The Role of Context in Sustaining Knowledge of Radioactive Waste

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In March 2002 the International Atomic Energy Agency (IAEA) held a meeting of people from outside nuclear industry to examine issues surrounding the preservation and transfer to future generations of information important to the safety of radioactive waste disposal. Although this problem had been identified by the industry much earlier, they found that their thinking about the issues always led to a similar set of intractable problems. Their strategy was, therefore, to look outside the nuclear industry for expertise, new ideas and guidance. Due to my work with science and technology archives I was fortunate to have been chosen to contribute. This paper summarises the outcome of what became a series of meetings over the subsequent four years and draws heavily on the report by the working group published by IAEA under their Safety Report Series. The International Council on Archives have published an electronic edition of the full report in May 2006.[1] This article does not attempt to couch the discussion within the context of recordkeeping and archival literature – indeed, preliminary documents prepared for the IAEA that attempted to convey the concepts presented in this paper in the language of archival profession were deemed too technical.

Introduction

The radioactive waste management community has long acknowledged the imperative to manage accurate and comprehensive information to meet a variety of needs.[2] This information, much of it in the form of records, is recognised as necessary for the management of the waste today, but the community is also aware that some of it will be required to ensure that radioactive waste continues to be safely managed over the long term.[3] In practice, this deceptively simple requirement has been difficult to implement.

The influence of the World Commission on Environment and Development (the Brundtland Commission) of 1987 has been most noticeable in influencing the radioactive waste community in the development of its thinking about these issues under the rubric of socio-technical sustainability. The Commission stated that 'sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs'.[4] This principle underpins the work of the International Atomic Energy Agency in its attempts to help the nuclear industry work towards processes that will effectively manage the safety of radioactive waste both now and in the future.[5] However, the successful transfer of information about radioactive waste to future generations has been problematic in practice, even in the short term, and this indicates that there may not just be pragmatic issues but deeper conceptual issues to be addressed.

Information needs to be preserved in such a way that a future society has the trust to use it with confidence. In other words, the information must be readily comprehensible and pertinent to future audiences and this applies not just to people inside the industry but all others with some sort of interest or concern. However, experience gained thus far in the radioactive waste industry, as well as in the wider community, suggests that many existing systems and practices are ill equipped to meet this challenge. These shortcomings are not just confined to the nuclear industry. During the past thirty or forty years there have been some notable examples of the investment of considerable resources to obtain non-reproducible information (such as space exploration) only to discover years later that it cannot be accessed or used. As might be predicted, failure is not something readily reported in the scientific and professional literature. During the course of the project, the IAEA working group received a number of anecdotal reports of information failures that were not reported publicly but it was these 'stories' that formed the basis of the common knowledge that shaped the thinking of those in the industry. Although insufficient planning for long-term recordkeeping was often identified as a common factor, there appear to be two more general reasons why these failures have occurred:

- Epistemic failure: where there has been inadequate preservation of the knowledge necessary to explain the structure and meaning of information.
- Media redundancy: where physical changes in either the medium or the supporting technology have rendered information unreadable.

It was this first point, epistemic failure, which was targeted at the IAEA consultants meeting held in March 2002 and has since become a subject of ongoing investigation by the IAEA Waste Safety Section.[6] Prior to this time, the primary focus had been on techniques and technologies that would enable records (information) to last for very long periods of time.[7] At one extreme this led to development of laser etched silicon carbide plates that were confidently predicted to last 10 000 years.[8] But this just highlighted the reality of the situation that, using current disposal technologies, high-level radioactive waste from nuclear power stations would not reach its peak release into the environment until 300 000 years after packaging and deep geological disposal.[9] Furthermore, this approach did not address the question of socio-cultural and technological change, which poses a fundamental challenge to the transfer of the meaning embedded in the preserved information. The key issue is the need to sustain knowledge not just of the waste but also knowledge of the existence and content of the elements that comprise the complex socio-technical framework that maps the culture in which it was created.

