, development of guidelines and licensing procedures for deep geological repositories is ongoing, but one clear aim is to maximise consistency with already established regulations for near surface disposal facilities for lower level radioactive waste (NSC, 2004). This is complicated in Japan due to its location on an Island Arc, with its associated high tectonic activity and geological complexity (e.g. Apted et al., 2004).

Although current emphasis is on existing inventories of radioactive waste, the Japanese long-term commitment to nuclear power and a reference development programme over the next 100 years has to be considered in order to develop a consistent and compatible long-term waste management programme (Makino et al., 2009b). In addition, various types of

waste caused by Fukushima Dai-ichi accident occurred in 2011 will become significant subject to the Japanese waste management programme.

Taken together, these constraints on the KMS lead to a requirement for a holistic approach that will form the core of a programme to be implemented over a period extending beyond the 21st century. Clearly, major developments in technology are to be expected over this period, although these are inherently unpredictable in detail. Emphasis is thus placed on development of a fundamental KMS concept that will evolve in line with advancing technology, supported by tools and approaches that are, to the maximum extent possible, scale and platform independent.

The overall structure and key components of the KMS are illustrated in Figure 1. It should be noted that the remit of the Knowledge Office is very wide and the KMS thus includes all aspects of tacit knowledge management (e.g. focused training and experience transfer schemes – often denoted as human resource management), focused quality management (discussed in more detail below) and anticipation of technology developments and future requirements (e.g. using a think tank approach – elsewhere often part of strategic planning or requirements management). Therefore, the combination of the challenging boundary conditions and wide remit led to the decision to establish a support team (Knowledge Office) composed of staff with wide experience of radioactive waste management, and knowledge engineering, who can tailor established methodology and tools effectively and efficiently to the various requirements needed for development of the KMS. In retrospect, this strategic decision probably contributed significantly to the successes achieved to date.

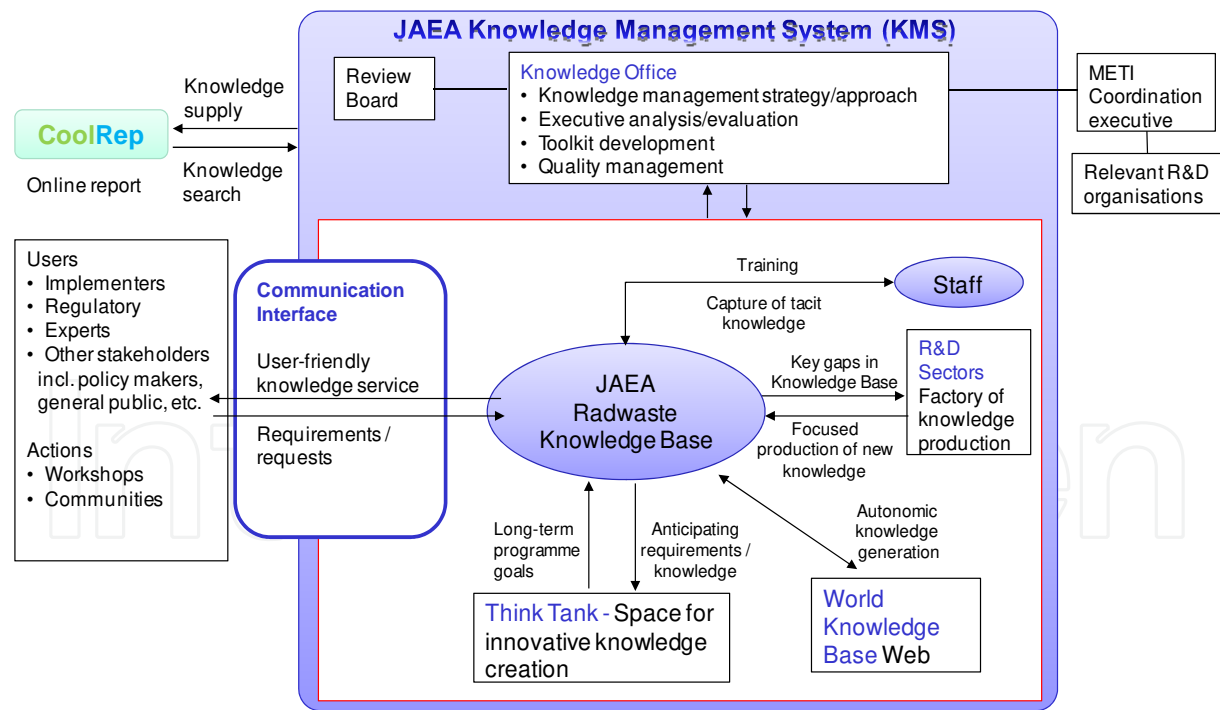


Fig. 1. Outline KMS concept: Structure and key elements

The various different types of knowledge involved and the management functions required are summarised in Table 1. This table also notes which functions have the potential to be, at least partially, automated or facilitated using advanced knowledge engineering tools. Automation and/or computer support of knowledge management functions is a key to

implementation of this novel approach – providing the potential to respond to the exponentially increasing rate of information production, but also giving the greatest challenge to the Knowledge Office team. The essence of what is aimed for has been summarised as an ‘intelligent assistant’ – an electronic toolkit that allows project leaders and coordinators to manage the huge fluxes of data that they have to control and to efficiently use their time by carrying out only the weighting and top-level synthesis and decision making that cannot be automated.

Form of knowledge	Management functions	Content	Planned/ongoing developments*
Data	Data management	- raw data (internal) - solicited data (external) - processed data	- <b>robust archive</b> - <b>internal and external data mining</b> - <b>autonomic data processing</b> - <b>autonomic QA</b> - <b>formal approaches for QA</b>
Documents	Document management	- internal documents - key external documents	- <b>robust archive</b> - <b>autonomic QA/cataloguing/cross-referencing</b>
Software	Software management	- archive of all relevant codes/databases - archive of manuals and handbooks - archive of relevant input/output	- <b>robust archive</b> - <b>autonomic change management</b> - <b>formal approaches for QA</b>
Experience and methodology	Resource management	- procedure manuals and guidebooks - expert systems - training materials	- <b>use of expert systems to capture and transfer tacit knowledge</b> - <b>advanced training and experience transfer</b>
Synthesis	Knowledge integration	- experienced synthesis team - expert systems	- <b>formal description of key integration processes</b> - <b>formal approach for QA</b>
Guidance	Knowledge coordination	- experienced coordination team	- <b>prediction of requirements (Think Tank)</b> - <b>process for filling key gaps in knowledge</b>
Presentation	User/producer dialogue	- user friendly interfaces (interactive – allowing dialogue)	- <b>high-end graphical methods for presenting complex information</b>

Note: \*Of the required developments, those highlighted in bold text may be supported by advanced IT/KE technology

Table 1. Typical contents and structure of a KMS based on initial studies carried out by JAEA

A key component of the KMS is the JAEA Radwaste Knowledge Base (KB). This is a dynamic entity, which will be constantly supplemented by new input – through focused production by Japanese (or international partner) R&D programmes or autonomically generated by directed searches of the internet. Unlike traditional databases, there is no imposed structure on the KB: it is simply an electronic library of all relevant information and documentation that is applicable to specific radioactive waste applications. It will be used to generate application-specific sub-databases, which are frozen and archived as required to ensure transparent documentation of the background to all major project milestones or decisions that utilise this KB. Utilisation of the KB will be facilitated by a user-friendly interface that allows the mode of access and the form and technical level of output to be tailored to the needs of different knowledge users.

