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RADIOACTIVE WASTE INFORMATION: MEETING OUR OBLIGATIONS TO FUTURE GENERATIONS WITH REGARD TO THE SAFETY OF WASTE DISPOSAL FACILITIES

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Radioactive Waste Information: Meeting Our Obligations To Future Generations With Regard To The Safety Of Waste Disposal Facilities

This study is the result of a project run by the International Atomic Energy Agency (IAEA) from 2002 to investigate the issues surrounding the preservation and transfer to future generations of information important to the safety of radioactive waste disposal facilities. As the project unfolded, one of the key aims became the production of a document for publication under the IAEA Safety Report series. As the principal authors of the study brought substantive experience from both the archival profession and the radioactive waste industry, it was deemed appropriate that the work be also published by the International Council on Archives (ICA). This study is almost identical to the document submitted to the IAEA for publication but has been given a different title and includes a few minor additions to highlight specific archival issues. Opinions expressed in this document are those of the principal authors.

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Foreword

The objective of radioactive waste management is to deal with radioactive waste in a manner that protects human health and the environment now and in the future without imposing undue burdens on future generations. Consequently, the imperative to manage accurate and comprehensive information to meet a variety of needs has long been acknowledged by the radioactive waste management community. More recently, the management of knowledge in the nuclear industry as a whole has been identified as one of its major challenges. Knowledge management studies have established that the simple preservation of data and information meets neither the short-term nor long-term knowledge requirements of the industry. This report, while focussed on the long-term intergenerational requirements for information about radioactive waste, proposes generalised strategies and activities that are designed to meet both short-term and long-term knowledge management needs.

Information about radioactive waste, generally contained in 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. The safe disposal of radioactive waste is a key responsibility of the entire nuclear industry community including those involved in electrical energy generation, medicine, the manufacturing and oil exploration industries, agriculture, scientific research and environmental protection. However, the community, more generally, as a primary beneficiary of the products of the industry, is also a key stakeholder with a responsibility for contributing to the safe and effective long-term management of radioactive waste. As such, it too has a requirement for access to reliable and accurate information.

Given the length of time that some radioactive waste remains hazardous, the preservation of information and its transfer to future generations must be a fundamental component of any waste disposal programme. The importance of the preservation of this information cannot be over emphasized as it provides the foundations for the transfer of knowledge between successive generations. Future generations will need information about radioactive waste disposal facilities and their contents so that they are aware of the potential hazards involved, can make informed decisions about the safety of the waste disposal facility, can minimize the risk of inadvertent intrusion and can determine the possible reuse of the site, its contents and surrounding areas. Importantly, they will also need additional information that will allow them to make decisions about the knowledge they pass to future generations who will be required to assume responsibility for maintaining the safety of the waste. The information must be preserved in a form that can be retrieved and deciphered over a significant period of time and that is suitable for transfer to appropriate media based on reliable and proven technology as the need arises.

The fact that society now requires new forms of risk governance when dealing with hazardous activities and expects new forms of dialogue with stakeholders further supports the imperative for active information preservation and transfer processes. The technical assurance and quality of the decision-making process are now seen as being as important as the scientific and engineering aspects of waste management safety. Therefore, both the ability to communicate to the general public and the flexibility to adapt to new operational contexts have emerged as critical factors in gaining and maintaining public confidence and trust.

The report highlights the fact that the creation and subsequent management of radioactive waste gives rise to a considerable amount of information. This information may be embedded in records and other resources, but is also in the form of knowledge accumulated by those directly involved in radioactive waste management today. Current industry standards and practices encourage the capture of information to meet present day needs. However, the processes required for equipping members of the wider community and future generations with the necessary knowledge to participate in the safe management of radioactive waste over the longer term is not being explicitly addressed in

many cases. In previous studies, the radioactive waste management community has tended to focus on the practical aspects of record preservation. Whilst these studies might have made passing reference to the role of common knowledge and contextual information, there have been few examples where the concept of an integrated and comprehensive radioactive waste knowledge management system have been tackled.

Information is always created in a context delimited by both time and space. It is not an absolute quantity and it always needs to be assessed in relation to a variety of parameters that will influence the meanings that can be derived. With regards to radioactive waste information these parameters or contexts will include the administrative structures, the governance framework, the financial arrangements, the regulatory environment, the status of scientific and technological knowledge, the evolution of the physical environment, the attitudes of special interests groups and the concerns of the community as a whole.

It is argued in this report that the systematic management of contextual information is currently the most likely means by which the risks arising from the failure of intergenerational knowledge transfer can be mitigated. Open network public information infrastructure technologies such as the Internet and the World Wide Web, provide a means by which a global framework of radioactive waste information can be built. This framework would utilise critical contextual knowledge to link related but distributed information and greatly assist the community in meeting its objective of creating a sustainable process of information preservation and transfer to future generations that would help ensure the safety of radioactive waste.

Archives, in particular national archival agencies, play a necessary and critical role in ensuring that adequate records are preserved to meet both national and international obligations. In light of the particular needs posed by radioactive waste information it may mean that archival collection policies and appraisal practices will need to be reconsidered. The relationships between nuclear industry-based archival programs and national archives should be examined in each country that has an obligation to manage radioactive waste and in all cases these relationships should be so structured to ensure that a sustainable management framework is established.

It has been a traditional role of archives to ensure that adequate contextual information is gathered in association with records to enable their use as evidence of past actions. To this end the International Council on Archives developed the International Standard for Archival Authority Records (Corporations, Persons and Families) [ISAAR(CPF)] to assist archives gather and use contextual information in a systematic and interoperable manner. Taking this as a starting point this study explores what might be achieved if the concept of contextual information management is extrapolated into the realm of open networked public knowledge.

Contents

1. Introduction

1.1. Background

The International Atomic Energy Agency (the Agency) has a Safety Standards publications programme that covers facilities and activities, for example, nuclear installation safety, radiation protection, radioactive waste management, the transport of radioactive material and thematic areas such as management systems.

Many of the Safety Standards identify a key role for the recording and preservation of information. To date, however, none have been identified that attempted to deal in a comprehensive manner with the challenge of information preservation and transfer to future generations. The subset of publications on management systems dealing with the safety of radioactive waste management underlines the importance of records creation, preservation and accessibility and provides guidance on their implementation from a management system perspective. In particular, the Agency safety guides for *Management Systems for the Safety of the Processing, Handling and Storage of Radioactive Waste* [1] and the *Management Systems for the Safety of Radioactive Waste Disposal* [2], make reference to the importance of information transfer to future generations. This report aims to stimulate further discussion on this particular issue.

Other publications [3,4] in the Agency TECDOC series examine in detail the types of records created during the course of radioactive waste management activities and the roles they play in meeting the reporting requirements of regulatory bodies and various other information needs. These publications also tend not to venture into the problematic area of information preservation and transfer to future generations.

The Agency had identified the challenge under the Waste Safety Action Plan Activities Action No. 6 – "explore ways to ensure that information, knowledge and skills concerning radioactive waste management are made available to future generations":

"This action arises from the need to ensure appropriate institutional control for all types of waste storage and disposal facilities (especially near-surface facilities containing intermediate and long-lived waste and facilities awaiting deferred decommissioning). One view on how such institutional controls might operate is that the present generation should pass on information, skills and knowledge to the next generation so that the latter can ensure the safety of the facility and decide on the need to continue with controls or to take some other course of action. It is thus a process, which emphasizes transfer between generations. The establishment of specific records is also a means of helping the process of long-term information transfer."

This report recognizes that preservation and transfer of information to future generations relevant to the safety of radioactive waste disposal facilities presents a complex challenge involving a variety of disciplines that include: nuclear science and technology, environmental science, archives and records management, sociology, the science of networks, morals and ethics, and economics. This report endeavours to acknowledge all these influences in considering how information preservation and transfer may be most effectively achieved.

1.2. Objective

The objective of this safety report is to examine the critical importance of the preservation and transfer of information in ensuring the safety of radioactive waste disposal facilities for future generations. The report will:

- Provide an overview of radioactive waste management and the implications these operations have for both record creation and long-term recordkeeping;
- Identify information preservation and transfer issues that are central to the requirement that future generations have access to the knowledge necessary for the ongoing safety of radioactive waste disposal facilities;
- Identify the core issues surrounding current practice that indicate that these practices are not sufficient to meet long-term requirements;
- Propose new strategies that will stimulate further discussion and help the industry adapt its information preservation and transfer practices to meet its long-term obligations.

This safety report is intended to serve the Member States managing existing radioactive waste disposal facilities or planning the development of such facilities. In particular it should be of interest to regulatory bodies and those agencies delegated with the long term responsibility for the safety of the community. In addition, this report is likely to be of interest to archivists, librarians, other records professionals and to members of society more generally who may in some way become associated with these activities.

1.3. Scope

The report explores the challenges relating to the effective use of information resources through time and the critical role played by contextual information in enabling them to be meaningfully understood. The intrinsic properties of contextual information are examined and a strategy proposed whereby a global network of contextual information could provide the framework for integrating all information resources related to radioactive waste disposal activities in a meaningful way. It is noted that the concepts developed in this report could be applied equally to other areas where there is a need for the preservation and transfer of information to future generations.

The report identifies the two key modes through which failures occur in the preservation and transfer to future generations of information important to the safety of radioactive waste disposal facilities, namely:

- **Epistemic loss** – where there has been inadequate preservation of the knowledge necessary to explain the context, structure and meaning of information; and
- **Physical loss** – where physical changes in or destruction of either the medium or the supporting technology have rendered the information unusable.

1.4. Structure

Section 1 provides the overall framework for the report. It covers the background, objectives, scope and outlines the structure.

Section 2 contains an overview of the sources and nature of radioactive waste and the regulatory environment that exists at both the national and international level.

Section 3 introduces the objectives of the information preservation and transfer process and discusses issues and challenges relating to it. In particular, this section outlines the factors that directly influence the nature of information preservation and transfer in the context of radioactive waste disposal.

Section 4 examines the issues of information media and the preservation environment. Rather than simply attempting to make recommendations for particular media for preservation of information this section attempts to elucidate the underlying issues and examines a sustainable strategy.

Section 5 brings together the issues and ideas raised in the previous sections and discusses networks and contextual information frameworks in more detail. It undertakes a reflective examination of the issues raised concerning information transfer systems and the social and operational networks that underpin this activity. Furthermore, it examines the issues surrounding the implementation of a global, multi-layered radioactive waste contextual information framework. An assessment of benefits and risks is presented.

Section 6 summarizes and concludes the report, reflecting on the many and varied issues covered. The report finishes by suggesting the next steps that could be taken to implement the proposed strategies. The authors invite and encourage feedback and discussion on the ideas presented in the report and trust that it makes a positive contribution to helping the nuclear industry meet its obligations to society.

2. Overview of Radioactive Waste, Its Safe Management and Regulation

2.1. INTRODUCTION

Activities involving the use of nuclear materials are possibly the most highly regulated in the modern world. The benefits enjoyed by society through the safe employment of these materials are manifest but the potential hazards to human health and the environment can also be significant. In order to establish a management environment that allows society to continue to safely coexist with these materials, it is necessary to ensure there is adequate and appropriate information about their location, their characteristics and their inherent hazards. Furthermore, there must be adequate and appropriate information available that establishes the case for the ongoing safety of the facilities and the effectiveness of associated management systems.

Most human-based activities result in the creation of waste and the activities involving nuclear materials are no different. The purpose of this chapter is to briefly summarise the source of these wastes, their management and the regulatory environment employed to protect human health and the environment both now and in the future.

2.2. SOURCES AND NATURE OF RADIOACTIVE WASTE

2.2.1. Sources of radioactive waste

For well over half a century, nuclear technology has been utilized in a variety of fields and has impacted on many areas of society. Consequently, radioactive waste is created in many different forms and from a wide range of sources. The Agency safety guide *Management Systems for the Safety of the Processing, Handling and Storage of Radioactive Waste* [1] provides examples of nuclear fuel cycle activities that result in the creation of radioactive waste. These include:

- Mining, milling and extraction of radioactive materials;
- Uranium conversion;
- Uranium enrichment;
- Fuel fabrication;
- Reactor operations;
- Fuel reprocessing;
- Management of spent fuel;
- Decommissioning of nuclear facilities.

Radioactive waste is also created as a result of a range of activities other than the civil nuclear power industry. These include:

- Mining, milling, extraction and processing of non-uranium minerals and resources, including waste containing naturally-occurring radioactive material (NORM) or technologically enhanced naturally-occurring radioactive material (TENORM), for example, in fertilizers, oil and gas, and mineral sands and rare-earth element minerals;
- Diagnostic and therapeutic treatments in hospitals;
- Use of radioactive materials in laboratories;
- Research and development activities carried out in academic institutions;
- Manufacturing in industry;
- Industrial radiography;
- Defence activities (weapons and propulsion).

