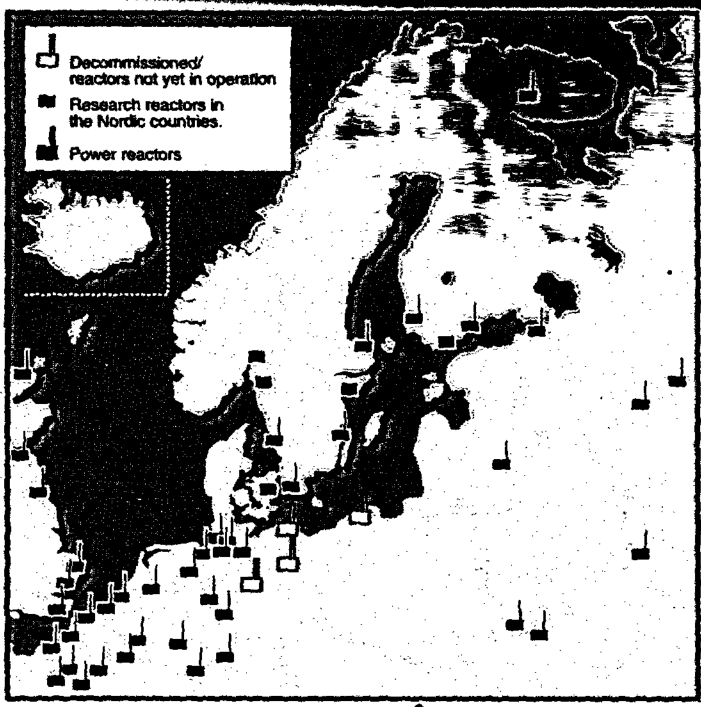
Nuclear Safety

# Conservation and Retrieval of Information




Nordiske
Seminar- og
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# Conservation and Retrieval of Information

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# Conservation and Retrieval of Information

## *- Elements of a Strategy to Inform Future Societies about Nuclear Waste Repositories*

Final Report of the
Nordic Nuclear Safety Research Project KAN - 1.3

*Mikael Jensen*
*August 1993*

**Nordiske Seminar- og Arbejdsrapporter 1993:596**

# Conservation and Retrieval of Information

***- Elements of a Strategy to Inform Future Societies about Nuclear Waste Repositories***


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## The Nordic Council of Ministers

**was established in 1971. It submits proposals on co-operation between the governments of the five Nordic countries to the Nordic Council, implements the Council's recommendations and reports on results, while directing the work carried out in the targeted areas. The Prime Ministers of the five Nordic countries assume overall responsibility for the co-operation measures, which are co-ordinated by the ministers for co-operation and the Nordic Co-operation Committee. The composition of the Council of Ministers varies, depending on the nature of the issue to be treated.**

## The Nordic Council

**was formed in 1952 to promote co-operation between the parliaments and governments of Denmark, Iceland, Norway and Sweden. Finland joined in 1955. At the sessions held by the Council, representatives from the Faroe Islands and Greenland form part of the Danish delegation, while Åland is represented on the Finnish delegation. The Council consists of 87 elected members - all of whom are members of parliament. The Nordic Council takes initiatives, acts in a consultative capacity and monitors co-operation measures. The Council operates via its institutions: the Plenary Assembly, the Presidium and standing committees.**

ABSTRACT

High-level waste from nuclear power generation will remain radioactive for thousands of years even though 99% of the radioactivity will have decayed within the first millennium. Certain information about the waste must be kept for long time periods because future generations may - intentionally or inadvertently - come into contact with the radioactive waste. Present day waste management would benefit from an early identification of documents to be part of an archive for radioactive waste repositories. The same reasoning is valid for repositories for other toxic wastes.

For a hypothetical group involved in future actions to retrieve or repair a repository, information about its location, design, and content would be necessary. The need of such groups can be used to design the information that should be kept in a waste archive.

At the outset, industry as well as the company operating the repository and the competent authorities, are in possession of a vast amount of information about the nuclear material and its history. Certain essential information should be extracted from this primary information in order to establish independent archives of different sizes, i.e. second and third level information sets.

Two main strategies exist for long-term information transfer, one which links information through successive transfers of archived material and other forms of knowledge in society, and one - such as marking the site with a monument - relying upon a direct link from the present to the distant future. Both strategies may be used, depending on site-specific circumstances.

The presently preferred archive media include high quality paper and microfilms which have estimated lifetimes of hundreds of years. Paper types, commonly used in the past, may have shorter lifetimes which may have to be considered when second and third level information set are to be established. Digital methods are not recommended for long-term storage, but digital processing may be a valuable tool to structure information summaries, and in the creation of better long-lasting records. Advances in archive management should also be pursued to widen the choice of information carriers of high durability.

In the Nordic countries, during the first few thousand years, and perhaps up to the next period of glaciation, monuments at a repository site may be used to warn the public of the presence of dangerous waste. But messages from such markers may pose interpretation problems as we have today for messages left by earlier societies such as rune inscriptions.

Since the national borders may change in the time scale relevant for nuclear waste, the creation of an international archive for all radioactive wastes would represent an improvement as regards conservation and retrieval of information. A legal strategy is discussed, suggesting that society should implement the right to information about environmental hazards such as disposed waste rather than implement restrictions near the site, which are not regarded realistic in the long term.

SWEDISH ABSTRACT

Högaktivt avfall från kärnkraftens elproduktion kommer fortsatt att vara radioaktivt under tusentals år, även om 99% av aktiviteten har avklingat under det första årtusendet. Viss information om avfallet måste hållas tillgänglig under mycket lång tid eftersom framtida generationer - medvetet eller omedvetet - kan komma i kontakt med avfallet. Det är värdefullt att dokument som skall ingå i ett avfallsarkiv tidigt identifieras. Detsamma gäller för förvar för annat farligt avfall.

Om en grupp i framtiden skulle vilja återta eller reparera förvaret har den behov av information om förvarets belägenhet, dess uppbyggnad och innehåll. Studier av sådana gruppers behov kan utnyttjas för att bestämma vilken information som ett avfallsarkiv bör innehålla.

Vid tidpunkten för förslutning finns det ett omfattande informationsmaterial hos de organisationer som har ansvaret för avfallet, och hos berörda tillsynsmyndigheter. Viss, särskilt viktig information bör väljas ut från den primära informationsmängden för att skapa oberoende arkiv av mindre omfattning, dvs andra och tredje nivåns arkiv.

Det finns två huvudstrategier för informationsöverföring, en där informationen överförs successivt från en generation till nästa, och en som utgörs av en direkt länk från nutid till en avlägsen framtid, t ex markörer placerade vid platsen för slutförvar. Båda strategierna kan användas i olika omfattning, beroende på olika omständigheter såsom nationell lagstiftning, förvarets placering etc. Ett exempel på den förstnämnda strategin är att samhället bör värna om rätten till information om miljöfaror. En strategi med restriktioner och förbud bedöms däremot ha låg trovärdighet i ett långtidsperspektiv.

Åldringsbeständigt papper och mikrofilm har båda en livstid på flera hundra år. Vissa papperskvaliteter som använts tidigare har dock sämre hållbarhet. Digitala medier rekommenderas inte för långtidslagring av information, men digital teknik kan användas för att strukturera stora mängder information och för att generera bra långtidsbeständiga dokument. Utvecklingen inom arkivtekniken bör följas så att de mest långtidsbeständiga informationsbärarna kan väljas.

Även om en nedisning i samband med en kommande istid kommer att förstöra markörer placerade på ytan kan markörer ha ett värde. Tolkning av meddelanden på sådana markörer kan ge problem för framtida samhällen, på samma sätt som vi idag har svårigheter med vissa runinskriptioner.

Nationella gränser kan komma att ändras i det tidsperspektiv som gäller för radioaktivt avfall. Ett internationellt arkiv skulle därför utgöra en värdefull informationskälla och öka möjligheten för informationens tillgänglighet under lång tid.

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The working group wishes to thank the following Nordic authorities and companies who have hosted meetings of the working group and taken part in discussions regarding the project:

- The Danish, Finnish, Norwegian and Swedish National Archives
- The Danish Institute for Radiation Hygiene (SIS)
- The Finnish Operating Waste Repository (TVO)
- The Finnish Centre for Radiation and Nuclear Safety (STUK)
- The Swedish Fuel and Waste Management Company (SKB)
- The Swedish Radiation Protection Institute (SSI)

APPENDICES

# CHAPTER 1
# INTRODUCTION

## 1.1 Purpose of the project

In 1990, the working group of the NKS project KAN-1.3 was formed and given the task to establish a basis for a common Nordic view of the need for information conservation for nuclear waste repositories, by investigating

- What type of information should be conserved.
- In what form the information should be kept.
- The quality of the information, as regards both type and form.
- The problems of future retrieval of information, including retrieval after very long periods of time.

## 1.2 Background

All Nordic countries have nuclear waste installations. Finland, Norway and Sweden are operating or planning final repositories for low- and medium level waste. Repositories for highly radioactive waste (High Level Waste, HLW) are in the planning stage both in Finland and Sweden. They are planned to come into operation in the first decades after year 2020.

In the design of repositories, all those factors are taken into account that contribute to safety during the various phases of storage, such as the physical and chemical form of the waste, the technical barriers, and the natural barriers of the site, in order to guarantee a sufficient protection to compensate for the risk that the wastes represent.

A principle has been formulated stating that a repository should be designed, sited, and constructed so as to allow for possible future remedial action while, at the same time, maintaining integrity and excluding the need for future monitoring. This principle of "repairability" not only assumes that future generations must take responsibility for their conscious actions that affect the repository. It also means that our generation must keep relevant knowledge accessible for these future generations. This is also relevant in view of inadvertent actions such as intrusions, that might affect the repository.

Information about the waste and about the repositories is available at a number of different locations, mainly within the nuclear industry and the regulatory authorities, but there is no generally accepted scheme as to the completeness of information to be kept, nor as to the duration for which it is needed.

The need for information is intimately related to the - time dependent - toxicity of the radioactive waste. The value of the information to future societies will decrease with time as the waste's radioactivity decreases.

The first 500 year-period is the time frame of main concern for medium active waste, since the major radionuclides will decay to insignificant levels during this period.

Similarly, the first 1 000 year period is of major concern for HLW, being the period where direct contact with the waste would result in high radiation doses. In the longer term, mainly some very long-lived radionuclides persist, and the actual risk is connected to inhalation or ingestion of the waste if it were transformed into a form that makes it fit for uptake in the human body. A few of the long lived alpha emitters may have some importance even up to a period of the order of 100 000 years before the level of natural background radiation has been reached. However, in the first 1 000 years, about 99% of the total radioactivity at closure have decayed.

An important question that arises in safety considerations is: "How long must information be available to society about the repository, its design, location and content?"

There are several reasons why information on repositories with HLW ought to be kept for a very long period of time. Some of these reasons are:

1) Information will give a certain level of protection against inadvertent human intrusion into the repository, because knowledge of the repository and its relative risks will be maintained. It might also reduce the risk for future human actions that might affect the safety of the repository.

2) Information will enable future generations to

   a) evaluate the safety of the repository system

   b) take necessary steps for retrieval or repair work

   c) take remedial actions, if necessary

3) Information will give future generations general information as a basis for decisions in the area of repositories.

To ensure conservation and future retrieval of information, archives must be developed to hold relevant information. The media types, the available data and information, and procedures for storing and retrieving the information must be developed.

Since the amount of details to be retained will diminish with time, periodic reviews of the stored information will have to be made. At the same occasions, advantage can be taken of progress in archive technology, so that information to be kept further can be transferred to the most appropriate archive form.

For some repositories, assessments of their performance and safety analysis must be carried out over time periods so extended that any aspect of national ownership or control may lose its relevance. It is therefore appropriate that research in this area is carried out on an international scale.

## 1.3 One task for waste management and one for the regulator

In order to devise a system for conservation of waste information, decisions must be made about the type and quantity of information to be archived, and decisions about the procedures for archiving and retrieving that information. Thus, this study addresses two major topics:

1. The type of information to be archived and the form of the archived information.

2. Archive safety and future retrieval of information after very long periods of time.

The first of these two questions, which information is to be stored, is mainly directed towards the waste-management community. The second question, dealing with archive safety and information retrieval, is primarily directed towards the regulatory authorities or the state in general.

**The first task** of making information available to future generations is not restricted to information about the repository and its waste, alone. It should also include information about theoretical and practical experiences obtained through waste handling and deposition.

One project goal is to provide a rational basis for determining archive needs. It is also necessary to define "second level information" - information about the primary information - to assist in the process of information retrieval.

Under **the second topic** it is assumed that documentation exists for repositories, and that the quality of the documents is sufficiently good. The question is "What will be the best strategy for both short, medium and long-term archives?".

In this study an attempt is made to analyze the present state of the art, and it is recognized that answers on these two questions will be changed as time passes by. **The first question** about the volume and quantity of information, must be solved once the repositories are in operation and the time for closure approaches. **The second question** concerning archives and other means of information conservation may need continuous follow-up so that better methods are identified and put into use for waste information.

CHAPTER 2
PROJECT DESCRIPTION

## 2.1 Project Components

A number of questions have been addressed in the project. Some have lead to formal sub-projects such as case studies, some have been carried out as seminars, while others are in the form of reports, or a series of reports. The areas of interest and sub-projects are discussed below.

### 2.1.1 Current information, rules and practices

This subproject investigates rules and practices for documentation for Nordic and non-Nordic nuclear waste disposal. This activity has dealt with the following issues:

- Information about existing repositories in Sweden including dose and waste registers, management operations records, and licenses.
- Records of radioactive waste from hospitals and other non-nuclear installations.
- The documentation of a shallow land burial of 1 000 drums of low and medium level nuclear waste.
- A description of the internationally available information about nuclear waste including waste dumped within the London Dumping Convention.

### 2.1.2 Information creation and selection

This subproject discusses documents created in the process of waste disposal. Also addressed are questions regarding:

- choice of information to be stored,
- documentation form, and
- presentation of the information.

### 2.1.3 Archive jurisdiction and longevity

This subproject considers archive rules in the Nordic countries, including standards for archive media and longevity.

Rules for archives are similar in the Nordic countries. Recent work leading to new regulations from the Swedish National Archive is presented.

2.1.4 Case studies of archives and information systems

Several studies of experiences with preserving information were undertaken to relate practical experiences with threats to archives and aspects of information retrieval. These case studies are:

Case study 1. The German archives during the 20th century prepared by Botho Brachmann, Matthias Herrmann, and Susanne Pollert, Humboldt University of Berlin.

The fate of archives in Germany from Kaiser Wilhelm up to the present day may provide a reference case for archives in states suffering political turmoil, dictatorships, occupation and war.

Case study 2. Information retrieval experiences at the decommissioning of the uranium reprocessing pilot plant at Kjeller, Norway.

The value of available information and some problems with loss of information are discussed relating to a practical experience. This case study was prepared by John Lundby from the Norwegian Institute for Energy Techniques.

Case study 3. The Vatican archives from their origin to the present prepared by Susan Pasztor of the University of New Mexico with the assistanoe of Stephen Hora of the University of Hawaii.

The archives of the Vatican are among the oldest in the western world with some items dating from the ninth century. These archives have been threatened on numerous occasions and have been moved several times.

2.1.5 The cost of long-term record keeping.

This report addresses the costs of archiving information including estimates of cost per page per 1 000 years using conventional media and practices. Cost-benefit analyses will be facilitated by some understanding of the expenses involved. This report was prepared by Dr. Lars Otto Berg of the Regional Archives, Uppsala.

2.1.6 Information preservation

Experts from various relevant fields were invited to a seminar to guide the working group in evaluating archive safety. The seminar was held in Oslo in September of 1991. Eleven papers were presented at the seminar and are included in a conference proceedings "Transmittal of Information Over Extremely Long Periods of Time," prepared by Per Ole Nielsen of Scandpower AS. Potential threats to archive integrity and possible countermeasures are discussed in the subproject. In addition to highlights of the conference, the proceedings contains the following papers:

> "Philosophical and Ethical Aspects," Nina Karin Monsen, Oslo.

"The Archaeological Side of the Problem," Lyder Marstander, Inspectorate of Ancient Monuments and Historic Buildings, Oslo.

"The Right to a Future," Helge Thue, University of Oslo.

"Legal Aspects," Knut Selmer, University of Oslo.

"On conveying Messages Out of Context," Helge Dyvik, University of Bergen.

"About Myths," Marie-Lousie Pettersson, Public Record Office, Uppsala.

"Warning of Hazards at Large Alterations or Upheavals," Synnøve Vinsrygg, Inspectorate of Ancient Monuments and Historic Buildings, Oslo.

"Longterm Planning and Uncertainty", Anders Kjølberg, Norwegian Defense Research Establishment.

"Survivability of Stores and Archives," Per Thoresen, Norwegian Defense Research Establishment.

### 2.1.7 Literature review

This subproject reviews literature and international work in progress on various aspects of archives that are devised to last more than 1 000 years. Appendix C contains the findings from this review in addition to some previously undertaken studies.

### 2.1.8 Expert judgment

The evaluation of archival systems designed to last several millennia requires a large amount of expert judgment to be acquired. This report is attached as Appendix E. It outlines formal methods that have been developed for collecting and processing expert judgments for use in quantitative evaluations of risk, for example in the assessment of safety of installations.

### 2.1.9 A theory of science perspective

The complicated task of long-term transfer of information is discussed from a theory of science perspective, see Chapter 3 and Appendix B.A list of all subproject is included in Appendix G.

# CHAPTER 3
# SCIENCE ASPECTS

This chapter discusses a scientific approach to solve the problem of information conservation over extremely long periods of time. See also Appendix B.

## 3.1 Statement of the problem

A technique is to be developed for conservation of information in order to warn future generations over a long time period about the presence of and risks associated with a deeply buried waste repository. In this context, information conservation has two seemingly different goals. The first goal is to communicate to those future generations, that are still culturally similar to our own, the risks of the repository. The second goal is to communicate this warning to other future generations so culturally different from our own that no understanding of our language or level of knowledge is likely to exist.

Both the unique nature of the problem and the heterogeneity of the disciplines needed to address the problem are obstacles to a rapid solving of the problem. Few scientific ventures have addressed information conservation over extremely long periods of time, and few scientific ventures can provide guidance in developing a solution to the problem. The need to include contributions from the fields of history, linguistics, sociology, information science, philosophy, archeology, and material science will increase the scientific basis for the solution to the problem. On the other hand, it can also lead to a diversity of interpretations and recommendations. This diversity may result in an inability for researchers in these various disciplines to communicate with one another and also preclude reaching an early consensus solution to the problem.

The uniqueness of conservation, over extended periods of time, of information related to waste disposal is a major problem in identifying a solution to the problem. Decomposition of the problem can identify components that can be compared with analogous problems in other disciplines. Some analogues to long-term information conservation can be studied by collecting data about such topics as historical markers and oral traditions.

No data can be collected to confirm or contradict estimates of the societal and cultural evolution of our current civilization into the long-term future. Because of this lack of data, the explanatory power of any theory devised to address long-term information conservation must be restrained. A theory that explains too much or is too definitive within this context is an unbalanced theory.

One help in solving the problem of information conservation is to retain flexibility so that the solution proposed at any particular time can be modified to address any new information and concepts that might be obtained or devised. Peer review by a multidisciplinary panel of specialists can be an important tool for evaluating a particular solution, suggesting modifications to the solution, and suggesting new areas or directions of research. The technique of expert judgement elicitation is described in Appendix E.

Although several decades are available to deal with the question of information conservation, the ideal scientific approach to solving this aspect of the overall problem may not become available. A solution may have to be reached without having the topic mature within the scientific community. A further account of this problem area is given in Appendix B.

### 3.2 Social context of scientific solution

An understanding of science has to include the insight that science is inseparable from society. Because science generally is a product of social goals, science and the knowledge that it produces are culturally dependent. The purpose of information conservation in this study is to inform future societies of the risks related to buried nuclear waste. Scientists in the future are likely to be living in societies totally different from our own. Societal differences may result in our information and knowledge being incomprehensible because of the lack of a common social context. This lack of a common social context may result whether a future society is technologically more advanced or more primitive than our own.

Nothing in recent history supports the notion that major societal and cultural changes are unlikely to occur during future centuries. These changes will transform societies' view and conception of knowledge. An archive designed to inform future generations should also convey what we take for granted about our society, culture, and science.

### 3.3 Possible solutions to the problem of information conservation

In formulating a solution, the basic issues are (1) the kind of responsibility that current society should accept toward warning future societies, (2) the time period we judge to be necessary for protection of future societies, (3) the resource expenditure that should be made to assure successful communication, (4) the selection of the information that should be conveyed, (5) the means of presenting the information, and (6) determining the likelihood that the information will be understood.

The problem of information conservation has two basic solutions. The **first solution** is a short-term concept that takes the position that humans should be trusted to pass important information to each succeeding generation rather than relying on objects such as archives. This approach is motivated by our inability to reliably predict future outcomes, the cultural dependency of our knowledge, and the difficulties of communicating between significantly different cultures. Responsibilities are traditionally passed from one generation to the next. Education is one mechanism that would increase the likelihood of information transfer.

This solution has two major flaws. The first flaw is the reliance on people in the future doing what we expect and require them to do. Nothing can assure that future societies will do our bidding, especially with the likelihood of major cultural changes. Another flaw is that the interpretation of information by each generation over a long line of generations is likely to result in distortions of the original information. These distortions could totally change the meaning of the information.

The **second solution** relies on archives and markers rather than humans to convey information. Archives exist on their own, and the information is available to future generations when needed. The major advantage of this solution is that the problem is solved now with no reliance on anyone in the future to do anything beyond maintaining the archive. But it presupposes that knowledge survives about the existence of the archives.

This solution also has two major flaws. The first flaw is that the durability of the archive cannot be assured, although duplication of the archive could increase the likelihood of survival at least in shorter time frames. Another flaw is that the cultural context of the information might be forgotten or misinterpreted, thereby rendering the information and message incomprehensible.

With both solutions having certain positive aspects, an alternative would be to combine the two solutions. The short-term solution allows for the information being passed on from generation to generation to evolve as culture evolves. The archives of the long-term solution can serve as original sources of information that can be consulted periodically to correct the errors in translation of the information.