The information explosion noted in the introduction is the key problem when considering how the KB will be utilised by the main user organisations such as implementer and regulator. Although huge volumes of material are already available and very much more will be generated in coming decades, much of this is (or will become) irrelevant for actual implementation or regulation of a repository project. A strict filtering process to develop application-specific subsets of the KB is thus essential for practical use – and also to develop a unified approach to quality management.

The process of developing a project-specific KB from the requirements specified by end users is illustrated in Figure 2 (Umeki et al., 2009; Umeki et al., 2010). Ideally, this would be facilitated with a direct interface to a formal Requirements Management System (RMS),

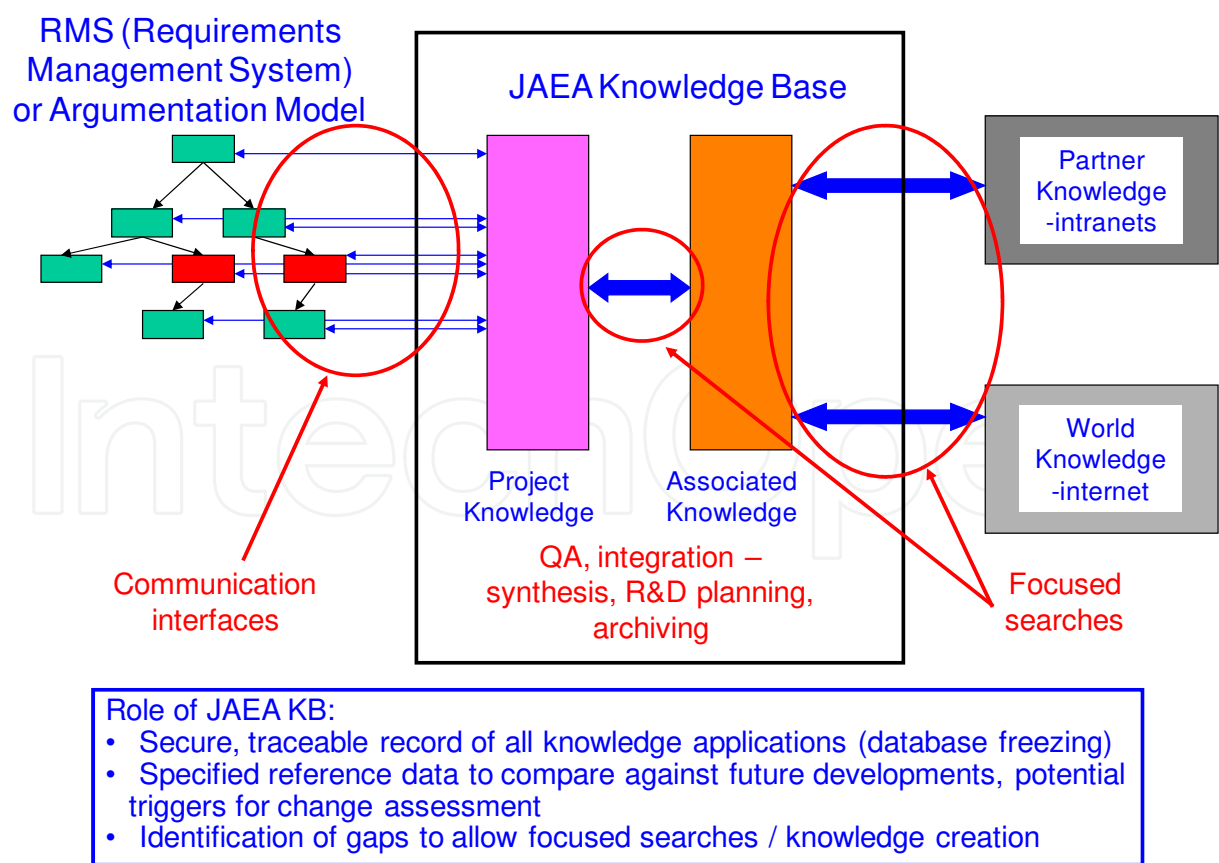


Fig. 2. The knowledge base and its interfaces to users and knowledge resources



which provides a hierarchy of project needs, identifies potential conflicts and establishes priorities or weightings (possibly as a function of programme progress). Although requirements management is recognised to be essential by NUMO and a formal system is under development (NUMO, 2007), it is not yet operational. To initiate work in the absence of clearly defined requirements, therefore, a prototype project-specific KB is being developed using a basic structure of a geological repository safety case, which will certainly be a key requirement for the implementer and a focus of programme review by the regulators (JNC, 2005; Umeki et al., 2008). In this context, the safety case can be clearly a common frame for R&D activities carried out in all relevant organisations. The safety case is also of great interest for all stakeholders.

A safety case is an extremely complex synthesis of a vast array of different information. Although this is supported by much of the technical work carried out by JAEA and other R&D organisations, development of the safety case is actually carried out by NUMO and reviewed by the regulators. To make the benefits of this advanced KMS by JAEA apparent to all relevant parties, it is important that it eases the work of specialists by highlighting the relevance of their research to the safety case and simplifying the processes of accessing relevant literature, synthesising data, producing and reviewing documentation and communicating their results to interested parties (see Section 3). Here argumentation modelling mentioned in Section 3.1 have played an additional key role of overviewing the essence of the safety case in an easily understandable manner.

### **3. Tools developed in the JAEA KMS project**

This section will discuss about development and application of tools comprising the JAEA KMS with practical examples.

#### **3.1 Argumentation modelling**

The safety case can be seen as the top-level goal of all works carried out within a geological disposal project. Knowledge can be classified in terms of its role in the safety case and prioritised in terms of its impact on overall safety case argumentation (Figure 3). The resultant argumentation model can be developed in a top-down manner, highlighting the constraints on decisions set by upper level requirements and the consequences of decisions on all interlinked topics.

Argumentation modelling is a well-established tool in Knowledge Engineering (e.g. Kirschner et al., 2003) and can be implemented in a number of different ways. In all cases, an initial claim is analysed to determine possible counter-arguments which are, in turn, analysed to identify supporting arguments that counter these. The process iterates until unambiguous hard evidence is provided or an open question is identified. Although such processes are well established in areas such as philosophy and law, they are less often used in technical fields. Nevertheless, experiences to date within the JAEA KMS project have shown that this approach is well suited to breaking down complex multidisciplinary problems in radioactive waste management.

