The Development of a Contextual Information Framework Model as a Potential IAEA Strategy to Maintain Radioactive Waste Knowledge

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ABSTRACT

A contextual framework comprises 'entities' that exhibit one or more definable relationships with a particular 'event'. People, organisations, concepts, ideas, places, natural phenomena, events themselves, cultural artefacts including records, books, works of art can all be conceptualised as entities. If these entities are registered in an information management system where the relationships between them can be defined and systematically managed then it is possible to create a contextual information framework that represents a particular view of what occurs in real life. The careful identifying and mapping of the relationships between these entities and the selected event can lead rapidly to the creation of an information network that closely reflects the human approach to knowledge acquisition and application.

The 'event' referred to in this paper is the safe management of radioactive waste. It is widely accepted that society will expect that knowledge about the waste will be maintained for many decades, if not centuries. Delivering on this expectation will demand the application of management approaches that are both innovative and sustainable. Effective intergenerational transfer of information using many 'conventional' techniques will be highly dependent on societal stability - something that cannot be guaranteed over such long periods of time. Consequently, alternative approaches should be explored and, where appropriate, implemented to give reasonable assurance that future generations of waste custodians will not be unduly burdened by the need to recreate information about the waste long after its disposal. In actual fact, the contextual information framework model is not 'new technology' but simply a means for rationalising and representing the way humans naturally tend to use information in the pursuit of knowledge enhancement. By making use of multiple information entities and their relationships, it is often possible to convert otherwise impossibly complex socio-technical environments into information architectures or networks with remarkable and useful properties.

The International Atomic Energy Agency, in its ongoing work to encourage the application of systems to manage radioactive waste information over the long term, has embraced the contextual information framework as a potentially viable approach to this particular challenge. To this end, it invited Member States to contribute to the production of a Safety Report that used the contextual information framework model, building on the wealth of existing IAEA guidance. The report focuses, not on the important area of records management, but on the benefits that can arise from the development of an information management approach that increases the likelihood that future generations will recognise the significance and value of the information contained in these records.

Our understanding of 'intergenerational transfer' should extend beyond the simple physical transfer of records into an archival repository towards the establishment of a working culture that places sufficient contemporary information into a form that ensures it remains accessible, and ultimately enhances, the knowledge of future generations. Making information accessible is therefore the key and whilst the use of

stable records media, storage environments and quality assurance are important elements, they cannot be considered solutions in themselves.

This paper articulates some of the lessons that have been learned about using the contextual information framework model when applied to the long term management of radioactive waste. The draft IAEA Safety Report entitled "Preservation and Transfer to Future Generations of Information Important to the Safety of Waste Disposal Facilities" [1], on which this paper is based, is expected to be published in 2007.

INTRODUCTION

The radioactive waste management community has long recognised the imperative to preserve accurate and comprehensive information. It is widely recognised that information is required to support management activities today but one of the conundrums faced by many organisations is how to identify the information that will be required by future custodians of the waste. The deceptively simple requirement of managing information over the long term is being seen as an issue that is difficult to implement in practice the more it is examined.

The radioactive waste community has been developing its thinking about these issues under the rubric of socio-technical sustainability. The influence of the Brundtland Commission in 1987 is most noticeable. It 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*" [2]. This principle underpins the work of the International Atomic Energy Agency (IAEA) in its attempts to help the industry work towards processes that will effectively manage radioactive waste both now and in the future. However, the issues surrounding the successful transfer of radioactive waste information to future generations have been significant in practice and therefore challenging conceptually.

There is only one driver for retaining information today – and that is the belief that a future society will wish to use it to enhance its own contemporary knowledge. The needs for knowledge enhancement can be manifold and diverse including, historical interest, regulation, transparency, decision making, and so on. Managing information in such a way that a future society can access and use it with confidence can be particularly challenging. The information objects, or records, must be readily comprehensible by an unknown audience with a completely different set (and in the long term, an unknowable set) of societal values, cultures and interests. The experience gained by the radioactive waste industry thus far suggests that existing 'information management' models may be ill equipped to meet needs over the longer term.