This hybrid solution also has limitations. The short-term solution can fail if the transition between generations is not smooth. Abrupt changes can result in a disassociation of the societal transmitted information from the archival record. The long-term solution can fail if the archives or markers systems are destroyed and no basic documentation exists with which to check the accuracy and meaning of the societal information.

Despite these potential problems, the combination of solutions has certain advantages over each solution by itself. The combination of solutions provides redundancy in the transmittal of information to accommodate cultures that evolve in different directions, flexibility in that the information being transmitted can be modified as cultures evolve, and duplication that allows for a partial information-transmittal system failure.

The following chapters contain an overview of information available today, some general discussions of the solutions mentioned above and of the state-of-the art for archival and retrieval methods.

## CHAPTER 4
## PRESENT INFORMATION ABOUT NUCLEAR WASTE

### 4.1 Major nuclear waste facilities

The facilities that are dealt with in this project are the Final Repository for Radioactive Waste (SFR) in Forsmark, the Central Interim Storage Facility (CLAB) in Oskarshamn, both of which are in Sweden, The Final Repository for Operating Wastes at Olkiluoto (VLJ) and the Interim Storage Facility for Spent Nuclear Fuel at Olkiluoto (KPA) both in Finland, see Figure 4.1.

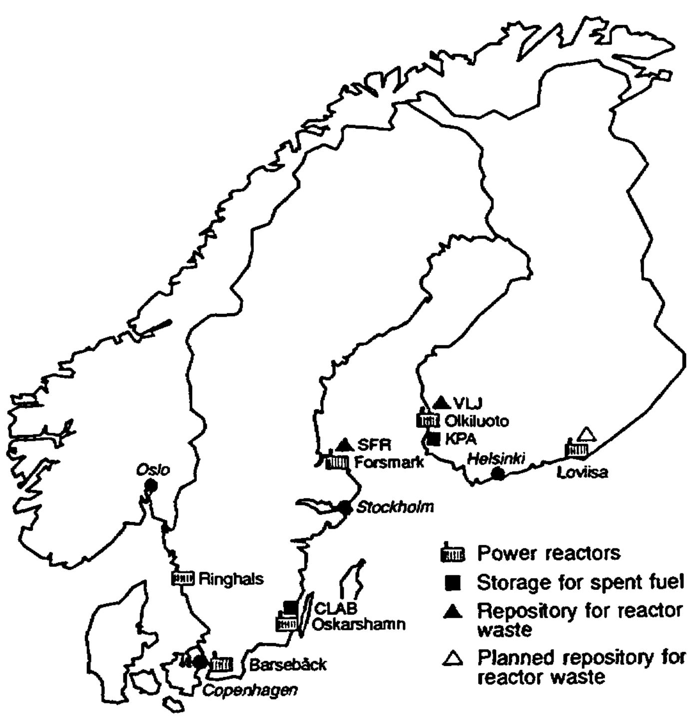


Figure 4-1. Major nuclear waste facilities in the Nordic countries.

#### 4.1.1 SFR

SFR is a final repository for low- and medium level radioactive waste that has been in operation since 1988. The facility is located along the Swedish coast north-northeast of Uppsala and consists of four rock caverns and a silo, see Figure 4-2. The present construction allows 60 000 $m^3$ of waste to be stored at the facility. About 3 000 $m^3$ of waste is disposed of per year. The repository is situated 1 km out from the coastline under the Baltic Sea and is constructed in bedrock about 50 m beneath the sea floor.

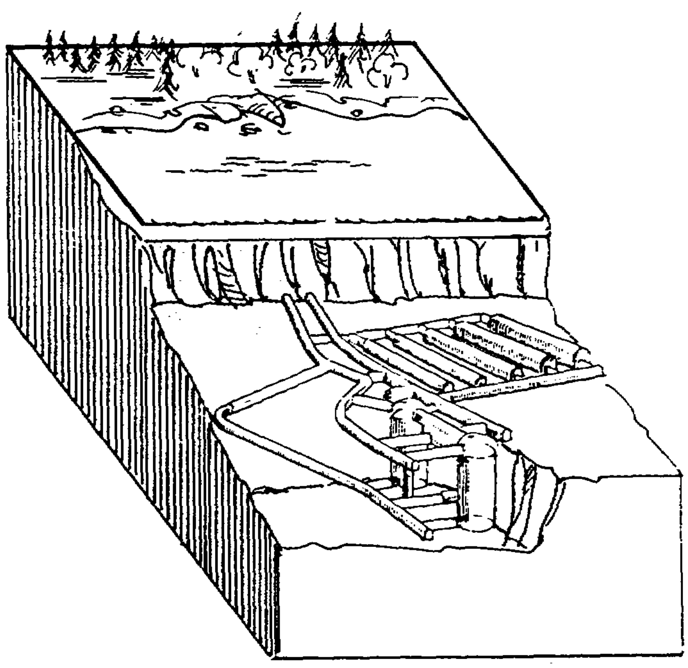

Figure 4-2. The SFR repository in Forsmark.

The radioactive inventory planned for the repository is short-lived, and the radioactivity will decay to a very low level, approximately corresponding to the concentration in the surrounding bedrock, in about 400 to 500 years. Only trace elements remain after this period.

It should be noted that one of the possible threats of human intrusion into the SFR repository has been taken care of already in the construction stage. Because the uplift in the area is about 0.5 cm per year and the depth of the sea above the repository is about 5 m, it will take about 1 000 years before the sea floor above the repository will be at or above sea level. During this 1 000-year time period, no one is likely to drill at this location for drinking water, which could be one severe type of inadvertent human intrusion.

The need to keep detailed information on the SFR facility will decrease as the radioactivity, and thereby the potential risk, decays. The 500-year decay period of SFR is technically, from information conservation point of view, not a very long time. Both information on paper and on microfilm will probably survive if properly stored.

SFR is run by the organization of the Forsmark nuclear power plant and the administrative parts of the accumulated data and information is handled within the normal information documentation system at Forsmark. The main bulk of the valuable information is stored at the SFR facility itself. The remaining parts, e.g. background data to safety assessments and related calculations are stored at Swedish Nuclear Fuel and Waste Management Company, (SKB).

4.1.2 CLAB

CLAB is the Swedish interim storage facility for spent nuclear fuel that has been built adjacent to the Oskarshamn nuclear power plant on the east coast of Sweden. It is intended that the entire amount of HLW from the Swedish nuclear program (about 7 800 tons) will be stored in this facility. The waste consists of spent fuel which will be stored for about 40 years before encapsulation and disposal deep down in the Swedish bedrock at a location to be determined. The CLAB facility consists of a large rock cavern at about 40 m depth with five pools of water in which the spent fuel is immersed, see Figure 4-3.

CLAB is run by the organization of the Oskarshamn nuclear power plant and the administrative parts as well as some of the technical parts of the accumulated information is managed inside the normal information system at the utility. CLAB has also a local archive where mainly technical information is kept. As in the case of SFR, SKB stores the rest of the available information in form of background material and calculation results for safety analyses.

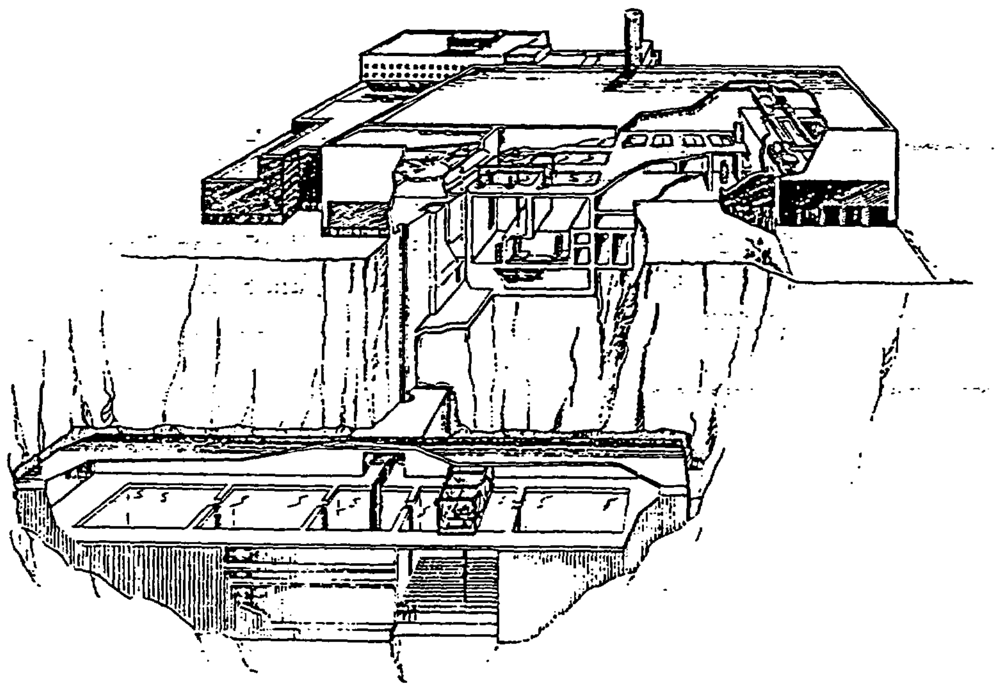

Figure 4-3 . The Swedish interim storage facility for spent nuclear fuel, CLAB.

Because CLAB is an interim storage facility that will be closed after the fuel has been transported to the final repository, information about the facility itself is not of interest in the long term. Details about the fuel itself, activity content, history from production to storage in CLAB, constitute the most relevant information to convey to future generations. Those documents will be copied/transferred to the archive at the Final Repository for HLW when it is built and in operation.

### 4.1.3 VLJ repository

VLJ repository is the Finnish final repository for low- and medium level radioactive waste, see Figure 4-4. The facility was built adjacent to the Olkiluoto power plant on the west coast of Finland and was inaugurated in 1992. This repository is, in contrast to SFR, located inland. The wastes are disposed of in two rock silos, one for low-level waste and one for intermediate level waste. The lowest parts of the silos are about 100 m below ground level. The repository is dimensioned for approximately 8 000 $m^3$ of waste from plant operation. About 150-200 $m^3$ of waste are disposed of each year.

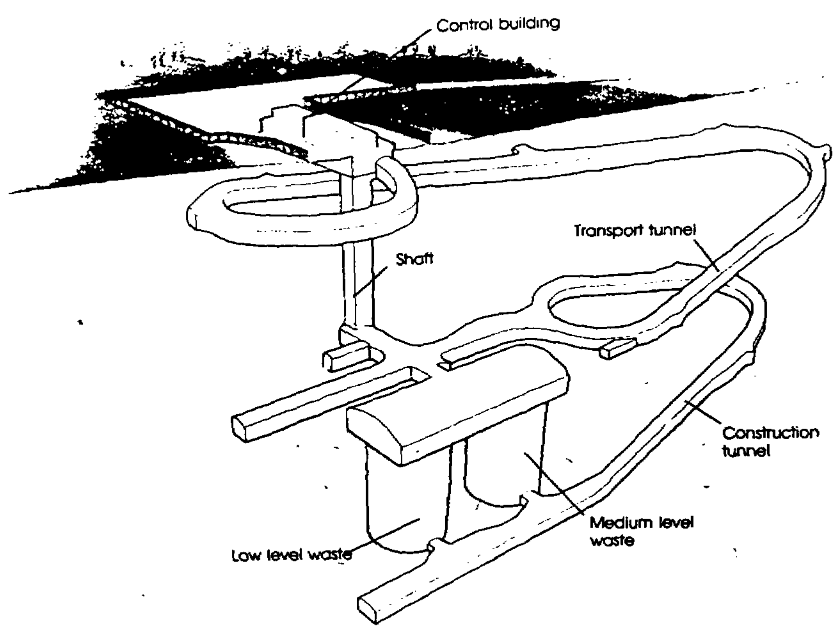


Figure 4-4. The Finnish final repository for low- and medium level radioactive waste, VLJ repository.

All information about the VLJ facility is stored at TVO in Olkiluoto and is handled in the normal documentation system at the utility. The nature of the waste is the same as in SFR and the time frame relevant for information conservation is of the same order, i.e. 400-500 years.

### 4.1.4 KPA storage

The interim storage facility for spent fuel, KPA, is located on the nuclear plant site at Olkiluoto. The facility was commissioned in late 1987. It consists of a storage building constructed on the stable bedrock and is partly situated below ground level, see Figure 4-5.

The facility receives about 45 tons of HLW in form of spent fuel per year from the TVO reactors. The storage section includes three water pools sufficient to handle fuel accumulating over a period of about 30 years. If necessary the facility can be expanded through construction of additional pools.

Information about the facility is kept in the normal documentation system on mainframe computers and archive systems at the TVO utility. Background information about the operational history of each fuel element is kept on special history cards which exist both as computer records and as manually handled documents. For spent fuel, three sets of information are produced of which one is transferred to the utility's Helsinki office and two are stored in Olkiluoto.

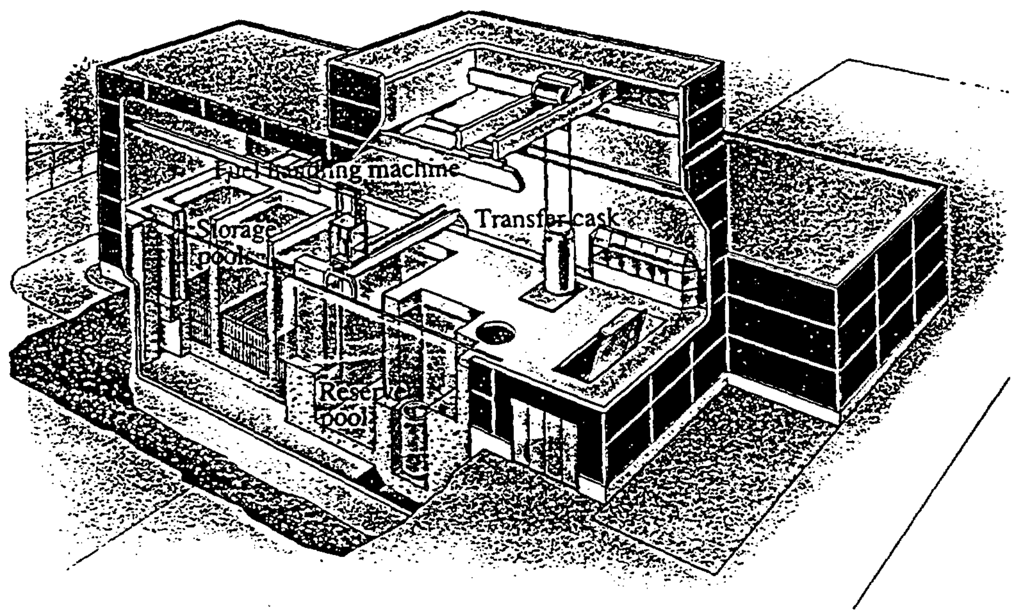

Figure 4-5.The interim storage facility for spent nuclear fuel at Olkiluoto, KPA, Finland.

## 4.2 Information about the repositories

### 4.2.1 Information needs

Several different aspects of information about waste facilities should be of interest to future generations. The obvious one is the geographical location of the facility. This type of information will be stored at many locations (e.g., local and regional authorities, nuclear authorities and so on) and is likely to be important no matter how the repositories evolve.

The actual layout of the facilities is another type of information of interest if future generations decide to enter the repository. The reasons for reentering could be retrieval of the waste as a resource, to make a "repair" or some improvement of the facility, or to address a totally new concept for the disposal of nuclear waste. In cases like these, very detailed information on the actual layout of the facility, the exact positions of the waste, etc., will be essential, as will the information on the waste itself.

In the case of retrieval of the waste, background data for the safety assessments performed before the construction of the facilities should be of interest. Since future generations may have the capability to make their own calculations, the safety assessments, made before the construction, might not be as interesting as the input data to calculations derived from the detailed investigations, which may also have a longer-lasting value.

Experiences from the operations of the repositories, such as unexpected events during operation, and so on, may also be of interest in the short and medium time scale. The value for long term conservation of such information may be decided later.

### 4.2.2 Locally stored information

Local archives contain the main bulk of relevant information from the construction work up to the present operation of the facilities. Part of the information is stored on paper and another part on microfilm or film-cards (photos, etc). Detailed drawings of the facilities can also be found. Other pieces of valuable information are the safety instructions and regulations as well as copies of the safety assessment. Records of unusual or abnormal events is kept as well as operation journals based on the daily operation.

### 4.2.3 Information stored at SKB and TVO

At SKB and TVO, all licensing documentation for the facilities are kept, as are originals of the safety assessments. In addition, all research literature in the form of scientific reports are stored in libraries. At SKB, all reports (bibliographic data as well as abstracts) have been put in a database called BIBAS, so that literature searches can be made.

### 4.2.4 Information stored at the authorities.

At the regulatory authorities, all correspondence from the licensing procedures are kept, as are records of all decisions from the authorities regarding the nuclear waste facilities.

## 4.3 Information about the waste

The information on the waste itself is obviously one of the most important parts of the knowledge to convey to future generations. Information on radioactivity content, types of radionuclides, volumes and type of container materials, geometry and so on is essential information to keep. The most valuable parts of the total information bulk should be identified at a early stage to ensure that extracts and summaries can be made in a correct and efficient way later on.

### 4.3.1 Low- and medium level waste

In the case of Swedish low-and medium-level radioactive waste the bulk of information is stored in a waste database. This information is stored on magnetic media in a condensed format, but parts of the information can also be found in various documents in normal paper based archive systems at the Forsmark utility as well as at the SKB office. It can be foreseen that the short lifetime of magnetic media (see chapter 7) will make it necessary to extract the most valuable information from this database on other more durable media.

An overview of the different types of information that are collected about radioactive waste in Sweden can be seen in Appendix F-1. This Appendix also contains some explanations of what the different documents contain. In Appendix F-2 the exact location for each type of information at the SFR facility is given as well as a suggestion for a first prioritization of the documents for transmittal to future generations.

In Finland, all data on low- and medium-level waste can be found in the documentation systems at the utilities. Data for spent fuel at the KPA facility, are also stored in the normal documentation system at the TVO utility. For the other nuclear power company in Finland (IVO), the situation is different. The spent fuel has so far been shipped back to Russia where it once was manufactured. Thus there is no need for long-term storage of documentation.

### 4.3.2 High-level waste

Information on spent fuel in Sweden is stored in two databases, "SPENT" /4-1/ at SKB and "DARK" at CLAB /4-2/. Parts of this information can also be found in normal paper based archive systems at the Oskarshamns utility, as well at CLAB and at the SKB office in Stockholm. An overview of the different types of information archived at the Oskarshamn utility and CLAB has been made. Other relevant information about the fuel includes the manufacturing and control documents as well as the fuel history, (burnup, operation history, number of scrams etc). This type of information is to be gathered from the manufacturers and the nuclear power plants. Another place where information is available is the Safeguards documentation (se section 4.4 below).

## 4.4 Documentation on Safeguards

Fissile materials used and stored in nuclear facilities are accounted for by the Swedish Nuclear Power Inspectorate (SKI) and The Finnish Centre for Radiation and Nuclear Safety (STUK) and supervised by the IAEA in a procedure called Safeguards. Inspectors from the IAEA can at times of their own choice inspect nuclear facilities to check that record keeping is up to the standards and that the amount and types of stored or used materials is present according to the records. These records contain information about the inventory of fissile material. This information might constitute a valuable source of information.

References:

1 Agrenius L, Bränsledata, Report to SKB, 1992-04-30. In Swedish.

2 Johanssson G, Dokumenthantering gällande CLAB ( Centralt Lager för Använt Kärnbränsle) samt OKG:s kärnkraftsanläggningar. Rapport OKG-633/90, 1990-11-15. In Swedish.

# CHAPTER 5
# INFORMATION MANAGEMENT

In this section, the identification of important information and the principle of second and higher level archives is described.

## The information needed

As mentioned in chapter 1, the type and amount of information that needs to be conserved depends on both the repository system in question and on the different future interest groups that would use the information. In the case of high-level waste, such information would mainly be useful during the first thousand years. After this time, most of the gamma-emitters will have decayed. After a period from now, of the order of 5 000 - 10 000 years, the Nordic countries are believed to have an extremely harsh climate and glaciation may start in this period.

The need for information also varies due to the information receiver. A potential work force "repairing" an existing repository will have a need for information quite different from a group looking upon the waste as a resource and interested in retrieval of the waste.

In the future, several different groups might have an interest or need for the information on the waste:

- The responsible authorities.
- Scientists and researchers.
- Potential retrieval and "repair" forces.
- Different security groups of the society, police etc.
- The public - for protection against inadvertent intrusion.
- Groups interested in environmental protection.
- International bodies.

The following basic questions, as previously mentioned in chapter 1, should be addressed as early as possible in the different countries that have programs for nuclear waste management:

- What type of information is of great value and should be conserved.
- In what form should the information be kept in short and long-term perspectives.

- What measures can be taken to ensure the physical, logical and technical durability of the information material.

The working group has come to the conclusion that the most valuable information for all systems and all interest groups would be the following:

- The geographical location of the repository. All more detailed information will be of less value if the location is not identified.
- The "source term" expressed by radionuclide content, chemical and physical characteristics of the waste, etc.
- The design of the repository, its physical shape, technical and natural barrier systems, etc.
- All background material to the final safety analysis regarding the facility. If this information is available, future generations will be able to make calculations on the safety level and act according to their findings.

Other valuable background material includes:

- Laws, general information from and about the society that disposed of the waste.
- The safety performance assessment, the final safety analysis itself.
- Records of the operation including
    - registers of dose received by operating personnel,
    - waste databases,
    - the operational records of the repository.

**Extracting information for future retrieval**

The working group has found that existing documentation on radioactive waste can be characterized as follows:

- For each storage or final disposal facility, the total volume of the documentation is relatively small.
- The relative changes in volume per year are also small.
- Much of the valuable documentation is placed on magnetic media
- Today all documentation is saved - nothing is culled.

- No specific rules or regulations exist at present regarding saving and culling.