Use of an argumentation model to represent key components of a safety case has certain advantages:

- The starting point of the argumentation model is a clear claim in natural language; this could be, at the top level, "The safety case justifies proceeding with the repository project

- at a particular programme milestone" or, at a lower level, "a particular system component contributes to the safety case". This puts any lower level input clearly into context.
- The initial claim must be supported by arguments, which can be usefully classified into different types. At present, different classes of arguments are used: these range from consideration of "hard" laws of science or defined exclusion criteria to "softer" assessments of common understanding and requirements for public acceptance.
  - Some, or all, of the arguments may give rise to counter arguments. The advantage of classifying the arguments is that particular classes of supporting argument lead naturally to counters. For example, in the case of "Argumentation based on analogy", some of the critical questions that might be considered would be the possible extent of any sampling bias or the potential existence of analogue counterexamples.
  - These counter arguments then lead to further supporting arguments, generally going into further technical detail, with links wherever appropriate to the supporting knowledge base. This is continued until the case is considered to be sufficient – which inevitably involves expert judgment. In practice, especially early in a programme, it may not be possible to develop a complete argument – some aspects must be covered by assumptions or result in open questions. These can be highlighted and used to focus and set priorities for associated R&D.

The formalised method involves classification of arguments, which allows the relative strength of associated evidence to be assessed (e.g. arguments based on scientific laws vs. those based on empirical data) and also allows associated typical 'critical questions' to be reviewed to check if the argumentation model is complete (Figure 4). Inevitably, argumentation models become increasingly complex as they go into finer technical detail and rapidly lead to cross-linking between different sub-systems. To manage the network, software tools are essential and after a number of existing packages were examined, a tailored argumentation model editor called Scarab (Supporting tool for Constructing ARgumentation models with Associated knowledge-Base) has been developed (Osawa et al., 2009b). Figure 5 shows an example of screenshots of the argumentation model editor.

Additional functions of Scarab include:

- a. Storing existing argumentation models in a case-base, allowing users to key-word search cases similar to the one at hand;
- b. Storing base information of arguments which is called knowledge note (Figure 6);
- c. Recording all the revisions made to each argumentation model, with comments explaining the reason for changes;
- d. Supporting discovery of new counter-arguments by using "deep" knowledge of the safety case structure;
- e. Link with group-ware that provides a collaborative internet working environment;

Finally, it should be mentioned that an even simpler form of argumentation modelling has proven useful in developing new communication methods, particularly aimed at non-technical (or, at least, non-expert) audiences. Here the argumentation model is developed not as a network as shown in Figure 4, but in the form of a dialogue between cartoon characters. Such presentation is very familiar in Japan and this option will be implemented in both static (*manga*) and animated (*anime*) forms. In addition, presentation form like common FAQ might be necessary for understanding of citizens.



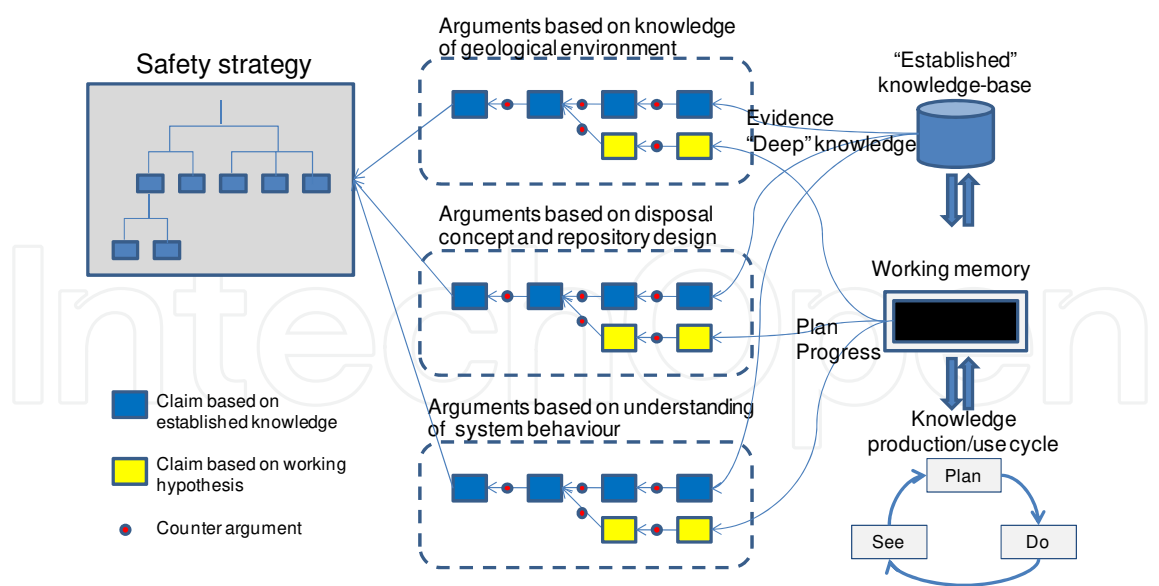


Fig. 3. Role of argumentation models in developing the safety case knowledge base