During the past thirty or forty years there have been some notable examples of the human race investing considerable resources to obtain non-reproducible data (such as space exploration) only to discover years later that the recorded information cannot be accessed or interpreted. Although this is often the result of ineffective planning and maintenance, there appears to be two major reasons why failures have occurred:

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

It is this second point (which is perhaps the most crucial) that, only recently, has started to be addressed by the radioactive waste community [1]. It is the need to sustain our knowledge of the existence of information about the complex socio-technical framework that underpins the data which is at issue. The nature of the technology and radioactivity itself has been the focus of the operational activities of nuclear scientists, technologists and engineers. Much of the knowledge created through these means is typically condensed and abstracted in scientific publications and managed through the library system. But what of all the other elements of socio-technical framework; the politics, the intra- and inter-organisational relationships, the day-to-day running of a nuclear facility, the regulatory framework, the human to human interactions - how is this related information sustained over time? Experience has shown that this information is critically important for interpreting both published and archival materials.

Where information has survived for very long periods of time (i.e. many hundreds or thousands of years), its accessibility is more likely to have been the result of fortuitous circumstances rather than flawless planning – examples being the Dead Sea scrolls and the Egyptian hieroglyphs. Whilst the loss of similar ancient information may have been detrimental to society's 'knowledge enhancement', it could be argued that it has not resulted in catastrophic consequences to either humankind or the environment. However, the information relating to radioactive waste is so important to future societies that the present generation cannot afford to side-step the challenges and ignore information management failures of the past. It must also be prepared to invest the necessary resources now - not just to remedy past inadequacies but to prepare adequate systems for the future.

Epistemic failure typically occurs when information is recorded or preserved in isolation and unconnected to the broader context which led to its creation. Information has limited value if, for example, its provenance is unknown, its significance is unclear and the creator cannot be consulted to explain semantic ambiguities. Relatively simple information systems can be designed and deployed but if they are not integrated within a broader contextual information framework there is a significant risk that they will not meet society's needs, either now or in the future. Epistemic failure could also be described as a failure to create and manage through time the meta-information (information about information) that is necessary for the meaningful interpretation of the information under examination.

It is argued in this paper that the systematic management of contextual information is currently the most likely means by which we can mitigate epistemic failure. The paper highlights the fact that the management of radioactive waste gives rise to a considerable amount of information. As a rule appropriate information is captured by the industry to meet its current needs, but additional information is necessary for non-industry sectors of society and future generations to interpret these operational records.

THE NEED TO MAINTAIN INFORMATION ON RADIOACTIVE WASTE

As geological repository projects are taken forward, 'systems' (comprising tools, processes and resources) for identifying information needs and subsequent management are being developed. One of the principal objectives of these systems will be to ensure that the information remains accessible to those who need it, when they need it and in a way that will ensure that they understand it. The absence of critical information necessary to safely manage radioactive waste over the long term is likely to compel a future society to replace it. This, inevitably, will include a financial penalty and possibly the necessary exposure of workers to ionising radiations.

It has been the norm, when developing ideas about the long term management of radioactive waste information, to adopt a 'bottom up' approach. That is, to identify records of past activities containing specific data that may be of use in the future. An alternative is a 'framework approach' where information types are defined and relationships are mapped between the resulting entities. An important characteristic of this approach is the building of information systems that can be interconnected with related information resources in other locations. Adopting this alternative approach should not be regarded as a criticism of the work performed to date on records and information management as, indeed, identifying sources of information is a vital component of any system. The implication is, however, that a system built in isolation, from the bottom up and without clear linkages to other systems is unsustainable in the long term and vulnerable to information loss.