The Safety Guides published by the Agency relating to management systems for the safe handling, storage and disposal of radioactive waste emphasize the requirement to create and preserve information such that it can be transferred to future generations. Some requirements will be of greater significance than others as determined by the nature of the waste, its safety impact and the level of regulation applied.

2.2.2. Nature of radioactive waste

For legal and regulatory purposes, radioactive waste may be defined as material that contains, or is contaminated with, radionuclides at concentrations or activities greater than clearance levels as established by a regulatory body, and for which no use is foreseen [5]. Because of the wide variety of nuclear applications, the amount, type and physical form of radioactive waste varies considerably: some wastes destined for disposal will remain radioactive for hundreds or thousands of years. Other wastes may be subject to a relatively short period of storage to allow short-lived radionuclides to decay prior to conventional surface or landfill disposal.

Radioactive waste is rarely uniform and will often comprise a complex mix of materials. For example, the dominant characteristics of one waste stream could be associated with high activity heat generating radionuclides as found in the acidic liquors resulting from fuel reprocessing whilst another may comprise low activity short-lived solid waste from medical diagnostic and therapeutic treatments. There are many variants representing a diverse array of characteristics. In an attempt to facilitate communication and information exchange and to eliminate some of the ambiguity, the Agency has developed a waste classification scheme [6] that takes into account both qualitative and quantitative criteria, including the activity level of the waste and its heat content.

2.3. THE SAFE MANAGEMENT OF RADIOACTIVE WASTE

When considering the safety impact of waste arising from activities such as those summarized in 2.2.1, the focus tends to be on the radionuclides present in the waste. However, radioactivity may not actually be the primary factor in terms of overall safety. Waste from these sources often contains other materials that have the potential to challenge safety limits (such as toxins and heavy metals) and it may be that the management of these materials takes priority.

Notwithstanding the potential impact of other materials, the safe management of radioactive waste will be determined by a number of key parameters, for example:

- The origin of the waste;
- The radiological properties of the waste including, half-life, heat generation, activity and concentration and dose factors;
- The non-radiological characteristics of the waste including, its physical state, size, volatility and dispersibility;
- The chemical characteristics of the waste including, organic content, reactivity, gas generation and corrosiveness;
- The biological characteristics of the waste.

The safe management of radioactive waste largely relies on the application of technology and resources in a regulated manner [7], so that the exposure of workers, the public and the environment to ionizing radiation is 'as low as reasonably practicable' (ALARP). The effective preservation and transfer of relevant information to those that need it will enable the waste management community to uphold this basic principle both now and in the future.

2.4. THE DISPOSAL OF RADIOACTIVE WASTE

As a consequence of the variety of sources and characteristics of radioactive waste, there have been a number of concepts developed aimed at its safe long-term management. Typically, the greater the radioactivity or radiotoxicity level, the greater the incentive has been to isolate the waste from the biosphere. However, it is the half-life of the dominating radionuclides that actually sets the isolation timeframe. It is the combination of these two factors that generally determines the nature of the waste management programme.

Most countries have developed, at least conceptually, waste management programmes that include disposal of some or their entire inventory. Various types of radioactive waste disposal facility have been developed in order to provide environmentally, socially and economically acceptable solutions that do not place undue burdens on future generations. Much low-level activity and non-heat generating waste can be disposed of in surface or near surface facilities whilst deep geological disposal is currently the preferred strategy in many States for dealing with high-level activity and heat generating wastes. In general, a disposal facility will be backfilled and sealed soon after the final waste package has been emplaced although there are exceptions where final sealing is delayed (so-called 'phased disposal').

Whichever concept, programme or facility design is adopted, once the waste package is emplaced in the disposal facility there is unlikely to be any further opportunities to supplement existing information on the package itself. All subsequent safety reviews and assessments will therefore be based on the information obtained prior to emplacement. The onus is on the waste management community - waste producer, conditioner and packager, the facility operator and regulator - to cooperate in the production of the waste package record ensuring that it is complete, comprehensive and accurate before the waste package is emplaced. Furthermore, adequate contextual information also needs to be captured documenting the administrative, operational, regulatory, financial, scientific, technical and social framework in which these records were created.

2.5. REGULATION AND RECORDS

2.5.1. The operational level

The Agency has produced safety requirements [8] and guidance documents [1,2] on the implementation of appropriate management systems for the safety of radioactive waste management. The guidance documents provide indicators for the type of information that should be created and preserved but they also recognize the need to transfer and share the information created between organizations to support the demonstration of continuing safety of operations.

The design, construction and operation of a disposal facility will be driven by a number of factors but clearly knowledge of the number of radioactive waste packages and their characteristics are fundamental requirements. The operational strategy implemented will be focused on ensuring that the basic safety requirements can be adequately met and that the integrity of the waste packages is preserved whilst the waste has the potential to affect safety and the environment. It is assumed that the disposal facility operators will be required to demonstrate that a safe operating environment is maintained and that the environmental impact is controlled for a significant period of time - even after facility closure. It follows that the information that provides objective evidence of these activities remains accessible for at least the same period of time. The period over which the facility is operated and subsequently monitored will be influenced by national and international regulation, but it can be assumed that it will range from a few decades for low-activity, short half-life waste to significantly longer time periods for high-activity and long half life waste.

Through continued research and development, it is inevitable that in the future new disposal concepts and technologies will be developed. However, as most disposal facilities will be designed for operation (emplacement of waste packages) over a long period of time (40 or 50 years), information concerning the original concepts and technologies will need to remain continually accessible to dem-

onstrate the ongoing safety of the facility irrespective of its operational status. That is to say that even after the disposal facility has been closed and sealed; there remains the need to preserve information that will help future generations to understand the significance and radionuclide inventory of the facility as a whole. Records that provide information concerning the decision to close the waste disposal facility will also need to be preserved.

The length of time for which information relevant to radioactive waste safety may be required is, therefore, determined by a variety of factors. In the short-term, or during the period of direct institutional control, the length of time will be determined by technical, regulatory, operational management and societal needs. In the longer term the primary determining factor could be the longevity of the radioactive waste itself.

2.5.2. The national level

The administrative and regulatory framework established to implement a waste management strategy will vary from one State to another. Indeed, there may also be variations within a State where regional or provincial authorities have the relevant legislative power. Overall institutional control of a radioactive waste disposal facility may therefore be the responsibility of a combination of bodies, for example, the facility operators, contractors, regulators and governmental agencies.

Ultimately, the State has a clear responsibility to establish a regulatory framework that is both coherent and comprehensive. The regulatory body will be empowered with the authority to enforce the legal requirements for all aspects of radioactive waste management, in cooperation with other stakeholders. These requirements will include the creation and subsequent management of information to demonstrate compliance and to provide an adequate inventory of the waste in that State.

The number of organizations having a stake in the safe management of radioactive waste will result in distributed collections of information, much of which will be relevant to the safety of the waste disposal facility. Some of this information may reside in government archive systems, whilst some will continue to be located within the facility operator's system. In order to provide for comprehensive reporting at a State level, access to this distributed information will be necessary and it is therefore important that the national framework recognizes the benefits of common systems for information preservation and transfer. The distribution of key information should not be considered a weakness as long as there are robust record-keeping controls in place to ensure consistency. Under the right circumstances, the distribution of information can be considered advantageous in terms of the security of the entire information set. Clearly, this does require an effective management system to be implemented at a national level.

Reporting requirements should provide the State with the opportunity to bring together the entire information set if required. This, ideally, would be undertaken by a single body under the authority of the State. The reporting body would be responsible for ensuring the information set is not only up-to-date but is also historically comprehensive and complete. Signatories to the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [[9]] undertake a regular reporting exercise and this provides an ideal opportunity for bringing together and summarizing all the information available on the radioactive waste in the State.

2.5.3. The global level

The Agency was established to provide, *inter alia*, assurance to the global community concerning the safety of nuclear-related activities. In terms of the safe management of radioactive waste it has published guidance that can be used as a basis for national strategies and this is now being supplemented by guidance on information management [3,4].

The Joint Convention also provides a framework for signatory States to report on a wide range of waste issues. The accumulated reports provide an overview of safety issues on a global scale. Through its centralized and formalized reporting processes, the Convention represents a tool for information preservation and transfer to future generations and a significant volume of information has

already been accumulated by the Agency from past reports. Embedded in the national reports is contextual information that could be systematically abstracted and used as the foundation for a global radioactive waste contextual information database. The aim of the database would be to document the regulatory, socio-technical environment for each Member State. It would also provide a means through which related information resources could be interlinked. This database would provide the basis for a web-based global contextual information framework for radioactive waste.

The Agency also provides a focus for collecting and disseminating waste-related information, an example being the Net-Enabled Waste Management Data Base (NEWMDB). More recently, the Agency has taken the lead in the provision of information network services for nuclear safety, for example, the Asian Nuclear Safety Network (ANSN). These types of information service could be included in a global radioactive waste contextual information framework, thus enhancing their use and effectiveness.

It has also been suggested that the Agency is an appropriate body for taking on the responsibility of managing an international radioactive waste disposal archive. The concept of a contextual information framework is entirely consistent with this suggestion as it would significantly enhance the utility of the archive as a recognised and accessible source of authoritative information.

2.5.4. Information categories related to radioactive waste

The activities that culminate in the emplacement of radioactive waste in a disposal facility involve the creation of information that can later be used to demonstrate the safety of the disposal facility itself. With the expectation that society will seek reassurance about the safety performance of the facility for many years, it follows that the information will be afforded an equivalent level of importance by future generations.

Below is a summary of the broad categories of record that would be expected to be preserved. Much of the information will be contained in paper or electronic files and these may cover some or all of the following aspects of facility management [3]:

- Waste processes, treatments and conditioning;
- Waste components, characteristics and inventory;
- Waste packaging and storage;
- Responsibilities, ownership and roles.

Records created through disposal programme and facility activities can include the following [4]:

- Site selection;
- Siting investigations and environmental impact assessments;
- Safety assessments and safety case;
- Licensing;
- Construction;
- Operation;
- Closure.

Records created as a result of the demands of institutional control can include:

- Regular monitoring and surveillance of waste packages and facilities;
- Formal inspections of waste packages and facilities;
- Education, training and qualifications of staff;
- Records management, archives and databases.

Records created through the activities of and relationships between the higher level organizations would include:

- Regulatory agency reporting;
- Financing agency reporting;
- Community outreach;
- Legislation;
- International conventions.

It is essential that all records are managed in systems that document the context of their creation and use through time. All records should be:

- Uniquely identified and labelled;
- Named – using meaningful titles;
- Dated – using singular dates or date ranges as appropriate;
- Coherent – the structure and content of the record should be inherently meaningful;
- Traceable to the persons or agencies responsible for the creation and subsequent life individual records;
- Described and/or annotated to provide a clear indication of their relevance, and this should include the addition of controlled index terms;
- Filed and documented in a manner that establishes links with related records, especially other records which collectively act as evidence of operational practice;
- Stored in humanly manageable units;
- Stored so they can be readily retrieved;
- Managed so that they can be integrated or interconnected to other information systems; and
- Managed so that their place in the record-keeping system is self-evident (i.e. it will be noticed if they are missing and can be easily returned if they are removed).

2.6. ONGOING RESPONSIBILITIES

The ongoing responsibilities for regulators and operators with respect to radioactive waste disposal facilities include various types of audit, in particular site monitoring and safety assessments. Safety assessments conducted in recent times have made use of site visits and inspections, published reports, archival records and data, and meetings with staff involved in the original design and construction of the facility. They have proven to be a useful tool in evaluating the range of records and contextual information required to understand the history of a facility and assess its current condition.

The waste facility safety assessment is an important document that summarizes the broader context in which the facility operates. As time passes and the facility ages, further safety assessments will be required and a key part of their function should be to document the subsequent changes in the operational and environmental context. Access to archival materials, which will need to be retrievable and understandable, will be a necessary part of any safety assessment process and this process itself could be used to evaluate the quality of the records and the archival management systems.

Archival records must therefore be well managed and accessible to those undertaking safety assessments. It is the responsibility of the archive manager to ensure that the records are preserved and the information contained therein remains accessible. However, it is also the responsibility of the safety assessment team to evaluate the archive and to establish that the records are indeed accessible, usable and able to be cited as specific sources in the safety assessment report. The safety assessment evaluation of the archive should also ensure that there is sufficient supplementary or contextual information available to facilitate the meaningful use of the records.