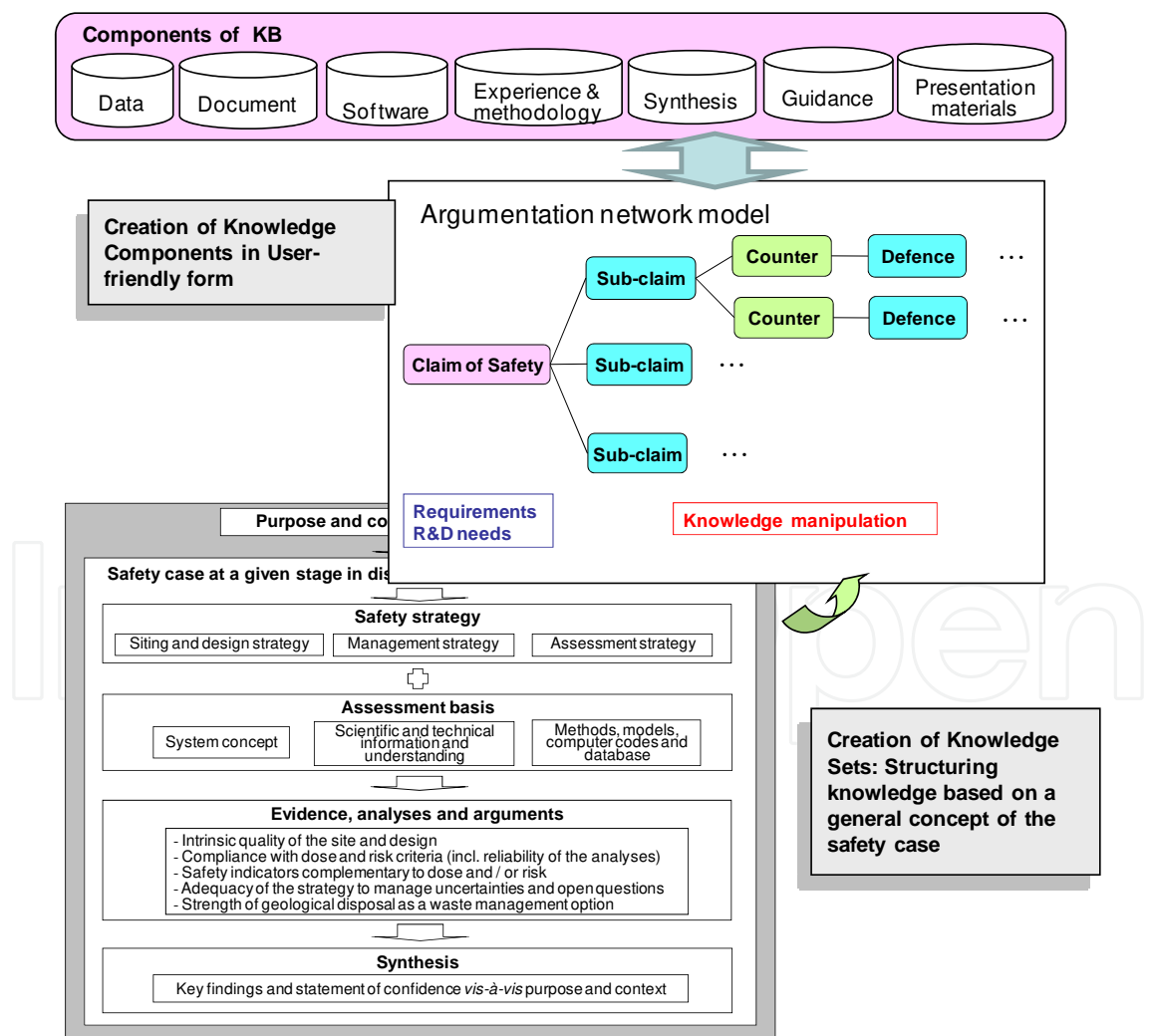


Fig. 4. Representing the safety case as an argumentation model in order to structure the KB

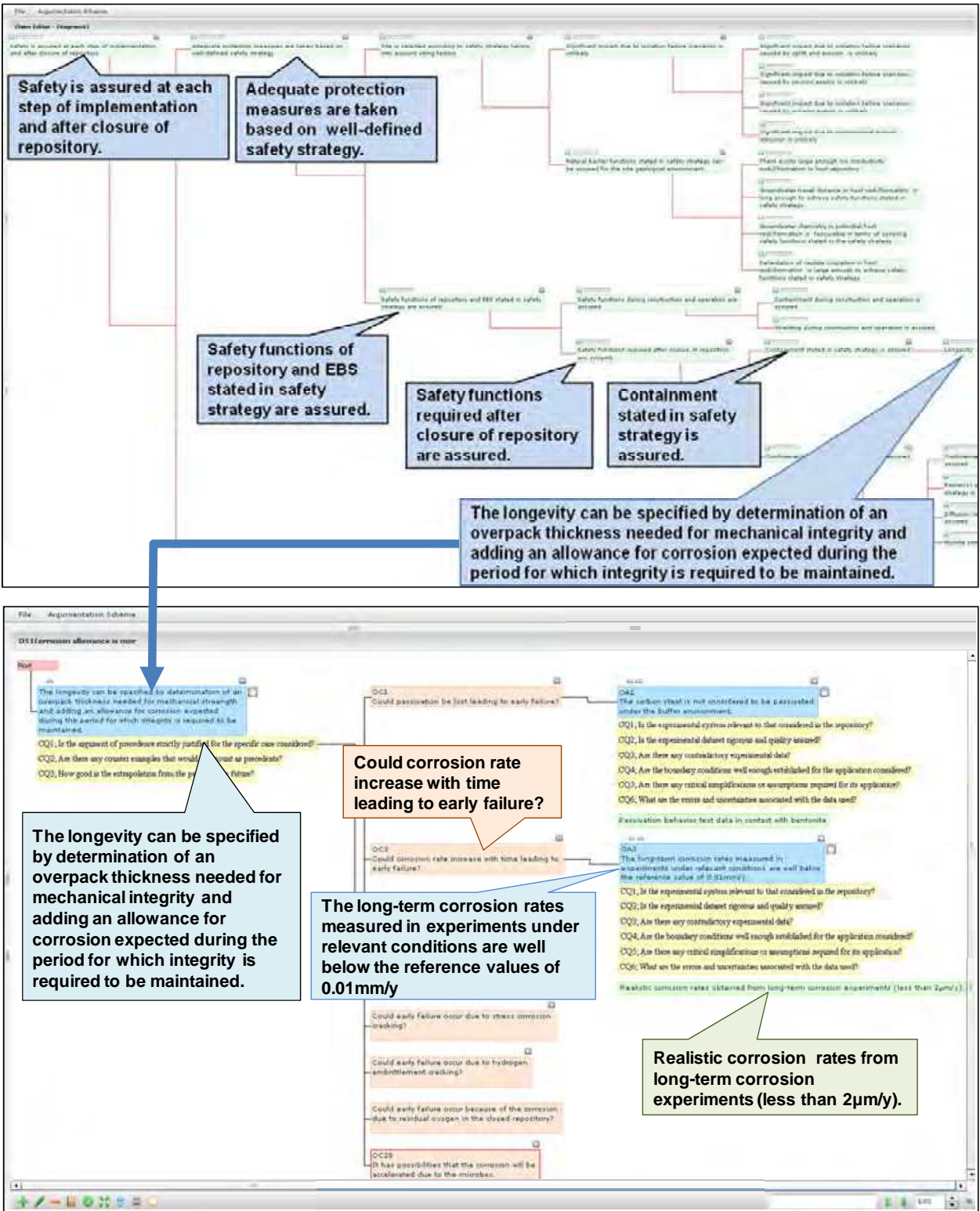


Fig. 5. Screenshots of the argumentation model editor (Scarab)



data handling that may be easily automated, much of it requires input of "tacit knowledge" (Nonaka & Takeuchi, 1995; IAEA, 2005), which involves the experience of expert staff. In particular, planning and managing the characterisation programme results in challenges, due to the inherent uncertainty in site understanding and the inevitable surprises that will occur.

To provide support for NUMO, which may need to run several field programmes in parallel - and also the regulator, which is expected to follow these and provide input for key decisions - JAEA is attempting to capture both Japanese and international geosynthesis experience within a KMS component, termed the Information Synthesis and Interpretation System (ISIS) (Osawa et al., 2009a; Semba et al., 2009).

ISIS is being developed by applying advanced electronic information technology and knowledge engineering approaches; it will include an extensive knowledge base, expert systems utilising an inference engine and an archive for rule-based and/or case-based reasoning as major constituent elements (Figure 7).