Information management must be considered a principal component of project management. In large and complex projects there are a number of priorities that have immediate or short term implications, for example, operator safety, environmental controls and finance. However, the creation of information that will contribute to the ongoing management of the product (i.e. packages containing radioactive waste emplaced in a geological repository) is sometimes viewed as a by-product rather than an essential component contributing to long term sustainability. Significant effort must be devoted to identifying the information requirements during the project planning stage in order to optimise the longer term management commitments.

Actions that make the complex arrangements for the safe management of radioactive waste more transparent and open are gaining in importance. The challenge of long term radioactive waste management has social, political and technical implications and industry must be prepared for its information to be shared with communities and groups having different interests, priorities, skills, cultures or beliefs. This information, underlying all that is done within the industry, must be made accessible in an appropriate form if it is to gain the support of society.

Insiders and Outsiders

For those without access to the shared knowledge that is common in the industry at any particular point in time, the task of comprehending publications and records from that period will increase in difficulty and complexity the further they are removed either in time, culturally or in a socio-technical sense from the originating context. For them to understand the information they will be required to undertake additional research, investigation and consultation. This division, which is created between those that share common knowledge and those that do not, that is, the insiders and outsiders, is a fundamental problem of intergenerational information transfer. It can be argued that the problem is not just confined to the transfer of information between generations but applies equally to the transfer of information within a generation where access to contextual information is required by an outsider.

Unfortunately, it has not been the usual practice to systematically document and manage this shared common knowledge or contextual information. This is a task that 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 inadequately documented records left behind by others. Occasionally the need for contextual information has been identified, for example, a publication systematically registering the policy, funding and regulatory frameworks in the year 2000 for a selected set of IAEA Member States [see 6]. These ad hoc projects, which may be 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 operational activities whether they are at they are at the waste packaging level or at the highest level of policy development within the IAEA. The capturing of information about operations in records is a standard practice of the industry and it is the primary means by which knowledge is externalised or made explicit.

It is not uncommon to relegate records management to the back end of a project and the staff responsible for creating the records to move on taking their implicit knowledge with them. This leaves other, possible less well informed staff, to make judgments regarding the long term management of the records. Given the emphasis placed on continuing safety, the documenting of contextual information surrounding radioactive waste records must be elevated to a high priority activity. It cannot be postponed to a later date and it must be an integral part of the project. This will inevitably require proper planning and resourcing with clearly defined outputs and objectives, just as with any other safety-critical activity.

Radioactivity, Society and Time

A radioactive waste disposal facility will typically receive waste over a considerable period of time. This period could quite easily be in excess of one 'worker generation'. Further more, society is likely to demand access to historical information - even after closure - for a period of time commensurate with the hazard. Thus, information management over a few hundred years may be required for low activity short-lived waste or a period in excess of current human history for long-lived wastes.

Whatever the 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 the 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 that knowledge and to pass it on to future custodians to support future decisions.

There are numerous information sources from which knowledge about radioactive waste has been accumulated. 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 posses a similar understanding, particularly when dealing with a relatively hazardous material, but history has shown that societal values do change and both explicit information 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 generation with the knowledge currently in our possession.

A number of very credible reasons for preserving radioactive waste records are cited 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 authors suggest that the fundamental and most important reason is to give the future societies the opportunity to make decisions based on the best information available.

THE NATURE OF KNOWLEDGE

Data, Records, Information and Knowledge

This paper has already made several references to terms such as *data*, *information* and *knowledge*. A fundamental measure of an effective information management system is that the recipient can 'understand' preserved information in a way that is in accord with the intentions of the creator. This will now be demonstrated by the authors defining some of the key terms used in this report.

Data is the term used to describe the elemental building blocks of information and, therefore, knowledge. They can be found in various forms, such a collection of bits (binary digits) stored on a computer disk, symbols on a piece of paper or images on a microfilm. Data in isolation are virtually useless – to realise their worth they must be used in consort with other information sources.