3. Information Preservation and Transfer

3.1. Introduction

Information will be required to help ensure the safety of the disposal facility during the implementation of a waste disposal programme, to minimize the risk of inadvertent intrusion and to enable decisions on the possible reuse of the site, its contents and surrounding areas in the future. Information will also be required to establish the safety case for the facility and for communicating with stakeholders including academics, politicians, the media, environmental interest groups and the general public. This information will be found primarily in the traditional records generated as part of a well regulated waste disposal programme but it may also include information in other forms such as living memory, publications, objects, monuments, markers, ideograms, and multimedia products. At any point in time, the stakeholder group will posses a broad spectrum of individual knowledge, experience and needs – thus the specific information that the waste management community makes available must reflect this reality and seek to meet the needs of the wider community by providing information at the appropriate level of detail and complexity.

3.1.1. Active and passive systems

Information can be preserved for future generations utilizing both active and passive systems. Active mechanisms require human activity or intervention to function effectively. A simple example is the training of successive cohorts of new staff engaged in a waste disposal programme. Conversely, passive mechanisms such as the creation of long-lasting monuments and markers do not require ongoing human intervention to ensure their continued viability. The use of an information system that necessitates active management would ensure that the information resources are regularly appraised and critically assessed for quality, meaning and relevance to both current and projected future societal needs. A passive system employed as one of the last lines of defence, could equally contribute to current and future societal needs by reducing the risk of inadvertent intrusion into a disposal facility, especially where other active systems have failed or have been intentionally suspended.

The use of both active and passive systems for preserving and transferring information should be considered together in order that a robust set of strategies is deployed.

3.1.2. Sustainability

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. Its report [10] 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”. This principle underpins the work of the Agency in its attempts to help the nuclear industry work towards processes that will effectively manage radioactive waste both now and in the future. However, the issues surrounding the successful preservation and transfer of information about radioactive waste to future generations have proved both problematic in practice and conceptually challenging.

3.1.3. Epistemic and physical loss

Information must be preserved in such a way that a future society has sufficient trust in its authenticity and veracity to use it with confidence. Furthermore, the information objects or resources 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, the experience gained thus far in the radioactive waste management community as well as in society more generally suggests that existing information infrastructure (that is both systems and practices) is ill equipped to meet this challenge. Failures of effective information preservation and transfer, whilst not restricted to the radioactive waste community, have occurred both within the current generation and between preceding generations.

During the past thirty or forty years there have been some notable examples of the human race investing considerable resources to obtain non-reproducible information (such as that obtained through space exploration) only to discover years later that it is no longer accessible. Although this is often as a result of the inadequate planning of its long-term curation, there appear to be two major reasons why these information management failures have occurred:

- **Epistemic loss** - where there has been inadequate preservation of the knowledge necessary to explain the context, structure and meaning of the information; and
- **Physical loss** - where physical changes in or destruction of either the medium or the supporting technology have rendered the information unreadable.

It is epistemic loss which is least evident to contemporary generations but is perhaps the most critical. Interestingly, early preoccupations in both the recordkeeping professions as well as in the nuclear industry were focussed on finding solutions to physical loss, whereas it is only recently that the issues of context, structure and meaning started to be addressed. It is the need to sustain knowledge of the elements that comprise both the complex socio-technical framework and the specific circumstances that surround any particular information resource which is at issue here. The nature of nuclear technology and radioactivity itself has been the focus of exhaustive study by scientists, technologists and engineers over the years. The knowledge generated by these studies is typically preserved as stylised information condensed and abstracted in scientific publications and transferred to future users through the established library system. Furthermore, the scientific practice of citation of related work captures part of the epistemic framework required for comprehension. But what of all the other elements of the socio-technical framework; the politics, the intra- and inter-organisational relationships, the day-to-day running of a nuclear facility, the regulatory framework, and the human-to-human interactions - how is this knowledge sustained over time? The recorded evidence of the activities of a radioactive waste program is not typically held in scientific publications but in records and other information resources that lack the robust public infrastructure that supports scientific literature.

Where information has survived and remained accessible for many years it has often been the result of accidental circumstances rather than well-planned and adequately resourced processes. The information required to manage the long term safety of radioactive waste is so important that the present generation cannot afford to ignore information preservation failures of the past. It must also be prepared to invest the necessary resources now not just to remedy the inadequacies of past practice but prepare more robust systems for the future.

Epistemic loss typically occurs when information is recorded and preserved in isolation and exists, therefore, out of context. Information has limited use, for example, if its provenance is unknown, its significance is unclear and the creator cannot be consulted to explain semantic ambiguities. Relatively simple systems designed to preserve records can be deployed but if they are not meshed 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.

3.1.4. Information infrastructure

Traditionally the management of the variety of information resources has resulted in the archives looking after records (unique resources); libraries looking after published resources and museums looking after objects. This tripartite information infrastructure is common across the world but these essentially artificial distinctions based on aspects of physical form pose challenges for unified access, management and control. The information communities are well aware of this issue and are endeavouring to deploy new information architectures, for example, contextual information frameworks, to provide a better service to users. These frameworks use shared contextual information to link information resources in separate systems.

It is necessary that the radioactive waste industry creates information resources (for example, documents, reports, waste inventories, photographs and material samples) in such a way that they can be

managed in accordance with prevailing international standards that require the documentation of contextual information [11]. This not only will enable interoperability, system migration, data re-use, and the development of a substantive workforce with common skills but it will enable the establishment of interlinked information networks that meet local, national and global needs. Compliance with national standards is also a desirable goal and in some countries may be mandatory. The interoperability between international standards and national standards will need to be addressed on a case-by-case basis.

With regards to records management more generally, the International Standards Organization (ISO) has produced standards for information and documentation structures, records management, and metadata structures for describing records [12]. The International Council on Archives (ICA) has also produced standards designed to ensure that records are described, indexed and managed in a form that permits users to recreate the context of their creation and use [13]. The archival profession has a traditional role in ensuring that adequate contextual information is captured in association with records to enable their use as evidence of past activities. Although the profession has tended to limit its vision of the extent and utility of contextual information, the concepts embedded in its archival authority record standard could be applied more widely and to great effect.

3.2. OBJECTIVES OF INFORMATION PRESERVATION AND TRANSFER

3.2.1. Information preservation

Outside the information management community, the term 'information preservation' is often viewed as a discrete, short duration activity that results in information being converted into a form that is suitable for long term storage. In the context of this report, however, it has a much wider definition in that it represents a process that allows subsequent users of the information to approach the same level of knowledge about a particular topic as those involved in the original activities.

The objective of information preservation therefore, is to continually manage information (usually in the form of records) such that it delivers equality to all users in terms of original meaning, significance and interpretation.

3.2.2. Information transfer

Information is created as a result of all human activities and the safe management of radioactive materials is an example of an activity that has the potential to create significant amounts of information – much of which is likely to continue to posses a high level of relevance for a long period of time. The objectives of radioactive waste information transfer are many and varied. The objectives may also vary over time as a result of the need to meet changing needs, but are expected to include:

- Engaging stakeholders including the general public, academics, environmental interest groups, politicians and the media;
- Ensuring management system compliance;
- Establishing the case for the safety of the facility;
- Explaining intent;
- Providing detailed technical description of facilities for handling and disposing of radioactive waste packages;
- Providing information on the host site geosphere and biosphere;
- Demonstrating safe and effective practices in creating radioactive waste packages;
- Providing evidence of regulatory compliance;
- Alerting successive generations of the potential hazards involving radioactive waste;
- Informing societies of the presence of radioactive waste.

The 'transfer' of information should be viewed not so much as the physical transfer of information resources but the action of making information available in a form that can be accessed by future gen-

erations. 'Transfer' of information implies that the information set can be defined in advance to meet known needs. However, the information necessary to carry out a revised or retrospective safety assessment may be broader than anticipated and it could be necessary for a future generation to gain access to a considerable amount of supplementary data or contextual information.

3.2.3. Importance of information preservation and transfer

Successful information preservation and transfer is absolutely necessary as part of the responsible management of radioactive waste as defined at all levels within the operational and governance frameworks and for all relevant timeframes. Information management activities that rely solely on preservation are highly likely to fail to meet the needs of future generations. Transfer activities require the assessment of the physical condition of the media and the accessibility of the information, and the associated meaning. Transfer activities should be undertaken on a regular basis within each working generation.

Information preservation and transfer is required:

- in the very short term (the intra-generational phase) to ensure that radioactive waste disposal facilities and related organizations function effectively on a day-to-day basis, for example: that new staff are appropriately trained, that operational processes and technologies are understood, that necessary implicit or tacit knowledge is maintained, that regulatory compliance is assured, and that all reporting requirements are met;
- in the short-to-medium term (the beginning of the inter-generational phase) to ensure that the implementation of a waste disposal programme including site selection, construction, operation and closure and any organizational or regulatory framework change is undertaken with access to all necessary information; and
- in the long term (the inter-generational phase) to ensure that access to information relevant to the safety of radioactive waste is available to whomever may require it.

The importance attached to the need for systems of information transfer stems from the fact that society considers that there are immediate and on-going safety issues associated with the creation, processing, handling and disposal of radioactive waste. In addition, by accepting the need to minimize the burden on future societies, there is an inherent responsibility on today's society to provide accurate information to enable informed decisions to be made that contribute to the safe management of the waste.

3.2.4. Objectives of information preservation and transfer processes

No matter what the perspective, whether short term or long term, the basic principle of radioactive waste management with regard to future generations applies. That is, the actions of the current generation should impose no undue burden on future generations (that is not to say that a future generation should absolve itself from the safe management of facilities used to dispose of radioactive waste). From this premise, the objectives of a system designed to preserve and transfer information to subsequent generations can be summarized as the following:

- It should minimize the risk of inadvertent intrusion into a radioactive waste disposal facility whilst the content still has the potential to pose a threat to safety. In simple terms, current and future generations need to know that the facility exists, exactly where it is located and why it may pose a threat to safety;
- It should enable the subsequent generation to evaluate the safety of the radioactive waste disposal facility and to make its own decisions as to what further action should be taken with regard to the continuity of the disposal programme, the physical maintenance of the facility and the further transfer of relevant information to the next generation.

It is the absolute responsibility of each generation to create and preserve information about radioactive waste in a form such that it can be transferred to the following generation. The next generation

may wish to use the information to ensure that their safety-related decisions are founded on an accurate and reliable understanding of the waste.

3.3. CHALLENGES

During all phases of a waste disposal programme, including pre-disposal, emplacement and repository post-closure, a programme of systematic and managed information preservation and transfer will be necessary. Those involved in the preparation of information for transfer will face significant challenges, which may begin even before waste packages arrive at a disposal facility since the chain of events preceding the disposal could itself span a considerable period of time. This process should be one of the very first functions implemented at the outset of a radioactive waste management programme.

3.3.1. Continuity of responsibility

The ownership of the disposal facility and the responsibility for its operation and maintenance may not necessarily rest with the same organization, especially over long periods of time and there may well be a loss of management system continuity. Indeed, it is likely that a succession of different organizations will be responsible for the management of the disposal facility each utilizing variances of the original management systems and governed within an evolving technological and regulatory framework. Experience in other industries has shown that it is at times of change in operational control, organizational structure and/or industry regulations that the information preservation and transfer process is at most risk of failure. Due to the nature of the radioactive waste and its implications for safety, it is critical that any failure of the process is anticipated and that strategies are implemented to minimize the effect.

3.3.2. Changes in the socio-technical framework

Significant change is inevitable, not just within the organizations directly responsible for managing radioactive waste but in all the ancillary organisations and other stakeholders with an interest in the safety of the waste disposal programme. Change is also an inevitable outcome resulting from advances in science and technology. There are a range of key parameters that represent the broader context within which the waste disposal programme will exist. Changes in these parameters will likely influence the nature and character of the framework that underpins radioactive waste safety. These parameters include:

- Waste management policy;
- Waste management regulation;
- Societal structures;
- Scientific and technological advancement;
- Evolution of the facility and package;
- Changes in land use;
- State and organizational governance;
- Language and meaning;
- Climate change.

It is presumed the next generation will be aware of the social, political and natural climate in which it operates. In addition, it is likely that they may have a requirement for the same information that influenced the generations that undertook the initial steps in the waste management programme. Indeed, they may need to recreate the context surrounding any previous event, to understand the significance of the information resources associated with that event and, ultimately, to understand the consequences of the event. As a result, each generation may need access to the wide range of information sources that document relevant historical, regulatory and operational frameworks from all time periods in the life of the facility.

3.3.3. Information formats and interpretation

Aside from the issues associated with the subject matter of information resources, which in relation to radioactive waste management were covered in the previous section, there are two essential aspects of information that play a major role in determining the ultimate viability of the preservation and transfer processes:

- The format of the content; and
- The interpretation of the content.