There are no incentives today for waste management to make any extensive culling since there is ample storage capacity for documentation at the waste facilities.

To ensure redundancy and long lifetime of the information, different sets of information should be gathered.

First, the archives with all (or almost all) of the information should be preserved. This information is called the Primary Information Set.

To ensure that the most relevant information will be summarized and kept, an additional set of information should be extracted, copied, and put in a regional archive. This Second Level Information Set should also include information on where to find the Primary Information Set.

To ensure an even higher level of redundancy, a Third Level Information Set could be considered. This set could consist of short summaries of the essential information as well as pointers to the other levels of information bulks. It is proposed that this Third Level Information Set be kept at national and/or international institutions.

An example regarding SFR information that might be relevant to extract to be part of a Second and Third Level Information Set is shown in Appendix F-2. In this Appendix a first attempt has been made to assess the importance of the different files found in the SFR archive.

# CHAPTER 6
# SYSTEMS FOR CONSERVATION AND RETRIEVAL OF INFORMATION

## 6.1 The problem

This section addresses the question of general systems for information conservation mentioned in Chapter 3. We may assume that information has been gathered in agreement with the suggestions in Chapter 5, a task primarily for the waste management. The process of information transfer is then a responsibility for society in general.

It is a popular assumption, or hope, that future societies will be able to recycle all wastes, thus avoiding the problem of toxic waste disposal. In this context, the problems related to waste storage and its safety assessment are limited to the present historical epoch.

Disposal of waste with long-term consequences is a relatively new phenomenon. The problems of long-term information conservation is new and, as pointed out in Chapter 3, there is little guidance to be found in the scientific fields traditionally employed by nuclear scientists. Nevertheless, some literature in this field exists, and the findings of a survey made within this project is published in Appendix C. The literature is predominantly of American origin and related to markers. Some recent work has been made by Sandia National Laboratories[1,2].

## 6.2 Conservation of information, its protection, and safety issues.

The safety analysis of a disposal system must take into account the possibility of human intrusion near or into the repository. For this analysis, it is relevant to discuss whether information about the repository will be available in some form, and if it can be retrieved and understood. The question of information conservation is therefore closely interlinked with other safety issues for a repository. The question of human actions at radioactive waste disposal sites is being studied by a working group within OECD's Nuclear Energy Agency (NEA) and a report is being published at the end of 1993.

The design of an information retrieval system must take into account the value of the information within the system. It is therefore not possible to design a system without knowledge of the repository and of the toxicity of the waste. Archives with information about nuclear repositories will probably be given special attention, but the present society will have to weigh cost against effect and must judge how much energy and resources should be spent on documenting and marking a repository which may be considered safe in relation to many other generators of danger in society, even in a long term perspective. We assume that the same need to weigh cost against benefits applies to future societies in their effort to guard and distribute the information.

It follows from the two paragraphs above that the safety analysis and the system for information conservation and retrieval are dialectically dependent. The safety analysis which includes the human intrusion issue must take into account the probability of future societies retrieving information about the repository. In the same process, when designing the information system, the outcome of the safety analysis must be known in a certain sense. The size of the documentation effort will be influenced by the degree of risk the repository is judged to represent.

In recent years, data have been compiled[3] which may be used to characterize risk from both radionuclides and other toxic substances. Such efforts may eventually enable society to make better comparative risk assessments and to direct resources more effectively to various disposal systems for several types of wastes.

For high-level radioactive waste, the first 1 000 years are the most important in terms of the wastes' toxicity. Even if this were not the case, such as for non-radioactive waste, it would still make sense to pay special interest to the first centuries for reasons given below.

## 6.3 The problems of prediction

It may be true that the future can never be predicted by anyone, within either the social or natural sciences. However, society is depending on projections made every day by individuals and groups. What is usually perceived as long-term projections may be in the range of 50 to 100 years. Stretching this time scale somewhat, it can be argued that projections the first few centuries into the future can be included in accepted societal practices, whereas projections beyond that range falls into a different category, especially if the projections involves human actions. Some reasons are given below for remaining within the framework of the first centuries.

Predictions in general

- Most predictive mechanisms decrease in accuracy with time. They are more accurate in their projections for a near future than for a more distant one.

The radionuclide's decay

- One exception to the above statement is the radioactive decay. The radioactivity of spent fuel decreases sharply during the first 1 000 years. The danger from the dominant nuclide, cesium-137, is obvious to potential intruders during the first part of this period. After 1 000 years, the radioactivity of cesium-137 in the repository is 10 orders of magnitude lower than at the time of repository closure, and the total radioactivity in spent fuel is 2 orders of magnitude lower.

Philosophical reasons

- We are ignorant of both capabilities and needs of a society 1 000 years (and more) into the future. For that reason alone, we are forced to design the information system to serve the interests of the societies in the nearer future.

- Generations are dependent upon each other. It is therefore in the interest of societies in the distant future that earlier societies receive the benefit of adequate information. A solution designed to serve the interest of societies in the first millennium will therefore in some sense also be beneficial for later societies.

- Societies in the future are in a better position to assess changing needs of their successors and adjust the information system according to those needs.

### 6.4 A generic, multicomponent approach

It follows from the project goal, which is to establish a common Nordic view on information conservation, that the solution proposed must be generic. A system of general recommendations is proposed rather than detailed suggestions.

Multicomponent strategies have been suggested by other authors[1,4]. The working group presents a strategy of information conservation made up by three components: archives, markers and information in society, the latter as a result of education and society's legal systems. The three substrategies are described below.

### 6.5 Information conservation by archives

#### 6.5.1 Terminological problems

The concepts "original" and "copy" in some situations loose their meaning since any document recorded in digital form may be used to produce an identical copy. In addition to this, the post-closure perspective introduces still another aspect of ambiguity.

A document describing the design of a repository sent from the nuclear industry to an authority constitutes an original to that authority. Similar information may have been sent to another or several different authorities and may also be considered originals. Assume that these documents were contradictory. In this case, a crew involved in post-closure remedial action, would refer to the copy which best reflected reality as "the original", regardless of its former legal background. The original could be a document drawn up by the operator as a draft for the licensing process.

Also, the use of the word "archive" in the documentation of a nuclear waste repository is somewhat different from an archivist's normal use. To an archivist, the records from one source (for example a national authority, an industry, a person) constitute an archive. Information on the nuclear waste repository is available from several sources. We must therefore consider information on various levels:

1. The sum of all records, from all official sources, industry and authorities. This information is accumulated from several archives.
2. The nuclear industry's own archive.
3. Summaries and subsets of valuable information, for example the previously mentioned Second Level information.

Each Nordic country will decide on the need for a record of the waste. Their choice may not necessarily constitute a formal archive. The waste management's collection of records may be converted to a formal archive, protected by archival legislation, if the record is delivered to a responsible authority. The record then becomes a subset of that authority's archive.

### 6.5.2 Archives in a short- and long-term perspective

To avoid inadvertent intrusion, the availability of repository information in national archives will, also in the long term perspective, enable distribution and reconstruction of important data.

An international nuclear waste archive, can be seen as a source of information, but also - and perhaps mainly - as a guarded, long-term source for reconstruction of national and local archives.

### 6.5.3 Maps

Identification of a nuclear waste site on a map is an obvious way in which future societies may retrieve information. Weitzberg[4] presents a 4-component strategy of information conservation, similar in structure to what is suggested in the present report, where one components is "widely distributed maps". The maps' paper media is of limited durability and the need for information in maps may change. In the long term, the information in an archive can be used to generate new maps. The availability of maps is therefore seen by the working group as part of the archive component of the information conservation strategy. In appendix F is shown that a detailed layout of the SFR facility is part of the local municipal's archive.

It has been pointed out that mining is an international field and that bodies interested in mining may be located anywhere on the globe[1]. This supports the idea of an international archive for, and international maps depicting, nuclear and/or other waste sites.

### 6.5.4 Elements in safety analyses for archives

For the medium and long term time frame, an attempt has been made to carry out an archive safety analysis, that is - by analogy to the safety analysis for high-level waste disposal systems - to identify potential threats to the archive's integrity and to describe possible counter-measures to protect or to mitigate the possible harm to an archive from such threats.

A seminar was held in Oslo, in 1991, mentioned in section 2.1.6, with experts in various fields, predominately the social sciences that were deemed relevant to the study, to guide the working group. Also, consultants were commissioned to provide reports on relevant topics, including a study of the Vatican Archives and the fate of the German archives in the 20th century[11,12]. The German archives were studied to supply a case study of a dramatic period in history, while the study of the Vatican archives was meant to give an example of an archive of a 2 000 year old institution. The Vatican archives contain documents more than 1 000 years old, although the archive in its present form was established by Pope Paul V as late as 1612[11].

6.5.5 The Threats

The threats identified by the two studies can be described in terms of events leading to archive losses. Below are listed examples of such losses of material from the Vatican archives:

| Year | Event |
|---|---|
| 410 | Rome attacked by Alaric and the Goths. Rome sacked 5 times during the 5th century. |
| 1308 | The papacy transferred to Avignon. Many documents were left behind and some of them destroyed during their transfer to France. |
| 1404 | The Vatican Palace of the Roman Pope Innocent VII were sacked by a mob. Valuable manuscripts were thrown into the streets. |
| 1527 | Rome was sacked by imperial German troops. |
| 1810 | Napoleon moved the archives, in 3239 chests, to Paris. One third of the archive was lost before they were brought back after the defeat of Napoleon. The last wagon train with documents arrived in Rome in 1917. |
| 1870 | The Italian army occupied Rome. Documents were "lost" to another archive, the State Archive of Rome. |
| 1939 - 45 | Few losses during World War II. |

The German archives suffered most of their losses during World War II. Losses are attributable to the Allied's bombings, destroying the archive storage building, or by fire following the bombings. However, many losses occurred simply because of the extreme poverty during the end of the war. This made the archives' insufficiently guarded paper attractive as a commodity, to be used for wrapping groceries, burning etc. The same happened to a substantial part of the Vatican archives in Paris during the 19th century. Some losses were technical: the prevailing general poverty during the end of the war made high quality paper scarce and led to the use of "Kriegspapier" of low quality and persistence. SS troops raided some archives, like the Staatsarchiv in Danzig. Some archives, including the Staatsarchiv in Wolfenbüttel, were, in part, placed in mines, and survived the war but were later plundered. Finally, the occupation powers removed records from many archives, for instance the Landeshauptarchiv in Dresden.

6.5.6 Countermeasures and strategies for preserving archives

History gives many examples of successful attempts to protect and shelter information during times of unrest. From the Vatican's history examples can be given of hiding and "walling up" archives. At one time at the end of the 13th century, Pope Boniface VIII hid his personal archives in the caves of Mount Soracte near Rome -"the same caves in which

Mussolini, during the second World War, established an emergency headquarters and storage place for important documents[13]".

The study of the German archives also reveals efforts to protect archives. From 1933, unofficial discussions and experiments took place to study the problem of archive protection. Some archives were moved to shelters in mines. Also, because of the political and racist-defined research, church books and personal acts received special interest after the emergence of the Nazi party, leading to increased protection of these documents. As the allied bombing were stepped up gradually, various protective strategies could be implemented: important archives were transferred to underground shelters in mines, and archives were rearranged within existing buildings to the central parts of the buildings.

### 6.5.7 Elements in a "copy strategy"

Modern techniques offer a way to improve the safety of information conservation by copying all records in an archive to create a second version of the archive. It is common archive practice to arrange copies of text in a hierarchal structure to restrict the use of the original. Even if the "original" and the copy or copies were identical from the outset, it would be meaningful to declare one copy as original to be used as a master for further copying, and to avoid ambiguity in defining the archive content if two archives should differ. A third strategy, not necessarily a strategy including copies, is internationalization, that is placing a copy - or the original - in the custody of an international organization. Various alternatives to a centralized international order may exist in the form of bilateral agreements.

Copying thousands or tens of thousands of pages introduces the problem of cost to future societies of keeping copies for thousands of years. The marginal cost of keeping one shelf meter for one year is about USD 40, according to a recent Swedish investigation[14]. This corresponds to a reference cost of USD 400 000 for one shelf meter, about 7 000 sheets of paper, for 10 000 years. Microfilm and paper are assumed to have similar costs for equal volumes of text. It should be kept in mind, however, that no consensus exists on the problem of the treatment of costs in the far future, but extra copies of entire archives will represent extra costs, no matter how they are calculated.

### 6.5.8 Generalizations from case studies

In order to draw reasonable conclusions from the two case studies, it must be kept in mind that both archives contain vast amounts of material. Guarding a limited volume of 10 000 or 100 000 pages would have presented few problems to the German officials. It is obvious that losses of Vatican records were often made as a result of conscious actions, by actors and forces both inside and outside the Vatican. Also the German archives suffered from actions outside the nation. The allied bombing raids, although not directly aimed at the archives, were certainly conscious actions (of the allied powers). This gives a new facet to the discussion mentioned about future societies and their responsibility for their own conscious actions. To judge whether the label "conscious actions" applies to the destruction of archives in Germany during the second World War, it would be necessary to distinguish between the German society, for whom the bombings were detrimental and unintentional, and societies interpreted as the World Society.

It is difficult and perhaps premature to generalize from the German study, to the authors' knowledge the first of its kind, other than to mention the relatively large amount of material that the society, in spite of the allies' massive bombings, was able to safeguard through World War II. Both the German and the Vatican study support the general feeling that because threats often come from forces outside the structure that created the archive, an international and internationally respected archive would represent a robust strategy. This was also a point where a strong consensus was presented at the Oslo seminar. For spent fuel, IAEA safeguards may guarantee the continuity of certain knowledge about nuclear waste up to and including the time of closure of the repository. The IAEA is therefore a candidate for long-term guarding of information about nuclear waste.

### 6.5.9 An international archive for the environment

In the Oslo seminar, it was argued that, in the long term, nuclear waste archives seem more credible if they were part of a larger archive including all information about the environment. These larger archives would be better staffed and in a possible post-nuclear era they would still be living archives. A post-nuclear waste archive exclusively for radioactive wastes, would require the skills of exclusive experts in the historic field of nuclear technology and perhaps only be realistic on an international scale.

## 6.6 Information conservation by markers

Markers may share some functions in common with archives, but, more importantly, markers may be complementary to off-site archives in initiating a search of the archives. While markers are incapable of delivering the wealth of information that are contained in archives, they are more assessable and may warn intruders who would otherwise have no reason to search an archive for information regarding a waste repository. Thus, markers might be considered as one component of an information conservation system.

Markers, themselves, may consist of subsystems. Markers of various designs and purposes may be used to counteract different threats to the integrity of a repository. Moreover, markers may bear different levels of messages where the levels are differentiated by both accessibility of the message and the amount of information. Givens[5] introduced a hierarchy of four message levels. A Level I message is easy to comprehend but rudimentary. For example, a large earthwork of obviously unnatural origins may signal that something manmade is here. The Level I message may not inform the receiver of the message of the purpose of the marker nor even of any danger. It is an "attention getter" designed to initiate the search for additional information.

Level II messages, in Givens hierarchy, convey a warning through iconic, symbolic and/or linguistic signs. Examples of Level II messages include a sequence of drawings showing a human drinking from contaminated water and dying, an international emblem such as the radiation trefoil, or a written statement such as "Danger radioactive waste. Do not drill here!" Level III messages contain basic information explaining what (that radioactive waste is present), why (the waste is dangerous and should not be disturbed), when (when were the materials implanted and when will they be safe), where (a map and description of the repository), who (who fashioned the site), and how (instructions for maintaining and updating information). Detailed information including inventories, technical specification, repair procedures, etc. constitute the Level IV information.

The demands placed upon a marker system are significant. First, the marker system must survive for extremely long periods of time. Examples of human edifices that have survived for long periods of time include the Egyptian Pyramids, Stonehenge, the Narzca lines of Peru, the Serpent Burial mound in Ohio, the Acropolis, and the Great Wall of China[6]. Older examples of "messages" left by earlier societies are found in cave paintings and rock carvings throughout the world.

Threats to the survival of markers come from both natural causes and from human actions. Surface markers are subject to erosion through weathering processes. Thus the selection of materials becomes an important consideration. The markers should be durable with respect to the particular environment. Changes in the chemistry of the earth' atmosphere are also possible because of increasing levels of pollution. The onslaught of an ice age, of course, will destroy, obscure, or move surface markers.

Human actions are apt to be as significant as natural processes in determining surface marker survival. As Kaplan notes, "A marker which is likely to survive for an extended period of time will be made of a material which is durable and of such low intrinsic value that it is unlikely to be recycled." History demonstrates that relics of value will be scavenged. In the future, if resources become more scarce, the likelihood of markers made of durable, but valuable, materials such as titanium, being removed is substantial. Vandalism should also be considered as a threat to markers.

A government, at some time in the future, may also wish to remove markers. This might occur if the economic value of the land above the repository would be enhanced by the removal of the markers. The consequences of this action, however, would be the responsibility of that government. Alternatively, a radical change in political or religious beliefs could lead to government destroying all signs of our nuclear age or all relics of earlier culture.

Even if a marker survives, to be effective, the message must be perceived and correctly interpreted. As time passes, the likelihood of the message being effective will decline because of loss of memory and intervening cultural changes. Languages change. For example, the following quote is from Sir Gawain and the Green Knight (unknown authorship written approximately 1375 a.d.[7])

> The stele of a stif staf the sturne hit bi gripte
> That was wounden with iron to the wandes ende,
> And al bigraven with grene in gravios werkes[1].

is virtually unintelligible except to scholars even though the work is in English and only a little over 600 years old.

It has been suggested that presenting linguistic messages in several languages will help ensure translation of the message by future generations. This idea is based on the experience with the Rosetta stone, which lead to the understanding of Egyptian

[1] The grim man gripped it by its great strong handle, which was wound with iron all the way to the end, And graven in green with graceful designs.

hieroglyphics. Combinations of icons, symbols, and language will further enhance the interpretation of messages. In the far future, say 1 000 years and beyond, messages left today will require interpretation by scholars and, thus, the linguist messages will not be immediately interpretable by potential violators of a repository.

Even if the message is discernable and understood, it is possible that it will not be heeded. An example exists of a rune stone in Norway with a very strong plea not to touch the stone - the stone was placed face down and according to the runes was never to be seen by the sun. This plea was not heard by the scientists who felt that the message was not aimed at archaeologists of the 20th century. The message on the stone translates as:

> It (the stone?) is not shone on by the sun, and the stone was not cut by an (iron) knife
> No one shall uncover the stone while the moon wanes, and neither shall misguided men lay it aside.
> This (stone) the man (=runemaster) splashed with corpse-sea (=blood) and scraped with it (=corpse-sea) the oarlocks in the way-weary cub (=boat)
> As whom did the god of armies (Odin?) come by boat here to the land of Goths (=people)?
> As the fish, swimming out of the river of terror(?) as the bird...shrieking.
> Protection against the wrongdoer.

The attitude of future civilizations to the warnings about nuclear waste may be as cavalier as the attitude of archaeologists to the plea of the runes.

Markers should include icons and symbols as well as language because the mix of media is more apt to be interpretable. Alternate media reinforce each other. While language carries a very specific message that is less subject to errors of interpretation, icons and symbols can be pan-cultural and may be better understood in the future when today's languages are ancient. It was remarked by a philosopher that, referring to the American philosopher W.V.O. Quine[8], that any interpretation of a message by an alien culture would allow for mutually inconsistent results, indicating that we may be overconfident in our attempts to communicate over millennia.

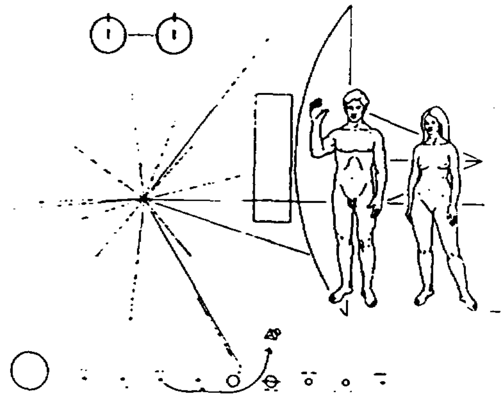

Figure 6-1. Pioneer plaque with human figures, a symbol for the hydrogen atom, a map of the solar system and lines which give relative distances to pulsars.

An example of an icon with alternative interpretations is the man with a raised hand, palm forward, that was placed on the Pioneer spacecraft. The icon was intended to be interpreted as a sign of peace although it could be interpreted as an indication to halt, perhaps because of danger.

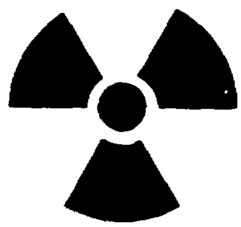

Figure 6-2. The trefoil. A warning symbol for ionizing radiation which may be out of use 1 000 years from now.

The trefoil is widely used as a warning of radiation hazards. One cannot say that this sign, which is noniconic, will be in use 500 or 1 000 years from now. However, by using this symbol in conjunction with other indicators of radiation (words, icons, materials, etc.) the symbol, even if forgotten, might be resurrected. The internationalization of symbols and icons for buried radioactive waste should be considered. Discovery of markers at one site could results in other sites being rediscovered through interpretation of common symbols and icons. The trefoil is devoid of any emotional impact other than that learned through our culture. Thus, it does not intrinsically carry a message of hazard.

The design of a marker system should be made in light of the specific site and the threats to that site even though international symbols and icons are included in the messages. Different threats may require different marking systems. Archaeologists, for instance, are likely to intrude by digging into the shafts or tunnels used in the construction of the repository. Markers placed in the shafts are likely to be noticed by the intruders. Drillers, in contrast, are not apt to encounter individual markers, but instead, a Level I warning might be given by a treated marker bed such as a layer of brightly dyed earth.

There is also the possibility of not marking a site. It can be hypothesized that markers are apt to draw the curious and, therefore, may lead to inadvertent intrusion. In deciding this issue, moral and legal obligations must be considered. In the U.S., for example, the regulation for radioactive waste disposal requires that a waste repository be "..designated by the most permanent markers, records, and other passive institutional controls practicable to indicate the dangers of wastes and their locations." Once a repository is constructed, it will be permanently "marked" by the mass of metals and radioactive materials contained within. Realistically, a site cannot be totally unmarked.