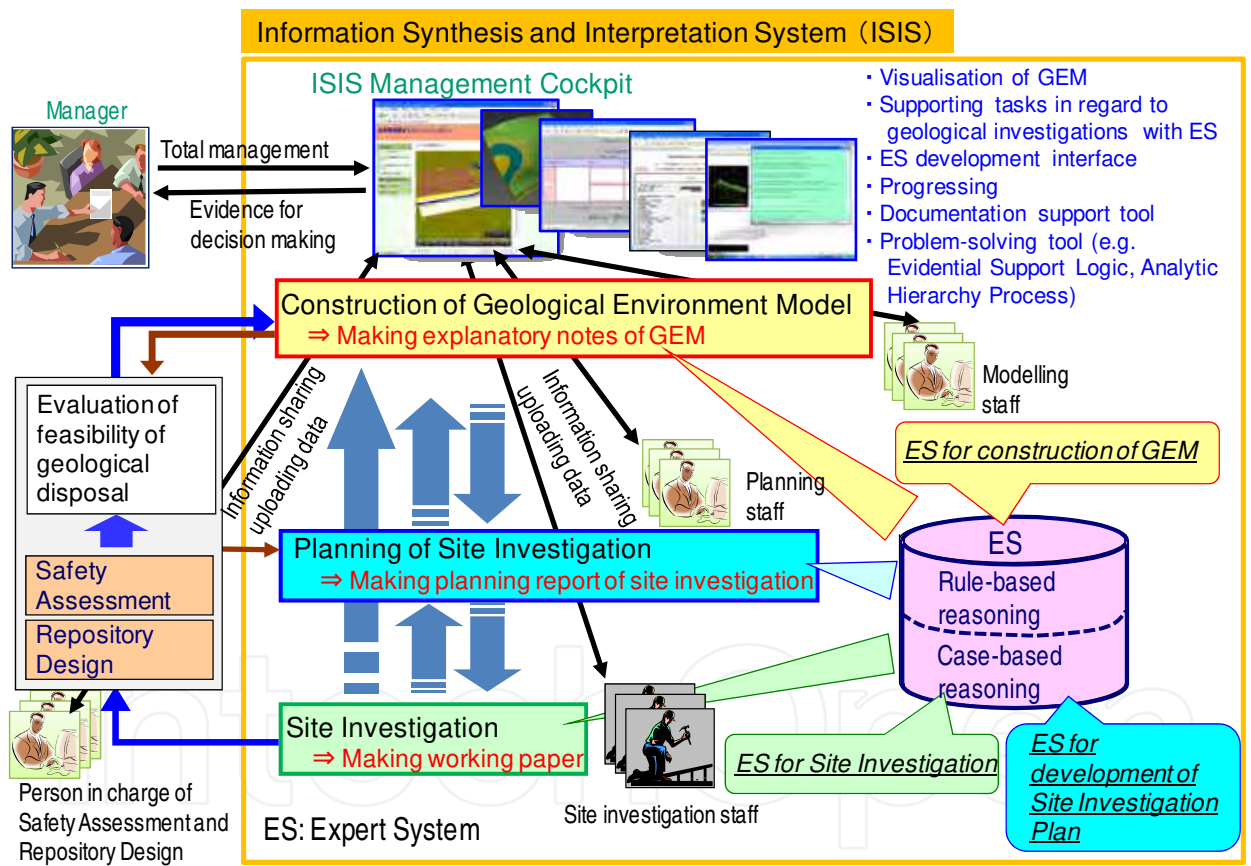


Fig. 7. Basic concept of ISIS

Although the Japanese knowledge base will need to be complemented by input from international partner programmes with wider practical experience, all indications to date suggest that development of such an intelligent system is feasible with existing technology. Based on the requirements and goals specified above, ISIS has investigated implementation of the following tools:

1. Expert system (ES) development tools: particularly focused on capturing tacit knowledge using rule-based or case-based approaches.



2. Management cockpit: integration of ISIS tools and communication tool.
3. Problem-solving methodology: formal approach for identifying and resolving conflicting requirements.

The first stage of ES development involves a formal process of knowledge acquisition. This can be illustrated as a detailed task flow diagram resulting from expert elicitation. An example is shown in Figure 8, which shows the sequence of tasks for establishing on-land seismic reflection surveys resulting from interviews with experts.

The next stage involves knowledge modelling; carrying out syntax analysis of the component rules and cases (Figure 9a). This allows representation of knowledge in a form that is accessible to methods from the field of knowledge engineering.

The final stage is creation of the operational ES; this involves establishing a user interface based on established templates (Figure 9b) and formulating knowledge elements as a menu, based on the results of the syntax analysis. The interface is used to create the rule-based and case-based procedures, by selecting appropriate knowledge elements and syntax. A knowledge engineering tool then produces the ES automatically, based on this formalised input.