Defining the term *information* is more difficult but to allow the management process to be described, it will be thought of here as a source of data that is associated in some way with other information enabling the data to be understood by at least one person. Information can therefore be viewed as a source of data that shares a degree of commonality or context. If this is accepted, it may be argued that a source of information is not a haphazard collection of data but something that reflects order, connection and relevance. In academic works, information has been described as *"data endowed with relevance and purpose"* [3] and *"data becomes (sic) information when its creator adds meaning"* [4]. Information can be regarded as a commodity that can be stored, processed, transferred and lost by either an individual or a group.

Information is often brought together in a *record*. The record is simply a means to retain and, if required, transmit data - in itself, the record does not constitute information. It can, however, be associated with other information entities that together position their content in time and space and thus imbue the records with evidential qualities. A record may, in itself, be of limited value (unless it has an inherent financial value) but it is important that it is managed in such a way that its evidential value is maintained and in order that the data it contains remains accessible. A museum may value the record itself, for its historical interest (for example, a stone containing ancient Egyptian hieroglyphs), but in the situation being explored here, there is less interest in preserving the 'physical' record over the long term than preserving the data it contains. This is a vitally important subtlety that will have an influence on the management strategy.

Knowledge is equally difficult to define and has exercised academics and philosophers for centuries – it is not intended that this paper challenges any of the great works but one thing that is certain is that information and knowledge are not synonymous. One suggestion is that knowledge can only be created and retained in a person's mind (the 'knower') where it comprises *"framed experiences, values, contextual information and expert insight that provides a framework for evaluating and incorporating new experiences and information"* [5]. This statement highlights the fact that the creation of knowledge is a continuing, evolving and non-physical process. If this definition is broadly accepted, then it is possible to argue that the very act of recording knowledge in a physical record means that it is instantly time-related (it is 'fixed' in time). This means that the record simply contains a statement of knowledge at a point in time – and hence it becomes a source of information.

Knowledge management is an increasingly common term that is used to describe an act or collective process that seeks to record, or by some other means, preserve knowledge. It is suggested that most knowledge management systems are, in fact, information systems. However, the information that these systems manage is the lifeblood of knowledge creation and thus extremely important.

Explicit Information and Implicit and Tacit Knowledge

The terms *explicit*, *implicit* and *tacit* are often used as qualifiers for the more generic term *information*. Explicit information is defined as that which is openly accessible and can be found in a variety of records (digital, photographic and physical formats). The vast amount of information is explicitly recorded which makes its transfer from creator to recipient relatively straightforward (this should not be confused with so-called 'knowledge transfer').

Some references imply that *implicit* and *tacit* are interchangeable and synonymous so an attempt will be made here to distinguish the difference. *Implicit knowledge* can be defined as that which resides in personal memory and which is not physically recorded elsewhere. This knowledge will have been acquired through experience, communications with others and learning opportunities. An important, yet fundamental, characteristic of implicit knowledge is that it can be verbally expressed (and, if required, recorded) relatively easily thus creating an explicit source of information. The relatively recent trend to develop sophisticated processes to capture 'implicit knowledge' (for example from a retiring member of staff) can be viewed as a simple exercise in converting implicit knowledge into explicit information.

Implicit knowledge can be found in two forms: common and individual. Common (or shared) knowledge is that which a community holds, that is taken for granted and usually not documented. It is contingent upon a whole variety of shared practices and experiences which often subtly define culture and the 'secret' rules that allow organisations and societies to function. If this common knowledge can be documented (codified) it could provide a means for enhancing the knowledge of future citizens. Individual knowledge is partly accumulated by virtue of the occupation of the individual and is therefore more specific. This aspect of implicit knowledge may be of significant value, especially where the individual has been part of a relatively small group involved in a highly specialised activity (such as radioactive waste management).

