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ÄSPÖ HARD ROCK LABORATORY SWEDEN

PROJECT START CEREMONY
MAY 14, 1991
AND FIRST INTERNATIONAL SEMINAR
MAY 13, 1991

ÄSPÖ HARD ROCK LABORATORY, SWEDEN

SPEECHES MADE AT
THE PROJECT START CEREMONY,
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Foreword

The aim of the new Äspö Hard Rock Laboratory is to demonstrate state of the art of technology and evaluation methods before the start of actual construction work on the planned deep repository for spent nuclear fuel.

The nine country OECD/NEA project in the Stripa mine in Sweden has been an excellent example of high quality international research co-operation. In Sweden the new Äspö Hard Rock Laboratory will gradually take over and finalize this work.

SKB very much appreciates the continued international participation in Äspö which is of great value for the quality, efficiency, and confidence in this kind of work.

We have invited a number of leading experts to this First International Seminar to summarize the current state of a number of key questions. The contributions show the great progress that has taken place during the years. The results show that there is a solid scientific basis for using this knowledge on site specific preparation and work on actual repositories.

Stockholm, April 1992

Sten Bjurström

Chairman of the Board

Mr. Carl-Eric Nyquist
Chairman of the Board, Swedish Nuclear Fuel and Waste Management Co, Sweden

County Governor, ladies and gentlemen!

On behalf of the Swedish Nuclear Utilities, SKB, I would like to welcome you to Äspö. Today marks the start of a project which is an important milestone in nuclear waste management.

Our research on storage of long-lived waste is based on a method presented when our most recent nuclear power station began operating. This, in fact, was the result of extensive research which began in the middle of the 1970's.

Sweden is the leader in nuclear waste management. We have a complete transport system for nuclear waste, final underground storage facilities for low and medium level waste (Forsmark) and an interim storage facility for spent fuel (CLAB).

Tremendous progress has been made since the nuclear waste debate began in the 1970's. We now possess extensive knowledge about nuclear waste. In fact, we probably know more about this area today than any other environmental problem. In many ways, nuclear waste management efforts could serve as a model for dealing with other difficult environmental issues.

The Project Start of the Äspö Hard Rock Laboratory also means that research on methods for final storage of nuclear waste has entered the last phase. Those of us who work in the industry are extremely pleased that we have reached this point.

As I mentioned earlier, efforts to improve knowledge and technology for final waste storage have been under way for quite some time. It can be difficult to follow the progress that has been made and to fully appreciate the successive improvement in knowledge that has garnered international recognition. This is why yesterday's seminar focused on explaining what has been achieved to date and on charting the direction of future development.

Management of radioactive nuclear waste is the subject of much debate in Sweden. We believe, however, that a substantial number of facts are missing from the current debate. We can help to rectify this problem by telling the general public how to handle waste from our reactors, as well as other types of radioactive waste. We all know that nuclear waste exists and that it must be handled within Sweden.

The Swedish nuclear technology act places the major responsibility for nuclear waste safety on the shoulders of the nuclear power industry. I believe that we have fully accepted this responsibility.

Swedish nuclear utilities and SKB have worked together for more than 15 years. SKB has provided a framework that has enabled these companies to cooperate with universities, research institutes, engineering firms and consultants to resolve technological and scientific issues involving nuclear waste. Experts are now convinced that waste can be managed in a fully satisfactory manner. The Äspö Hard Rock Laboratory will focus on applying the methods and systems that have been developed.

The decision to place highly radioactive waste in interim storage provides a high degree of flexibility when it comes to the final storage of waste. We could, in fact, suspend development efforts for 20-30 years, utilize existing storage and waste management systems and simply monitor international development.

But we do not believe that this strategy is correct. Nor do we believe that the principle on which our final storage system is based will change much in the foreseeable future. If it does, however, we can easily change directions to accomodate any new findings.

When we weigh the advantages of continuing to develop existing technology against risks involved with doing nothing, the conclusion is obvious. We will continue to strive to place nuclear waste in final storage facilities as soon as it is practically possible. Our basic position is that final storage must take place in cooperation with the municipality offering the most suitable prerequisites. Consequently, we must be thoroughly prepared and ready to allocate sufficient time to discuss potential sites.