Both format and interpretation are the result of human actions and play a major role in determining the likelihood or not of epistemic loss. In other words, if the technology used to code the information content (the format) remains viable and the evaluation of the information content for meaning and comprehensibility is possible then the foundations are established for effective information preservation and transfer.

Information exists in many forms, but for the purpose of developing techniques for information preservation and transfer it is assumed that it exists in discrete units that are variously referred to as information objects or information resources. The content of an information resource can be expressed in various ways including the spoken word, actions, text, pictures, sound, moving images, ideograms, computer codes, and as physical objects. As well as content being of human origin it may also be an inherent property of the material of the resource, for example, a biological sample, a chemical sample, or a geological sample.

In relation to radioactive waste, these information resources will generally comprise discrete data sets, documents, publications and samples, many of which are produced in vast quantities.

3.3.4. Implicit and explicit knowledge

In broad terms, the information resources created during the course of a radioactive waste programme comprise:

- knowledge created by direct experience and preserved in living memory; and
- records, including objects, samples and other documents, created either deliberately or as by-products of transactions and activities

Knowledge created through individual and group experiences is one of the principal means by which humans are able to work successfully together. Common knowledge, on-the-job training, complimentary world-views and the building of trust are some of the key elements of this shared information environment. The transfer of this knowledge relies predominantly on people. More accurately it involves a succession of people from different generations accumulating the knowledge in question.

Knowledge preserved only in the minds of individuals can be very long-lasting in cultures without a tradition of written records, but as a rule is less so in most modern societies. In order to establish a greater robustness of memory and information transfer, human knowledge in modern society is often transferred to externalized information objects in the form of records of processes and activities.

It is recognized that issues associated with person-to-person transfer of implicit knowledge and expertise are critical for successful information transfer in the short term. The key point to note is that it is this common knowledge that enables things to function and provides the contextual framework in which work is undertaken. Some of this context must be documented and made explicit if the records created as a result of the work are to be understandable in the future. The management of knowledge has been recognized by the nuclear industry as an area of critical concern if it is to meet continuing organizational, security, safety, regulatory, social and scientific needs.

Recordkeepers, librarians and other information custodians need to ensure that they have the capability to link their explicit information resources into larger information networks. To achieve this they will need to ensure they maintain relevant contextual information in a form that enables interlinking or citation between systems. Furthermore, individual custodians may have to manage a broad range of information resource types including archival, museum and library materials and ensure that their resource management and contextual information registers (metadata) meet the appropriate international standards.

3.3.5. Selection of information for future use

It may not be possible, necessary or desirable to keep all information for all time; however, it will all be kept for some period of time. Those periods will be determined by the roles the information plays in meeting the reporting and accountability requirements of the work environment.

The issue here is identifying the factors that lead us to selecting which records are to be preserved, and for how long. The relevance of each information object can change with time and circumstance and it is not possible to predict, with absolute certainty which records will be required in the future. As a rule, we find it easier to identify those records that will be required for the present and immediate future because we understand the social, political and ethical environment. The risk here is that we may not create an information resource that documents the common knowledge of the time and leave associated records open for misinterpretation.

Appraisal of records is an ongoing management process that will continue from one generation to the next. This process will naturally lead to the selection of records for preservation. It is to be expected that some records, for example, the waste inventory, will be critical for the well being of society and the environment and will be singled out for special management as long as the facility has the potential to impact on safety. Experience has also shown that records that establish the identity and mandate of organizations not only capture important contextual information but also play a critical evidential role for legal and historical purposes and will need to be preserved for substantive periods.

The nuclear industry, of which radioactive waste management is a sector, is one of the most highly regulated and actively managed industries in the modern economy. Quite naturally the industry creates records containing important information in the expectation that they will remain accessible and interpretable as and when they are required. However, many regulations tend not to recognize explicitly that some records are produced not only to demonstrate compliance but also to inform both current and future generations. Indeed, the records that demonstrate compliance may not contain information in the form that is helpful for future generations. Regulatory requirements clearly vary from country to country but few appear to address systematically the very specific long-term epistemic complexities.

3.3.6. Managing contextual information

Records documenting the construction of a radioactive waste disposal facility in a certain year and certain country will have specific form and content determined by the record creation protocols of the day and the regulatory reporting requirements of the country. Moreover, the records will reflect the local organizational context which is again specific to the particular time and place. The records will include details of actions taken, of decisions, design, siting, and of process. These records are not generated in isolation but within a multi-layered contextual framework that extends beyond the local waste disposal operations in which they were created. This extended contextual framework is defined by a number of factors including the individuals and organizations involved; the regulatory framework; governmental structure; the geographical environment; the international community; climate change; major events; and the scientific basis for the industry. The records themselves cannot therefore be accurately interpreted in isolation but must be understood in the broader context. Contextual information provides insight to the waste disposal operations and is essential for the accurate interpretation of the detailed waste records.

The required contextual information will be partially documented within the waste information records themselves. However, the contextual framework is rarely (or only occasionally) recorded in its own right as it tends to exist as a body of tacit or implicit knowledge readily accessible to those working in the field at the time. Information about context, as a rule, is generally accumulated in an *ad hoc* manner in records created by the relevant bodies over time. Occasionally attempts will be made to draw together this contextual information in the form of organizational histories. These compilations are often useful but rarely sufficient to meet the systematic requirements of a fully functioning contextual information database or framework.

3.3.7. Special challenges for radioactive waste safety

The previous sections list some of the issues and challenges that apply to information preservation and transfer more generally. When applied to the safety of radioactive waste disposal facilities, some further specific issues should be considered. Some of these issues extend the needs for information preservation and transfer beyond the capabilities of existing information management systems.

- There is a premise that future societies cannot afford to be unaware, at any time, of the presence of sites that have been utilized for radioactive waste disposal while the waste has the potential to pose a hazard to life and the environment.
- It is known that some of the wastes disposed of at these sites will have long half-lives and are therefore likely to pose the hazard far into the future.
- In order to address these issues, managing information not only about the waste itself but about the facility (for example, its location, physical size, waste capacity, waste types, backfill materials and monitoring strategies) is clearly important. The need to manage this potentially vast amount of contextual information, whilst ensuring that it remains accessible to those taking on the responsibility for the safe management of the facility or the site, is a challenge as important as any yet to be faced by the nuclear industry.
- Amongst the many variables, the important factors influencing safety are the nature, quantity and characteristics of the waste packages and the design of the disposal facility. Detailed records must be kept of the contents of the waste packages, the technology used in their production and the technology used in the building of the disposal facility itself. The Agency has issued guidance on how the vast amount of potentially useful information should be categorized [3] and subsequently managed [4].
- Information is created during routine operations in order to meet regulatory requirements. However, not all of this information will be subject to intergenerational transfer. Appropriate processes must be developed that allows the relevant safety information to be identified and prepared for transfer.
- The natural evolution of the facility and the waste packages will eventually lead to their degradation and this makes it necessary that information on the original design, construction and operation (including data collected during operational and post-closure periods) is retained to support ongoing safety assessments.
- In order that adequate information on the status of the facility is created, monitoring records and details of changes to facility design and equipment refurbishment must be preserved in order that future custodians of the facility or site are sufficiently well informed. These records will establish a continuous link between the present and the past and will enable future societies to maintain a continuous awareness of the safety issues involved.

The Agency recognizes that the State will need to determine the quality, level and detail of the information that will need to be retained when "taking into account that the information required will be used by future generations" [3] as it is the State that will have the ultimate responsibility for ensuring safety.

4. Information Media and the Preservation Environment

4.1. Information media issues

Earlier sections have contained brief references to the range of information media available. It is not the purpose of this report to recommend a particular type or category of media as the choice will be determined by each States' waste management strategy. However, the opportunity is taken to highlight some of the generic issues that may arise from the selection of certain media and the need to prepare the information for preservation and transfer. Media selection is a key issue that must receive appropriate consideration.

For reasons discussed elsewhere, there will be a requirement to manage radioactive waste-related information for a significant period of time as a result of the long-term potential hazards associated with the waste. It is not unreasonable to assume that society will continue to have an interest in the information for a period in excess of the accepted 'lifetime' of much of the media in common use today. It is the implications of information loss resulting from the use of inappropriate media that has provided the driver for the radioactive waste information strategies adopted by some waste management organisations rather than the value to present and future society of the information itself.

A strategy that could be adopted is for the regular assessment and migration (copying) of information using existing, commonly available media. By adopting this strategy, a migration exercise may need to be carried out on cycles as short as three to five years depending on the media selected. A variation of this strategy might be to employ media that has an extended and proven lifetime, such that the migration cycle can be defined in terms of several decades. This would allow a more measured approach enabling information custodians to consider alternative management strategies whilst ensuring the integrity of the information. Another strategy may involve the development of a medium that requires virtually no active management over very long time periods (several hundreds of years). Each of these strategies could be effective and each will have distinct advantages and disadvantages. It may be that a combination of these strategies will provide the most appropriate solution.

A key principle when developing a strategy is to 'keep it simple'. Particularly complex 'media systems' where it is necessary to have access to specialist expertise, knowledge or non-standard equipment to recover and convert recorded information into a 'readable' form should be avoided - especially where it is envisaged that access to the recorded information will be infrequent. Where specialist equipment is required it may be necessary to preserve and transfer it as well as the record.

Ideally, information will be preserved in such a way that:

- it can be recovered and converted into a readable form without the need for proprietary technology or knowledge;
- it can be accurately copied and migrated to new media without loss of content; and,
- it preserves the metadata that contains information on the record creation, history, provenance and means of access (particularly important when using digital media).

Before adopting any strategy a number of factors, in addition to the media, should be considered. These include the time period over which the information is required, the quantity of information created and the need to provide an effective information management system that comprises content referencing, description and indexing.

4.2. MEDIA SUITABLE FOR RADIOACTIVE WASTE RECORDS

4.2.1. Hard copy media

Hard-copy media are defined as those for which information can be recorded with the minimum amount of conversion and from which the recovery of the information is a single operation. The principal candidates in this category are paper and microform.

Information has been recorded on paper variants for thousands of years. The information is generally easy to recover (assuming the language is familiar) and the medium is relatively robust and sufficiently long-lasting for most needs. Paper also tends to degrade slowly (unless subjected to conditions that result in a catastrophic loss of integrity) and this offers a reasonable timescale for a conservation programme to be invoked or for the information to be duplicated elsewhere. Many paper-based products are well characterised and this allows us to predict its evolution under normal circumstances. The increasing demand for recycled products, however, does introduce an element of risk where long-term records are concerned, if there is insufficient knowledge concerning their manufacture.

The duplication of paper-based records does tend to be a time-consuming exercise and once produced they can occupy a significant amount of space, especially if multiple copies are maintained to reduce the threat of total loss. The records in themselves also have the disadvantage that, without the introduction of a separate management system, they can be difficult to search and, thus, identify pertinent information.

Some specialist paper manufacturers produce paper to exacting standards that is intended to remain in a stable and usable form for many decades. These papers are manufactured to international standards [[14],[15]] and may be considered entirely appropriate as part of a strategy for the preservation of radioactive waste information.

The copying of paper-based information to microfilm or microfiche (collectively termed 'microform') was common practice in the late twentieth century in an attempt to reduce the amount of storage space required. The production of the microform requires relatively straightforward photography techniques to produce and the recovery of the information requires only a light source and optical magnification to make them readable. Some manufacturers claim a life expectancy of 500 years for silver halide on polyester base films, whilst silver halide on a cellulose triacetate base is said to be stable for 100 years in accord with the requirements of international standards [[16],[17]]. The use of microform media is somewhat less popular today with the advances made in digital data recording techniques. However, it does have the advantage of requiring relatively simple technology to both produce and recover information with relatively low inherent costs.

4.2.2. Digital media

In contrast to hard-copy media, 'digital' media are defined here as those for which the information is converted into an electronic form that requires subsequent processing to make it intelligible to humans. 'Digital information' includes both information that is created and presented electronically (so-called, born digital) and that which is subsequently digitised (for example, electronically scanned hard-copy records).

There are a wide range of digital media and it is not the purpose of this report to review or even list each one. However, for simplicity, they can fall into one of a number of categories, including magnetic tape, magnetic disc and optical disc. Also included in this category is mass data storage devices such as network servers.

The management of information preserved on digital media requires specialized technology however common the technique appears. Experience of the use of digital media in the past fifty years suggests that it has a relatively short life expectancy and the information stored on them (for example on mag-

netic disks, tapes or CD ROM) can be subject to sudden total loss without warning. Digital media are also entirely dependant on complex hardware and software for accessing the digitised information and converting it into a form that humans can read.