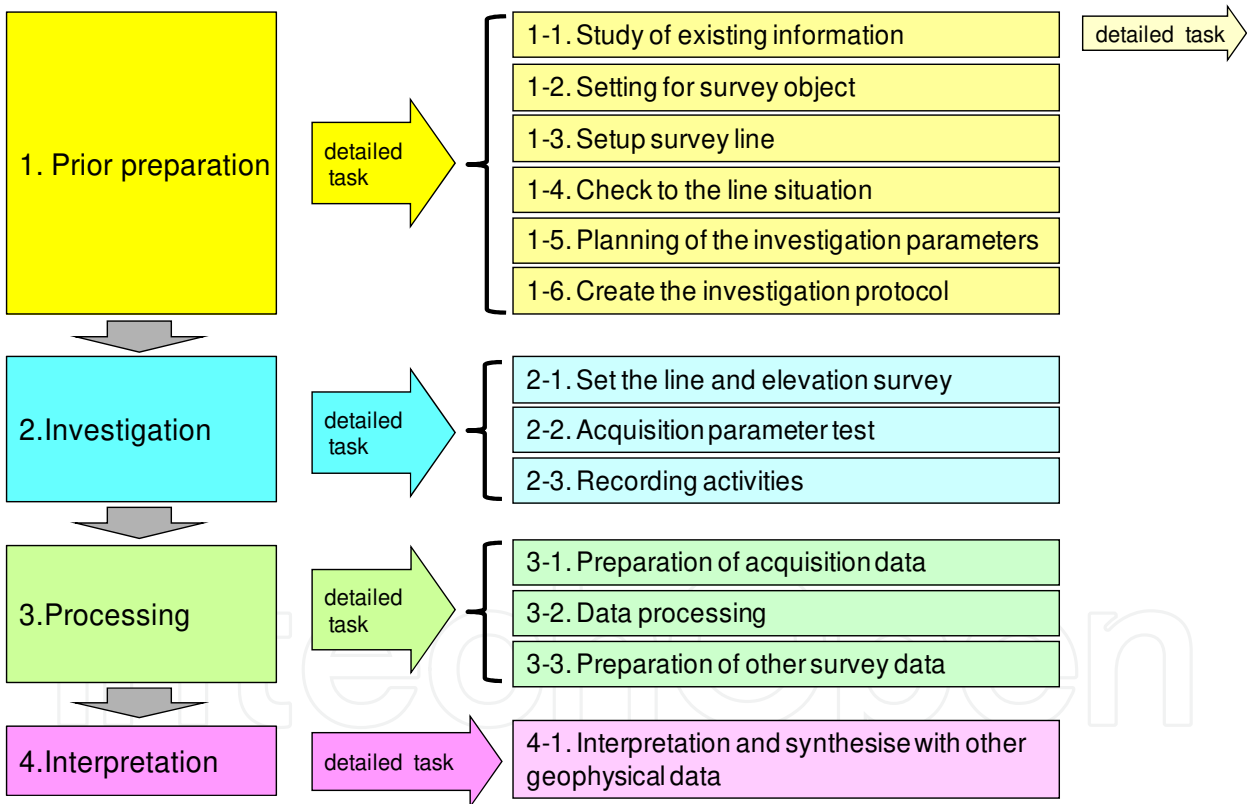


Fig. 8. An example of flow of elicitation of task knowledge

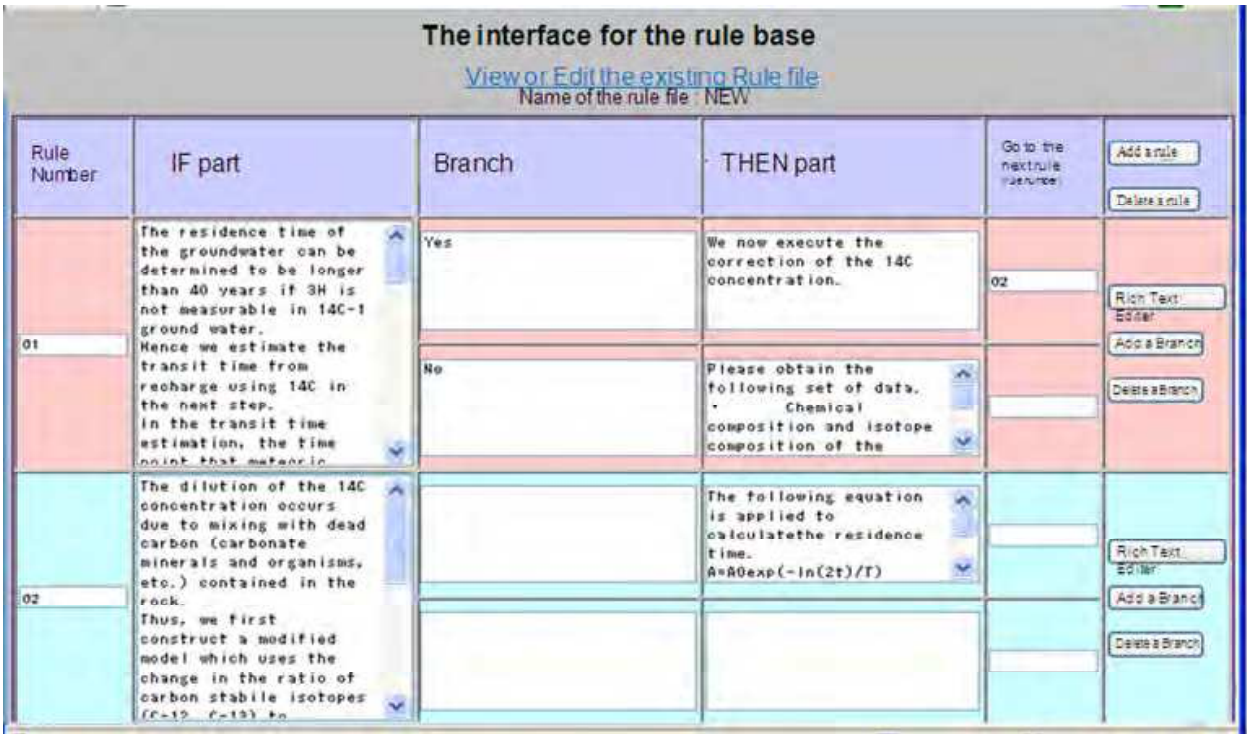
3.3 Support tool/method for performance assessment

Regarding total system performance assessment, it was recognised that routine tasks in PA, e.g. development of input datasets, groundwater flow and transport modelling, interpretation of model output, integration within a total system PA, etc., are repeated many times. This may occur whenever there are changes in assessment scenarios, geological environment models, repository design, relevant databases, etc. Introduction of advanced



Rule-base	Decision-making rules within tasks of site investigation, represented using IF...THEN format	e.g. Selection of drilling methods <div><div>If full core recovery needed</div><div>YES</div><div>Then a wireline drilling method should be selected</div><div>NO</div><div>then a non-core drilling method should be selected (tricon bit etc.)</div></div>
Case-base	Cases how a problem in site investigation was solved in the past, to suggest ways to handle similar problems in the future	e.g. Troubleshooting of drilling fluid loss

a. Identification of relevant knowledge elements



b. ES development interface for the rule-base

Fig. 9. Knowledge modelling and ES development

knowledge management technologies and tools should increase efficiency, traceability, transparency and repeatability of such PA tasks (Makino et al, 2009a). They will also ease the process of auditing contents of PA and support QA of the input, analytical methodology and resulting output.

The overall toolkit under development is termed PAIRS (Performance Assessment Integrated Report System) (Figure 10). A significant feature of the PAIRS is that this comprises a linked set of not only text, tables and figures corresponding to conventional PA report but also applications that have been used through PA tasks. The key components of this system are as follows:

- Electronic Performance Assessment Report (e-PAR): the electronic report developed with support of PAIRS, which contains a core of quality-assured text, tables and figures linked to calculation by encapsulated tasks for a specific dataset (e-PAR case-base means a library of developed e-PARs)
- Operator: an encapsulated application library that includes numerical tools and assessment softwares used for certain tasks in a user friendly form
- User interface: an intelligent user interface facilitates reconfiguring the input dataset and encapsulated tasks, management of calculations and then editing the resultant output to create/modify contents of e-PAR; this will be supported by change management tool to provide a top-level overview of all changes implemented, their justification and their consequences in terms of overall performance
- Application knowledge base: a central library of all PA data (both raw and derived) together with all relevant information supporting their selection and application, together with an associated historical record of all changes and modifications.