During the early 1980s, there was a concerted effort in the U.S. to examine markers for a proposed repository in basalt. This work generated several interesting reports which are summarized in the Human Interference Task Force Report of May,[9] 1984. Recently, the question of marker design and marker efficacy has reemerged in studies done for the U.S. Waste Isolation Pilot Plant (WIPP) project. Two experts groups were formed in this study. The first group examined potential future societies and what these societies might do to intrude in the WIPP, while the second group, using the findings of the first group, examined marker systems to deter intrusions[1,2,10]. While the report on markers development is still in draft form, presentations by the experts given at a NEA Working Group on Human Intrusion Meeting recommended marker systems with large earth works, monoliths and other surface markers, multiple rooms containing information, and subterranean markers. The cost of developing such a marker system might run into tens of millions of dollars.

Some form of on-site marking of a radioactive waste repository would seem to be needed. Markers provide the initiator that results in consultation of archives. While the design of a marker system is site dependent, there is room for international cooperation in the development of symbols and messages and for the sharing of ideas and designs.

### 6.6.1 Markings within a hard rock waste repository

Other issues pertaining to the concepts presently discussed in the Nordic countries are marking the waste canisters and/or placing written material in the repository.

If a repository is located in an area assumed to be of low importance for extraction of natural resources and therefore having a low probability for intrusion by prospectors, the need for surface markers is less than for other repositories in areas where resources are or may be extracted. For such a case, however, the question of conscious intrusion to improve the safety of the repository must still be considered and may be a reason to mark the site. For this case, and for repositories with waste canisters in chambers of hard rock, other marking systems are also possible: Information kept in a rock chamber and marking of the individual canisters.

### 6.6.2 Not marking the site

The option of deliberately not marking the site has been considered and rejected in the Oslo seminar (Appendix G). As a general recommendation it has been suggested that markers should be considered in an information conservation strategy and such an idea is included in the working group's recommendation. Also the Sandia Markers Panel discussed not marking the site and rejected this strategy.

## 6.7 Archives versus Markers

For any information preservation scheme there must be reasonable balance between the cost of the preservation and the potential value of the information preserved. See also Appendix D. Compared with information archives, passive markers can be inexpensive. On the other hand, some markers described in the literature require substantial investments.

Sweden has the worlds largest number of markers in the form of rune stones, all around 1 000 years old. 3 000 stones were inventoried in the 17th century. According to the

Swedish Central Board of National Antiquity, about 1 600 of the stones are fully, and 1 000 partially, conserved. More than 10% have been completely lost over about 300 years. Some have been used as building material in one piece or in a fragmented form. Still, the rune inscriptions contain more information than written text from the Viking era in Sweden. Kaplan[6] describes the Great Wall of China: "the /Great Chinese/ wall itself does not contain much information about the pre-Ming history. It is the written information which carries this data, and China is an example of how this tradition can survive in spite of various invasions and changes of government." Perhaps this "marker" helped to protect the country's archives.

Many arguments have been made in favor of archives as opposed to markers and vice versa. There are many examples where information have been available which, had it been properly retrieved, might have helped to avoid construction of dwellings on unsuitable land. There are just as many examples of marker text being ignored. It therefore seems reasonable to consider both strategies and to assess their relative usefulness in a concrete situation.

### 6.7.1 Archive information as a continuation of marker messages

Leaning on Given's hierarchy of marker information levels[5], it may be possible to describe a nuclear waste information system in a hierarchy of information levels, where the first four levels previously have been described as levels in a marker system. Much work has been done on the first levels, when these are understood as signs, symbols and text on markers on or near the site, some of which is described by the markers panel[1,2] .The list of levels can be used and expanded to include a complete waste archive.

### 6.7.2 General levels of information for both archives and markers

It is also possible to take a somewhat different vein, in which the levels refer not exclusively to markers, but to a broader concept: an information system where also some of the lowest levels may be viewed as societal information to be found for example as cross-references within literature and in other archives or other parts of a national or international archive, rather than being exclusively on-site phenomena. In this view, information about a repository exists on several levels:

- Level 1: Rudimentary information to promote a notion of caution. Example: a sign or symbol. An international radioactive waste sign (not yet established).
- Level 2: A warning message. One sentence, containing a warning.
- Level 3: Basic information about the repository. Example: A short description of the waste on one sheet of paper or carved into a stone of the same text volume as on a gravestone.
- Level 4: Detailed information about the repository. A 100 page book; the information content of a poster session of a scientific conference.

- Level 5: The complete technical records of the repository: The archived information in the national archive or at the responsible government agency. Some non-technical information.

- Level 6: Documented information about the repository from all sources in society, nationally and internationally, including broader technical information about the repository, such as legislation and non-technical information such as account of the political debates on the issue of nuclear waste and related topics.

- Level 7: All information in society relating to the existence and the features of the repository.

In particular, participants in a philosophy of science's seminar held in Göteborg, Sweden 1991 took pain in underlining the importance of living information in society, pointing out that in a sense this element must rate higher than others, since it can be viewed as a precondition for a meaningful retrieval of the other information. The Primary, Secondary and Third Level Information Set mentioned in chapter 4 correspond to Level 4, 5 and 6 above. It can be seen as a natural continuation or expansion of the information levels 1, 2 and 3, often suggested to be addressed by marker messages.

## 6.8 Information conservation by continuing processes in society

There is no strategy of information conservation insensitive to the transfer of cultural heritage between generations. This process may influence the function of the largest and most durable marker, by moving, changing or destroying it, or by changing the concepts in which the texts or signs must be understood. Is has been pointed out that there are also strategies or scenarios completely relying on society. Examples are the conscious strategy of legal support for the public's access to information, the information transfer in school teaching, and the possible occurrence of legends and myths.

### 6.8.1 A legal strategy

Laws are created by states and states may disappear or change in the time scale relevant for nuclear wastes. Internationalization in the form of the creation of a common international archive for all radioactive wastes represents a credible improvement of both conservation and retrieval of information. In the Oslo seminar there was consensus between experts in all academic fields on this point.

Another strategy or viewpoint presented in the seminar related to the legal framework for the waste archives. Waste archives may be referred to in the context of a law defining various illegal activities in order to impose restrictions on the waste repository site. Such laws would have a very poor prognosis of survival in the long run, according to legal experts. If, on the other hand, the use of archives were invoked as a process of guarding the right to information, the strategy would link the protection of the archives to legal principles defined in Roman law and still in use after more than two thousand years.

### 6.8.2 Teaching in schools

Teaching in schools has been suggested as a way to keep memory of repositories alive. This idea may be a natural extension of - or complement to - the other strategies mentioned. It must be emphasized, however, that a strategy or scenario of information in schools is credible only as long as society considers the repository of special importance. The contents in a national archive may be less sensitive to changes in public concepts of important knowledge.

### 6.8.3 Psychological markers, tales and myths

Studies of symbol interpretation, sometimes including archaeological studies, are heavily represented in the findings of the literature search given in Appendix C. Such studies may be particularly relevant for designing the upper level marker signs and messages. It has also been pointed out that memories of a waste repository may live their own life in tales, legends and myths and that they have a potential both for strengthening and weakening the information conservation process. The strategy of markers as emotion generators[1], depicting the site as a bad place, is an example of suggested use of unconscious processes, and the Buried Treasure[10] scenario exemplifies the failure of information conservation.

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# CHAPTER 7
# ARCHIVE MEDIA

In this chapter two main long-term media, paper and microfilm, are discussed. Both store information in analog form and they are relatively technique-independent as compared to digital media. Digitized systems, especially the imaging techniques, are referred to because these techniques can be used to convert both paper documents and microfilm images into digital raster form for distribution into networks by telefax etc. They may also be used to structure information summaries and in the creation of better long-lasting records. The working group is aware that potential archive media such as metal or ceramic may be less sensitive to changes in the environment than paper and microfilm. Such media may be available in the future but they are not in use today and they must be investigated substantially before any recommendations can be made regarding their use as archival media.

## 7.1 Paper documents

Figure 1 shows a fragment of a document on paper made of plant fibre in China in the third century A.D. Generally, hand-made paper, from before the wood pulp era, has in general a very good quality and can be regarded as permanent for more than 1 000 years if stored under appropriate climate conditions. The older stock of documents in the European archives is written on this type of paper.

Figure 7-1. One of the world's oldest known paper fragments. From the third century A.D., found by the Swedish explorer Sven Hedin 1901, in Lou Lan, Xinjiang, China. From the National Museum of Etnography, Stockholm.

Since the middle of the 19th century, when industrial production of machine-made wood-pulp paper started in large scale, there have been problems with the permanence and quality of paper. In the last decade, these problems have been discussed and various investigations undertaken. University libraries and archive institutions from all over the world have been concerned with the long run deterioration of wood-pulp paper in their collections of books and documents. It depends on various factors that require different measures to help preserve information for the future. One method to improve permanence of this material in danger is "Mass Conservation" meaning the deacidification of large batches containing hundreds of volumes. Different mass conservation methods are now being evaluated.

For the same reasons a special project on paper preservation ("FOU-projektet för papperskonservering") concerning the problems of paper permanence, was initiated and by the central library and archive institutions in Sweden and has run since 1987. The project has three goals: (1) to build a competence resource, (2) to evaluate mass methods concerning deacidification, (3) to initiate the development of long lasting writing and printing paper. The project has among other things initiated work carried through in cooperation with the paper manufacturers in the Nordic countries to achieve a product of permanent quality for all types of writing and printing paper. This Nordic cooperated project has run under the name of "Fine Paper" ("Bättre finpapper").

Sweden has taken active part in developing a draft of the ISO-standard for "Permanent paper", ISO/DIS 9706, Information and documentation - Paper for documents - Requirements for permanence . This standard is elaborated within ISO/TC 46/SC 10 and has been balloted as a Draft International Standard. It is intended for publishing as an ISO-standard during 1993 or 1994. The proposed standard requires that the tearing resistance of the paper in any direction shall be at least 350 Mn (millinewton). The "kappa"-number (a measure of easily oxidized contents) shall not be more than 5. The permanent paper shall be neutralized (pH-value between 7,5-10) and contain "an alkali reserve corresponding to at least 0,4 mol of acid per kilogram" (this corresponds to a minimum of about 2% calcium carbonate). Nothing is said about the fibre contents or proportions of mechanical pulp, since these characteristics are specified by resistance to oxidation (denoted by their Kappa-number).

Another paper quality that is standardized is "Archival paper" ("durable paper") to be used for special frequently used documents. The standardization of this paper quality is carried out within ISO/TC46/SC 10.

Paper documents are a combination of paper and writing, printing or copying. In Sweden the technical requirements on the writing, printing and copying media have been regulated by the National Archives with respect to their use within the public authorities. Work within ISO/TC 46/SC 10 on these matters was initiated by Sweden some years ago and is still on "New Work Item" stage.

A general conclusion is that an ISO-standardized "permanent" or "archival" paper quality for office documents of the same strength and stability as the old paper - made of plant fibre or linen rags from the time before the wood-pulp era - cannot be expected. And the same goes for the traditional writing materials in combination with this type of paper, iron-gall ink or coal-solution Chinese (Indian) ink.

In the future, there may also be limits on the world supply of wood pulp. Recycling paper products must be considered as a strategy for the future. Libraries and archives representatives should influence all those within the industry and others to get paper products of a sufficient quality. It is known that documents written and printed with different techniques on a "permanent paper" made of different kinds of pulp and glue will only last for a limited period of time, they probably have the same longevity which is estimated for silver emulsion microfilm on polyester base, that is at most 200 years for each generation.

Books and archival volumes must still be kept as a part of our cultural heritage. Moreover, the original documents have a unique historical patina that cannot be transferred into copies or converted media.

If Nordic countries want to keep the human heritage of written or printed material alive, they will have to create a National plan for preservation which will require cooperation between libraries and archive institutions. This planning will certainly include preservation microfilming as a method to solve the problem of "mass conservation" of paper documents.

Norway has provided an example in establishing a national repository of photographic material at Mo i Rana, which is built on the Norwegian museum collections. Copies can be distributed from this repository in analog form (microfilm or photocopies) or in digital form (electronic images).

### 7.2 Microfilm

Micrography started already in the 1840-ies when the first micro-image was obtained with a reduction ratio of 1:150 exposed on a Daguerreotype plate by the use of a reversed microscope.

The first rotary microfilm camera was constructed in the U.S.A. in the 1920-ies by the Eastman Kodak Company for management of business documents. Microfilm became an important archival medium when the "safety film" on acetate base replaced the older inflammatory and even explosive nitrate film base during the 1940-ies at the time of the Second World War, when the experiences of air raids and the total devastation of whole cities by massive bombing lead to large projects of microfilming important archives and documents for security reasons.

Microfilm as replacement for paper documents was introduced in large scale in the Western European countries and the U.S.A. during the 1950-ies. Such a grand scale of microfilming was never introduced in the Nordic countries.

7.2.1 Document microfilming procedures

Documents can be microfilmed with different forms of film such as 16 mm, 35 mm and 105 mm. Documentfiche on 105 mm film (step and repeat-technique) is more and more replacing filming on 16 mm with a planetary-camera. Large batches of documents are often filmed with a rotary-camera and 16 mm film cassettes. Technical documentation (drawings, designs) is usually filmed with 35 mm film and stored as a system of aperture cards. The aperture card system is by itself limited as the silver emulsion microfilm must be separated from any paper products for long-term and archival storage.

The standard of scale reduction is related to the quality of the originals and is normally to be selected between 1:10 up to 1:48 for planetary cameras (cf ISO 6199). When using a rotary-camera (duplex-format) the scale of reduction in practice is somewhat greater, usually up to 1:50.

When microfilming documents, the following considerations are important and should be regarded as check-points of a quality-system according to the ISO 9000 standards:

- Test film

  A test film must be made to judge the quality of the process and to provide limit values for control of the process.

- Control of production

  The quality of the film must be checked (residuals of processing chemicals, resolution, density etc).

- Indexing

  An index must be made (usually digitized) using "blips" from a film in a rotary-camera.

- Protocol of film

  Must be adhered to for ensuring quality and security control. Those doing the work must be certified or licensed. The originals can be sorted out for cancellation.

- Documentation

  A description of the system, content (keys of code etc) and a technical description is necessary.

- Distribution

  The decision of what is archival film, intermediate-film and filmduplicates for use must be made. No other than the film-duplicates for use must be distributed.

### 7.2.2 Computer Output Microfilming

The performance of COM-film (Computer Output Microfilm) is good. The quality of density is often better than in other films. According to ISO 5126 the standard of scale reduction for fiche is 1:48 respectively 1:24.

There are two main forms of COM-film, the fiche format (105 mm) for pages of texts and the aperture card format (35 mm) for graphical COM (mostly concerning output from CAD-systems).

### 7.2.3 Microfilm as an archival medium

Microfilm is good as an archival medium because:

1) it gives closely packed information in analogue form. One fiche contains about 500 pages size A4, while a cassette with 16 mm film contains about 5 000 pages size A4.

2) it is relatively technique independent. Information from microfilm can easily be read with standardized equipment.

3) its permanence is good when properly climatized and stored. Silver emulsion film has existed for more than 100 years (in the beginning on glass, then nitrate, then acetate and now polyester base).

The lifetime of a generation of silver emulsion film has been estimated to about 200 years provided that the film is properly processed, managed, climatized and stored. Regarding the first camera film as first generation, and changing polarity for each generation, four generations of good quality can be made to produce a readable paper copy which may last for another 200 years. In this way information on microfilm may be preserved for 1 000 years, which corresponds to the estimated lifetime of high quality paper documents. Color film is not at present considered as an archival medium.

There are still many risks that endanger the longevity of microfilm. Though many silver emulsion images have been ruined by improper fixing and washing already when processing the film, the more important deterioration mechanism for the majority of not properly stored silver film is image oxidation. Image oxidation (reduction-oxidation) may occur when the relative humidity (RH) is too high. Microfilm should never be stored at a higher humidity than 40 % RH and is specifically vulnerable to the kind of oxidation known as "red spots". Outbreaks of this problem are becoming more frequent and severe. Recent research done by the Image Permanence Institute, Rochester, U.S., has shown that sulfiding treatment ("Brown Toning") gives excellent protection for microfilm against red spots (red blemishes) and very well can replace earlier recommended gold and selenium treatments. A very large number of microfilm rolls kept by the Illinois State Archives have been protected by sulfiding treatments (confer articles in Inform, The Magazine of Information and Image Management, Published by AIIM-association, Sep 1988 and May 1990).

Polyester filmbase can be regarded as a very stable material and could last for 500 years. However, silver emulsion film is still a laminate product with certain lack of qualities that most probably will reduce its lifetime.

### 7.2.4 The integration of microfilm and digitalized media

Storing information on microfilm in digitalized form is achieved by a variety of techniques. Normally, the file that generates the COM-film is stored in a character coded form (ASCII and EBCDIC-standards) or vectorized as a CAD-drawing (built up by vectors). Pictures can also be stored in raster form (bit-mapping). Bit-mapping is now the usual form of digitalizing microfilmed documents. A raster form can also be combined with character coded forms or vectorized forms. Certain text information within the image can be character-coded and retrieved by the database system.

The scanning of paper documents and subsequent storage on digital media (mostly optical disks) is now competing with microfilm as an imaging archive medium. On the other hand microfilm could be a complement to these new imaging technologies as a backup-medium. The major microfilm manufacturers are now presenting systems that integrate microfilm with data networks and telefax. It has been shown that it is easier to scan from microfilm than from the original paper document. For example, a document scanning system could be organized in two steps. First, batches of documents are microfilmed during the daytime, when the documents can be prepared and indexed. The microfilm is then scanned at night when there is time available and rates are low for distribution by fax. At present, about 200 microfilmed text pages can be processed each minute by a microfilm-scanner.

## 7.3 Digital media

The development in the field of "imaging" is progressing quickly. Imaging is the creation of digitalized document pictures. A general term for this field is Electronic Image Management (EIM). EIM has among other things produced a connection between the world of computers and the world of microfilm. EIM involves the scanning and storage of document pictures in a raster form combined with character coded or vectorized forms. The technique of storing image databases has developed through "Document Image Processing" (DIP). The advantage of the relatively powerful laser-written optical disk as a storage medium for the image databases is the possibility of establishing a direct access link of digitalized images into computerized systems by using a standardized interface between the computer system and various peripherals (SCSI 1-2 = Small Computer System Interface 1-2). Other advantages of the optical disk is its physical stability as compared to magnetic tapes, and also the easy distribution of large quantities of image information that is made possible on each single disk.

The scanning technique in general has also been developed for converting raster form into character coded form, and for input of other typography than OCR-B. By now the capacity of storage in the "family" of optical media is said to be doubled every second year.

At present there are discussion about how to select an appropriate image compression method to match different user requirements, for example the possibilities of using different compression standards without losing too much of the information of the original picture (the resolution into pixels).

## 7.4 Lifetimes of various media

Today, the nuclear industry information is largely written on the type of permanent paper mentioned in section 7.1. Paper from the eighties or older may have poorer permanence. When reviewed at the time of the closure of a high level nuclear waste repository, the bulk of paper documents will be from after 1990.

These circumstances imply that there is no imminent need for large scale improvements of the permanence of the paper documents, provided that the documents are printed on permanent paper. Documents on other media such as drawings on full-scale transparent (and/or reproduction) film need to be reviewed before the final archive is created.

There is no obvious way to attribute a lifetime to today's permanent paper. It is reasonable to assume that the efforts described in section 7.1 will lead to standardization of higher quality paper. This certainly is the intention of the various working groups involved. The future permanent paper is therefore expected to last longer than a few decades, and sometimes the goal is described as a lifetime of several hundred years. This also requires adequate and correctly adjusted printing equipment e.g. photocopier/laser printer.

In Table 7-1, estimated maximum lifetimes possible - assuming passive storage and ideal storage conditions - for four different archive media are given, all depending to some extent on subjective expert judgement. There are additional requirements on different levels for air filtration for all the media. The magnetic and optical media may have a longer physical lifetime than quoted in the Table 7-1. The table gives the "technical life expectancy", which is related to availability of the equipment on the market.

Microfilm is assumed to give a readable hardcopy from the fourth film generation. There is no long-term experience of the storage performance of paper documents presently used generally in Sweden. Standards are being developed for many combinations of writing and printing material and paper which may suggest review of the lifetime estimations on a regular basis.

**Table 7-1: Possible lifetimes and climate conditions of different archive media**

| Medium | Lifetime years/generation | Temperature °C | Rel. Humidity % |
|---|---|---|---|
| Paper | hundreds | < 18 | 30 - 40 |
| Microfilm | up to 200 | < 15 | 25 - 35 |
| Magnetic | approx 10 | < 18 | 35 - 45 |
| Optic | approx 10 | < 18 | 35 - 45 |

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4.5 ISO 9003
Quality Systems - Model for Quality Assurance in Final Inspection and Test (1987)

4.6 ISO 9004
Quality Management and Quality System Elements
- Guidelines (1987)

4.7 ISO 9004-2
Quality Management and Quality System Elements
- Part 2 Guidelines for Services (1991)

# CHAPTER 8
# CONCLUSIONS AND RECOMMENDATIONS

The working group has recognized that information about nuclear waste repositories needs to be transferred to future generations. The reason is to enable them to make their own conscious desicions regarding the repositories. This might involve retrieval of the waste if it is considered a resource, "repair" work, or remedial actions on the repository if this is deemed necessary. In the following, some of the working group's considerations and recommendation are summarized.

## 8.1 General considerations

These recommendations are formulated in 1993 as a result of a joint project with the purpose of establishing a common Nordic basis for conservation of information about nuclear waste repositories. The project is a first attempt to study an information conservation system for nuclear waste and to give recommendations to the Nordic countries regarding management of the records presently available.

Both international and national studies may follow before the question of waste information has to be solved. Moreover, when these recommendations are implemented in individual countries, detailed regulations may differ from one country to another.

Future societies will need information about a large number of activities in today's society. Disposal of radioactive waste is one such activity. Future societies may consider other activities of higher or equal importance. The general techniques for information conservation is therefore not an exclusive concern for waste management.