Tacit knowledge is fundamentally different to explicit information and implicit knowledge. The term 'tacit knowing' was first used by Michael Polanyi in 1958 but it has since evolved into the less specific 'tacit knowledge'. The word *tacit* was originally given to mean 'hidden' reflecting the fact that every individual possesses 'unconscious knowledge'. It has been suggested in more contemporary works [6] that *"we can always know more than we can tell, and we will always tell more than we can write down"* which appears to support the concept that an individual possesses both tacit and implicit knowledge. It is not intended to further develop the discussion in this report but it is important to ponder on the point of whether personal knowledge can be transferred or indeed managed if it is not actually possible to express it in full.

MULTIPLE INFORMATION SOURCES

Measures that could be used to assess the effectiveness of an information system include the degree of access to information sources. Information about a particular topic will often reside in a wide range of related sources (records) which, when taken together, can significantly enhance one's personal knowledge. Knowledge is generally enhanced when an individual is able to compare and contrast and indeed, it is often necessary for multiple sources to be used. There are many reasons why this is done, including:

- comparison of similar information from different sources;
- complementing one source of information with another;
- contrasting sources and identifying differences;
- justifying the use of a particular source(s);
- providing a more comprehensive picture;
- using related information resources to expand, explain, qualify or quantify information in a source record.

Many activities undertaken on a routine basis require information from disparate sources – it is therefore important that any management system reflects this reality. An individual possessing shared implicit knowledge about a particular topic will make contextual connections between sources of information. Very often, this type of information is not explicitly documented. Therefore, when developing a system that is capable of providing access to complex information sources, it is important that the characteristics that link them together are identified and recorded to replicate the presence of 'common knowing'.

The framework of links between multiple information sources is often referred to as context. Information which is well contextualised is more likely to have a beneficial impact on the recipient by improving their understanding and enhancing their personal knowledge.

Context

The importance of *context* cannot be underestimated. It has already been stated that the value of information is adversely affected if it is provided without context. At the point of enquiry, it is vital that the recipient of the information is provided with an understanding of the prevailing environment in which the information was created together with relevance, associations and links between information sources and the source's provenance.

The contextual information associated with a record or information object should not be conflated with the current use of metadata that is used in a restricted way to describe the data contained in the record (that is, data about data). Whilst contextual information is indeed similar to and will include metadata, it would be better to describe it as 'meta-information' (that is, information about information). When used to create a framework, it can be thought of as the defining detail that positions the information object in the overall information environment. It is difficult to provide a generalised contextual information set, but it could include:

- when (date) and by whom (person/organisation) the information was created;
- the 'owner' (person/organisation) of the information and their location (place);
- the type or category of information based on function and purpose;
- keywords, topics and ideas (concepts);
- the reasons why the information was created (i.e. its original purpose);
- relationships with other information sources;
- location of this and related information sources;
- factors that could affect the validity, accuracy or relevance of the information;
- the broader set of entities reliant on, with an interest in, or connected to, the source information.

As a rule, contextual information is shared by numerous entities in an operational framework and provides the 'glue' that enables otherwise unconnected information to be interlinked.

Understanding

Understanding is as an intangible skill that each person possesses in various degrees. It is strongly influenced by experience, learning, exposure to explicit information, shared and individual implicit knowledge as well as the intangible tacit knowledge. Understanding can also be linked to personal judgement, recognition of significance and relevance. When the individual is presented with an information it is likely that they will consider its:

- relevance – is this information likely to support, confirm, supplement or contradict other related information?
- appropriateness – does this information relate specifically to a particular event or does it contribute to a contextual scenario?
- reliability – was the information created with a known and appropriate level of accuracy and precision and what is likely to be its impact on other information?
- provenance – is it known from where and when the information originated and is this source known?
- outcome – how will the presence of this information impact on an individual's existing world view?

Understanding is highly personalised and to a degree subjective. However, it plays a significant role in the continuous creation of knowledge as it forms the essential link between 'raw' information and personal knowledge.