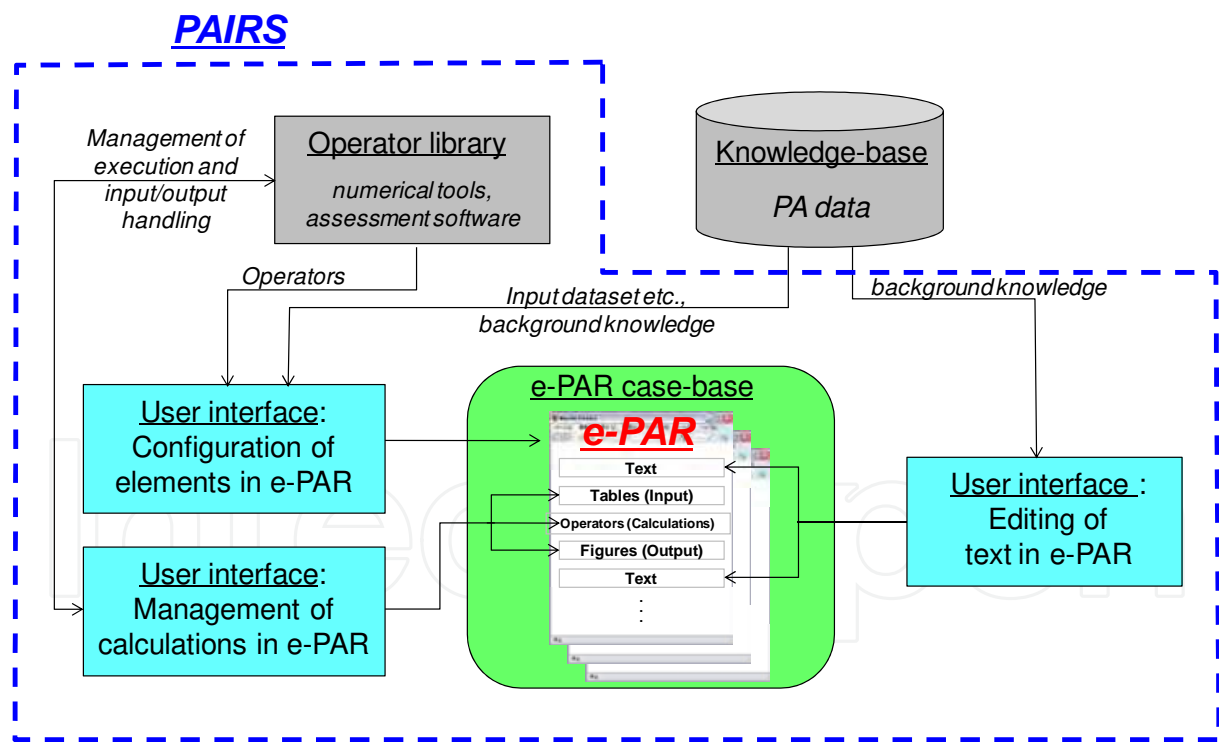


Fig. 10. Schematic overview of PAIRS and component tools

Figure 11 shows an example of e-PAR and outline of operation on e-PAR (browse, edit and reanalysis). Functions of operator library and calculation management on e-PAR are currently being tested with an existing post-closure PA code (for example, a code based on GoldSim (Golder Associates, 2001)), but will be flexible enough to incorporate other existing codes and next generation models/databases when they arise.

- Main features and advantages of e-PAR in practical viewpoints are:
- Easy access and operation with browser
  - Easy execution of PA tasks in an easy and understandable operation, which allow application of PA tools by non-PA experts and expedite communication among different disciplines
  - Storing context and procedure of PA tasks with all relevant data, information and knowledge (both domain knowledge and task knowledge) in an easily accessible format
  - Recording all the changes in a systematic manner for future reference
  - Dynamic, interactive and user-friendly, while a conventional paper/electronic report is static, one-way and, to some extent, user-unfriendly.

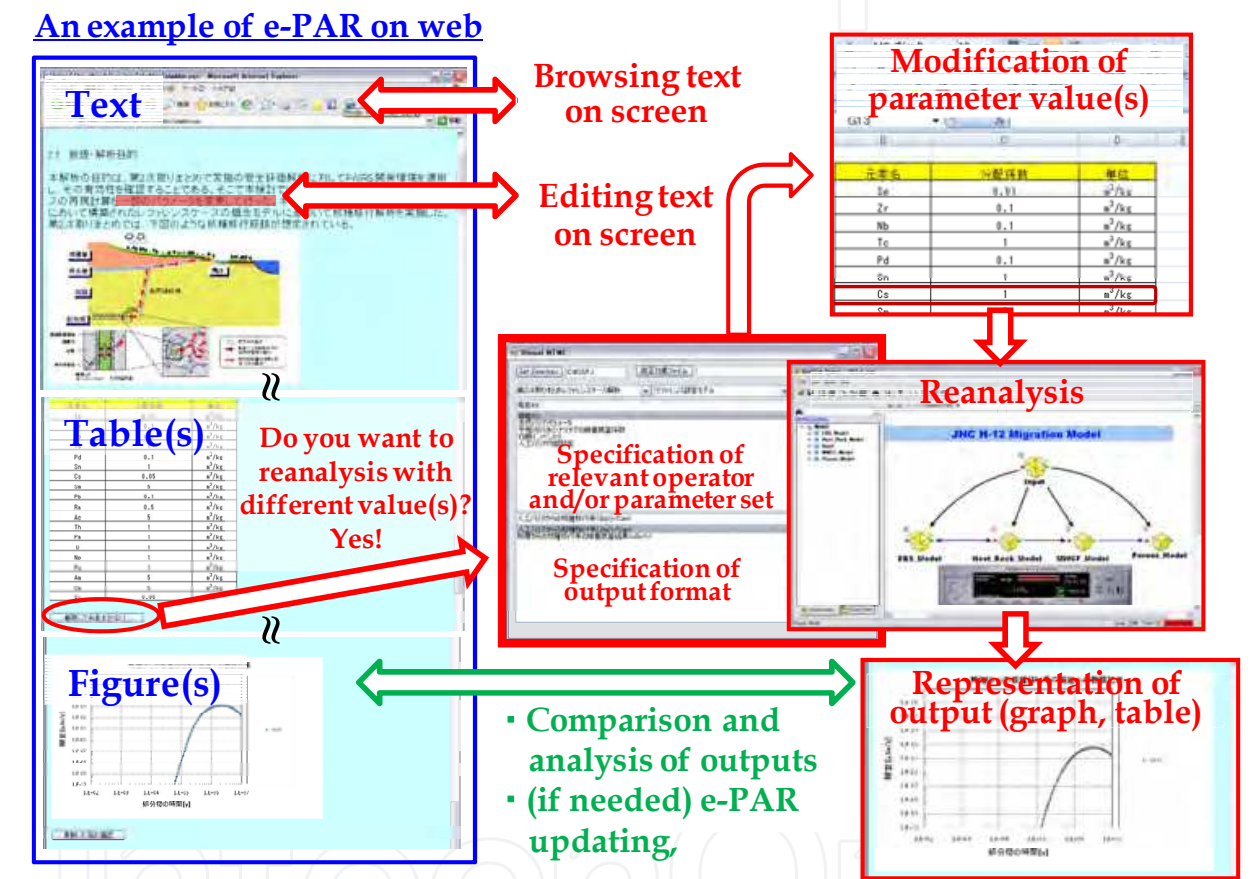


Fig. 11. Flow of functions and operations on e-PAR (browsing, editing and reanalysis)

**3.4 CoolRep**

As indicated in Figure 12, at a top hierarchical level the key tools utilised are, in addition to Scarab for argumentation model development, CoolRep and a smart search engine.

‘CoolRep’ is an advanced, internet-based approach to management of documentation and providing an interface with users – both technical and non-technical. It allows the vast volumes of relevant information to be presented in a user-friendly manner, with different access options for different stakeholder groups. Since March 2010, the CoolRep 2010 version in Japanese language is available (<http://kms1.jaea.go.jp/CoolRep/>) and demonstrates the capability of JAEA (in the future, together with other Japanese R&D organisations) to support production and review of safety cases for deep geological disposal (Figure 12). An

English version is under development. Here, the name ‘CoolRep’ was chosen for this environment friendly option that minimises the use of hard copy, which was developed on the basis of lateral thinking by analogy to the CoolBiz campaign in Japan ([http://en.wikipedia.org/wiki/Cool\\_Biz\\_campaign](http://en.wikipedia.org/wiki/Cool_Biz_campaign)).