It must be assumed that the best methods for information conservation for radioactive waste repositories are the methods which adhere to common and accepted practices at the time of the repository closure. The exclusive reliance on experimental or unique systems for archiving nuclear waste information is therefore not recommended.

The working group considers that continued efficient management of records will lead to the ultimate objective of a well organized post-closure archive. Establishing an optimal system of information conservation is not contradictory to the actual needs for record keeping within waste management, national licensing authorities, or national archives. Neither the present recommendations, nor later national implementations are intended or expected to create a great amount of extra work or cost.

It is worth noting that the first 1 000 years are the most important. The goal therefore has been reached to a large degree if information can be conserved and retrieved during this period.

8.1.1 To whom are recommendations directed?

The recommendations in this chapter are directed towards the Nordic countries and, in particular, waste managers and authorities. Furthermore, it is recommended that the public be informed of measures to conserve information about nuclear waste repositories.

8.1.2 What kind of repositories are addressed?

Recommendations are given about information conservation for all types of waste. For extremely low level waste in shallow land burials, it is assumed that normal practices will be followed and that records should be handled as they are handled for a county disposal of non-radioactive waste.

## 8.2 Recommendations

8.2.1 High-priority records

Records about waste properties, waste disposal facilities and handling of waste are kept at several locations, both by waste managers and by the national authorities. In order to gather and summarize this information, to create redundancy and to ensure that the information has a good chance of long term survival, it is recommended that relevant extractions are made and placed in regional and national/international archives.

The most important records to be kept nationally are those relating to

- The geographical location of the repository.
- The chemical and physical properties of the wastes.
- The design of the repository, its physical shape and barriers.
- Background information and data used for the final safety assessment,

and background material such as:

- The final safety assessment.
- Laws, general information from and about the society.
- The operational records of the repository.

It is assumed that the data for the safety assessment are more important than the safety assessment itself, and that background information and reports provide valuable information of society's considerations in dealing with waste repositories.

All primary information is not equally important. It is recommended that guidelines be established to describe the relative importance of records so that records can be managed within a national and international consensus.

It is recommended that summaries of information on different levels are created:

1 The main record, including all (or most of the) information. This is referred to as the Primary Information Set.

2 An extraction of the most important part of the main record with added information about location and contents of the Primary Information Set as referred to in chapter 4 as the Second Level Information Set.

3 A Third Level Information Set, which is a summary of the Second Level Information Set.

The Nordic countries should strive for the creation of a central international radioactive waste archive. There has been agreement among many experts consulted that an international archive would increase the availability of essential information, and increase credibility for long term information retrieval. It is proposed that the Third Level Information Set be kept at international institutions.

At an early state - as soon as practically possible - a brief identification of valuable information should be carried out. Also, a review of the quality of the presently used information carriers should be made, to ensure acceptable longevity. Summarizing and extracting of information should take place no later than at the time of closure of a nuclear waste repository.

### 8.2.2 Periodic review and future reduction of archive volumes

It can be seen from the archives in the nuclear waste facilities in Sweden and Finland, that no reduction of volumes will be needed during the facilities' operating life-time. The annual growth of the archives is not expected to change drastically for the years to come and the available archive capacity is large. The growth of the archives does not in itself call for culling and removal of less valuable information material at the present stage in the repository programs, or in the near future.

There are other reasons, however, to review the archives' contents, such as the need to prepare for a second level archive, and it is recommended that, during the operational or pre-closure phase, reviews are made of the information system on a scale to be decided in each country. As a minimum, the reviews should be made frequent enough to allow relevant information to be passed from one generation of operating personnel to another. The reviews should include information about decisions taken to discard or include existing information.

### 8.2.3 Responsibilities

It is the responsibility of the waste management to handle and review the records up to the time of repository closure. After this time is recommended that the governments takes responsibility for the waste archive. It is assumed that, after closure, periodic reviews may be carried out by the authorities.

### 8.2.4 Archive media

Techniques for information storage will develop during the years from now to closure, which for all Nordic nuclear waste repositories lies decades into the future. The best long-term archive media now are not necessarily the best ones in the middle of the next century. It is therefore not meaningful to formulate detailed requirements regarding media for records to be created fifty years into the future. It is recommended that new development be followed.

Permanent multi-copy paper used widely in the Nordic countries in combination with accepted copiers and printers is considered adequate for records management. Therefore, there might be no reason for a large-scale transfer of information on paper to any other media for reasons related to permanence. It should be noted, however, that documents from ink jet printers may not have sufficient permanence. This is also true for some older paper qualities.

Digital media are far too technique-dependent to be accepted as an archival medium in the perspective of hundreds or thousands of years, but digital processing may be a valuable tool to be used for structuring information summaries, and in the creation of long-lasting records. It is recommended that information be represented in an analog form with a minimum of codes. If codes are used, keys must be available.

### 8.2.5 Complementary information carriers - markers.

The working group presumes that archives will constitute the basic information carrier to future generations. However, markers may constitute a complementary source of information. It therefore recommended that simple marker systems of some kinds are investigated. For a period up to the next glaciation, passive surface markers may constitute a method for transfer of information about nuclear waste repositories to future generations. Within the next 20 000 - 50 000 years parts of the Nordic countries will probably be covered by an ice cap and some glaciation as early as in the next 3 000 - 5 000 years cannot be ruled out. Long-term marking of the waste site may therefore be considered for high-level radioactive waste. In addition, it should be considered whether information in some form could be supplied within the repository itself in the form of marked individual canisters or underground chambers for archive copies near the repository.

### 8.2.6 Further work

Further work should be directed to guide the implementation of information conservation systems on the national level. Since this project is the first of its kind in the Nordic countries, it is recommended that all findings are thoroughly reviewed. Important items to study are

- Evaluation of threats to a repository and the ability of information systems to successfully thwart such threats.

- The cost effectiveness of information conservation measures.

- The types of information to be stored and the procedures used to extract and summarize information.

## APPENDIX A
## ARCHIVAL LEGISLATION

Arne Fryksén
The Swedish National Archives

### 1. Legislation in general

### 1.1 Archival legislation in the Nordic countries

The principle of the right of access to public documents has been the base for both Swedish and Finnish legislation. In Finland there has been an Archival Act since 1939. Sweden, Denmark and Norway have just recently passed Archival Acts. In the archival legislation of all the Nordic countries, the government gives the National Archives the right to regulate archival matters for the public authorities.

There are regional archives (public record offices) in all the Nordic countries which maintain records. If a local or regional state authority has been closed down the records are handed over to the regional archives. In all the Nordic countries but Sweden the National Archives are entitled to inspect municipal archives.

### 1.2 Swedish Archival legislation in the Past

At the turn of the last century in 1903, the first ordinances concerning documents and archives management within the state authorities (central and regional agencies) were passed by the Swedish government. Up to that time, the state authorities were required to ask the National Archives for advice regarding the cancellation of documents (governmental ordinance 1885). Following in 1907, the first ordinance of the use of writing material (paper) was passed by the government, when the problems of wood-pulp paper became obvious for the first time.

Just before 1990 when the first Swedish Archives Act was passed by the Parliament, the most important ordinance about archival matters was the General Archival Ordinance (1961) in which among other things the National Archives for the first time by principle was authorized by the government to decide on the appraisal and cancellation of documents in the state authorities´ archives. There were also the ordinances about appraisal and cancellation of certain documents (1953) and about writing materials (1964), which were in force parallel to the General Archival Ordinance.

### 1.3 Swedish Archival legislation in the Present

The first Swedish Archives Act, into force on 1 July 1991, contains provisions applicable to the archives of public authorities and certain other bodies and applies to the various record offices. This Act is linked to the Freedom of the Press Act, which has the status of a constitutional law.

There are four categories of "authorities" relevant to the concepts of the Freedom of Press Act and to this discussion of archive legislation:

(1) An authority in the sense given by the constitution; where one distinguish between administrative authorities and judicial courts.

(2) An authority in the sense given by the Freedom of the Press Act, where one states that the Parliament, the Synod of the Church, and Municipal Decreeing Meetings are authorities.

(3) Institutions that administer/manage state-owned investments and assets/resources.

(4) Private institutions that have administrative tasks given to them by the constitution or "ad-hoc authorities". Official documents coming under the Official Secrets Act can be found within the "ad-hoc authorities".

As mentioned before the Swedish Archives Act provides legislation concerning archives held by the parish authorities and the bodies referred to in Chapter 1, section 8, of the Swedish act on Secrecy, and the regional social insurance authorities. The act requires that the archives should be maintained so as to satisfy the following demands:

(1) The right of public access to public documents

(2) The need for information for the administration of justice and public administration, and

(3) Research requirements.

## 2. Regulations about different archive media

### 2.1 Regulations in the Nordic countries

Most of the Nordic countries have some regulations concerning "archival" quality for paper. In Finland there also are regulations about writing materials in combination with paper to be used within the public sector. It should be noticed that both Denmark and Norway in the years about 1960 have withdrawn their regulations about writing materials in combination with paper because of the financial costs.

All the Nordic countries also have special regulations about digital media and microfilm with information that is to be handed over to the public archive institutions. In Norway there are special regulations about the production of microfilmed documents within the public sector.

There is a general belief in the future possibilities to regulate the preparation of paper documents within the public sector by references to the coming ISO-standards concerning permanent paper, archival paper and writing materials. In this respect there is no difference between the Nordic countries.

## 2.2 Swedish regulations

### 2.2.1 Paper documents

In Sweden the National Archives have given regulations concerning the technical requirements on the production of "permanent paper" (RA-FS 1991:10). These regulations require that permanent paper is made of fibres from cotton, linen and/or bleached chemical pulp. At most 5 % of the total fibre contents may hold another kind of pulp, e.g. mechanical pulp. The fibre content shall be determined according to the Scandinavian standard (SCAN-G 3:90). The "kappa"-number (a measure of easily oxidized contents) shall not be more than 5 corresponding to SCAN-C 1:77. The permanent paper shall be neutral sized (pH- value between 7,5-10) and contain an alkaline reserve corresponding to a minimum of 2 % Calcium carbonate.

Another standardized paper quality according to the National Archives technical requirements is "Archival paper" ("durable paper") for special use. Archival paper shall meet the requirements for permanent paper and in addition have a fold number of at least 150 double folds in the weakest direction (SCAN-P 17:77).

There is in fact a trend today towards the general use of the mentioned type of permanent paper within the public sector in Sweden. This type of permanent paper is definitely less expensive than the high quality paper marked "Svenskt Arkiv" (according to the previous Swedish archive regulations this quality paper product is made from pure cotton fibre). Still the permanent paper is considered to match a sufficient permanence to be used by the public authorities. Only if the paper documents are to be used frequently, archival paper must be used.

Paper documents are a combination of paper and writing, printing or copying. According to the previous regulations the high quality paper marked "Svenskt Arkiv" has been tested and standardized for use in combination with different writing, printing and copying media. The today´s requirements on writing, printing and copying media to be used when preparing documents on paper (permanent paper) are presented in the National Archives regulations (RA-FS 1992:4 and 1992:6). Such combination standards are now being developed for combinations with permanent paper. Materials tested and approved with reference to these regulations (or to the previous regulations) are listed in a yearly publication from the Swedish National Testing and Research Institute (SP).

### 2.2.2 Microfilm

The new regulations from 1991 and 1992 about microfilm build on the assumption that different media have different properties and values and should be treated with regard to their uniqueness.

The regulations about methods of production and treatment of microfilm (RA-FS 1991:4) deal with both film that should not be sorted out for cancellation and film that should (after a long period of time). Another distinction is made between microfilming of documents and microfilming by COM (Computer Output Microfilming).(RA-FS 1992:8 and 1992:9).

Microfilm with information that is to be preserved for the future shall correspond to the demands of a technical and physical quality, that are stated by the National Archives (RA-FS 1992:8 and 1992:9).The microfilm shall be tested and certified by an officially accredited certifying institute. These regulations are also connected to the National Archives demands concerning the selection of products and quality systems (RA-FS 1991:7 and 1991:8).

According to the archival regulations for the public sector the replacement microfilming of documents is to be regarded as an act of cancellation, since the authenticity of the disposed originals as a matter of fact is lost. In order to give the microfilmed documents an optimum of legal admissibility you will have to manage certain demands concerning the microfilming procedures, the quality of the documentation of the system and the future management of the microfilm. Most of these demands can be standardized according to the concept of quality system (confer the ISO 9000 standards).

### 2.2.3 Digital Media

The new regulations of 1991 about digital media build on the same assumption that goes for microfilm. The different media have different properties and values and should be treated with regard to their uniqueness.

In the old General Archival Ordinance, the National Archives gave instructions about storing information on magnetic tapes. As the (state) authorities, in general, could not keep the magnetic tapes themselves (in climate controlled archives) procedures were developed for handing over magnetic tapes to the National Archives at a time much earlier than normal.

The regulations from 1991 about methods of production and treatment of EDP-media (EDP = Electronic Data Processing, RA-FS 1991:3) contains instructions about how files must be treated by the authorities. The regulations state that it is important to take the whole chain of "production - treatment - keeping" into consideration before new applications/systems are introduced.

The documentation of EDP-systems is very important as the documentation makes it possible to understand and use the stored data and to understand the connection between different types of information within an authority. The file must also have a standardized structure and a logical format which allows conversion of the file, if it should be handed over to the National Archives to be kept for the future. As a matter of fact every EDP-system producing files for archival storage should correspond to certain demands concerning the management and the documentation of the system as well as the relevant procedures (confer the ISO 9000 standards on the concept of quality system).

Data can be stored on spools of ½ inch magnetic tape, tape cassettes, or optical disks. The logical format of the stored data is more important and interesting, however, than the physical medium. It's also important to make it possible for the state authorities to choose between different alternatives (but the choice must allow longterm keeping in the National Archives).

REFERENCES AND NOTES

## 1. Paper Documents

1.1 RA-FS 1991:2
Riksarkivets föreskrifter och allmänna råd
om framställning och hantering av pappershandlingar

1.2 RA-FS 1991:10
Riksarkivets föreskrifter om tekniska krav
för papper

1.3 RA-FS 1992:4
Riksarkivets föreskrifter om tekniska krav för
skrivmedel för framställning av skrift på papper

1.4 RA-FS 1992:6
Riksarkivets föreskrifter om tekniska krav för kopiatorer, laserskrivare,
telefaxar m m för framställning av skrift på papper

1.5 SCAN-G 3:90
Massa, papper och papp - fibersammansättning - allmänna anvisningar (1990)

1.6 SCAN-C 1:77
Massa - kappatal (1977)

1.7 SCAN-P 17:77
Papper - vikstyrka - Köhler-Molin apparat (1977)

Note: The SCAN standards are developed in cooperation between the central laboratories for the pulp and paper manufacturers in Denmark, Finland, Norway and Sweden. The standards are distribudet by the secretariate under the address:

Scandinavian Pulp, Paper and Board Testing Committee,
Drottning Kristinas Väg 61,
Stockholm

## 2. Microfilm

2.1 RA-FS 1991:4
Riksarkivets föreskrifter och allmänna råd om
framställning och hantering av handlingar på
mikrofilm

2.2 RA-FS 1992:8
Riksarkivets föreskrifter om tekniska krav
för mikrofilm

2.3 RA-FS 1992:9
Riksarkivets föreskrifter om provningsmetoder vid utvärdering av mikrofilm

2.4 RA-FS 1991:7
Riksarkivets föreskrifter och allmänna råd om val av produkter och kvalitetssystem

2.5 RA-FS 1991:8
Riksarkivets föreskrifter om ändring i riksarkivets föreskrifter och allmänna råd om val av produkter och kvalitetssystem (RA-FS 1991:7)

## 3. Digital Media

3.1 RA-FS 1991:3
Riksarkivets föreskrifter och allmänna råd om framställning och hantering av upptagningar för ADB (ADB-upptagningar)

## APPENDIX B

# TRANSMITTAL OF INFORMATION OVER EXTREMELY LONG PERIODS OF TIME[1]

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### Introduction

In this chapter the complicated issues relating to science as the instrument to find a solution to the problems of *Transmittal of information over extremely long periods of time* (TIELPT) will be discussed[2]. The following will focus one particular problem: How do we communicate with and warn future generations over extremely long periods of time about the dangers connected with the presence of a hidden nuclear repository?

One difficulty is that the aim of TIELPT is seemingly twofold:

1) To communicate fully to future generations close to our culture about the dangers of the nuclear repository.

2) To communicate a warning to future generations that are so culturally different from us that they do not understand our language and knowledge.

The second problem is the most difficult. But the first one contains major difficulties too. Culture can change dramatically over relatively short periods of time and such transformations have effect on our way of producing and interpreting knowledge. Another point then is that any given solution to be acceptable must satisfy the criterion that its design is flexible and shows sensitivity to several kinds of cultures.

It also appears that there is a basic tension between two goals within the project. One is the desire to transmit a vast amount of material. The other is to communicate over extremely long periods of time. Somehow a choice needs to be made about whether one wants to design a solution for speed or distance. An alternative would be to use several types of solutions.

### 1. Which are the problems?

### What kind of scientific problem is TIELPT?

TIELPT can be conceived of as a *cluster of scientific problems*. To be treated scientifically TIELPT needs to be broken down into several distinct questions. At the same time the search for knowledge must not be reduced simply to a number of isolated solutions, since this could mean that opportunities and flaws that can only be seen when TIELPT is studied as a whole, might be missed.

TIELPT seems to encompass two meta-problems:
1) What technique can we use to communicate with people in future societies?
2) How can we prevent the social flow of the future from disrupting our message?

Both problems are very difficult to solve. The first one poses the question of how we are to construct a message that will have an optimum chance of being understood. The second one concerns safety: how can we make sure that the message will survive. These questions are also interlinked: they can not be solved separately.

Several different scientific fields may be involved in the TIELPT research effort, such as archive research, historical, linguistic, social and philosophical disciplines. Since the questions are so complex, a large number of disciplines should be involved and scientists from a wide range of subjects be consulted about TIELPT. This would increase the scientific base, and also lead to a diversity of interpretations and results.

Another difficulty is the unique standing of the problem of TIELPT, since few scientific ventures have been made in this field earlier, and since it is not comparable with many other problems. This also means that no single discipline can dominate. On the one hand this freshness of outlook can lead to a fruitive openness of approach. On the other hand, no direct help is available from earlier results within given research traditions.

## The difficult scientific problem

Since the knowledge sought for in part can be found within many hermeneutical disciplines, integration becomes a major difficulty. This means that different perspectives must be considered and at times be integrated with each other[3]. The interdisciplinary problems involved in TIELPT are enlarged if one looks at the problem of KAN 1.3 as a whole. The other problems are all closely linked to TIELPT. What type of information should be conserved? In what form should the information be kept? What should be the quality of the information, regarding both type and form? These are all problems which depend on the answer to the question of what communication is possible, before work can begin. But since TIELPT is the most difficult question, it is probable that answers to the other problems are produced before work is finished with TIELPT. Therefore, the design of the solution can easily become dependant on work done on the other questions than on the basic problem of TIELPT.

## Social and human sciences, TIELPT and truth

There is a danger that the field may be dominated by approaches from the natural sciences, since these have had a key position when it comes to technical questions. However, because of the centrality of human communication and the role of culture, TIELPT constitutes to a large extent a problem for the social and human sciences. In the scientific venture the goal is always *verisimilitude*, rather than absolute truth[4]. A scientific theory is represented in a language and can never completely represent reality. There is always a distance between the signifier and the signified and a translation from the object into a system of signs or code, even when the most elementary observations are involved.

Another important problem is that we are not in direct contact with the object. Instead it is our *conception* of the object that is studied. Different scientists and traditions conceive the same object in varying ways, which leads to what Thomas Kuhn has called *incommensurability*, referring to scientists' inability to communicate over the same issue, since they perceive it in different ways[5].

The goal of science is to arrive as close as possible to truth". The approach is not necessarily the most beautiful theory, nor the best, the morally superior, or the most effective. This also tells us something about the limits of science. The scientific way of producing knowledge is one of many avenues. Since in TIELPT truth is extremely difficult to reach and ethical, political, economic and practical problems play an important part, it is not self-evident that science is the best avenue to success. The advantage of science in the case of TIELPT, though, is that systematic methods can grasp all the clues available.

**The non-researchable problem**

Science can be said to have certain limitations as to what is possible to investigate with these methods. If we are unable to collect data about an object, it will be difficult to do research on it. Also, if data is not regular in its character, then it will be difficult to create an interesting systematic pattern. In these cases, it will obviously be more difficult to use theories for accurate predictions. There is a point in realizing that the types of claims made when the object is within a closed system compared with an open system, are totally different. Within the sociology of science, though, scholars have for many years claimed that the difference between the natural, social and human sciences is not all that drastic[6]

It is crucial that we in TIELPT lack a stable object that can be investigated in a systematic way. Another difficulty lies in the fact that the instruments available to measure the object are incomplete and insufficient. We are therefore neither able to see our research object (the social future) nor are we in possession of powerful instruments to handle it in the way that the goals of the project would have it.

Since it is of great importance that the study of TIELPT can produce solutions that are valid over an extremely long time, it is problematic that the traditional explanatory power in dealing with these kinds of research objects is so low. Also, since there are so many problems in predicting the social future in a scientific way, scientists have usually avoided these kinds of issues. This means that the study of TIELPT is fairly unique within the scientific sphere.

## 2. Quality in science

### Appraising quality in science

Scientific quality can be said to be measured through several factors and entail many things[7]. This section will focus on the methodological aspects of the scientific quality -appraising process. A starting point in a discussion of control of quality in science is that one cannot use the same kind of criteria for radically different scientific ventures. Criteria must in some sense be appropriate to the aims of the investigation. Some general factors though, seem to be common for most types of research. Below five general factors will be discussed.

### Five general factors

The first factor is *harmony between empirical data and theory*. Data in itself is seldom interesting and theory in itself is often shown to be lacking in an understanding of the subtle shifts of reality. Harmonizing the two is extremely difficult. But almost always science can be made better by integrating the two in a flexible way[8].
The second factor is *paradigmatic entrenchment*.