THREATS TO EFFECTIVE INFORMATION TRANSFER

As time goes on, locating, accessing and understanding information becomes more difficult in inadequate or poorly managed systems. The inevitable loss of unrecorded contextual information is particularly significant and this is exacerbated by the fact that skilled and knowledgeable staff tend to be more mobile these days, moving on to other projects. For a nuclear industry at the dawn of a new age of challenging projects arising from the disposal or long term storage of radioactive waste, it is more important than ever to recognise the existence of specialist knowledge and to prevent its loss.

Physical Threats

The loss of information contained within records can be extreme, total, immediate and irreversible (catastrophic loss); for example, destruction of a records archive by fire. In contrast, information loss can be limited, selective and relatively slow (graceful degradation); for example, the natural disintegration of the recording medium. The severity of information loss may be reduced or indeed eliminated by planning and implementing counter-measures. These may include making multiple copies of records in a variety of different media, migrating records to new media and the regular sampling of records to assess the state of the media.

Change and the Dispersal of Knowledge

Since 1985 staff at the Australian Science and Technology Heritage Centre have undertaken work in a broad range of science and technology settings. Studies have revealed that one of the most serious and likely sources of information (and consequently, knowledge) loss is institutional or organizational change. Change can occur at a personal level when a particular expert retires taking with them valuable implicit and tacit knowledge. At the other extreme a State might become a victim of some form of major disruption such as war or terrorist attack resulting in the destruction of materiel and professional intellect.

An everyday example of how knowledge can be lost through change is the increasing use of short term contract staff. In order to spread costs, reduce timescales and improve efficiency, many organizations use third-party experts who meticulously build up a knowledge base which is subsequently lost when the contract ends. Thus, the accumulated knowledge becomes increasingly dispersed and disconnected. If this knowledge dispersal is then combined with organizational change, the likelihood of losing the information increases dramatically.

Responsibility

Although information at all levels faces these risks, it is the critical contextual information which is not systematically managed that is most at risk of loss. Organisations managing information must therefore recognise their responsibility for identifying the full range of risks and implement effective mitigating or counter-measures. Generic approaches can be problematic as the risks tend to be context-dependent varying from organisation to organisation and from one State to another. Any top tier policy should recognize the different risks and allow custodians to develop systems best suited to counteract local threats.

PAST THINKING AND NEW IDEAS

In the radioactive waste community, previous studies have tended to focus on the practical aspects of record preservation. Whilst these studies might have made passing reference to the role of knowledge and contextual information, there have been few examples of studies that have tackled the conceptual issues surrounding an integrated and comprehensive radioactive waste information management system. The following section summarizes some recent work in this area undertaken by the authors for the IAEA.

A Three Tier Information Hierarchy

The IAEA has provided generic guidance on the preservation of radioactive waste records through the creation of a radioactive waste information hierarchy [7]. Although the records which embody this information exist in a multi-layered complex socio-technical framework, this guidance is modelled on a simplified hierarchal structure. It has identified three levels of information, as follows:

- **Primary Level Information (PLI)** – records or dynamic information that relates to all phases of a waste disposal system and includes: *inter alia*, site and waste characterization details, performance measures, operations and monitoring output.
- **Intermediate Level Information (ILI)** – condensed information (some sourced from PLI) that provides *an understanding* of the waste disposal system. This will be based on licence, legislative and regulatory requirements. Importantly, the guidance states that ILI should make reference to specific records in the PLI set.
- **High Level Information (HLI)** – top level information that is further condensed but provides a fundamental understanding of the waste disposal system.

The IAEA guidance states that it is the HLI that has to meet the needs of future generations. It also recognises that the State will need to determine the level and detail of the information contained in this set based on contemporary regulations and, to quote directly, "taking into account that the information required will be used by future generations". So here is a veiled indication that the information is context-dependent and that it will need to be comprehensible to outsiders.