The nature of nuclear technology and radioactivity itself has been the focus of exhaustive study by scientists, technologists and engineers. The knowledge generated by these studies is typically condensed and abstracted in scientific publications and managed through library systems. Information about actual activities, including radioactive waste production quantities, radionuclide profiles, packaging and disposal is typically held in records and organisational information systems. But what of all the other elements of socio-technical frameworks; the politics, the intra- and inter-organisational relationships, the day-to-day running of a nuclear facility, the personal knowledge, the regulatory framework, the human-to-human interactions - how is this knowledge sustained over time? Currently most of this information is held as common knowledge by the practitioners and has been gained through education, research, on-the-job training, and accumulated over long-term careers. Given the age of the industry and many of its key professional practitioners it is possible to conceive of a looming crisis of knowledge. Indeed, it is not possible to seriously consider the preservation and transfer of information to future generations if the mechanisms that transfer information from one generation to its successive generation are not operational.

More generally, epistemic failure typically occurs when information is recorded and preserved in isolation and exists, therefore, out of context. This lack of connection between information (especially records) and context can occur at any time during the life of the materials and it is most likely at times of change. This may be a simple as the replacement of one contractor with another or something as dramatic as the disestablishment of a country, for example the former Soviet Union. Information has limited use if its source or provenance is unknown, its significance is unclear and the creator cannot be consulted to explain semantic ambiguities. Relatively simple systems designed to preserve records may work well locally, but if they are not meshed within a broader information framework that documents context, there is a significant risk that they will not meet society's needs, either now or in the future.

The product of the IAEA consultancy project is an IAEA Safety Report. It argues that the systematic preservation of contextual information is the most likely means by which we can mitigate epistemic failure. The report highlights the fact that the creation and subsequent management of radioactive waste gives rise to a considerable amount of information and knowledge. As a rule, adequate information is captured in the information resources generated by the industry for its current use, but the knowledge necessary to understand that information by outsiders to the industry and by future generations is not being effectively preserved.

The need to maintain knowledge of radioactive waste

Despite industry guidelines to the contrary, it is not uncommon to find in nuclear businesses that the process of managing and preserving radioactive waste records for the long term is considered as a potentially costly and low priority activity that uses valuable human resources whilst contributing little or nothing to business viability. Indeed, experience suggests that records management is viewed as an overhead that can be relegated to the 'back end' of a major project. A common outcome of such an approach is that the contextual information vital for understanding the outcomes of a project, particularly in the long term, is either not captured or not linked to the resultant records. An important contributing factor to this phenomenon is that people continually accumulate tacit and implicit knowledge, or contextual information, enabling them to understand the work they undertake and comprehend the records associated with their work.[10] This implicit knowledge may be highly contextualised to their specific job or organisation. When workplaces or communities accumulate implicit knowledge through shared experience it becomes common knowledge and it is generally not appreciated how important the documentation of that shared context is for comprehension and understanding by outsiders. Scientists and technologists appear to be particularly prone to this form of short-sightedness.

Insiders and outsiders

For those without implicit knowledge of their profession, the task of comprehending information increases in difficulty and complexity the further they are removed either in time, intellectually, culturally or in a socio-technical sense from the originating context. For them to understand the information they will have to undertake additional research, investigation and consultation. This division between the insider and outsider is an essential problem facing intergenerational information transfer. Moreover, the problem is not just confined to the transfer of information between generations but applies to the transfer of information within generations, for example when access to contextual information is required by an outsider.

A limited survey of the vast nuclear industry literature available through the IAEA has indicated that it has not been common practice for the nuclear industry to systematically document and manage contextual information through time. When the need has arisen, this task has often been left to archivists and historical researchers whose primary endeavour is to make information about the past accessible but who are often saddled with the burden of making comprehensible the inadequately documented records left behind by others. Occasionally the need for contextual information has been identified; for example, a report was recently published that systematically registered the policy, funding and regulatory frameworks in the year 2000 for a selected set of IAEA Member States.[11] These *ad hoc* projects, while useful in the short term and valuable historical resources, in no way constitute a sustainable or workable strategy for effective information transfer.