The CoolRep is produced entirely in electronic form and is provided on the internet in the form of a short, easily readable overview (2010 Japanese version is equivalent to around 75 pages) with extensive hyperlinks to:

- support text providing more detailed technical input of major technical components (termed KERNELs – Knowledge Elements incorporating Requirements, Novelty, Experience and Limitations)
- both the generic, overall safety case structure and the component KERNELs in the form of argumentation models
- further nested hyperlinks in both text and argumentation models that provide more technical detail, including ultimately full text of key references
- provide access to other knowledge management tools and knowledge base
- visual support material, including graphics, videos and animations
- all review and QA records
- provide access to relevant external websites.

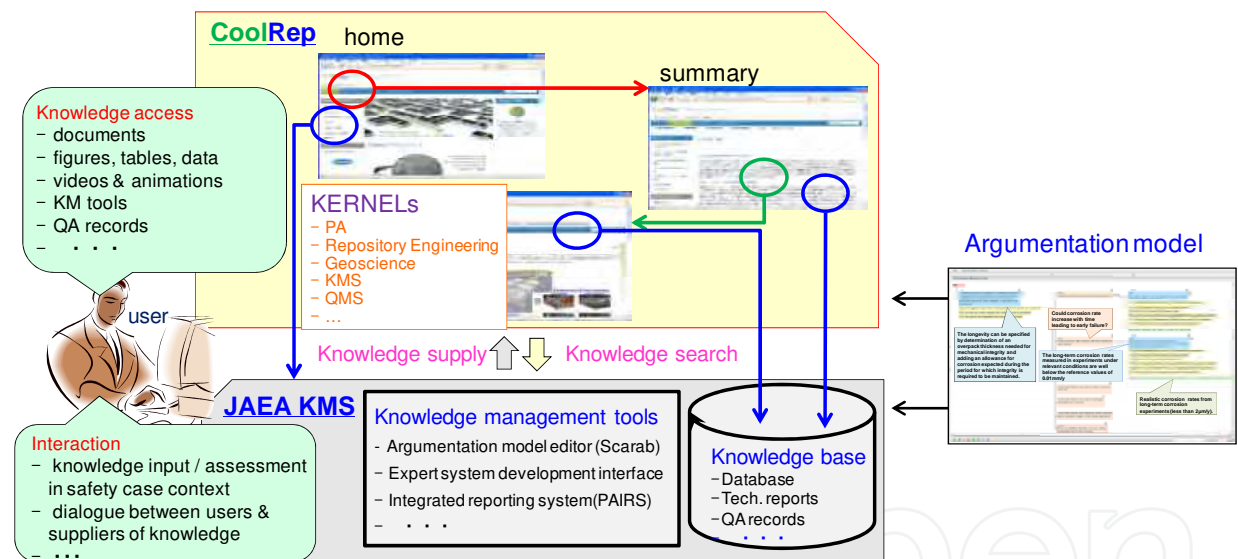


Fig. 12. Links between CoolRep, the JAEA KMS and argumentation models

The advantages of this approach include:

- The overview can focus on logical presentation of the safety case; technical support information is accessed directly when desired, rather than either clogging development of argumentation model with superficial detail or being isolated in abstruse specialist reports
- Technical depth can be increased to the level desired by the user via the nested hyperlinks
- Wherever relevant, contained material is reviewed via a rigorous internal quality management system: comprehensive quality records (review comments, author responses, issue resolution forms) can be viewed by direct links



- During production, a single read-only master exists containing the accepted version; amendments of components may be produced in parallel, but contain digital signatures of the authors and are opened officially only after acceptance and digital signature of the report coordinator (assures implementation of the QMS and prevents different versions of information and data being used by different groups).

So far, not all functions are fully implemented – but sufficient test cases are available to assure fundamental applicability of this tool.

As noted previously, transparent quality management is particularly important for the JAEA knowledge base. Even though guidelines are not yet agreed by all stakeholders, a demonstration of QA review for some text in CoolRep 2010 version and supporting kernels has been implemented. A further contribution to technical QA is the capability to solicit feedback from users. Such feedback can, in addition, be used to improve the structuring of information and the presentation software and play an important role in establishing dialogue with users, which includes the implementer, regulators, involved researchers, academics and the general public. CoolRep provides a portal that not only gives technical users access to KM tools and the KB, but also includes demonstration cases and user manuals (both conventional and video format).

In terms of the tools shown in Figure 12, progress has been slowest on smart search engine development. This is because an early decision to develop new software can be seen in retrospect to have been made without realisation of the extremely rapid rate of progress in this field. The effort is now focused on tailoring existing tools to the particular requirements of the JAEA KMS. In order to use smart search engines, it is critical to establish a clear vocabulary or taxonomy for the complex and multidisciplinary waste disposal field, in order to allow structured contextual searches that go beyond simple keywords. Much of the ongoing development in this area involves some form of semantic analysis, which has been claimed to be the key to 'next generation' knowledge management (e.g. Kawata et al., 2006; Umeki, 2007; Umeki et al., 2008). In order to form the basis to test such approaches, efforts have first concentrated on definition of clear ontology and examination of approaches to 'ontology cleaning' that have been used in other areas (e.g. Borrego-Díaz and Chávez-González, 2006).

#### 4. Discussion and conclusion

The structured approach to initiating the development of a new KMS seems to be paying off – tools and methodology have been seen to be applicable to a wide range of JAEA activities for deep geological disposal of radioactive waste and provide a better overview of context that was previously available. The need for a major change in approach of the JAEA activities to introduce KMS concept, processes and technologies/tools is now widely accepted by senior managers and younger staff, in particular, has provided positive feedback to the initiatives investigated. Nevertheless, in some critical areas – especially associated with the development of smart search engines – progress has been limited to defining project specifications and a key challenge will be assembling the support team to carry out the required software tailoring work. Probably most promising is the observation that, even at an early stage, the tools used provide hints of how increasing numbers of knowledge management functions can be automated, which will be a key to any next generation system.



So far, progress on the knowledge communication side has been focused on CoolRep and the range of concepts and proposals implemented within this platform, utilising the concept of cultivating communities of practice (e.g. Wenger et al., 2002).

Further development here will, however, be one of the main focuses of work in the coming years as the Japanese geological disposal programme moves closer to site-specific work. It is also applicable to implement disposal of many types of radioactive waste generated by the accident of the Fukushima Dai-ichi nuclear power station. There is no doubt that the envisaged system is at (or even beyond) the limits of what is feasible with existing technology. Nevertheless, this is an extremely dynamic and fast-moving field and there seem to be good chances that all defined goals can be met.

The works will be very challenging but, as the fundamental requirement for a 21st century approach to the management of knowledge becomes more widely accepted, the opportunities to share the load in collaborative projects will expand. Certainly, JAEA will work closely with other relevant organisations in Japan that are producers and/or users of knowledge, but extended cooperation with international partners is also a high priority goal for the near future.

## 5. Acknowledgment

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