With the range of technology currently available, digital information can be readily converted to analogue (or physical) forms and stored on more stable media with longer life expectancies, for example, archival paper and microfilm. It could also be stored in stable forms that permit its transformation back into an active digital state. Information preserved in this way also occupies far less space, can be easily searched (providing the appropriate indexing protocols are implemented) and can be copied quickly and efficiently with good levels of accuracy. One of the principal disadvantages of preserving information on these media is that the information can easily become 'de-contextualised', for example, the context surrounding the creation and use of information is likely to be lost if the file is copied elsewhere. This will reduce the value of the information or, in the worst case, cause it to become completely unusable for its intended purpose or indeed for any other purpose.

However, the strengths of digital media and technologies include:

- Ease of copying, for backup security and re-use;
- Ability to link information using network technologies;
- Substantive and improving storage capacity;
- Searchability;
- Ability to create a variety of contexts in which the information can be utilized; and
- Separation of storage and work stations.

4.2.3. Specialised media

With the increased recognition that there is a need to preserve selected radioactive waste related information for periods of time in excess of those traditionally associated with records management programs, some organisations have developed specialised media. An example of a system that has been recently developed is that of laser-engraving data onto silicon carbide plates by the Japanese [18]. Studies carried out during research have suggested that the silicon carbide plate is an extremely durable material that is very strong and is resistant to corrosion and wear from abrasion. The use of precision laser-engraving has enabled the issue of quantity to be addressed - an early trial of the system demonstrated that information contained in five hundreds pages of an A4 sized report could be transferred onto 42 silicon carbide plates measuring 10 cm x 10 cm x 1 mm. The durability of the silicon carbide medium suggests that it would be possible to preserve documents without the need for sophisticated preservation environment controls, further migration or other human intervention for at least 1,000 years.

Recovery of the information is relatively straightforward using appropriate magnifying equipment. An alternative approach to recording the information in common text is to inscribe digital information converted to analogue form directly onto the silicon carbide tile as an alternative to microfilm. An extension to this, which echoes back to the strategy used by the creators of the Rosetta Stone, is to provide dual transcription where the information is provided in both digital (in binary code) and human-readable textual form on the same tile.

As technology continues to progress it is conceivable that other media and recording systems will be developed and there are likely to be alternatives to those described above. Those responsible for future information management are to be encouraged to consider the full range of classical and novel media and recording systems in order that access to key information is maintained.

4.2.4. Considerations when selecting media

Within the last twenty years the technology available to document and manage records has gone through revolutionary changes with the introduction of computer-based information technology. However, experience in a variety of industries has shown that while the new digital technologies

have appeared to bring short-term gains, in the longer-term it appears that what has resulted is a surfeit of poorly controlled information resources in systems that make it difficult, if not impossible, to locate specific records.

The selection of media type for records should be made with the expectation that the information resource will be required for longer term preservation and, ultimately, migration to new media. When high value, mission critical information is migrated, it is recommended that at least two copies be kept. At least one copy should utilize long-term non-digital archival media. Where high value information is in digital form it should be preserved using non-proprietary digital technologies.

Issues that must be considered when selecting media include:

- Technical characteristics - consider the need for specialist equipment and techniques for recording, recovering and converting the information into a human-readable form;
- Availability - the media should be readily available in sufficient quantity to meet the immediate need;
- Cost - the cost of preparing the information, obtaining the media and preserving both should be considered. Exotic media are likely to be more expensive to purchase;
- Environmental conditions - the media selected should be durable and, as far as possible, resistant to degradation under 'normal' environmental conditions;
- Handling - media requiring special handling techniques in order to preserve integrity should be avoided;
- Quality – bulk supplied, low quality media should be avoided;
- Proven performance – media with demonstrated performance characteristics and an established user community should be preferred.

4.3. MEDIA PRESERVATION

4.3.1. General considerations

The long-term durability of most media is highly dependent upon environmental conditions such as temperature, humidity and the presence of potentially harmful substances. Within reason, the environment in which the records media is handled and subsequently stored can be optimised using relatively inexpensive mechanical systems. Experience in managing information resources over recent years has demonstrated that the maintenance of an appropriate storage environment can significantly enhance the long-term preservation of information media.

For optimum material stability and preservation, there are recommended temperature and relative humidity levels that vary with the media. However, a compromise may be required if staff are to have ready access to the materials within the storage facility. The information management system will need to take account of the media storage regime, which is likely to be either:

- Optimum preservation storage - where information resources are stored in ideal conditions with limited access and disturbance;
- Access and retrieval only - where information resources are infrequently handled or accessed;
- Combined storage and usage - where the information resources are frequently handled or accessed but where controlled conditions are maintained.

The environmental conditions should, above all, remain stable within the recommended range. Environmental conditions should be monitored and controlled, ideally, by an automated environment management system.

The following sections provide an indication of the issues that should be considered when storing media. The requirements are not exhaustive and reference should be made to manufacturers' instructions and the appropriate international standards for a definitive guide.

4.3.2. Specific considerations for paper-based records

Poor storage conditions will have a detrimental effect on the condition of paper and its useful lifetime. Appropriate management arrangements should be made such that they are consistent with national standards for the preservation and handling of paper-based records.

Records, and copies of records, should be stored at specifically selected locations and an effective standards-based record management system implemented. Paper-based file covers, folders, wallets and envelopes used to store the records should conform to the same standards as the paper record itself. Before placing the record in any protective packaging, it is important to ensure that it is free of dust and unaffected by mould, insects or contaminants.

4.3.3. Specific considerations for magnetic media

As with hard-copy media, temperature and humidity will affect the longevity of magnetic media. A high humidity level will present the main risk as this may promote hydrolysis in the binder material. The risk is increased where high humidity is coupled with higher temperatures (that is, above 'normal' room temperature). Air conditioning and dehumidifying equipment may be necessary to maintain the optimum conditions. Where high humidity cannot be controlled by this method, a desiccant material may be used but care should be exercised as there may be a tendency to reduce humidity to such an extent that static electricity becomes a problem.

Atmospheric impurities can adversely affect the magnetic particles on tape. In addition to corrosion caused by excess moisture, some volatile chemicals can reduce tape lifetime by attacking the binder and the polyester substrate. It follows, therefore, that the atmosphere in the storage area should be kept as clean as possible. Sources of pollution include cleaning agents, paints and fumes.

Magnetic tape can be damaged by a variety of storage and handling practices. Possibly the most important preventative measures are that tape should be wound to the recommended tension and that the tape reels or cartridges should be constructed such that the tape is wound evenly without irregularities that could cause it to deform over time.

Finally, magnetic fields created by electronic equipment have the potential to alter the orientation of iron particles on the tape thereby deleting or indirectly altering the recorded data. Magnetic media should therefore be stored in cabinets that eliminate this particular risk.

4.3.4. Storage of optical media

Disks can be damaged by a variety of storage and handling practices. The particularly vulnerable part of an optical disk is the coating protecting the reflective and data carrying layers. The storage temperature should be maintained just below normal room temperature and significant variations in both the temperature and the humidity avoided.

The precautions taken to optimise storage of magnetic media are equally applicable to optical media. Indeed, the problems associated with magnetic and optical media are such that the content of the media, if not already digital, should be digitized and transferred to an active server-based network that is regularly and systematically backed-up.

4.3.5. Storage of other media

Ideal conditions will clearly be dependant on the media. Extensive research has shown that silicon carbide tiles, as described in section 4.2.3, are very resilient and less susceptible to degradation due to variations in storage conditions. They may well survive catastrophic failures which would be ex-

tremely harmful to most 'conventional' media. However, as with all media they do rely on an active management system and institutional control for access.

Before any media is selected, consideration must be given to the need for specialist procedures or environments. The greater the need for human intervention the greater the risk to the media if there should be a loss of institutional control.

4.4. MARKERS AND MONUMENTS - A SPECIAL CASE

It has been suggested that an all-embracing set of strategies covering information transfer should include the utilization of permanent monuments and markers on the sites of the radioactive disposal facilities. Stone and earth-based monuments and markers designed to withstand tens of thousands of years of natural erosion have been proposed. Some strategies suggest that the information transfer component of the monuments and markers should be entirely symbolic and suggestive and not based on the need to use 'conventional' language. However, inscriptions providing essential information in multiple languages, such as was used by the creators of the Rosetta Stone, are also deemed possible.

Clearly, while a disposal facility is in operation and during the period immediately after closure, there is likely to be a need to maintain detailed information on the contents of the facility. However, many years after closure, detailed information may not be necessary. It may be sufficient to record the fact that potentially hazardous materials are present in a certain location and that their intentional or accidental extraction should be avoided. It is at this point in time that marker systems may be of prime importance. Numerous studies have been undertaken in an attempt to better understand how disposal facility marker systems will be used but it is not intended to reproduce the conclusions here other than to acknowledge that they are simply another addition to the range of information resources.

Strategies developed to mark disposal facilities are likely to acknowledge the fact that there is a possibility of collapse of the socio-technical society as it is known today. Marker systems will undoubtedly form an element of the broader strategic solution but they are unlikely to fully address the essential and pressing problems facing information transfer during the operation and immediate post-closure phases of a radioactive waste management program.

4.5. REPLICABILITY

A key issue that needs to be addressed in addition to media is that of replicability of information. Information replicability must be timely, accurate, complete - not only the data contained in the previous record but the contextual information that enables the recorded information to be understood and correctly interpreted. The transfer of information from one media to another must be accompanied by a history that tells the story of the migration and transfer of the original source through time - this ensures traceability to the original, and preserves as far as possible the evidential qualities, that is veracity and authenticity, of the information..

The replicability of records has always been a part of records creation in all cultures. In early cultures multiple copies of records were made by hand. With the introduction of the printing press, the mechanical reproduction of information in multiple copies became accepted practice. Mechanical reproduction of information in print form probably reached a zenith in the late twentieth century with the development of the photocopier and the laser printer.

However, perhaps the most significant development in record replicability came about with the introduction of digital technologies for document creation and transmission. A key strength of digital information is that, with the appropriate hardware and software systems, it can be copied and mi-

grated with high levels of accuracy. Management systems should be employed to ensure that the process of replication is appropriately controlled and documented.

The weaknesses of digital technology are concerned with the ease of tampering, maintenance of authenticity and the difficulties in imbuing the records with sufficient contextual information (metadata) that ensure the capture and preservation of their evidential qualities. It should not be possible to alter records without there being evidence that changes have been made. It is preferable that qualifications or additions be done through the creation of new records that are linked to the original. A strategy that required a copy of records to be made on a medium that is difficult to alter, such as paper, microfilm or silicon carbide would help deal with this issue.

5. Networks and Contextual Information Frameworks

5.1. INTRODUCTION

In order to better understand the concepts underpinning contextual information frameworks and their relationship to knowledge management it is worthwhile introducing the research foundations on which they are based. The last decade has seen a blossoming of studies looking at the nature of complexity and context in human society. These have emerged from a variety of perspectives drawing on the humanities, social sciences, mathematics and physics. The relationships between society and technology and the resultant intricate interdependencies, referred to as 'socio-technical complexity', have become a distinct field of study for social theorists and historians of science. During a similar period mathematicians and physicists have managed to characterise and better understand the complex social and operational networks that result from human activity.

5.1.1. Socio-technical complexity

Helga Nowotny, Chair of the European Research Advisory Board (EURAB) and based in Switzerland, has tackled such issues as the need for socially robust knowledge in evolving complex environments. 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". She reflects that Luhmann's reference to the ultimately unfathomable complexity of the world – that which happens simultaneously – implies also its ultimate uncontrollability. However, coming from the social sciences, this definition of complexity has an elegance that differs from that used in the natural sciences and 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.

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 conceptualize these abstracted complex environments as networks of entities (for example: people, organizations, places, concepts, and events) that are linked by defined relationships.

In recent times the nuclear safety and radioactive waste communities have created a number of examples of these information resources which range from traditional print publications including a narrative history of the IAEA and the *Institutional Framework for Long Term Management of High Level Waste and/or Spent Nuclear Fuel* [IAEA-TECDOC-1323, IAEA, Vienna (December 2002)], to the web-based Asian Nuclear Safety Network (ANSN).

5.1.2. Complex networks

In mathematics and physics, studies of the nature of complex networks really got underway in the mid 1990s. In 2002 Albert-László Barabási, a leader in this field, published *Linked* (Perseus Publishing, Cambridge Massachusetts, 2002), 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". The surprising and ubiquitous properties of a particular subset of these complex networks were not only shown to share mathematical foundations but also to have links with the now popular idea of the small-world effect that had its origins in sociological work of Stanley Milgram in the 1960s. 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 it [the network]". This work provides an intellectual and conceptual milieu in which new strategies can be conceived to deal with the persistent problems of effective long-term knowledge management. It is possible to conceptualise the radioactive waste industry as a complex socio-technical network with the added explicit need to preserve and transfer information over very long periods of time. An information network based on these ideas would appear to be ideally placed to take advantage of the benefits associated with open complex networks, such as robustness, utility, traceability, navigability, universality, sustainability, historical integrity and the ability to evolve through time.