It starts with records

The information transfer process starts with the creation of records documenting daily activities whether they are at the operational waste packaging level or at the highest level of policy development within the IAEA. The tendency to relegate records management and archives to the back end of a project was noted by the IAEA working group. This was not generally problematic when the project was active and the level of shared common knowledge was high, but became an increasingly high-risk strategy as time passed. A typical scenario is that as a major project reaches a conclusion, it is not uncommon for the staff responsible for creating the records to move on, taking their implicit knowledge with them and leaving others to make well-meaning judgments regarding priorities for long-term preservation. Given the emphasis placed on the very long-term safety of radioactive waste, the effective management of associated contextual information or knowledge must be considered a high priority activity that cannot be postponed to a later date. It must be an integral part of the project, being properly planned and resourced with clearly defined outputs and objectives, just as with any other safety-critical activity.

International standards for archives and records management have been developed that highlight the importance of the capturing of contextual information and provide guidance on the informatics required for its capture. However, the standards are relatively silent on how this information could be situated in open information networks in extended socio-cultural environments to meet a broad range of needs both now and in the future.

Radioactivity, society and time

A radioactive waste disposal facility typically will receive waste for a considerable period of time (maybe in excess of one human biological generation) and society is likely to require access to historical information, even after closure of the facility, for a period of time commensurate with the inherent hazard. Thus, information management over a few hundred years may be required for low-activity/short-lived waste and a period in excess of current human history for long-lived waste. Whatever one's view on nuclear energy and the exploitation of the properties of radioactive materials in general - waste has been created - it exists now and it will undeniably impact on both present and future societies. The longevity of the potential hazard means that the present generation, with its knowledge of the waste, has a clear obligation to preserve this knowledge and pass it on to future custodians so informed decisions on its future management can be made.

There are numerous sources from which knowledge about radioactive waste has been accumulated. The scientific and technical literature on its own is vast and the IAEA endeavours to provide access to these materials through its International Nuclear Information System (INIS) which can be accessed via the World Wide Web. Our present knowledge includes an implicit understanding of its significance, provenance and societal value. It may seem inconceivable to us today that a future society would not possess a similar understanding, particularly when dealing with a relatively hazardous material, but history has shown that societal values do change and both explicit and implicit knowledge can be lost. The drivers influencing changes in societal values are not the subject of this paper but we cannot shrink from our responsibility to take reasonable measures to empower the next generations with the knowledge currently in our possession, so that they have a chance to hand it over to the next ones.

A number of very credible reasons for preserving radioactive waste records exist, such as support for monitoring programs, re-assessment of safety arguments, potential retrieval of the waste, repackaging, disposal facility closure and the prevention of human intrusion. However, the fundamental and most important reason is to give future societies the opportunity to make decisions based on the best information available.

Past thinking and new ideas

In the radioactive waste community, previous studies have tended to focus on the practical aspects of record preservation.[12] Whilst these studies might have made passing or indirect reference to the role of common knowledge and contextual information, there have been few examples that have addressed the conceptual issues that would underpin an integrated and comprehensive radioactive waste knowledge management process. Perhaps one reason for this shirking of the topic is an innate recognition of both the breadth and complexity of the information and the socio-technical systems involved.

Socio-technical complexity

The last decade has seen a blossoming of studies looking at the nature of complexity from a variety of perspectives drawing on the humanities, social sciences and mathematics. Helga Nowotny, in the early 2000s, Chair of the European Research Advisory Board (EURAB) and based in Switzerland, has been tackling such issues as the need for socially robust knowledge in evolving complex environments.[13] She draws on the work of Niklas Luhmann, one of Germany's foremost figures in social systems theory, who notes that complexity is inherent in social systems - it is 'the unobserved wilderness of what happens simultaneously'.[14] She continues:

> Luhmann's reference to the ultimately unfathomable complexity of the world - that which happens simultaneously - implies also its ultimate uncontrollability. While this definition of complexity has an elegance that differs from that used in the natural sciences, it has the advantage of leaving space for the invention of social mechanisms of coping, aimed at reducing its otherwise unbearable degree of uncontrollability. All human societies have therefore invented means of coping with uncertainty and ways of reducing complexity.[15]

Street directories, maps, encyclopaedias, biographical registers, dictionaries, glossaries, tourist guides, administrative histories, archival guides, library catalogues and more recently Web-based search engines and knowledge networks are all examples of systems of abstracted information that help individuals cope with the complex and sometimes foreign environments in which they find themselves. It is possible to conceptualise these abstracted complex environments as networks of entities (for example: people, organisations, places, concepts, and events) that are linked by defined relationships.