Although limited, this particular model is helpful when illustrating the multiple layers of information that are created. However, its application implies that the current generation is required to make decisions on the content of the HLI set for all future generations. This strategy does not acknowledge the dynamic nature of society, the ubiquity of change and the necessity for each generation to learn about the radioactive waste; its history, its nature, and the issues it brings with it.

Radioactive Waste Information Management Strategies

In 1990, a working group of the Nordic Committee for Nuclear Safety Research project (KAN-1.3) was formed to establish a basis for a Nordic view on radioactive waste information preservation. The resultant report [8] concluded that there were well proven systems available that would support the preservation of information for the first 1000 years after closure of a radioactive waste disposal facility; a bold and confident claim.

The KAN-1.3 report recommended, *inter alia*, that Nordic radioactive waste records be gathered together and key safety information extracted and placed in regional and national/international archives. It noted that some elements of the PLI set will be considered more important than others for inclusion in the HLI set and that selection guidelines and criteria would have to be established.

The Nuclear Energy Agency (NEA) of the Office for Economic Co-operation and Development (OECD) produced a report in 1995 [9] that recognised the need to preserve contextual information (and thus enhance knowledge) in addition to the data records. A number of points relevant to epistemic failure were raised. These included:

- the presence of inherent knowledge in societies;
- records are only of use if people are aware of their existence and significance;
- preservation systems must be monitored and assessed;
- there must be a legal framework for knowledge preservation.

The IAEA has produced, with the assistance of representatives from Member States, a number of guides concerning records management and in 2002 published a one-off report that brought together in a structured and systematic way an institutional framework surrounding the management of high level radioactive waste and spent nuclear fuel [10]. This represented a helpful, if limited, attempt to capture contextual information as it existed in 2000 – by the time of publication, some of the contextual information in the report was already out-of-date an of historical significance only. More recently, the authors were involved, with colleagues from a wide range of Member States, in the production of a safety series document which explicitly focused on the need to retain radioactive waste disposal facility safety-related information. This document started to examine the need for an integrated system that makes reference to a much wider range of physical and social information residing in comparatively disparate locations.

Socio-Technical Complexity

The key challenge for contextual information management stems from the observation that unconstrained contextual networks in real life tend to become unmanageably complex. Therefore, understanding social and operational complexity and the creation of means of abstracting this complexity for human purposes is critical.

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. The European Research Advisory Board (EURAB), based in Switzerland, has been tackling such issues as the need for socially robust knowledge in evolving complex environments [11]. It draws on the work of Niklas Luhmann, one of Germany’s foremost figures in social theory, who notes that complexity is inherent in social systems – it is “*the unobserved wilderness of what happens simultaneously*” [12]. The author of the EURAB's reports states that: “*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 reducing complexity*” [13].

In mathematics and physics, studies of the nature of open 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*” [14]. The surprising and ubiquitous properties of these complex networks were shown to share mathematical foundations such as power laws but also to have links with 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*].”

Although this field is evolving quickly and in a range of disciplines, it 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 nature of the radioactive waste industry, in itself a complex socio-technical network, would appear ideal for a networked approach to contextual information management.

A CONTEXTUAL INFORMATION FRAMEWORK

If captured and documented, contextual information accumulated over the years should enable subsequent generations to recognise the significance of preserved archival records. If systematically documented (in an abstracted form) to record 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 information each generation should have the necessary confidence to make informed judgments and decisions about the safe management of the radioactive waste legacy. Conversely, if no action is taken, valuable shared, but unrecorded, knowledge will be lost and may ultimately render any associated records and other information objects unreliable and even incomprehensible.