5.1.3. Human capabilities and large information sets

As noted earlier the radioactive waste industry currently produces vast amounts of information and has accumulated substantial amounts of information and knowledge from past activities. These resources are highly distributed, decentralized and managed using control systems that vary though time and from place to place, and with varying degrees of success. As it is currently configured, the totality of information is large and complex beyond the ability of any single human being to fully comprehend or utilize. In all information systems, past, present and future, there is one common element that will remain essentially unchanging in its capabilities – human beings. It could be argued that despite the limitations of current information and communications technology humans still manage to locate the information they require to sustain operational objectives. This is attributed to their remarkable knowledge-processing abilities and their natural ability to create contexts or conceptual frameworks that provide meaning and aid memory.

That said, there have been notable failures of information technology to meet society's information preservation and transfer needs. Experience suggests that there is a relationship between the size of the information set and the incidence of failure. What appears to be happening in these cases is that the information set becomes too large and amorphous to enable the intuitive use humans make of contextual information to filter out the irrelevant information sources and focus on the subset of sources that may hold the information they seek. In other words there are limits to human capability.

In order to transform large information sets into information systems that optimize human capabilities the following issues should be considered:

- Codification of information (metadata) about the information or data set in a structured and systematic manner;
- Establishment of a good overview or 'road map' that defines the scope, structure and depth of the information set;
- Registration of known and respected sources to build confidence and trust;
- Containment of the information set to sources of relevance to the particular purpose;
- Capture and codification of implicit knowledge or common knowledge of those involved in the creation of particular sources but not necessarily shared by all users;
- Provision of sufficient processing power wherever it may required in the system to match users' work capabilities and capacities;
- Creation of informatic architectures, search algorithms and interfaces that support work on a human scale;
- Utilization of feedback from users to improve the quality of the information set to meet its particular purposes; and
- Utilization of information architectures based on context and defined relationships between sources.

5.1.4. Utilizing contextual information to create a network

It is argued in this report that through the systematic use of contextual information it will be possible to transform large complex, disparate and distributed information sets into interconnected networks of usable resources. At its most general, contextual information is the tacit, common knowledge of relationships and links that enables a community to function. It is focused around what people know

of their environment and the experiences they share but is naturally limited by the amount individuals can know. By definition, contextual information is bounded by both time and place, in the same way the people are constrained by both time and place.

For the purposes of this report, context is further conceptualized as information derived from the relationships between elements in an information set. For example, when considering the information associated with an individual person, the context of their life could be conceived as being defined by a set of relationships with other people (family, colleagues, chance encounters etc), organizations (employer, sporting club, the tax office etc), events and rituals (birth, marriage, birth of children, world cup victories, tsunamis etc), places (place of birth, of residence, of work, nationality), and cultural constructs (books, movies, ideas, languages). Contextual information is therefore information that documents these elements or entities and their relationships.

The context of an information resource, especially a record, is primarily determined by the relationships between the resource and the entities (for example, people, organizations, places, events, technologies and concepts) that:

- enabled its creation;
- have allowed it to continue to exist;
- have used it, for whatever purpose;
- have linked it to other resources or entities.

As context is defined in terms of entities and their relationships, the assembling and interconnecting of information using contextual elements (surrogates that represent the real-life entities) results in an information architecture or framework that mimics the social and operational networks of real life – a contextual information framework.

5.2. Networks

5.2.1. General properties

In the field of information systems, networks are defined simply as a graph or conceptual space that is composed of nodes and arcs. For the purposes of this report the terms "entities" or "agents" are used in place of "nodes", and "relationships" is used instead of "arcs" when discussing contextual information as they better fit the concepts being examined. When discussing networks more generally the terms "nodes" and "arcs" will be used.

Another distinction worth noting is that the term "information network" can be used to describe both the physical infrastructure (servers, cables and protocols) used to transmit information and the network established through the linking of information resources as described in section 5.1.4. It is the latter sense that is used in this report unless otherwise indicated.

Networks come in a variety of forms and have a range of properties that are determined by the way nodes are linked to each other (arcs). For example, a network comprised solely of one-to-one relationships will have very different properties from one that is composed of one-to-many relationships. Furthermore, the actual distribution, incidence and quality of the arcs can have a profound effect on the properties of the network and how it will behave under differing circumstances. Network behaviour will be an important aspect to consider when evaluating contextual information frameworks as a strategy for information preservation and transfer.

5.2.2. Societal networks

Interest in the properties of societal networks, those networks created by human relationships, was stimulated by the work of Stanley Milgram, a Harvard professor who in the 1960s undertook studies into human interconnectivity. One his seminal works was "The Small World Problem," published in

Physiology Today Volume 2 in 1967. His work contributed directly to 'the small world effect' and 'six degrees of separation' becoming widely accepted network concepts. They embody the remarkable phenomenon that despite the fact that the total network of human beings is composed of billions of nodes (people or entities), the number of arcs (links or relationships) that connect any two people is rarely more than six. More recent mathematical research into these types of networks has led to the use of the term 'scale-free' to characterize their particular properties. One means that was used to measure this property of networks was to analyse the distribution of the number of arcs per node (relationships per entity). In so called 'random' networks this distribution takes the shape of a 'bell' curve whereas in scale-free network it is described as having a power law distribution whereby very many nodes have only a few links but there are a few nodes (hubs) that have a large number of links.

As Barabási noted in *Linked*:

> "The slowly decaying power law distribution accommodates such highly linked anomalies in a natural way. It predicts that each scale-free network will have several large hubs that will fundamentally define the network's topology. The finding that most networks of conceptual importance, ranging form the World Wide Web to the network within the cell, are scale-free gave legitimacy to hubs. We would come to see that they determine the structural stability, dynamic behaviour, robustness, and error and attack tolerance of real networks. They stand as proof of the highly important organizing principles that govern network evolution." [Reference: Barabási, *Linked,* Perseus Publishing, Cambridge Massachusetts, 2002, pp.71-72]

The radioactive waste community has identified the need to foster knowledge networks based around the sharing of knowledge through the social and operational relationships established between individuals. They have identified activities such as conferences, meetings, workshops, and collaborative projects as important means by which this goal might be achieved. The nuclear safety community has taken this challenge to a new level by using Internet technologies to create an information service that supports the Asian Nuclear Safety Network. At this stage ANSN is focusing on providing access to training materials and the sharing of information about national standards and practices. Japan has proposed that ANSN be expanded to include radioactive waste management. ANSN is an example of how information resources can be placed in a context that enhances their use and supports actual social and operational goals of Member States, organizations and individuals who are the members of network.

5.2.3. Information networks

The question that is then raised is whether network concepts, in particular scale-free networks, can help us manage large quantities of information. Evidence of the significant potential of this area comes not just from the academic research mentioned earlier but can also be seen in the way the World Wide Web has become the most significant piece of information infrastructure ever to evolve. This is further reinforced by the successful way search engines, for example, Google, have exploited the network qualities of hyperlinked web resources to enable topical information to be located quickly. These systems are useful in locating information resources that have many links (act as hubs) but are far less successful in reliably locating specific information resources which may or may not have many links. However, it is the latter ability that is a necessary requirement for evidence-based operations such as radioactive waste management. Despite current limitations, the wide acceptance of the web is an indication that it has basic human-scale properties. This would indicate that studies to better understand how best to develop the evidence-based capabilities implicit in web technologies would be well worthwhile.

In recent years there has been an extraordinary increase in the amount of information published on the web or accessible via the web that relates to radioactive waste management. Some sources or services are relatively old and have not been kept up-to-date while others are restricted to limited communities by either requiring a financial subscription or some other form of password authorization. Much information is freely available but it is not uncommon for users to locate a resource, use it, but not be able to find it again. The advent of Wikipedia, the online open encyclopaedia, has become a

highly used and well respected information source covering a huge range of subjects and radioactive waste topics are well represented. However, for radioactive waste management there is an important role for sites of systematically networked authoritative information with historical depth. It is a common misconception that the web is only suitable for presenting current information. While this might be the case for booking an airline flight or hotel room, the web is also extremely well suited to publishing sustainable historical information.

5.3. CONTEXTUAL INFORMATION FRAMEWORKS

5.3.1. Structure and function

A contextual information framework, which generally exists within a broader information network, is usually composed of interrelated information objects (or metadata records) that represent entities found in real life. Its framework structure stems from the relationships between these entities. The information entities act as surrogates for real-life entities that could include people, organizations, concepts, ideas, places, natural phenomena, events, cultural artefacts including records, books, works of art and, indeed, radioactive waste disposal facilities. [See section 5.4.1] The structure is actually established through the codification and mapping of relationships between these entities. This creates a network or framework that mimics what actually occurs in life and is therefore at the human scale. The selective use of entity and relationship types can convert otherwise impossibly complex real-life socio-technical environments into information frameworks with the remarkable and useful properties of scale-free networks. Relational database systems with web publication capabilities are ideally suited to manage contextual information frameworks.

The term framework is used to indicate the structural role that contextual information can play within an information network. Unlike the physical world where a framework establishes a singular structure, in the open information universe multiple frameworks can exist simultaneously and indeed can be linked to each other at key points.

The primary function of a contextual information framework is to provide a higher level structure that links together resources based on shared contextual attributes. It acts as the 'glue' that binds together information resources that would be otherwise isolated. Where this differs from cataloguing or indexing practices is that the context entities exist in the network in their own right with their primary role being to facilitate links and relationships. For example, records created by a work unit would be linked to a information surrogate (entity) that represents the work unit and includes sufficient historical background to define its role over time, its relationships within the organizational structure and any other attributes as may be deemed useful.

5.3.2. Properties and qualities

Contextual information frameworks, which can be created utilizing internationally accepted archival standards [13], have a variety of properties and qualities that include the ability to:

- Grade the selection of contextual information to meet the particular needs of the management system and information network in which it is established;
- Update information documenting contextual entities and the creation of new entities determined by rate of change in its particular jurisdiction. If this is relatively stable, little work will be required to keep the contextual information current. At times of significant change, however, more input will be required;
- Create new types of entity as needs arise. For example, it is conceivable that at some time in the distant future a whole new range of regulatory and administrative bodies are created which are significantly different from the bodies they replaced. In this case new entity types may have to be created;
- Link to other contextual information frameworks particularly those that share common entities. Entities will be duplicated in a variety of separate clusters or nodes depending on local

informational requirements. This redundancy is viewed as one of the key tools for preservation of information. For example, if contextual information is lost, issues of language, meaning and interpretation become problematic for future generations. Although research may enable the re-discovery of relevant contextual information, this is a time-consuming process and may impose undue burdens on future generations;

- Share structured information about entities thus saving significant time and resources when creating or updating frameworks;
- Provide multiple pathways to resources;
- Use of analytical tools to undertake complex search, mapping and research tasks;
- Graphically visualise the network to improve the human-network interface;
- Locate related resources across the full breadth of the network;
- Develop a deeper understanding of the context of resources; and
- Reveal connections and relationships between entities which were otherwise obscured or difficult to ascertain.

Systems and software to build, manage and web-publish contextual information frameworks are emerging and are being implemented in an increasingly wide variety of applications. Academic researchers have been early adopters as they have seen their potential to map complex historical or intellectual environment. Various sections of the archival community have also adopted these techniques as a means of significantly improving the services they offer the community at large. Digital library systems are increasingly looking to contextual information management, for the example the Resource Discovery Framework (RDF), as means of dealing with large, undifferentiated sets of catalogue metadata.

5.4. A RADIOACTIVE WASTE CONTEXTUAL INFORMATION FRAMEWORK

The issues facing the radioactive waste community with respect to the preservation and transfer of information to future generations have been well covered in previous sections and the potential of networks and contextual information frameworks introduced. This section brings the two together and examines how a radioactive waste contextual information framework could be conceptualized and implemented.

5.4.1. How it is conceived

The radioactive waste management community may be conceptualized as a multi-layered complex scale-free network established through defined relationships between entities:

- At the global level, for example Member States (collectively and individually) and international bodies like the IAEA;
- At the international level, for example, sets of Member States forming groups such as the Asian Nuclear Safety Network;
- At the national level, for example, organizations within Member States such as regulators, financing agencies, operators and suppliers;
- At the operational level, for example, operational units within organizations and between organizations operating at the regional level;
- At the personal level, for example people working on common projects or tasks.
- Across adjacent levels, for example, people and organizations;
- Across all levels, for example, people, organizations, events, technologies, places, facilities and indeed even concepts and language; and
- Within levels but across time, for example, organizations, events, technologies, roles, concepts and language.