In mathematics and physics, studies of the nature of open scale-free complex networks really got underway in the mid 1990s. In 2002 Albert-László Barabási, a leader in this field, published a major work that explored the issue of 'how everything is connected to everything else and what it means for science, business and everyday life'.[16] The surprising and ubiquitous properties of these complex networks were shown to share mathematical foundations, such as power law distributions, which provide a stronger foundation for analysis and utilisation of network properties for useful ends. This worked stemmed from the work of anthropologists and sociologists from the 1930s as they attempted to move beyond just using the idea of a social network as a metaphor, to using a defined network as a tool for analysis.[17] One result of these network studies was the now popular idea of the small-world effect. Barabási noted:

Real networks are not static, as all graph theoretical models were until recently. Instead, growth plays a key role in shaping their topology ... there is a hierarchy of hubs that keep these networks together, a heavily connected node closely followed by several less connected ones, trailed by dozens of even smaller nodes. No central node sits in the middle ... controlling and monitoring every link and node. There is no single node whose removal could break [the network].[18]

This work provides an intellectual and conceptual milieu in which new strategies could be conceived to deal with the intransigent problems of information transfer to future generations. The radioactive waste industry, in itself a complex socio-technical network with an explicit need to preserve and transfer information, would appear an ideal case for utilising network thinking and technologies.

A contextual information framework

If captured and documented, contextual knowledge that has been accumulated over the years should enable subsequent generations to understand the significance of preserved archival records. This could be used to form the nucleus of a continually evolving sustainable knowledge base. If systematically documented to record its location in both time and space, this contextual information, by its very nature, will map the changes in the socio-technical environment. Through access to this comprehensive, reliable and accurate knowledge each generation should have the necessary confidence to make informed judgments and decisions about the safe management of the radioactive waste legacy.

Therefore, the proposed strategy for preserving knowledge about radioactive waste is through the development and maintenance of a contextual information framework, a network that binds together all the relevant information sources in the broader network of radioactive waste information. The purpose of this framework would be to link together sources of knowledge that may be of value to a future society. The framework would thus be constrained by this purpose and therefore, as Nowotny suggested, it would provide a means of coping with uncertainty and a way of reducing complexity to something useful, but without necessarily compromising on detail.

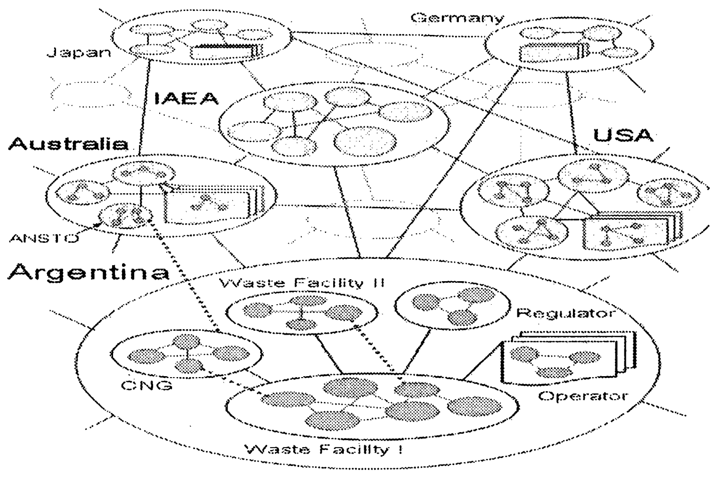

Figure 1. This schematic diagram represents the multiple levels of clustering and linking that result from the creation of a contextual information framework. Diagram credit: Gavan McCarthy, 2004

More generally, a contextual information framework is composed of information objects that represent the agents that participate in events. People, organisations, concepts, ideas, places, natural phenomena, events themselves, cultural artefacts including records, books, works of art and radioactive waste could all be defined as entities and play the role of agent. The mapping of relationships between these entities creates a network of nodes and arcs that mimics actuality.