Science can be made better if it is thoroughly integrated in a theoretical framework within an established perspective. It must be coherent with and compatible with other studies. The third factor is *critique*[9]. Theories should be constructed in such a way that it is possible to criticize and falsify them[10].

The fourth factor is *comparative form*. The data collected and the theories built upon them must be presented in such a form that they are comparable with other cases.
The fifth factor is *rationality*, meaning that a theory must adhere to some kind of rationality - it must be consistent with its own framework.

### The uniqueness of TIELPT

As already noted, the uniqueness of TIELPT is a major problem. Still, the project can be broken down into smaller factors and these in turn can be compared with similar problems elsewhere.

Obviously, a lot of this has been done in the Nordic work with TIELPT. Current and historical data have been made available by looking at similar issues. Data have in the same way been collected about the history of markers, oral traditions, etc.
In finding similarities and in collecting data about these cases, one constructs a balance between theory and data that is somewhat more even. This is very important in a case like this where theoretical statements can be proven neither right nor wrong on the basis of current available data.

A further step can be made in evaluating the research done on similar cases. How well entrenched in a paradigm are the theories that are proposed here? Have they passed the control machinery of science? Can TIELPT be put in a *comparative form* so that those who have done research on similar cases might criticize them?

## The tension between soft and hard science

There is a danger in theorizing about a social future where claims may be impossible to criticize. Since there is no data, there is neither affirmative nor contradictory evidence available.

Here the principle of harmony between data and theory necessitates that caution be exercised. Since the research object is unknown, then the explanatory power of the theory must be restrained. A theory that explains too much with this obvious lack of data, is an unbalanced theory.

The endless number of possible futures is also a factor that will make the theory with a lesser explanatory power survive tests where "stronger" theories will meet innumerable problems.

## Integrating different approaches

Since there are many different issues involved, TIELPT must be regarded as an interdisciplinary problem. In principle two ways are open[11].

*Disciplinary pluralism.* It is possible to allow a researcher from each discipline to be responsible for a particular aspect. These as well as the disciplines included, should be so separate that no interdisciplinary conflicts arise. In the following discussions these distinctions are respected and the project may result in a compilation of different aspects within a common theme. This method may show signs of success, but it does not solve the problem as such. A serious and qualitative approach must be organized on the basis of criticism.

*Interdisciplinary research.* By selecting scientists from closely related disciplines to study similar problems, results are produced that are good both for the project and the disciplines involved. The drawbacks lies in the time spent in reconnecting with the core of the disciplines, since these often are questioned when confronted with an opposing perspective. Conflicts and delays may follow, but it is a very productive way of doing science[12].

Problems may also follow in integrating perspectives and in the attempt to ease together theoretical elements from opposing paradigms. The term *interpretation package* is sometimes used to signify that a concept or an argument seldom can be used out of context from the theoretical foundation in which it was produced[13]. Often one has to use the complete perspective to find it meaningful. Scientific concepts are often so embedded in a certain way of looking at things that there are grave problems in transferring it into a different perspective. Here it is important that there is made an effort to make theories capable of comparison to enable interdisciplinary criticism.

With interdisciplinary research both sides of a controversy will in a natural way be involved. Flaws that would not have been apparent with disciplinary pluralism will be revealed.

**Finalization and flexibility**

The research goal on TIELPT should be to find the best possible solution and make what is already safe even safer. The solution tentatively accepted at Time $T_1$ should be adhered to in such a way that it may be upgraded or replaced by a better solution at time $T_2$ corresponding to the fund of new knowledge and techniques that have arrived at the scene after $T_1$. It is difficult to know when one has reached the best solution. Peer review can give us some clues. It is also difficult to know if there will be shifts in our paradigms. Since the solution produced is intended to have an effect over such a long period of time, it is problematic to freeze our knowledge base at a certain stage ($T_1$) and build upon it. In the case of TIELPT this is even more of a complication, since the issues are so new and unexplored. Thus social and cognitive factors should be promoted to prevent an ultimate finalization of the solution.

**Time and resources**

Time and resources are two necessary ingredients of good research. To optimize the qualitative aspects it would be necessary to establish several durable research projects. For example one might have two parallel contending projects following different perspectives, so as to facilitate a constant openness.

Having said this, one could pose the question of quality in another way: Could we have done better? Why did we not begin to discuss and accumulate knowledge about this issue fifteen years ago which would have enabled us to plan ahead and put us in a better situation today? What factors in the discussion of the repository of nuclear waste contributed to the late start of this discussion? The probable answer is that the issue of the repository of nuclear waste for many years was considered a question solely for the technical and natural sciences and there was nothing in the existing political or legal framework to attract support for alternative research. The same reasoning could be applied to the question of nuclear waste storage. If this had been a "hot" issue during the 50's and 60's, we would obviously be better prepared today[14]. In both cases important problems are ignored or underestimated. What we can learn from this is that one way of upholding quality is to attempt to look behind the immediate.

**To organize a qualitative study over the future**

To organize a project according to principles that ensure quality is one of the best ways of furthering the production of good scientific knowledge. This is especially the case if, as in TIELPT, it is often hard to apply traditional scientific criteria[15].
Such a project organization should consist of a core of persons with competence from research who can supervise a number of projects. These key-persons must also play an active role in formulating problems and in making concepts and distinctions. Other important elements are the formation of a creative environment, where results, theories and concepts are criticized and developed. It is important that a network of contacts is developed with people from many different areas of life and particularly with scientists within the university from various disciplines. Continuous feedback must be secured and scientific and methodological integrity must be guaranteed. They must stand free to come to any conclusion.

## 3. Science in society

### Science within a culture

An understanding of science has to include the insight that science is inseparable from society. Scientific achievement is almost invariably tied up with social goals. We can see science as a typical product of our highly industrialized western society. It has developed from certain demands that this particular society has placed on it and its high social position is related to its ability to produce knowledge which fits the bill and can be used in particular contexts. It also stands for a knowledge production which emphasizes certain aspects: systematic methods and data collection, technical tools, the theoretical and specialized language, etc. In principle it excludes other aspects, such as feelings, ethics, intuition, etc. Science and the knowledge it produces must therefore be regarded as culturally dependent[16]. This insight has at least two major consequences for TIELPT which I will discuss below.

### Knowledge without a knowing subject

Our language and our tools are understandable in our context, by our scientists. But scientists of the future will probably live in a totally different kind of society. Since their way of producing knowledge will be different from ours, we will run the risk of having our knowledge become incomprehensible, since we do not share a common context with future generations.

There are two basic ways of understanding knowledge and cultural context. One is found in its archetypical form with Karl Popper in his image of a disembodied or transcendent science. The other emphasizing the social nature of knowledge.

Popper, for his part makes a distinction between three worlds[17]. The first is the world of physical objects or of physical states. The second is the world of consciousness, or of mental states. The third, which is the one that interests us here, is the world of objective contents of thought, which contains theoretical systems, problems, problem situations, critical arguments and states of discussions.

Popper argues for the independent existence of the third world. He illustrates this by two thought experiments:

Experiment (1). All our machines and tools are destroyed, also all our subjective learning, including our subjective knowledge of machines and tools, and how to use them. *But libraries and our capacity to learn from them* survive. Clearly, after much suffering, our world may get going again.

Experiment (2). As before, machines and tools are destroyed, and our subjective learning, including our subjective knowledge of machines and tools, and how to use them. But this time, *all libraries are destroyed also*, so that our capacity to learn from books becomes useless[18].

Popper makes a distinction between two kinds of knowledge: subjective (second world) and objective (third world). The latter is *knowledge without a knowing subject.* The third world can therefore be conceived of as a knowledge repository, existing independently from the social sphere.

### Knowledge in context

Another perspective can be said to build upon the idea that knowledge is always subjective, social and contextually grounded. From this perspective Popper's reasoning has many flaws. The major one being that Popper has a static view of language, culture and science. If indeed all machines and tools were destroyed it is reasonable to assume that a large part of our culture, our common ground is destroyed too. The hermeneutical problems in trying to decode world three when starting from a different cultural base, are totally ignored. Popper has even less readiness for exotic future scenarios which presupposes a total break with our culture[19].

It is important to emphasize that science is a young and dynamic institution in constant transformation. There are great difficulties in explaining to a more primitive future society what purpose our advanced machines had. Almost as great would be our difficulty in communicating to a more advanced society, where it is our machines that are too primitive to fathom. This may be the case, since the specialized form of knowledge dealing with nuclear energy that we have, may well die out when we cross over into other forms of energy production.

Often important ideas and thoughts may not emerge until the context is right. An archetypical example of this is the way TIELPT has appeared at a relative late stage on the scientific agenda, despite the meticulousness with which the problems with the repository have been scanned with the help of engineering and natural science.

Today's cultural context may very well change dramatically in a matter of a few decades as a new Europe is constructed. National cultures and even languages may easily disappear in a matter of generations. Cultural contexts have been transformed radically during this century and there is nothing that today speaks for a stable state for centuries to come. Such changes transforms our world view and our way of conceiving knowledge.

An archive aimed at future generations should therefore contain an attempt at contextualizing key-concepts in order to make understandable what we take for granted. We have a tendency to ignore the most fundamental things about what we are and these keys are needed if people from other contexts are to understand us from the signs and codes we leave behind. We have to transmit both the message about the nuclear waste *and* the sociocultural context in which we do this. The code has to supply its own interpretation packages for future generations to link onto ours, conceptionally and technically.

## Fallible science

The concept that scientific knowledge is embedded in a cultural context also leads to the insight that it is in some sense relative, i.e. other cultures would value other theories higher, use other methods and reach different conclusions in another language. Science as we know it recommends a certain way of looking for knowledge which is not very old. Science in its modern form with targeted-research, big science, high-tech instruments, etc. has only evolved since World War II. It would be strange if science would *not* continue to change in the future as well.

There is an excellent chance that in 100 years our most well established types of knowledge might be considered completely obsolete and maybe even as false. Our theories are aimed at the needs of our society and there is a risk that these are misdirected in their reflection of the dominating trends in science and society at present. As anthropologist Claude Lévi-Strauss has noted, "Every civilization tends to overestimate the objective nature of its own thought and this tendency is never absent[20] .

## Problems with a changing context

The social context is always in transformation. And when the context changes, almost nothing within it remains the same. The scientific problem of TIELPT is therefore of a completely different form than those that deal with a closed system. TIELPT can be compared with another difficult problem, that of constructing a nuclear waste repository - a task well known to be extremely difficult. But this is also a problem of much the same character. It is one of those well-researched similar cases that we need for comparative studies.

The most troubling aspects of dealing with the future have been cut off from the problem of constructing a repository, when seen as solely a technical/scientific problem. By making the repository hidden deep down in a mountain it can be said to be a kind of closed system. This liberates the issue from contact with future social societies and it is possible to deal with the problem with the future Ice Age. In TIELPT these complications remain.

The question of constructing a repository and hiding it from the social sphere for ages to come, is basically a challenge both for social and natural sciences. It is usually, though, perceived as two different projects; one technical/scientific and the other interlinked with problems concerning the social sphere. In part this can be said to be a natural consequence of the scientific method. To be scientific one has to strive for a closed system for problems that are specific and researchable. Especially it is common in natural sciences to delete social and contextual factors from the problem.

An important point to be made here is that the problems such as we know them are not objectively put to us. Indeed, they can be said to be at one and the same time both social and scientific products[21]. The way we pose questions are typical for a certain scientific philosophy of our time. It is a philosophy in which science and social context are a priori divorced from each other. This also has methodological implications, giving prominence to natural science and engineering disciplines, while negating the relevance of human and social scientific perspectives and results. A future culture may see these two problems as more closely interlinked, or even more separated.

This division also has dramatic consequences for the way predictions about the future are seen as possible[22]. In many other projects the future can be conceived of as a continuation of the past and present. Therefore, with enough data it might be possible to make accurate predictions. This method, though, can only be successful and productive if the same conditions are present in the future as well. In the case of the social future we can make no such claims.

There is another way in which TIELPT would seem to be more difficult to solve then the problem with constructing a repository. TIELPT has been recognized rather late in the problem-solving project, while the question of the repository for spent fuel has been discussed for decades. TIELPT is a latecomer and enters the scene when other solutions seem to be within reach. Time is therefore short and we may be forced to settle for a solution without having the issue mellow within the scientific community.

## 4. Two different alternatives

### To construct a solution

In formulating a solution for TIELPT, basic problems seems to be: What kind of responsibility should we take? How long, until what time $T_x$, shall we assume responsibility? To what lengths can/shall we go to enable a successful communication? How do we select information? How shall we present it? How can we know that it will be understood?

### Short-term concept

Based on the arguments listed earlier: the lack of empirical data and functional instruments, our inability to predict future outcomes, the interdisciplinary complications, our cultural dependency, the difficulties in communicating over cultures, etc. it could be said to be better to trust humans then objects (archives). It is more likely that knowledge will survive if it is assimilated by every generation in an unbroken line. Since media, language, culture and science can change dramatically over time it is more probable that a generation six times removed from us will be able to communicate to the seventh generation, than that we could communicate to that sixth generation directly. The seventh generation has a better impression of who to communicate to. Responsibilities are traditionally handed over from one generation to the next. It is difficult for us to change this. Generations should be seen as sets of two: one who fosters, supplies wisdom and values and one who receives this education.

Every generation should take responsibility for its own actions and handle the information. They should ensure that it is related to their knowledge, culture and language. The important thing is that the knowledge is constantly read, assimilated, interpreted - in short - kept alive. This assimilation can work in several ways. One way is to integrate this information in the learning process. Education would therefore guarantee that this knowledge be kept alive. Every generation must also see to it that the knowledge be transmitted to the next coming generation. It also makes revisions possible and new archive media may be found and used[23].

Flaws in this solution is that the survival of the information depends on people in the future doing what we want them to. Another problem is that interpretations over a long line of generations will probably lead to distortions.

### Long-term concept

The short-term concept can be contrasted with a *long-term concept.* Here the basic idea is to rely on the objects rather than man. One or many archives are constructed once and for all and they exist for generations to come. Certain routines are followed which update the material constantly. Also there appear different summaries in the archives which makes it easy to get access to information.

This archive lives a life of its own, much according to the third world of Karl Popper. There are no links between the archive and the generations to come, other than that it is available. This solution has obvious advantages. The problem is solved here and now. We leave information for future generations and they can tap into it when they need to do so.

A flaw in this concept is that it is hard to guarantee the durability of the archive, something which could be corrected by producing several archives. But the longer the time, the more uncertain one must be that the archive and its information will endure. Another problem is that our cultural context might be forgotten and our messages rendered incomprehensible.

### The scientific base

Both solutions have a certain scientific foundation. The short-term concept is based on theories concerning knowledge. The theories that are important here, and which are supported by empirical studies and well entrenched within a paradigm, are:

1) All types of knowledge are dependent on the micro- as well as the macro-context.

2) The scientific context change over time.

3) Knowledge is always embodied within individuals and institutions.

4) Knowledge is transformed and reconstructed in new ways when assimilated by an individual within institutional contexts.

This way of reasoning takes some of the major problems into account by exercising caution and by building on a sophisticated view of knowledge. The long-term solution is also supported by theories, the most important ones being:

1) Knowledge on paper can survive independent of a changing context.

2) Knowledge has such a character that it can be communicated from paper to man, regardless of context.

3) Archives can survive over long periods of time and through different social contexts.

The third point is problematic. It can to some degree, though, be supported by the empirical studies. These supply material on successful examples, but many more have been unsuccessful and we do not know all the reasons that made them fail. We do not know if the archive proposed for information on nuclear waste disposal has what it takes to survive.

Point one and two are controversial. Both solutions are produced only in part by using scientific theories. Conjectures play a large part.

**Combinations**

One way of approaching the problem, would be to make use of several types of solutions, each one of them specially designed to cover a certain future. One concept would therefore be to combine the alternatives discussed above, since they balance each others' weaknesses. In the short-term concept there will always appear problems whenever knowledge is activated, communicated and reinterpreted. When human kind absorbs knowledge, it also reshapes it to suit world view and present knowledge base. Therefore it is quite likely that the knowledge will gradually change in a process over a large number of generations. But in this we can be helped by the long-term concept. If original sources are available, then corrections can always be made. Just as our interpretation of the Bible is corrected by old sources, so can future corrections of nuclear information be made by going back to sources produced by our time.

The weakness of the long-term concept is in part that the knowledge will "die" when the culture that produced it becomes more and more distant and in part that it is an inflexible way of communication for the great multitude of futures that may come. Since the idea with a short-term concept is that every generation must activate the knowledge, lest it be forgotten, it has both the life and the flexibility that the long-term concept lacks. Knowledge can change in two ways: One by having the content reinterpreted which is the danger with the short-term concept. The other way is a change of context and this is what we can fear will happen to the long-term concept. But together they may complement each other.

At the same time that a combination of these two solutions seems to be quite successful, it is important to add that there still are many problems left. The archive can still be destroyed and then the short-term solution has to work on its own. Also, a generation could easily fail in transmitting the knowledge. Total discontinuity threatens both written and oral attempts.

It should furthermore once again be pointed out that what empirical evidence we have is based on too few examples. We know too little about future outcomes in order to say much with certainty. In the end, one of the most likely statements that can be made is that things will change and probably do so in ways in which we today cannot fathom.

NOTES AND REFERENCES

1 The following is a compressed version of an article by Jan Nolin, Scientific Problems, Methods and Solutions in the Transmittal of Information over Extremely Long Periods of Time.

2 Transmittal of information over extremely long periods of time was the phrase used to describe the problem at a Conference in Oslo, 26-27 September, 1991.

3 Problems within interdisciplinary research have been discussed by Göran Wallén, Tvärvetenskapliga problem i ett vetenskapsteoretiskt perspektiv. Institutionen för Vetenskapsteori, Göteborgs universitet, Rapport nr 130.

4 This has been the consensus in most philosophical schools, ever since Karl Popper introduced the concept. For a discussion on verisimilitude, see Karl Popper, Conjectures and Refutations: The Growth of Scientific Knowledge. Routledge and Kegan Paul: London, 1963, p. 228-240.

5 Thomas Kuhns arguments for incommensurability are most convincingly made in the postscript of the second edition of The Structure of Scientific Revolutions. University of Chicago Press: Chicago, 1970, p. 198-204.

6 For a review of this discussion, see Bruno Latour, The Impact of Science Studies on Political Philosophy in Science, Technology & Human Values, Vol 16, nr 1, Winter 1991.

7 For a discussion, see Quality in Science. Marcel Chotkowski La Follette (ed.). The MIT Press: Cambridge, 1982.

8 A dimension of this has already been discussed, the balance between micro- and macro-approaches.

9 This and the following general factors that I list, are borrowed and translated freely from those used by Aant Elzinga in his discussion of qualitative criteria for investigating the future. Aant Elzinga, Ett forum för framtidsbedömning i 1980-talets Sverige. Appendix 4 in SOU: 1986:34. Att studera framtiden. Del 2 bilagedel. Stockholm, 1986, p. 55-57.

10 This requirement originally stems from Karl Popper, The Logic of Scientific Discovery. Harper Torchbooks: New York, 1959 (originally 1934).

11 This distinction is made in Claes Edlund, Göran Hemerén & Tore Nilsson, Tvärskap. Studentlitteratur: Lund, 1986, p. 25.

12 For some other strong arguments for interdisciplinary research, see Tvärskap, p. 37.

13 The term interpretation package is originally used - somewhat differently - by William Gamson and Andre Modigliani in Media Discourse and Public Opinion on Nuclear Power in American Journal of Sociology. Vol 95, no 1, 1989.

14 Harvey Brooks makes this point in Science Indicators and Science Priorities in Quality in Science.

15 The following is borrowed from Aant Elzinga, who has worked with science and technology forecasting and written about the problems of studying future events. Elzinga, p. 63.

16 For a review over the current discussion on the contextuality of scientific rationality, see Ernan McMullin, The Shaping of Scientific Rationality: Construction and Constraint from Construction and Constraint. Ernan McMullin (ed.). University of Notre Dame Press: Notre Dame, 1988.

17 Karl Popper, Epistemology without a knowing subject in Logic, Methodology and Philosophy of Science III: Proceedings of the Third International Congress for Logic, Methodology and Philosophy of Science. B. Van Rootselaar and J. F. Staal (eds.). North-Holland Publishing Company: Amsterdam, 1967. P. 333-373.

18 P. 334.

19 Here one could instead agree with the linguist Helge Dyvik, who stated that if we assume cultural discontinuity, then the conclusion is that texts in ordinary written language is not a suitable medium for the message. Helge Dyvik, On Conveying Messages Out of Context, paper from a conference on the Transmittal of Information over Extremely Long Periods of Time in Oslo, 26-27 September, 1991, p. 4.

20 Claude Lévi-Strauss, The Savage Mind (English translation of La PensΘe salvage). Weidenfeld & Nicolson: London, 1966, p. 3.

21 The way that scientific disciplines shape their problems in specific ways, have been the object for several studies. See for instance Gérard Lemaine et al. (eds.), Perspectives on the Emergence of Scientific Disciplines. Paris: Mouton, 1976 or David Edge and Michael Mulkay, Astronomy Transformed: the Emergence of Radio Astronomy in Britain. New York: Wiley-Interscience, 1976. A good overview over this subject has been made by Daryl Chubin, The Conceptualization of Scientific Specialties, Sociological Quarterly XVII, Autumn 1976.

22 I borrow this line of reasoning from Mats Friberg, Deltagande framtidsstudier, Appendix 7 in SOU: 1986:34. Att studera framtiden. Del 2 bilagedel. Stockholm, 1986, p. 5.

23 This concept is also much in line with the one presented by Nina Karin Monsen, Filosofiske og etiske aspekter, a paper from a conference on the Transmittal of Information over Extremely Long Periods of Time in Oslo, 1991, p.10.

## APPENDIX C

## LONG-TERM INFORMATION CONSERVATION AND RETRIEVAL, SOME STUDIES


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# APPENDIX D,
# OPTIMIZATION

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## 1 Cost-benefit considerations

This chapter discusses the reasonable price for an information conservation system in terms of its capacity to avert or reduce future doses to intruders.