Simultaneously, the radioactive waste community could be viewed as comprising networked clusters of entities based around technologies, themes or other common interests, for example, the cluster of all low-level waste repositories that utilize bore-hole technology.

Although this list looks impossibly complex, this is deceptive as the implementation of the framework is based around each administrative or operational unit, which are, as a direct result of their operational activities, at the human scale. Indeed, the information needed by each unit to create its own contextual information framework will, for the most part, already be documented in the records and reports it creates. The contextual information framework provides the vehicle for the systematic registration of that information.

The schematic diagram in the Appendix I, an example of schematic representation of a contextual information framework, illustrates the way the operational relationships between entities at the national and international levels form clusters. It also reveals, through links to the IAEA, the way the radioactive waste community forms a global network.

An information network, as illustrated in the Appendix I, which reflects a large-scale operational network is not something that could be created immediately in its totality. However, its component parts could be readily assembled and the various sub-systems or clusters interlinked as they become available. The process of implementation could be phased and graded in a way that supported the evolution through time of the global framework.

Appendix II, A schematic example of the development of a contextual information framework for radioactive waste management, illustrates how the growth of such a network could be achieved through a staged process that commenced at the lowest level, that is, with the records created by the waste operators.

Indeed, the recordkeeping and reporting requirements established by industry regulations within Member states and by conventions at the global level provide the foundations for a means of identifying the primary functional relationships that already exist within the community. These start with records generated at the fundamental level – for example, in work logs, and proceeds through management reports to organization reports to regulatory bodies and ultimately to national reports as required under the terms of the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [9].

What is envisioned is a contextual information framework based on the clusters, levels and interconnections as outlined above. Contextual entity surrogates would be required to represent all the key agents in the network, for example:

- International bodies like the IAEA, the NEA, etc.;
- International Conventions like the Joint Convention;
- Member States;
- Regulatory bodies;
- Scientific bodies;
- Other related government agencies;
- Waste disposal facilities;
- Waste disposal operators;
- Waste management organizations;
- Community bodies;
- Individuals;
- Major events;
- Technologies;
- Significant concepts and language; and
- Any other entities that may be deemed necessary.

With respect to radioactive waste management, contextual information should document the entities and events involved in all phases of a disposal programme. For example, it should be a function of the archive system to record (document) the relationships between the context entities involved in its local operations and the records themselves. At each level and for each operational unit only those entities that relate to their activities and obligations need to be registered. The Agency management systems guidelines for each organization already specify the documentation of this information. A contextual information framework implemented at the operational level will provide organizations with a knowledge management tool that will help them meet their reporting obligations and responsibilities. This applies equally to short-term requirements for accountability as well as providing a sustainable system that will help them meet their obligations for long-term preservation and transfer of information.

As can be seen in the Joint Convention example mentioned earlier, contextual frameworks and related information often exist without the participants being fully aware of it and that they create it as part of their job without fully realizing it. What is missing is the formal recognition that contextual information frameworks exist in real-life but are not being transferred into information systems in a systematic and sustainable manner. As a rule, the information is already there which means that the creation of a contextual information framework is not a huge added burden but an innovative and clever use of existing knowledge and resources. The fundamental requirement is that each context surrogate be a uniquely identified, citable information object in the network.

5.4.2. Information network capabilities

An information network, including a contextual information framework, to support radioactive waste management will need to meet a minimum set of requirements. This report will not attempt to define these in detail but in summary these requirements should include:

- Robustness – able to withstand catastrophic events, attempts at sabotage – not reliant on individuals, organizations, technologies, distributed responsibility, independent of time, gives it longevity and builds trust;
- Reliability – capable of capturing and managing and delivering all the records that need to be transferred; performs in a predicable manner; delivers according to the accepted rules; and fulfills expectations;
- Transparency – not a black box technology, the structure and workings of the system must be open and clear, software tools should be 'open source' and allow full export of the data in structured standardized form;
- Standards-based structures – applying to the records themselves, the contextual information, and the rules that underpin the network;
- Sustainability - able to be managed through time without the need for complete rebuilding of the content;
- Security – protection from corruption and abuse of information placed in the public domain network; and
- Traceability – all information should be clearly traceable to its creator and the moral rights of authorship and ownership should be respected as necessary.

The information service that has been built to underpin the Asian Nuclear Safety Network may well meet its immediate goals but it does meet the requirements for long-term sustainability as outlined above. It is unknown if any of the information systems, at any level, within the radioactive waste community meet the above requirements.

5.4.3. Organizational obligations

In an ideal implementation all organizations involved in the radioactive waste community with responsibilities for information preservation and transfer should incorporate a fully compliant, standards-based contextual information framework as an integral part of their information management system.

Specific organizational obligations would include:

- The creation and preservation of appropriate information resources in accordance with relevant standards;
- The management of those resources in a system that documents and preserves the context of their creation and use;
- Making available to the wider waste community the information surrogates representing context entities in a form suitable for citation, linking and data exchange;
- Linking to the relevant context surrogates in other sites or clusters in the broader radioactive waste information network;
- The documentation of their information resource management system as part of quality management system processes;
- Responsibility for the quality of the data and information in their own systems;
- The sharing of any knowledge, technologies or systems they develop to facilitate the utilization of contextual information;
- Financing this activity as a part of standard operational practice.

Bodies that currently have responsibilities for the standards, protocols and training programs that support the radioactive waste community should take on the responsibility for developing and managing the standards, protocols and training programs that may be required to sustain the utilization of contextual information frameworks over time.

5.4.4. Implementation

If the radioactive waste community or any part of it decided to implement a contextual information framework their first task would be the development of an implementation strategy. The issues that such a strategy should consider include:

- Setting up a pilot project to evaluate the approach and develop a detailed implementation strategy;
- Assessing the existing information resource management systems and planning their upgrade to include the required capabilities. Particular attention needs to be paid to archival, record management and knowledge management systems;
- Defining the purpose and limits of their particular contextual information framework. These can be scaled or graded to meet particular needs and circumstances as required;
- Gearing the contextual information system to work with existing information systems as far as possible without compromising functionality;
- Reusing existing contextual information resources wherever possible to minimize duplication of effort;
- Identifying and utilizing the appropriate open source or non-proprietary contextual information management tools;
- Involving of all staff concerned with the management of information, in particular the officer(s) responsible for the management system, knowledge managers, archivists, records managers, librarians, and information officers;
- Training of staff, including senior management, and defining new tasks and job descriptions;
- Maintaining the hardware and software to support the system, including backup strategies; and
- Establishing information quality review processes.

5.4.5. Benefits and risks

In addition to the generic benefits, mentioned previously, that stem from knowledge managed in open network systems, it is possible to identify specific benefits that would arise from the implementation of contextual information frameworks across the radioactive waste management community. These would include:

- Facilitating the capture of critical implicit technical knowledge, mutual learning, and the sharing of experience both within organizations and between organizations;
- Utilizing existing technical and operational knowledge and information that has already been accumulated and therefore building on existing resources in a structured way;
- Enabling all stakeholders to understand the bigger picture, thus promoting trust and confidence in the community;
- Complementing existing practice as it is a non-invasive technique that builds frameworks that will enable much more to be done with existing information;
- Helping avoid contradictory decisions being taken in the future and improve decision-making more generally;
- Enabling the knowledgeable appraisal and selection of information resources for future needs based on shared experience and information;
- Enabling the knowledgeable, confident, systematic, responsible and registered destruction of information resources no longer deemed to be of value;
- Providing a quality feedback mechanism;
- Improving transparency both within the industry and to the wider community;
- Facilitating indirect review of information content by regulatory and other appropriate external organizations.

However, all strategies and technologies have inherent risks that need to be considered and evaluated. In presenting the risks, which are representative of the commonly asked questions about contextual information frameworks and web more generally, possible solutions are also offered. The risks to such an approach could include:

- 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 concern would need to be carefully considered. However, it is not being suggested that all data and information be placed on the open network. Each organization responsible for a contextual information framework (node or cluster) would decide what information should be placed in the public domain. Much information that is required to make the framework effective is already in the public domain but not systematically managed. As time passes the security implications associated with much of the information are likely to reduce as it becomes of historic rather than operation value. Indeed, the actual location of records and the precise location of the materials prior to their disposal need not be placed into the public domain for this concept to be effective.

- Concerns about the longevity of electronic information technologies. It is indeed the case that the strategies advocated in the report rely on contemporary technologies and expertise and it is recognized that there is nervousness about using the digital technologies and digital networks. However, as mentioned in Section 4 it is not being advocated that critical information be stored in only one form or on one media and this applies equally to contextual information. It is assumed, however, that the universality of web and its implementation across the globe will ensure the viability of resources managed using standardized web technologies. Historical studies of other novel information technologies that were universally adopted, such printing, would support this contention. It is noted that it may be necessary to convince people that the use of this technology is worthwhile and the case for its sustainability will need to be demonstrated.

- Concerns that such strategies will lead to increased costs and increased work loads. There is no question that these strategies will involve work and cost however, it is contented that as these strategies are primarily making better use of information that already exists and that the systems once in place will add significantly to administrative and governance productivity, and thus reduce costs over time.

- Concerns about unintended consequences. All new activities and technologies run the risk of resulting in unintended consequences. It might be argued, for example, that global climate change was an unintended consequence of fossil fuel technologies and that future generations will have to deal with those consequences. The web and networked information systems are still technologies in their infancy and their ability to transform society is in many ways only now starting to emerge. The use of contextual information frameworks may well have a profound effect on the nuclear industry as an agent for evolution and change. The adoption of these technologies should be undertaken in a measured and self-reflective manner to ensure that they are not counterproductive.

There are also risks associated with the failure to implement the network strategies proposed in this report. The decision not to proceed with these strategies would by default leave the industry with current practice which has been shown to be inadequate. Indeed it could be argued that the industry could be seen to be negligent if it failed to implement strategies that have been codified by international archival and records management standards.

More specifically these risks could include:

- Increasing the degree of burden on future generations;
- Criticism from the community that the industry is not meeting its responsibilities;
- Increasing the likelihood of accidents;
- Criticism for not using best practice tools and concepts;
- Loss of critical information through poorly managed organizational change;
- Duplication of work and inefficient use of resources. As the quantity of information increases over time the chances are that work will be duplicated because the records of earlier work cannot be located in the mass of poorly controlled data and records. This is already a documented problem in the industry;
- Loss of implicit knowledge. The strategies proposed in this report provide a framework for capturing implicit knowledge which is lost from the industry when staff retire and lost permanently when the die. The process of decommissioning of nuclear power plants has revealed the need to capture this type of information and indeed there are case where staff have been brought back from retirement to enable their personal knowledge and expertise to be used to improve and safety and effectiveness of the decommissioning process; and
- Increasing the likelihood of inaccurate information having a misleading influence on community attitudes and political decision making. The strategies recommended in this report provide a mechanism for the industry to ensure that public knowledge is authoritative and trustworthy. Furthermore, the contextual information framework approach provides a natural grading of information so that users can easily locate the level of information they need to answer their questions.

6. Summary and Conclusions

6.1. RADIOACTIVE WASTE INFORMATION MANAGEMENT

As with any highly technical endeavour, the safe and effective use of nuclear technology is based upon the accumulation and dissemination of accurate and reliable knowledge. Where it is perceived that this knowledge will have to be repeatedly preserved and transferred without loss of meaning or capability to inform, the inherent challenges begin to raise issues. If we then combine the 'informatics challenge' with the challenges of disposing radioactive waste in a responsible and safe way such that it does not harm human life or the environment then there is a need for concerted action.

Society expects that people in the nuclear industry 'know' about radioactive waste. Knowing about radioactive waste is more than just acknowledging its existence or developing techniques for conditioning and packaging it – it is about understanding the impacts, making informed judgments and making relationships. The potential impact on society if people lose this knowledge could be catastrophic and so there is a fundamental need, indeed a fundamental requirement, to ensure that knowledge is created, responsibly managed and passed on to future generations. This knowledge includes a wide range of technical information in the form of scientific research, engineering analysis, design documentation, operational data, maintenance records, and regulatory reviews. It also includes the knowledge embodied in people who work with radioactive waste, in those who regulate it and those who report it. Finally, it reflects society's values and codes of conduct, all of which are vital to establish understanding.

In recent years, a number of studies and reviews have highlighted the need for the improved management of nuclear knowledge. These reviews have recognised that factors such as an ageing workforce, declining student enrolment figures, the increased use of contractors and the pace of technological change are all contributors to the global loss of the 'nuclear knowledge' accumulated over the past sixty years.