Therefore, a possible strategy for preserving knowledge about radioactive waste is through the development and maintenance of a distributed contextual information framework – a network of systematically documented shared common knowledge to which multiple records would be linked. This framework would be designed to link together information objects that acted as surrogates for entities such as people, organisations, concepts, ideas, places, natural phenomena, events, physical artefacts (records, books, works of art) and radioactive waste that may be of value to a future society. The mapping of the relationships between the surrogate entities creates a network of that mimics actuality. The carefully planned and selective use of entities and relationship types has the potential to convert an otherwise impossibly complex socio-technical environment into an information network that has remarkable and useful properties but most importantly creates a human-scale framework for managing vast quantities of information. The internet could be used as the basis for establishing such a network and making it widely accessible.

An electronic information network of this type could be seen as similar to neural and other open complex networks [see 14] where many information entities are interlinked via defined relationships. A fundamental requirement of the framework is that the entities can be referenced or cited and new relationships added at any time, upgraded or utilised to create new entities. The system would be both recursive in structure and reflexive, with entities grouped in clusters reflecting groupings that occur in actuality, and the nodes themselves 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 many clusters or contexts, but have a slightly different role. The establishment and implementation of an identity relationship type to systematically link these multiple representations of the same agent will create a higher level network structure that will greatly assist in the navigation and usability of the system.

A major benefit of this type of system is that information relating to key records becomes duplicated in a variety of separate clusters depending on local contextual informational requirements. This redundancy is viewed as one of the key tools for ensuring the preservation of information records.

The world wide web is an example of a relatively unconstrained 'open network' that is evolving through time. However, the current use of hyper-text markup language (HTML) as the standard web mark-up language lacks the semantic elements that would allow the development of a more functionally empowered contextual information network. The increasing use of extensible mark-up language (XML) is seen as a move towards a mechanism that will add significant usability and functionality to contextual information frameworks. A network of this type could be implemented on any scale (from local to international). It is recognized that stricter management processes, or rules of use, will improve both the quality of the information sources and the usability of the framework.

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 network but that references can be made to it even if access is restricted. 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. Just about all the information required to make this concept successful is already in the public domain, it is just not being systematically documented and utilised.

The Australian Science and Technology Heritage Centre recently undertook a case study for the IAEA that involved developing a representative set of sample networked web pages [15] that used public domain information relating to the Pűspőkszilágy 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 web pages created demonstrate 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.

Implementation of an information network to cover the whole of the radioactive waste industry world-wide may take many years to develop. However, the Pűspőkszilágy study has shown that the basic framework can be established very quickly (the public domain information contained in the Pűspőkszilágy web pages took a few days to locate and hyperlink). The key sources utilized 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;
- Organizational information - structure, mission statement, goals and objectives, timescales, programmes, key milestones, regulatory requirements, history;
- State information – organization entities, roles and responsibilities, regulation, international cooperation, reporting requirements, principal skills and disciplines;
- Community information – State profiles, key organizations, roles and responsibilities, guidance and regulation, legislation, international cooperation programmes, agreements and protocols;

There are a number of benefits of using this approach, which include:

- Making information transfer easier, encouraging the sharing of waste management experiences within and between organizations;
- Enabling existing information sources to reside within a structured and visible system;
- Increased visibility of information sources will 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 discovery, accessibility and comprehensibility 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 entities at the start, nor immediately populate those that have been identified. Further sources can be created and populated at any time and linked to other sources as the information 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 organizations 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 could 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.

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. Great strides have been taken in recent years to develop processes and systems that will enable both this 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 the information remains accessible to those having to make critical decisions.

Much commendable but limited work has been reported where the issues related to record management and preservation have been addressed. The purpose of this paper has been to extended this by considering how all elements of the knowledge base might be managed. The long term preservation of the records containing data and explicit information is only a part of the challenge and we must recognize 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 the 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 are 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 in empowering future custodians of our legacy is to recognize the information sources and to develop bold 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 organization, 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.

There is clearly much more work to be undertaken in developing firstly an acceptable case for a contextual information frameworks that is widely understood by both the industry and society at large, and, secondly, a strategy that is acceptable to all potential contributors in the radioactive waste community. 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 we avoid a potentially disastrous epistemic failure.

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