Optimization as an important, perhaps the most important, concept in radiation protection was suggested by ICRP[1] in 1977. It was pointed out that keeping doses as low as reasonably possible was a powerful tool in radiation protection and that dose limits were to be seen mainly as a limit for the optimization procedure. Governments were advised that, for the activities where uses of ionizing radiation were justified, regulations should ensure not only that dose limit rules were met, but also that efforts were made to reduce individual doses further below those limits.

## 2 Optimization categories for nuclear repositories

The reasons for optimization calculations for repositories are described in three categories below and followed by an example of the optimization.

### 2.1 Optimization as guidance for choosing strategy

To assist in decision-making, the full cost of different disposal options are weighed against each other in terms of dose and cost. The options often consist of conceptually different methods of disposal such as direct dilution and dispersion into the sea, sea disposal, and disposal in a geological repository. This choice is less problematic than others, because several of the options are already identified and empirical data are available to assist in the decision. Optimizations of this kind, for example, may be carried out to decide whether some low-level, short-lived nuclides in hospital waste must be stored or if they can be disposed of by dispersion into the sewer system.

### 2.2 Optimization regarding marginal effectiveness

For one specific repository, the question maybe asked whether more could be done to reduce doses to man in the future. Alternatively, the question could be posed whether the solution proposed offers more than ample safety and protection.

A safety assessment may exist (for the undisturbed disposal system). If the repository is for low-level waste with few engineered and natural barriers, such as a shallow land burial, extra hypothetical barriers can relatively easily be described along with their costs. For a repository for spent fuel, or other repositories designed to meet the highest safety standards possible, it may not be easy even to describe the extra safety or protection for society. The political and public concern may be such that if extra safety existed at all, it would already have been included in the repository concept. Perhaps it may be possible to describe the consequences of a hypothetical removal of some of the barriers, that is to make a one-sided optimization study on the lower-cost side.

Repositories designed for maximum public protection, usually contain extremely long-lived radionuclides so that the repository performance must be described over longer time periods than has ever been made for any other man-made structure. This adds to the uncertainty of the parameters used in the calculations which also may include conceptual or paradigmatic uncertainties. The task of making a realistic protection optimization for an (undisturbed) high-level repository is often regarded as prohibitively difficult. Calculations of this kind are more often used for qualitative guidance.

### 2.3 Optimization for inadvertent human action

What is balanced in this optimization is the cost of establishing an information conservation system against the potency of such a system to prevent doses to man by deterring inadvertent intrusion. In principle, other costs could enter the calculation, such as choosing a site for which a repository would cost more, but that has not been taken into account in this presentation.

In this case, actions by individuals or groups must be described as an element in the calculation. Such calculations are always problematic, but they are easier for a shallow land burial where analogues may exist (e.g. experiences with community plans regarding waste dumps).

It is worth noting that, for a given repository, the optimization of the benefit from the information system may not have much in common with the protection optimization of the repository itself. The difficulties are not necessarily less than for the optimization of the repository, but they are different.

## 3 A numerical example of an optimization calculation

In the following example, an optimization study of category 2.3 is described for a high-level waste repository. The calculation is meant as an illustrative numerical example of the calculation, and a demonstration of the uncertainties involved, including the problem of making a distinction between the case of human intrusion/action and the undisturbed case. The time span may be assumed to be 10 000 years.

3.1 Probability of intrusion through loss of memory

Some estimates of the probability of intrusion has been given in work presently carried out by Sandia National Laboratories for the US Department of Energy's Waste Isolation Pilot Plant (WIPP) in New Mexico[2]. Panels of experts have been asked to estimate the probability of inadvertent intrusion by future societies up to 10 000 years into the future. Some panelists have estimated the probability of intrusion to 0.1 in 10 000 years. This is for a case where nothing denotes the location of the site. Another panel discussed to what extent information at the site (markers) could be a remedy for loss of knowledge. The effectiveness of markers, that is the ability to deter inadvertent intrusion, was believed by some panelists to be near 0.9 for 10 000 years and higher (0.99) for the first 1 000 years. For these estimates, and for the period 1 000 years the probability of intrusion can thus be calculated to lie between $0.1 * (1-0.99) = 0.001$ and $0.1 * (1-0.9) = 0.01$.

In another site-specific study[3] regarding a repository in Boom clay at Mol, Belgium, the authors themselves assigned values to probabilities for loss of information, interest in drilling and a geometrical factor giving the probability of drillers hitting the repository. They combined these probabilities to arrive at a slightly lower value for intrusion: less than 0.001 for 2 000 years after closure.In this work, probabilities are attributed to intrusion as far as 250 000 years into the future.

It is worth noting that if two works give roughly the same probability for intrusion, it may be arrived at in different ways. D'Alessandro and Bonne[3] calculated "loss of memory", "interest in drilling" and the drilling cross section, whereas the Sandia expert panels on future societies and on markers considered all possible modes of intrusion.

It is assumed, in this example, that direct intrusion, in the absence of an information conservation system, has a probability of 0.1 over 10 000 years.

3.2 The collective dose from intrusion scenarios

In a study of doses from inadvertent drilling intrusion into the repository made for the Swedish Radiation Protection Institute[4] high doses are presented for direct hits of a fuel waste canister followed by routine examination of cuttings in the field, and even higher doses for close inspection of samples in a laboratory (from inhalation as the sample is cut). For intrusion into an area outside the repository, which has been contaminated by a failing canister leaking through the barriers, the doses are many orders of magnitude lower. No probability is given for either mode of intrusion, except that intrusion into a waste canister or its backfill material is considered "very low". Doses are received by one or a few members of the drilling crew and laboratory personnel.

The collective dose in the example is taken to be such that the probable outcome of each intrusion or disturbance is one case of fatal cancer (20 person-sievert) for the members of the intrusion (drilling) crew and that the damage done by the intrusion in terms of a dose received by a larger number of people does not exceed nine times this value, so that the total collective dose is taken to be 200 person-sievert.

There can be no strong rationale for this value for the collective dose as a consequence of the drilling scenario. But one line of argumentation could be that if the collective dose was one order of magnitude higher, it would be more easily detected (from acute radiation effects in the crew) and knowledge about the repository would be reimposed upon society. Such a reimposed knowledge might limit the damage made by the intrusion to the intrusion crew.

### 3.3 Risk per sievert

The value 0.05 excess cancer deaths per person-sievert is assumed for simplicity. In a detailed calculation, different risk estimates should apply to members in a drilling crew and a whole city population with a different age distribution. The estimate of this value by international expert organizations such as UNSCEAR (United Nation's Scientific Committee on the Effects of Atomic Radiation) and ICRP has changed over the years, but the estimate has always been within the interval 0.01 to 0.1 cancer death per person-sievert.

### 3.4 Reference cost for an effort to avoid one person-sievert

It is assumed, in the field of radiation protection, that efforts are made to lower the dose as long as such efforts are deemed cost-effective. This assumes that the practice has been approved by the proper authorities and that doses are below the relevant dose limits. The limit where dose reduction is regarded barely cost-effective may be given in USD per person-sievert (1 sievert = 100 rem). This limit is often taken to be about USD 100 000 per person-sievert, although both higher and lower values are employed in individual cases.

If the probability of death is 0.05 per person-sievert, a value can be obtained giving the reasonable cost of increased safety in terms of cost to be taken to save one life (on the average). This reference cost may the be used by individuals and society to direct safety measures where these are most cost-effective.

A combination of the death risk of 0.05 per person-sievert and the marginal cost of USD 100 000 per sievert yields 100 000/0.05 = USD 2 000 000 per saved life.

### 3.5 The result: the cost of the information system

The result of the calculation presented in Table 1 is that if intrusion can be avoided by information conservation in some form, it would be worth USD 2 000 000 to establish such a system. It can be seen that if the intrusion probability is set to 1 rather than 0.1 in the above calculation the reasonable effort for information retention would rise to USD 20 000 000. The somewhat arbitrary values in the calculation is discussed in section 5.

Table 1. The value of an information conservation system.

| Probability of intrusion or disturbance (no information conservation effort) | Collective dose per scenario in sievert (Sv) (1 Sv=100 rem) | Risk per sievert (fatal cancer) | Protective effort (million USD per death) | Total protective cost (million USD) |
|---|---|---|---|---|
| 0.1 * (multiplied by) | 200 * | 0.05 * | 2 | = 2 |

3.6 Bounding calculation in the general case

In view of the conceptual problems mentioned in the preceding sections, it must be kept in mind that the calculations are made assuming certain scenarios, and that maximum values of the doses are scenario specific. With such reservations, it is possible to infer some maximum and minimum values for the product of intrusion probability and the collective dose (i.e. the expectation value of the collective dose as a result of intrusion). The maximum value for the first term is 1 and as mentioned earlier 200 sievert constitutes a possible maximum collective dose to the crew and to the public assuming 20 person-sievert to the crew members which is enough to give life-threatening health effects to all members in the crew if the dose is distributed evenly and with some certain deaths if not.

The lower set of parameters could be 0.001 for intrusion and 10 sievert for the collective dose to the crew plus the exposed public. It is possible to postulate a lower level of collective dose by considering natural analogues, such as doses from radon in ground water from a drinking water well. A dose of one millisievert (0.001 sievert or 100 mrem) per person and year is not uncommon for small wells in Sweden, for example (which does not emanate primarily from drinking, but from inhalation of radon daughters brought to indoor air by other uses of water). It seems reasonable that the family collective dose: 4 persons * 0.001 Sv/year * 50 years = 0.2 personSv can give an example of an intrusion with a collective dose which may only deserve moderate concern.

Table 2. Estimated lower bound for intrusion risk and detriment in dose and money.

| Probability of intrusion | Collective dose in sievert (Sv) (1 Sv=100 rem) | Risk per sievert | Protective effort (MUSD per death) | Total protective cost (MUSD) |
|---|---|---|---|---|
| 0.001 * | 10 * | 0.05 * | 2 * | = 0.001 |

The lower bound given in Table 2 represents such a low cost that further calculation seems uninteresting, because in no case would waste management hesitate to pay this amount if safety could be improved.

Table 3. The upper bound for intrusion risk and detriment in dose and money.1

| Probability of intrusion | Collective dose in sievert (Sv) (1 Sv=100 rem) | Risk per sievert | Protective effort (MUSD per death) | Total protective cost (MUSD) |
|---|---|---|---|---|
| 1 | 200 * | 0.05 * | 2 | 20 |

Perhaps not even the upper bound in Table 3 may seem completely prohibitive for such a large scale project as a high-level waste disposal.

For a repository in salt, such as the WIPP there is no use of ground water by nearby cities. This may limit the collective dose. If 20 person-sievert to the crew members may be taken as a reference as mentioned earlier members, perhaps 40 person-sievert can be taken as the collective dose as a result of a drilling intrusion followed by some additional exposure through some less efficient pathways. If the probability of intrusion is 0.1, the acceptable cost for the planned information conservation system (of markers) is given in Table 4.

Table 4. The lower bound for intrusion risk and detriment expressed in dose and money.

| Probability of intrusion | Collective dose in sievert (Sv) (1 Sv=100 rem) | Risk per sievert | Protective effort (MUSD per death) | Total protective cost (MUSD) |
|---|---|---|---|---|
| 0.1 * | 40 * | 0.05 * | 2 | 0.4 |

If only the crew's dose is considered, the lower bound would be USD 200 000.

### 3.7 Qualitative descriptions

Finally, it is possible to give a qualitative judgement of the need for information conservation illustrated by the following example: in a recent permit for continuous use of a repository for medium level waste in Sweden it was stated that optimization consideration indicated that some effort towards information conservation should be taken and it was regulated that the waste management should present an information conservation strategy.

## 4 Reference conditions

Because the analysis of human-intrusion or human-action scenarios are intended primarily to serve illustrative purposes, it seems worth while to introduce reference conditions. On the other hand, it is reasonable to leave room for site specific calculations and not to lock all parameters by reference values. Some parameters are mentioned below:

- The time scale of 10 000 years has been mentioned. It is already in use in some countries.

- Representation of intrusion by drilling, and the concept of an intrusion/drilling crew (of perhaps 10 people)

- The dose to others than the crew. Perhaps 1 or 10 times the dose to the crew.

Some reference conditions are presently being discussed within the OECD/NEA Working Group on Human Action at Radioactive Waste Disposal Sites. Their report is scheduled to be published by the end of 1993.

## 5 Side issues. Conceptual problems and data uncertainties

In addition to the parametric uncertainty in the above example, conceptual uncertainties also occur. In the following sub-section some of the problems and side-issues are discussed.

### 5.1 Minor disturbances

The concept of human intrusion/human action is not well defined and therefore the borderline to the scenario of the undisturbed repository may create problems in the calculation needed for the safety optimization. Following an intrusion into a fracture zone near the repository such as described by Charles and McEwen, the crew might receive very small doses. It cannot be excluded that as a result of the intrusion a large population may receive doses in excess of that of the undisturbed case. The recipient may be the population of either a small town near the repository or a larger, more distant city. This could be represented in orders of magnitudes as demonstrated in Table 5.

In Table 5 demonstrates various population sizes, the source of pollution being diluted 10 times more and distributed to a 10 times larger population in each step, so that the collective dose is constant, taken to be 20 Sievert in this example.

Table 5 Intrusion scenarios bordering to the case of the undisturbed repository.

| Number of people | Mean dose (Sv) | Comment | Collective dose (person-Sv) |
|---|---|---|---|
| 100 | 0.2 | Small settlement | 20 |
| 1 000 | 0.02 | small town | 20 |
| .. | | .. | .. |
| 10 000 000 | 0.000002 | Large distant city | 20 |
| .. | .. | .. | .. |

The large population centers in Table 5 gives a bordering case to the scenario of an undisturbed repository. For example, a very large city which through its interaction with the ground water flow, alters the direction from the source of contamination towards the city, thereby increasing the collective dose through many small contributions of individual doses. In order to qualify as human induced disturbance and therefore separated from the case of an undisturbed repository, it must be assumed that the ground water flow is manipulated in some unusual manner.

## 5.2 One intrusion or many?

The distribution in time of the events studied and the time range should also be mentioned as conceptual problems. Is it possible that more or less the same inadvertent intrusion (followed by remedial action) can be repeated every 1 000 years? If so, a study of 250 000 years would have a large uncertainty arizing from this effect alone. The time range also presents a similar problem. It seems that in several countries 10 000 years has been chosen as a reference time scale. In Scandinavia, a glaciation is expected in the next 10 000 years, perhaps starting in about 5 000 years. Permafrost conditions could prevail at the repository after perhaps 3 000 years. Climatic changes will also effect many other countries in Europe during this time. This would limit the time scale for which mistakes could be repeated.

## 5.3 The crew vs the general public

If the intrusion establishes a link from the disturbed repository to the outside ground water, the collective dose may be dominated by doses to the public and not to the crew. If on the other hand there is no transport mechanism present, the crew's doses may dominate and the collective dose is reduced by a factor of about 10.

5.4 Cancer prevention vs prevention of acute effects

USD 2 000 000 per saved life refers to cancer prevention and not to acute effects from very high doses that a crew also could encounter. The dose reduction philosophy mentioned above is not intended for use in situations where individuals receive doses high enough to give acute effects.

A hypothetical crew intruding into the repository might receive a collective dose of 20 person-sievert. If 2 members of the crew each received 10 sievert both of them would be killed, and if we could prevent this, it would be worth USD 4 000 000, this time using the value USD 2 000 000 for safety measures which would be appropriate, since society is willing to pay a corresponding cost in cancer prevention.

Thus, if the reference value is applied to a crew, receiving high doses outside the regime of proportionality assumed for dose and cancer, it only introduces a correction of a factor of about 2 in this example (3 workers might be killed if they shared 20 person-sievert evenly).

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# APPENDIX E,

## FORMAL ELICITATION OF EXPERT JUDGMENTS

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Important sources of information for analyses of nuclear waste repositories include the results of experiments and observation, mathematical/computer models of the physical and chemical processes, and expert judgments. Expert judgments may take many forms, such as recommendations and criticisms, scenarios, value judgments, estimates, and uncertainty distributions for unknown quantities.

The evaluation of risks for the purpose of policy and decision making has led to the development of formal methods for the collection of expert judgment[1,2,3,4,5,6]. In this appendix the steps that comprise a formal expert judgment process are discussed. These steps include the selection of experts, the selection and definition of issues, the organization of multiple experts, preparation of elicitation, elicitation procedures, the processing of judgments, and the documentation of procedures, findings, and rationales.

### Expert knowledge and experts

Who is an expert? An "expert" may be someone who has special skills and training resulting in superior knowledge about a particular field and access to that knowledge[5]. The identification of experts is an important stage in the process of acquiring expert judgments. Quite aside from the danger of selecting an expert who is not "well qualified", risk analyses of nuclear waste are performed in the public view. Therefore, because the stakes go beyond science, the criteria and process of selecting experts become critical.

Experts can be identified through literature searches, registries of professional organizations, consulting firms, research laboratories, governmental agencies, and universities. A formal nomination process is sometimes used, particularly when controversy is possible. The nomination process should be designed to preclude bias in selection. A first step is inviting those with different values to nominate experts. A second step is using an independent external selection panel to evaluate the nominees.

The criteria for selection should be specific, documented, and should include:

1. Evidence of expertise, such as publications, research findings, degrees and certificates, positions held, awards, etc.

2. Reputation in the scientific community, including knowledge of the quality and importance of the nominee's work and the nominee's ability to provide the desired judgments.

3. Availability and willingness to participate.

4. Understanding of the general problem area.

5. Impartiality, including the lack of an economic or personal stake in the potential findings.

6. Inclusion of a multiplicity of viewpoints.

Biases from economic stakes affect an expert's judgment. Yet, excluding an expert because of potential bias may prevent relevant information from being discussed. A solution to this dilemma was used in the NUREG-1150 study of reactor safety[1,7], where potentially biased authorities were allowed and encouraged to give testimony. In one instance, an employee of a pump manufacturer testified on the performance of a pump under severe stress. The employee had access to relevant information that the members of the expert panel did not have. However, inclusion of the employee on the expert panel could have been perceived as conflict of interest. Presentation of the employee's testimony allowed the expert panel to judge the value of the testimony.

Organizing experts

There are alternative approaches to organizing a group of experts. These approaches vary with the respect to the scope of the issues being addressed, the amount and type of interaction among the experts, the amount of redundancy, and the role of the experts in defining objectives.

The simplest organization is either one expert or several experts working in isolation from each other. When there are several experts addressing the same issues, there is some useful redundancy because multiple experts alternative viewpoints increasing the potential for describing uncertainty. The difficulty with isolated experts is that information is not shared, thus reducing the individual expert's knowledge.

When there are multiple, redundant experts addressing the same questions, panels may be organized in which experts work together sharing information and approaches to the issues. The study of nuclear reactor safety[1], allowed for two meetings of the experts, with an intervening study period of about eight weeks. Issues and background information were presented in the first meeting while the experts presented their analysis in the second meeting.

Interaction among experts can lead to problems. However, methods exist to deal with them. The Delphi method[8,9], for example, limits expert interaction to the exchange of anonymous evaluations among the experts. The method was developed to reduce potentially negative interaction such as dominance by one expert from position or reputation. These problems can result from reluctance to give truthful answers before a superior who holds different views, when judgments go against "company policy," or may damage the organization.

Merkhofer and Runchal[4] employed a combination of individual elicitation procedures and the Delphi technique. After independently collecting judgments as probability distributions from each expert, the resulting probability distributions and rationales were shared among the experts, who were allowed to revise their estimates.

Panels may provide a consensus assessment or individual assessments; each has advantages. When experts work together to obtain a consensus assessment, there is no need to combine assessments. It may be the case, however, that opinions vary so greatly that a consensus cannot be reached. Then, it may be necessary to combine judgments using a quantitative rule such as the arithmetic or geometric mean. In contrast, when experts provide individual assessments, the potential is better for capturing the full uncertainty about the issue, but the effort does not produce a consensus assessment.

Isolated panels of experts are efficient with respect to the experts' time, but require coordination. The views, assumptions, and findings of a panel may shape the issues addressed by another. When coordination between experts or panels of experts is necessary, the work may be accomplished sequentially. An example of such a situation is the coordination between a panel of experts judging how fast and how high pressure will rise in a reactor containment vessel; while a second panel considers the pressure at which the vessel will fail. Knowing the relevant range of pressure-rise parameters will help establish the assumptions for the second panel's assessments of containment failure probabilities.

Another strategy for the analysis of complex issues consists of using multi-disciplinary teams of experts. This approach is relevant when the issue to be addressed is difficult to decompose into a series of smaller, independent or conditional issues. A difficulty with decomposition is that there are significant linkages or information requirements among the issues. Redundant teams were used by the Electric Power Research Institute[3] study of seismicity in the Eastern United States. A main limitation of using several teams is that their organization is difficult. A second problem is bringing the team members together to perform their analyses. This is costly. In the seismicity study, the teams were formed within companies and institutions to facilitate communication. Each team was allowed some flexibility in determining how to decompose the problem into the individual experts' specializations. Coordination assured that the assessments made by the various teams would be compatible with the overall study objectives.

Technical issue selection and definition

The selection of specific issues to be studied by experts may be done by analysts studying the problem, by policy-makers, and by the experts themselves. Important issues can be identified through sensitivity and uncertainty analyses. Sensitivity analysis shows the relation between the value of the dependent variable(s) (model output) and the independent variables (model inputs) by varying the inputs and observing the change in the output variables[10].

Uncertainty analysis is often used as an adjunct to sensitivity analysis. The goal of uncertainty analysis is to determine the relation between the statistical uncertainty in the dependent variables measured by such criteria as the variance, the interquartile range, or other measures, and the uncertainty in the independent variables. Sensitivity analysis identifies those variables that produce the largest relative changes in the output; as such, it is also directed towards identifying those independent variables whose uncertainty is chiefly responsible for the uncertainty in the dependent variables. These analyses, however, are model dependent. The sensitivities and uncertainties reflect the true sensitivities and uncertainties only to the degree that the model reflects the real phenomena.