Information, which is fundamental to knowledge creation, is of limited value if there is no understanding of the context in which it was originally created or subsequently amended. Therefore, whilst the physical preservation of records is essential, the issue of knowledge preservation can only become a reality when it combines information with context.

It has not been uncommon for society to become unaware of records transferred to archives, enabling subsequent generations to discover materials that had been forgotten. While the discovery of forgotten works of art may be of historical and cultural interest, it would be difficult to argue that their absence from public consciousness posed a threat to the safety of society. However, this cannot be said for information about radioactive waste. Information transfer which maintains its links to its contexts must therefore be a planned and continuous process undertaken by society. It must utilize systems that maximize its accessibility and societal information requirements.

6.2. THE ROLE OF CONTEXTUAL INFORMATION FRAMEWORKS

Information preservation and transfer via the use of archives and records has rarely, if ever, been instilled with such a high requirement for continuing accessibility and awareness as that expected for radioactive waste.

At various times, human societies have tried to create structures that would last in perpetuity, for example, the pyramids in Egypt. Other structures created in stone, such as Stonehenge in England, have also lasted many thousands of years but it is still unclear exactly why they were built and what pur-

poses they served in society. Our knowledge of what these entities were for and why they were built is directly proportional to the amount of surviving contextual information associated with them. Radioactive waste disposal facilities, especially those for long-lived waste, will stand alongside these monuments as the longest-lived physical entities created by society. However, future generations must never be in doubt as to why these facilities exist and the risks they pose.

This report attempts to use the example of a proven concept called 'contextual information frameworks' as a model for preserving and transferring our knowledge of radioactive waste to future generations. Contextual information frameworks recognize that there are multiple information resources and that many of these will be associated and linked by some common features. By making these links visible an information network can be developed thus making a key contribution to knowledge preservation and transfer through distribution, sharing and relationship mapping.

6.3. THE DEVELOPMENT OF AN INTEGRATED GLOBAL RADIOACTIVE WASTE INFORMATION NETWORK

Society as a whole has the responsibility to preserve knowledge and the implementation of a system such as a radioactive waste contextual information framework accessible by all could go a long way to addressing this responsibility. The Agency can play a key role in providing a focus for discussion and debate about the structure of a global system that will enable members of the nuclear industry, in addition to those outside, to contribute to the continuance of radioactive waste knowledge.

The concept of a contextual information framework is not size dependant in terms of the number of information sources and corresponding contextual relationships. The model can, and indeed should, be applied at organizational as well as national and international scales. An appropriate starting point would be to establish national systems which would then provide natural links (relationships) to other national systems thus creating a global network. The concept therefore lends itself to being developed on a small research scale such that a better understanding can be developed and a common approach to information gathering adopted.

6.4. CONCLUSIONS

The application of a contextual information framework at organisational, national and international levels, supported by traditional records preservation and transfer techniques, has the potential to address an increasingly pressing issue of the long-term management of radioactive waste information.

The aim of this report is to stimulate further discussion on the concept and to provide an indication of how the concept could be applied.

Furthermore, the report argues that the development and maintenance of a contextual information framework for radioactive waste disposal facilities based on the network of responsibility and accountability is currently the best means to make effective use of archival materials for the purpose of information transfer.

The report also introduces ideas and concepts from the archival world and the relatively new science of open complex networks to provide a foundation for examining methodologies, processes and systems that will enable the formulation of possible solutions to the challenges of intergenerational information transfer.

6.5 NEXT STEPS

What is now required is a first phase of implementation projects at various levels that would systematically put these strategies into practice. It is only through implementation in real environments that clear guidelines, procedures and protocols can be drawn up with a high degree of confidence in their practicability. The technologies and the methodologies all exist, have been tested in other industries and are ready for use. However, they have not been tested in the nuclear industry and certainly not in the context of the radioactive waste management.

The following is a list of activities that should be undertaken to deal with the historic legacy created by virtue of the *ad hoc* archiving and knowledge management activities undertaken since the first discovery and use of radioactive materials:

- Establishing National Historic Compendia of Radioactive Waste Organisations, Activities and Archives. These should be produced by each Member State. The responsibility for this project should be delegated to an organization with long-term stability. It some cases this may well be the National archives; and
- Establishing an International Historic Compendium of Radioactive Waste Organisations, Activities and Archives. This would most likely become an activity of the IAEA.

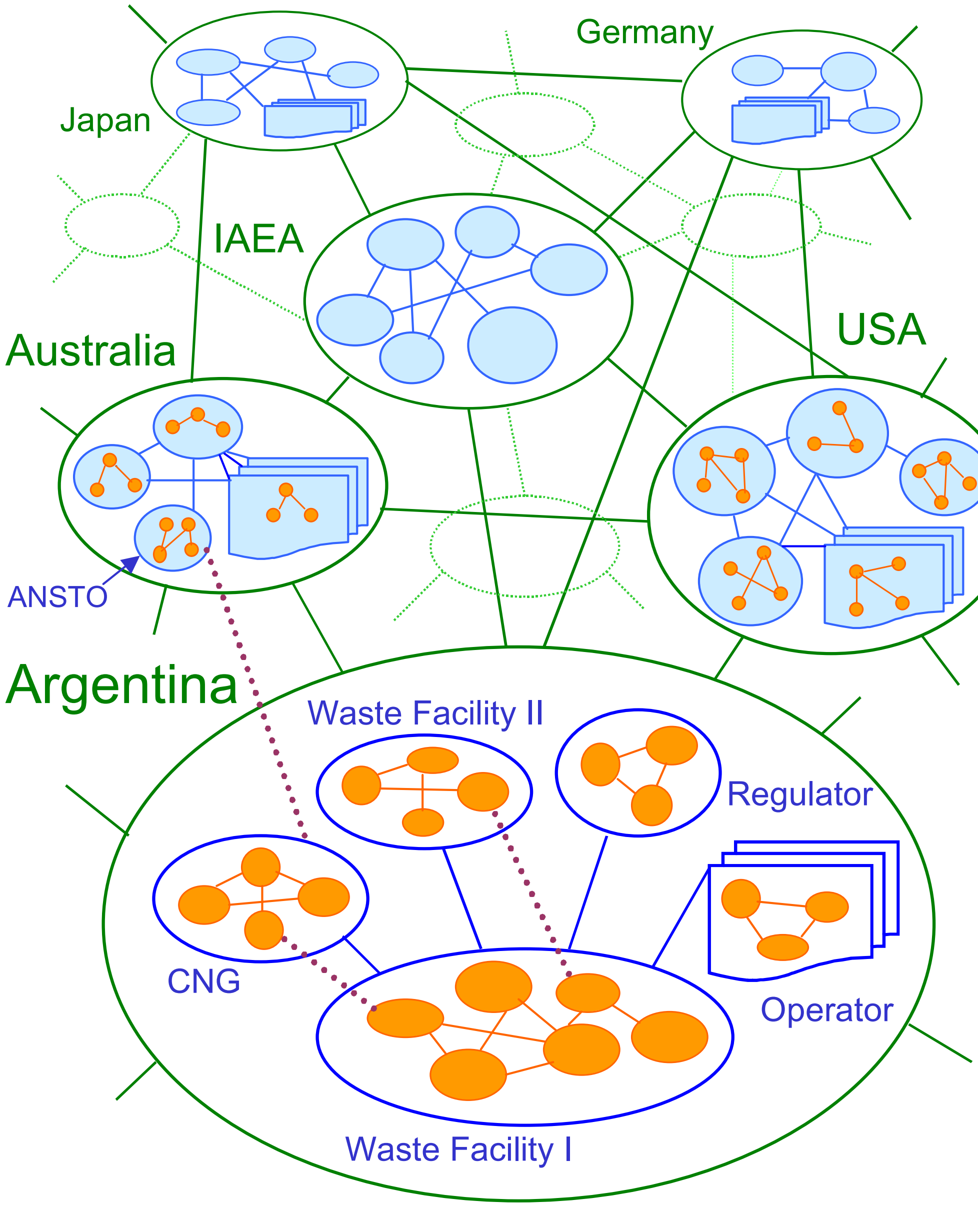
An example of the project tasks that would be involved in developing a pilot project at the national level to test the methodology is given below:

- Identification of a supportive Member State;
- Identification of a project team with the expertise to run the project;
- Preparation of a proposal detailing the scope and purpose of the project;
- Identification of the funding requirements;
- Identification of technical requirements;
- Identification of the timeframe;
- Identification of outputs and outcomes;
- Production of a detailed project plan;
- Implementing the project;
- Initiation of a iterative cycle of review and stakeholder input;
- Assessment of project outcomes and outputs;
- Reporting to stakeholders; and
- Reporting to community through workshops, conferences and similar meetings.

If successful there would then be a requirement to develop training and implementation packages, the formalization of general guidelines, protocols and procedures and the development of a community of practitioners with a range of support services and functions.

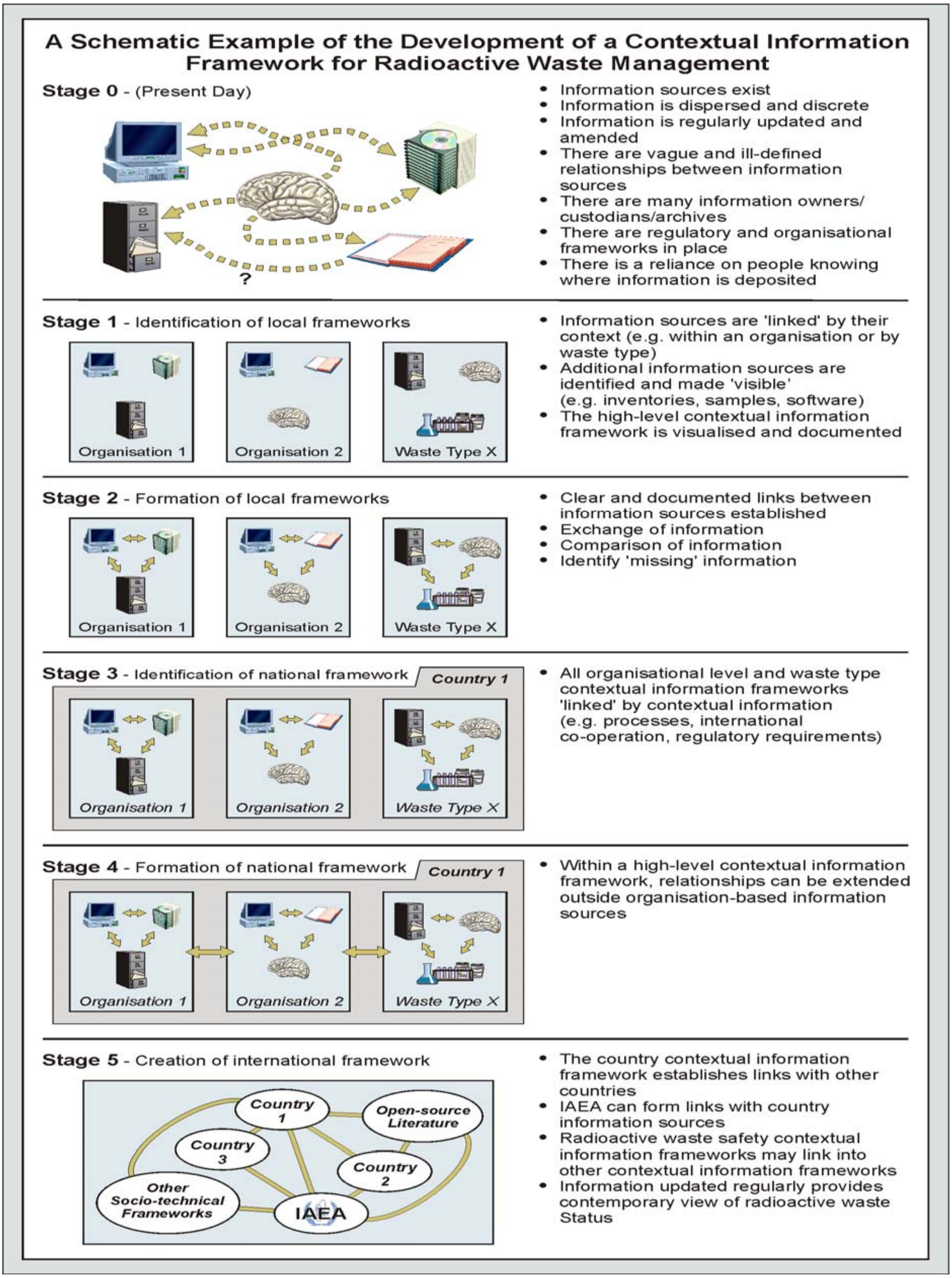
Appendix I:

An Example of Schematic Representation of a Contextual Information Framework



Appendix II:

An Example of Growth of a Contextual Information Framework



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