The selective use of defined types of entity and defined types of relationships can convert otherwise impossibly complex socio-technical environments into information frameworks or zones within larger networks with remarkable and useful properties. The Internet, more particularly the Web, has become the de facto home for many information networks servicing a wide variety of purposes and industries. The appearance of higher level structures within the Web and the discussion of the building of a Semantic Web indicate that the Web could be used as the basis for establishing such a contextual information framework in the public domain.

An electronic information network of this type could be constructed to have the scale-free properties of the open complex social network it mimics[19] where many nodes (information objects representing entities are created to meet international standards) are interlinked via arcs (using defined relationship types). They could be referenced or cited, and new nodes can be added at any time, upgraded or copied to new locations. The system would be both recursive in structure and reflexive, with nodes grouped in clusters reflecting groupings that occur in real life. The nodes themselves could be composed internally of similarly interlinked or networked objects.

One of the interesting aspects of a contextual information framework is that the same entity may appear in more than one cluster or context, where it may play different roles. The establishment and implementation of an identity relationship type to systematically link these multiple representations of the same entity will create a higher level standards-based framework structure that will greatly assist in the navigation and usability of the system.

The World Wide Web is an example of an 'open network' that is evolving through time. However, the current use of hypertext markup language (HTML) as the standard Web markup language lacks the semantic elements that would allow the development of a fully empowered contextual information network. The increasing use of extensible markup language (XML) is seen as a move towards a mechanism that will add significant usability, re-usability and functionality to contextual information frameworks. A network of this type could be implemented on any scale (from local to international) although it is recognised that stricter management processes might be desirable in order to control the quality of the information sources at all levels.

Open information systems and security

It is accepted that there will be concern in the radioactive waste industry about the use of an open network to reference potentially sensitive information about radioactive materials. The security aspects of this would need to be carefully considered. However, it is not being suggested that all data and information be placed on the open public network but that references can be made to it. The actual location of these records and, indeed, the precise location of the materials prior to their disposal need not be placed into the public domain for this concept to be effective.

Implementation

The Australian Science and Technology Heritage Centre recently undertook a case study for the IAEA that involved developing a representative set of sample networked webpages[20] that used public domain information relating to the Pûspõkszilágy Radioactive Waste Treatment and Disposal Facility in Hungary. The information contained in the example concerned the history, the nature of the operations undertaken and the documents and records describing the facility. The webpages created demonstrated a typical structure that could be adopted on a more comprehensive scale. It also shows how links can be made to other sources of information (ie AEA Technology in the UK and the IAEA).

Implementation of a knowledge network to cover the whole of the radioactive waste industry world-wide may take many years to develop. However, the Pûspõkszilágy study has shown that the basic framework can be established very quickly (the public domain information contained in the Pûspõkszilágy webpages took a few days to locate and hyperlink). The key sources utilised in compiling this contextual information comprised:

- Local records - data related to raw, conditioned and packaged waste, implicit and explicit information on the sources of the waste, references to contextual information (for example, specifications, local rules, safety cases), information on record creation (source of record, storage location, validity period, responsibilities).
- Organisational information - structure, mission statement, goals and objectives, timescales, programs, key milestones, regulatory requirements, history.
- State information - organisation entities, roles and responsibilities, regulation, international cooperation, reporting requirements, principal skills and disciplines.
- Community information - State profiles, key organisations, roles and responsibilities, guidance and regulation, legislation, international cooperation programs, agreements and protocols.
- Historic event information - dates, locations, key organisations, roles and responsibilities, historic literature, landmarks, memorials and contemporary reporting.

There are a number of benefits of using this approach including:

- Making knowledge transfer easier and encouraging the sharing of waste management experiences within and between organisations.
- Enabling existing knowledge sources to reside within a structured and visible system.
- Increased visibility of knowledge sources to promote their preservation and value.
- Introduction of a non-intrusive technique that complements existing business practice.
- Supporting the decision-making process by making available a wide range of information giving a view of 'the bigger picture'.