Uncertainty analysis has been used in the evaluation of the Waste Isolation Pilot Plant (WIPP) to identify important contributors to the uncertainty about radiological releases to the environment[11]. These analyses have identified the solubility of radionuclides in brine and the retardation of radionuclides, flowing through the Culebra Dolomite member of the Rustler Formation, as the most important contributors to uncertainty. Both issues are being examined through a formal expert judgment process[12].

Cost-effectiveness of gathering alternative sources is a consideration in selecting issues for expert judgment. In some instances, alternative sources of information may be available but only at great cost. It may also be that the alternative sources of information may be unreliable. This often would occur when data or models from studies made under circumstances different from those under investigation are used as when the behavior of a system, measured in a specific environment, is "extrapolated" to a different environment. For example, the geochemistry of experiments conducted in a laboratory environment is less complicated than the real systems. Estimating solubilities in a laboratory and then scaling-up to a nuclear waste-disposal system, for example, involves making a transition from a laboratory experiment with a relatively simple environment to a system that is spatially differentiated by many microenvironments.

When alternative sources of information--models and data--are available but conflict, the judgments of experts may be the preferred method for integrating the data into a single coherent view. Experts may be able to assess the uncertainty inherent in the various sources of information and, additionally, may be able to make adjustments to account for biases in the data. Experts, therefore, may provide a "calibrating" mechanism to account for differences in applications, environments, and other factors.

An expert may have depth of knowledge in a related field but, perhaps, limited knowledge about the specific issue. In recent work on the solubilities of transuranic elements in brine[12], done for the WIPP performance assessment, one of the experts was from the field of ocean chemistry. This expert had substantial knowledge of solubilities, but he did not have direct experience with the brines expected to fill the mined salt repository after closure nor was the expert initially knowledgeable of the relevant chemistry, including the Ph and the ionic strength of the brine, in the repository. To participate effectively, this expert required substantial information about the chemistry expected within the repository.

## Preparation for elicitation

The elicitation process is more than just the application of assessment tools to the judgement of experts. The experts must prepare and be prepared for the experience. Often, experts in a substantive field such as engineering or health, may not be effective in expressing their beliefs in a quantitative form such as a probability distribution[13,14]. Training the experts is an important step in elicitation.

Training has multiple objectives. One is developing an overview of the process including how the experts' judgments will be used. Another objective is to develop confidence in the experts' ability to express beliefs quantitatively and to develop confidence in the process because lack of confidence may undermine the effort.

Experts may object to the formal elicitation of judgments because they believe "opinion" is being substituted for "objective" scientific research. However, the experts' role is not creating knowledge, but instead, synthesizing disparate and often conflicting sources of information to produce an integrated picture. Experts who appreciate their role from this perspective are likely to be cooperative.

Numerous types of biases in judgment formation have been identified. Perhaps the most notorious is overconfidence, the tendency to give uncertainty distributions that are narrower than they should be. For example, studies of overconfidence using "almanac questions" (e.g. the height of Mt. McKinley) reveals that about 35% of the actual quantities fall in the most extreme 5% of the assessed distributions for these quantities. If the distributions were well calibrated, one would find approximately 5% of the true values in the most extreme 5% of the distributions[13,15,16,17].

A study of atmospheric scientists as experts[18] asked questions about atmospheric experiments and observations to judge the quality of probability distributions provided by them. The outcomes of the experiments and observations were known to the researcher but not to the experts. Again, the actual values appeared in the tails of the distributions far too often: 27% of the values falling into the two 5% tails. Earlier findings[14] have shown that overconfidence increases with the difficulty of the question.

Work with experts in technological risk assessment has shown another bias to be prevalent among engineers and scientists: judgments based on the results of a single computer model or experiment. Other information is ignored and the model or experiment is treated as infallible. The result is likely to be an understatement of the uncertainty. This bias is related to the anchoring and the availability biases (giving too much weight to readily available information and failing to adjust)[5,15].

A less known bias is the "base rate" bias[19]. It is the failure to consider population base rates when assigning probabilities. For example:

> *A greater number of one type of structure survived for two-thousand years than the number of a second type of structure. It should not be concluded, however, that the first type of structure is more enduring. If more of the first type of structure have been built, then the survival rate for the first type of structure may actually be less than that of the second type of structure.*

The potential for this type of bias was recognized in the study of markers to warn potential intruders into the WIPP of the dangers of their actions. The goal of this effort is to create markers that would communicate the existence of biohazardous radioactive waste for at least ten millennia. Experts affected by the "base rate" bias might incorrectly presume that the durability of certain types of structures (obelisks, pyramids, etc.) can be gauged by the number of structures surviving. Erroneous conclusions might be reached because of the unrecognized differences in base rates.

Experts may provide assessments that are biased toward a favorable outcome. This is the optimism bias. For example, engineers underestimated by one-half the time required to repair electric generators[20]. Similarly, if a researcher develops a theory or mechanism that predicts a particular type of failure, the person becomes vested and may give too much weight to the theory or mechanism.

Elicitation of probability distributions

The procedures for the elicitation of judgments are well established and can be found in decision analysis and psychology[13,16,21]. Successful elicitation is usually accomplished through the use of specialists, sometimes termed normative experts[21].

One useful design for elicitation is an assessment team working with one expert[1]. The team members might include a specialist who handles the elicitation, an analyst who is familiar with the subject area and assists in the communication between the specialist and the expert, and a person responsible for documenting the session. In the NUREG-1150 and the WIPP study of future societies, elicitation teams included a probability specialist and a staff analyst, but no documentarian.

Although employing two or three persons to do an elicitation may seem costly, the importance of the findings often justify the investment. Alternatives to using one-on-one elicitation include self-elicitation, elicitation by questionnaire (e.g. mail), and computer controlled elicitation. The drawbacks of these methods are the inability to determine and document rationales, perform consistency checks, and counteract biases.

Complex problems may be decomposed into a number of smaller issues. The principle behind decomposition is that better quality judgments can be obtained when the assessment tasks are easier. There is an increasing amount of empirical evidence to show that, indeed, this principle holds[23,24,25]. In the NUREG-1150 and EPRI studies, complex issues were expressed in terms of a mathematical model. When the values of the variables in the mathematical model are given, the result is the value of the issue variable. This type of decomposition has been termed "algorithmic decomposition" by MacGregor, Lichtenstein, and Slovic[25].

Another decomposition tool is the "influence diagram"[26]. The paths shown in the influence diagram are directional and noncircular and thus provide a sequence of conditional assessments that lead to the issue question. Both algorithmic decompositions and influence diagrams are useful in probability elicitation. Influence diagrams are also useful in structuring scenarios and assessing value or utility functions.

Decomposition can be done by the experts or by an external analyst. Moreover, when multiple experts are used, each expert can use a distinct decomposition, or a consensus decomposition can be reached. Using a single decomposition has several advantages. First, the costs of processing the judgments are reduced because only one model or decomposition, usually implemented as a computer model, is needed. Second, comparisons among the assessments for components of the decomposed problem are facilitated when all experts use the same decomposition.

A drawback of using a single decomposition is that all experts are forced to take a single view of the issue; diversity of opinions is subjugated. Experience has shown[25,27] that the decomposition is an important determinant of judgments. The unfortunate consequence of enforcing a single decomposition for all experts is that it creates the appearance of homogeneity of opinions; it can lead to the understatement of uncertainty and greater confidence than warranted.

Processing expert judgments

the goal of processing judgments is two fold: to produce a usable product for the ensuing analysis and to preserve intact the expert's judgments. Judgments usually require some processing to put them in a usable form by the policy-maker. Assessments obtained using indirect methods, for example, may be translated into probabilities or utilities. Distributions for continuous quantities are most often assessed by obtaining several points on the distribution function and then fitting and/or interpolating to obtain the remainder of the distribution.

Another type of processing is the aggregation of judgments from multiple experts[28]. Aggregation is often justified by one or more reasons (Bonano et al. 1989): an aggregated assessment provides a better appraisal of knowledge than the individual assessment (a sample mean is better than one observation); the aggregated assessment represents consensus; and it is easier to use a single assessment in the ensuing analysis.

The first two of these reasons for aggregating are somewhat suspect. Certain methods of combining expert judgments, those based upon Bayes' Theorem, for example, may suppress differences among experts and thus over-represent the precision in the judgments. This occurs because these models usually assume independence among the experts, although they tend to be dependent. The aggregate distribution produced by such procedures tend to be more narrow than is warranted.

Mechanical methods, however, do not lead to a consensus. Unless the experts agree on the rule for aggregation, there is no consensus. Even if they do agree to the rule for aggregation, they may not agree with the conclusions. The resulting distribution again will not be a consensus. The final reason for combining judgments is the practical aspect of working with a single distribution.

Documentation

Regardless of how well an expert judgment elicitation process is designed and implemented, adequate documentation is required. The entire expert elicitation process should include documentation of the procedures and criteria for selecting experts and issues, copies of the elicitation issues and supporting materials, and the results of the elicitation sessions. Most importantly, the detailed rationales for the assessments, the methods, and results of any post-elicitation processing of the judgments should be provided. Moreover, as new evidence becomes available, understanding the rationales behind the judgments will allow reinterpretation. For example, Sandia National Laboratories[29] has undertaken the updating of some judgmental probability distributions obtained in the NUREG-1150 study. Without explicit rationales, updating these distributions would be difficult.

## Conclusions

Although expert judgment pervades all scientific inquiry, it is often unacknowledged, poorly understood, and neglected. Faced with a complex problem, scientists will often concentrate on the parts of the problem where analytic tools are available, while ignoring those parts of the problem that cannot be dealt with in a quantitative and direct manner. In the study of waste isolation at the WIPP, for example, a great deal of time and effort has been spent on the geology and hydrology of the area. Extensive computer algorithms have been constructed and preliminary risk and uncertainty analyses made. Only, recently, however has the focus shifted to the effect of human intrusion, an area where the physical sciences have less to say. Yet, human intrusion is apt to be the dominant contributor to risk. Those uncertainties and risks that are analyzed using expert judgment are often dominant, and yet the effort applied to obtaining good expert judgments is small when compared to efforts applied elsewhere.

Setting up a successful expert judgment process is not an easy task. Expert opinion is often the "soft spot" in a study, being the easiest aspect to attack and having the least credibility among critics who do not have a sufficiently broad view of risk and uncertainty analyses. Because it is vulnerable, diligence and careful consideration are needed. Collecting judgments in an arbitrary manner or failing to give due consideration to what is known about the collection of expert judgments is apt to doom the effort.

The field of expert judgment is still emerging and there is much to be learned. The theories supporting decomposition and aggregation require further development. There is also a need to assemble and evaluate the results from various efforts to ascertain those methods and problems for which the results are good and those methods and problems where the results are less satisfactory. Only through the development of theory and the simultaneous empirical evaluation of these efforts will we be able to reach a more complete understanding of expert judgment processes.

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## APPENDIX F

## A LIST OF EXPRESSIONS FOR SWEDISH NUCLEAR WASTE DOCUMENTS AND THE LOCATION OF INFORMATION OF SUGGESTED HIGH PRIORITY FOR TRANSMITTAL TO THE FUTURE FOR SFR.

### F-1 A Glossary/List of Expressions for Swedish Nuclear Waste Documents

DATABASE FOR HIGH-LEVEL WASTE

Contains data on each fuel element. The database for Swedish fuel elements is called "SPENT".

DATABASE FOR LOW- AND MEDIUM-LEVEL WASTE

Following information can be found in the Swedish database for low- and medium-level radioactive waste:

- Number of each transport container (ATB)
- the exact location of each transport container at a given time
- the activity in each transport container (ATB) and of each waste package inside the container
- nuclide content of each waste package according to estimations/measurements done by the waste producer
- number of waste packages in each transport container
- data on each undeposited waste package
- the best possible location in SFR for each waste package
- work orders and work permits regarding waste containers and waste packages
- receipt of confirmation on exact location

DOCUMENT OF TRANSPORT

A document which follows the transport container during the transport. Data on the waste like its source, content, activity levels etc can be found in this document.

DOCUMENTATION OF TEST OPERATION (excluded from the documentation of tests one can find in the technical documentation system)

Results from test operations.

FINAL SAFETY ANALYSIS REPORT

A description of the repository consisting of one general (principal) part and one part where the systems (ventilation system, remote handling equipment etc) are described. There are also descriptions of the different kinds or types of waste (this on demand by the authorities).

INSTRUCTION

A description which gives working routines for safe operation of the plant.

INSTRUCTION OF OPERATION

Instruction given on operation and handling during disposal.

MESSAGE OF TRANSPORT

A message of intent to transport waste, issued before the actual transport takes place.

OPERATING JOURNAL/LOG-BOOK

All incidents, events, and so on are registered (such as date, time and what has been done). This is a document of judicial value.

OPERATING MANUAL

A collection of documents on how to operate the facility. Here one can find instructions and where to look for other type of documentation.

ORDER OF OPERATION/STANDARD ORDER OF OPERATION

Initiates and gives a description of a particular work activity. An order of operation is made for each type of waste. If the same type of waste is frequent a standard order of operation is created.

PERFORMANCE ASSESSMENT

Numeric calculations on the safety of the repository. Based on results from these calculations judgements of the different systems performance can be made.

PLAN IN GENERAL/PLAN IN DETAIL/LAY-OUT

Shows in general and detail the exact position and lay-out of the repository within the geological body.

RECORD OF THE LOCAL SAFETY COMMITTEE

Record from the meeting of the Local Safety committee in which information on amendments or modifications that have a value for the safety of any of the nuclear facilities at a site are given.

REPORT/MEMORANDUM

A description of incidents or events.

REPORT OF AN UNUSUAL INCIDENT/REPORT OF A REPORTABLE INCIDENT

A report created if the operation diverges from Technical Specifications.

REPORT OF ANALYSIS CONCERNING ROCKS, HYDROLOGY, WATER, ATMOSPHERE AND RADON

Summaries of actual tests, experiments, and measurements.

REPORT OF CONTROL AND INSPECTION

Gives the reasoning behind sanctions or ratifications given by the authorities, government, or parliament.

SAFEGUARDS DOCUMENTATION

Documentation on the content of fissile material in the nuclear facility. Requested documentation from IAEA.

SAFETY ANALYSIS

A description of scenarios, models, calculations and so on that form the fundamentals or bases for the FINAL SAFETY ANALYSIS REPORT.

TABLE OF CODES

A key to the specification denoting the producer of radioactive waste, the number of deliveries to the waste - plant, the category of waste, and form of treatment.

TECHNICAL DOCUMENTATION SYSTEM

The system used at each nuclear facility to systematize the documentation in a proper way.

TECHNICAL SPECIFICATION FOR OPERATION

Operating rules given by the authorities on how the plant should be run. Suggestions for modifications are made by the owner of the plant and are then sent to the authorities for approval.

WORKING ORDER/NOTICE OF FAULT/WORK PERMISSION

Documents created if there is any fault or if any work must be done on a particular subsystem in the facility. When a need for a particular action has been noticed, a working order are produced and a work permission is given.

## F-2 The Location of Information of Suggested High Priority For transmittal To The Future for SFR.

Below is a table of the information/documentation concerning SFR.

The type or kind of information/documentation is given in the first column, followed by where the information/documentation are kept in original and in copies (SKB or Forsmark Nuclear Power Plant - either in the Administrative F-ADM, or in the Technical Archives F-TE or in the Forsmark Information System F-IS). Some of the information/documentation is kept by the authorities (SSI, SKI).

In the third column, there are certain proposals given regarding the future handling of the documentation/information.

If the letter N is marked, the documentation/information is judged to be absolutely necessary in the future. If an I is marked, the documentation/information is judged to be interesting in the future. If the letter D is marked, the documentation/information is judged not to be interesting and can be destroyed. The last and fourth column contains comments.

The definitions of the documentation/information are given in Appendix 1.

| Documentation/ information | Kept by Orig./Copy | | Proposal | Comments |
|---|---|---|---|---|
| PERFORMANCE ASSESSMENT | SKB | | N | |
| DATABASE FOR LOW- AND MEDIUM LEVEL WASTE | F-IS | | N | |
| DOCUMENT OF TRANSPORT | SKB | SFR | I | |
| DOCUMEN TATION OF TESTS | SFR | | D | |

(excluded from the documentation one can find in the technical documentation system)

| | | |
|---|---|---|
| FINAL SAFETY ANALYSIS RE-PORT | SKB SFR | N |
| INSTRUCTION | F-ADM SFR | I |
| INSTRUCTION OF OPERATION | SFR | I |
| MESSAGE OF TRANSPORT | SKB SFR PROD. SSI SKI | D |
| OPERATING-JOURNAL/ LOG-BOOK | SFR | N (I) |
| OPERATING-MANUAL | F-TE SFR | I |
| ORDER OF OPERATION/ ORDER OF USE | SFR | I (D) |
| PLAN IN GENE-RAL/PLAN IN DETAIL/LAY-OUT | SKB, öST-HAMMAR COUNTY BOARD | N |
| RECORD OF THE SAFETY COMMIT-TEE | F-ADM | I |
| REPORT/MEMO-RANDUM | F-ADM | I |
| REPORT OF UNUSUAL IN-CIDENT/REPORT OF A REPORTABLE INCIDENT | F-ADM SFR SKB SKI SSI | N |

| | | | | |
|---|---|---|---|---|
| REPORT OF ANALYSIS CONCERNING ROCKS, HYDROLOGY, WATER, ATMOSPHERE AND RADON | F-ADM | SFR<br>SKB<br>SSI<br>COUNTY BOARD | N | |
| REPORT OF CONTROL AND INSPECTION | SSI | F-ADM<br>SKI | N | |
| SAFETY ANALYSIS | SKB | | N | |
| SANCTION/ RATIFICATION | SKB | F-ADM<br>SFR<br>SSI<br>SKI | N | |
| TABLE OF CODES | SKI | SKB<br>SFR | N | Can be included in the database |
| TECHNICAL DOCUMENTATION SYSTEM | F-TE | SFR | | |
| - A | N | | | |
| - B | I | | | |
| - C | D (I) | | | |
| - D | N | | | |
| - F | D | | | |
| - Building | N | | | |
| - K | I | | | |
| - V | N (I) | | | |
| TECHNICAL SPECIFICATION FOR OPERATION | F-TE | SFR<br>SKI | I | |
| WORK ORDER/ NOTICE OF FAULT/WORK PERMISSIONS | F-IS | I | | |

## APPENDIX G

### NKS/KAN-1.3 SUBPROJECTS REPORT[1]

| | |
|---|---|
| NKS/KAN1.3(90)1 | Johansson, G., Sammanställning av dokument från OKG. In Swedish. |
| NKS/KAN1.3(91)1 | Bennerstedt, T., Teknotelje AB, Radioaktivt sjukhusavfall Regler, praxis och spårbarhet. Available as SSI-report 91-09. In Swedish. |
| NKS/KAN1.3(91)2 a, b | Nielsen P.O., Scanpower, En litteraturstudie och identifiering av pågående arbeten inom området "Extremt långa tidsrom". In Swedish. |
| NKS/KAN1.3(91)3 | Nielsen P.O., Scanpower, Förberedelse, genomförande och rapportering av ett endags seminarium våren i Norge avseende arkivsäkerhet. In Swedish. |
| NKS/KAN1.3(91)4 a, b | Lundby, J.E., Informationsbevaring-Uranrenseanlägget/Kjeller och Informationsbevaring-Markdeponerte tönner/Kjeller. In Swedish. |
| NKS/KAN1.3(91)5 | Bachmann, B. et al., Archive Safety Analysis, Case study: German Archives During the 20th Century. In German. Also available in English. |
| NKS/KAN1.3(91)6 | Hora S.C. et al, The Vatican Archives, a Study of Its History and Administration. In English. |
| NKS/KAN1.3(91)7 | Berg, L.O., Arkivkostnader i ett långsiktigare perspektiv. In Swedish. |
| NKS/KAN1.3(91)8 | Nolin, J., Scientific Problems, Methods and Solutions in the Transmittal of Information over Extreme Long Periods of Time. In English. |
| NKS/KAN1.3(91)9 | Nielsen P.O., Scanpower, Förberedelse, genomförande och rapportering av ett tvådagars seminarium hösten 1991 i Norge avseende arkivsäkerhet. In Swedish. |

NKS/KAN1.3(91)10 Agrell, L., Bränsleinformation. In Swedish.

NKS/KAN1.3(91)11 Johansson, G., SSI: The London Dumping Convention Dokumentation. In English.

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1 Please observe that the project number in the KAN-1.3 series is not necessarily identical to the report number. For instance, editing the main report is a special project, but the project creates no seperate report.

# Conservation and Retrieval of Information

## *- Elements of a Strategy to Inform Future Societies about Nuclear Waste Repositories*

**For a number of years, certain types of radioactive waste have been disposed of in underground repositories in Sweden and Finland. Spent fuel elements are planned to be disposed of in a similar manner 15-20 years from now. Information about this waste may be needed over long time spans after the closure of a repository. Therefore a scheme is discussed for selection and conservation of essential parts of such information.**

**The Nordic Committee for Nuclear Safety Research - NKS**
**organizes pluriannual joint research programmes. The aim is to achieve a better understanding in the Nordic countries of the factors influencing the safety of nuclear installations. The programme also permits involvement in new developments in nuclear safety, radiation protection, and emergency provisions. The three first programmes, from 1977 to 1989, were partly financed by the Nordic Council of Ministers.**

**The 1990 - 93 Programme**
**the current programme, running until the end of 1993, comprises four areas:**

* **Emergency preparedness (The BER-Programme)**
* **Waste and decommissioning (The KAN-Programme)**
* **Radioecology (The RAD-Programme)**
* **Reactor safety (The SIK-Programme)**

**The programme is managed - and financed - by a consortium comprising the Danish Emergency Management Agency, the Finnish Ministry of Trade and Industry, Icelands's National Institute of Radiation Protection, the Norwegian Radiation Protection Authority, and the Swedish Nuclear Power Inspectorate. Additional financing is offered by the IVO and TVO power companies, Finland, as well as by the following Swedish organizations: KSU, OKG, SKN, SRV, Vattenfall, Sydkraft, SKB.**

**ADDITIONAL INFORMATION is available from**
**the NKS secretary general, POB 49, DK-4000 Roskilde, fax (+45) 46322206**

Nordisk Ministerråd