- Improving transparency within the waste management community and for external observers (transparency is fundamental to building trust).
- Referring to sensitive information within the system without it being reproduced.
- Vastly improved accessibility, comprehensibility and discovery of records.

From an implementation point of view, a significant aspect of the contextual information framework concept is that it is neither necessary to identify all the information nodes at the start, nor to immediately populate those that have been identified. Further knowledge sources can be created and populated at any time and linked to other sources as the knowledge base grows in much the same way as the World Wide Web developed. As with any information system, the information sources that form the network nodes must be reliable and relevant. It would be the responsibility of the separate organisations and the State to ensure that the radioactive waste information is properly prepared and managed and that quality is of the utmost importance.

One of the characteristics of the World Wide Web is that there is no body in overall control or with the responsibility for overseeing the placement of information in the system. It is envisaged that contextual information frameworks would adopt a similar strategy and thus evolve the robustness that comes with dispersed but shared responsibility. For peace of mind for the radioactive waste community it would be possible for the IAEA to establish itself as one of the principal nodes in the network, providing both a resource to Member States and a management function, particularly in the area of standards. The IAEA established the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management in 1997 which obliges the Member States who are signatories to provide regular comprehensive national reports. This data would provide an excellent foundation for an International focal node that would set standards and leadership for others wishing to connect to the network.

Conclusions

The management of radioactive waste is moving into a new era with the development and construction of disposal and long-term storage facilities around the world. The costs to individual countries of these activities are measured in tens to hundreds of billions of dollars. Significant strides have been taken in recent years to develop technical processes and systems that may enable both current and future generations to safely manage the waste. Justifiable and informed decisions are being made and will continue to be made on the basis of comprehensive knowledge about the waste characteristics, its source, conditioning processes and potential impact on the environment. Important decisions have yet to be made and, due to the longevity of some of the waste, can only be made many years hence. It is therefore incumbent on this generation to develop and maintain a knowledge base and to implement systems that ensure that the information remains accessible to those having to make critical decisions.

The purpose of this paper has been to extend thinking about archives and records by considering how all elements of the knowledge base might be integrated. The long-term preservation of the records containing data and explicit information is only a part of the challenge and we must recognise that informed decisions are also influenced by our implicit knowledge of the waste and the contextual framework within which the waste is to be managed. We live in a world of perpetual change and there is a very real threat that the accumulated knowledge that guides waste management today will be lost to the next generation.

This generation is unable to accurately predict either the technical capabilities or societal values of the future and therefore the regulatory and institutional environment in which decisions will be made. As a consequence, we are unable to predict accurately what information will be required for a future generation to make informed judgments. However, a first step to empowering future custodians of our legacy is to recognise the information sources and to develop bold and robust strategies for ensuring that they remain accessible.

A strategy based on a contextual information framework concept has been described. This type of network linking information nodes at organisational, national and international level would have a number of benefits, including clear recognition of the location of important knowledge sources and duplication of information, thus reducing the likelihood of catastrophic loss. Much information exists in the public domain to which links could be made to other stand-alone sources. The long-term viability of the network approach, which should never be solely dependent on any particular technology, will be only truly assessed through implementation. Studies into naturally occurring (open and complex) scale-free networks have been shown to have the properties needed to enable viability over time but it remains to be seen whether it is possible to consciously create such a network to meet specific needs.

There is clearly much more work to be undertaken in, firstly, further developing an acceptable case for contextual information frameworks and, secondly, a strategy that is acceptable to all potential contributors in the radioactive waste community. Future studies from an archival perspective that would be of value would include:

- A study of the laws or regulations governing the preservation of archival information relating to the storage and disposal of radioactive waste in all Member States.
- A retrospective study that examines what records relating to radioactive waste management are already held by national archives.
- An assessment of the guidance or direction that the IAEA should be giving to national archives with respect of radioactive waste information.
- A contribution from the archival profession as to what they can offer the issue of very long-term preservation.

However, the volatility of the knowledge base that has been created and its potential value to future generations is so great that concerted action at all levels must be taken to preserve it and ensure that we avoid a potentially disastrous epistemic failure.

Endnotes

1 G McCarthy and I Upshall, 'Radioactive Waste Information: Meeting our Obligations to Future Generations with Regard to the Safety of Waste Disposal Facilities (ICA Study 18)' International Council on Archives, Paris France May 2006 <http://www.ica.org/biblio.php?pdocid=454>.

2 International Atomic Energy Agency, *The Principles of Radioactive Waste Management, Safety Series No. 111-F*, Vienna: IAEA, 1995.

3 M Jensen (ed.), *Conservation and Retrieval of Information – Elements of a Strategy to Inform Future Societies about Nuclear Waste Repositories*, Stockholm: Swedish Nuclear Fuel and Waste Management Company (SKB), 1993.

4 World Commission on Environment and Development, *Our Common Future. Brundtland Report*, Oxford: Oxford University Press, 1987, p. 46.

5 Nuclear Energy Agency/Organisation for Economic Co-operation and Development, *Future Human Actions at Disposal Sites – A Report of the NEA Working Group on Assessment of Future Human Actions at Radioactive Waste Disposal Sites*, Paris: NEA/OECD, 1995.

6 International Atomic Energy Agency, *Preservation and Transfer to Future Generations of Information Important to the Safety of Waste Disposal Facilities* (draft), Vienna: IAEA, April 2005.

7 International Atomic Energy Agency, *Maintenance of Records for Radioactive Waste Disposal*, IAEA-TECDOC-1097, Vienna: IAEA, July 1999.

8 J Ohuchi, T Eng, T Tsuboya (eds.), *International Workshop on Record Management and Long Term Preservation and Retrieval of Information Regarding Radioactive Waste*, Japan: Radioactive Waste Management Funding and Research Centre, RWMC-TRE-03002, November 2003.

9 DV Easterling, 'Incorporating the interests of future generations into nuclear-waste policymaking: What would they say to us?', *Proceedings PISTA 2005, The 3rd International Conference on Politics and Information Systems: Technologies and Applications*, International Institute of Informatics and Systematics, July 2005, p. 16.

10 C Fricke and B Faust, 'Knowledge transfer – bifunctional method for knowledge conservation', *Proceedings PISTA 2005, The 3rd International Conference on Politics and Information Systems: Technologies and Applications*, International Institute of Informatics and Systematics, July 2005, p. 26.

11 International Atomic Energy Agency, *Institutional Framework for Long Term Management of High Level Waste and/or Spent Nuclear Fuel*, IAEA-TECDOC-1323, Vienna: IAEA, December 2002.

12 See note 5.

13 H Nowotny, 'The Need for Socially Robust Knowledge', *TA-Datenbank-Nachrichten*, Nr. 3/4, 8. Jahrgang – Dezember, S.12-16, Karlsruhe: ITAS, 1999.

Online at: <http://www.norfa.no/_img/nowo99a.htm>.

14 N Luhmann, *Die Politik der Gesellschaft*, hg. v. André Kieserling, Frankfurt, Suhrkamp, 2000.

15 H Nowotny, 'Coping with Complexity: On emergent interfaces between the natural sciences, humanities and social sciences', *The Founding of International University Bremen*, Bremen: International University Bremen, 2003, pp. 66–78. Online at: <http://www.nowotny.ethz.ch/publikationen_en.html>.

16 AL Barabási, *Linked, the new science of networks*, Cambridge, Massachusetts: Perseus Publishing, 2002. Publishing Company Inc., 1972.

17 JA Barnes, *Social Networks*, Module 26, An Addison-Wesley Module in Anthropology, Philippines: Addison-Wesley.

18 AL Barabási, *Linked, the new science of networks*, Cambridge, Massachusetts: Perseus Publishing, 2002. Publishing Company Inc., 1972, page 1.

19 See Endnote 14

20 G McCarthy, IAEA - 'Hungarian Radioactive Waste Disposal: Contextual Information Framework Demonstration' website, Melbourne: Australian Science and Technology Heritage Centre, 2004.

Online at: <http://barney.asap.unimelb.edu.au/iaea>.