We are pleased to welcome so many friends from the various nuclear waste organizations around the world to Äspö. As I previously mentioned, a positive attitude from regional representatives is extremely important. I am therefore please to welcome the County Governor, the County Administrative Board and representatives from the municipality of Oskarshamn.

We are also pleased to welcome representatives from the Ministry of Environment and Energy, the Swedish Nuclear Power Inspectorate, the Swedish Radiation Protection Institute and the National Board for Spent Nuclear Fuel as well as representatives from Swedish business and industry, universities and colleagues from the industry.

Finally, I would like to welcome many individuals involved in research and practical implementation of this project. I would like to thank the management and employees of SKB who have worked very hard to realize the Äspö Hard Rock Laboratory.

County Governor

Erik Krönmark
County Governor, Kalmar län, Sweden

Few issues in recent decades have affected people as deeply and emotionally as the nuclear energy issue. This is especially true in Sweden, where conflicting opinions concerning the problems and risks associated with nuclear energy have, on occasion, not only dominated the political scene, but even affected exchange rates and spawned a government crisis.

Uranium rods generate more than energy in the normal sense of the word. They seem to radiate a type of emotional energy that defies all logical barriers. No issue has proved so difficult to discuss objectively. Some people view reactors as the work of the Devil, while others see them as a symbol of the very forces that created the universe.

Despite differences in opinions, the demand for safety is the primary concern regardless of faction. While the systems used at Swedish stations are good, accidents can not be entirely ruled out. The type of accident and the ensuing events that took place at Tjernobyl, however, is simply not conceivable in Sweden. Still, the fact that the Swedish public and the Swedish politicians have devoted so little time discussing the risks involved with graphite reactors appears to indicate some form of mental block concerning problems that cannot be affected directly.

Final storage of waste is the last of the issues to be solved. Given the half-life of uranium, we are facing a technological-economical project with a hitherto unheard of time frame. Perhaps the builders of the pyramids in Egypt and Mexico thought that their work last an eternity. I doubt, however, that they were forced to comply with the same type of quality demands stretching over several thousand years which are facing today's technicians.

I do not wish to claim that the construction of the hard rock underground laboratory at Äspö represents an epoch event in the history of man. I do believe, however, that the set of requirements facing science today are the most stringent we have seen to date.

Nuclear Waste Issues during the 90's

Sten Bjurström, Dr, President
Swedish Nuclear Fuel and Waste Management Co, Sweden

Mr County Governor, Ladies and Gentlemen!

Typical for the nuclear waste is the very long time horizons. With today's planning we have given ourselves almost fifty years from start of research work on the final disposal in the 70's until we plan to have a facility in operation around 2020.

It is certainly difficult from outside to follow the work and its progress under such a long time. In this context I see the Hard Rock Laboratory at Äspö as a very important milestone in our work to a final repository.

My task today is:

- to sum up the State of the Art after nearly twenty years of research and development work in Sweden and abroad
- to show the influence of the result of the work for our planning during the 90's.

Large efforts

We have spent more interest, scientific resources, and money on nuclear waste than on any other hazardous material – this I believe is true in Sweden and abroad.

Very much has also happened since the 70's, more perhaps than one can believe when listening to the debate on nuclear issues.

In Sweden – and in many other countries with nuclear power – we have developed, built, and taken into operation a system for all radioactive residues in the country.

Equally important is that a system for administration, financing, and legal matters have been established. The Swedish system is relatively simple, efficient, and well functioning.

After twenty years of research the crucial questions for final disposal have been dealt with and the result is a comprehensive basis of general knowledge.

The long time perspectives involved and the unusually strict requirements we have on nuclear waste were in the 70's scientifically new.

The most important result of the research is therefore that we today have gained knowledge to handle the long-term perspectives; the very slow processes down in the rock will guarantee stable conditions for time periods far beyond the time needed for the disposal.

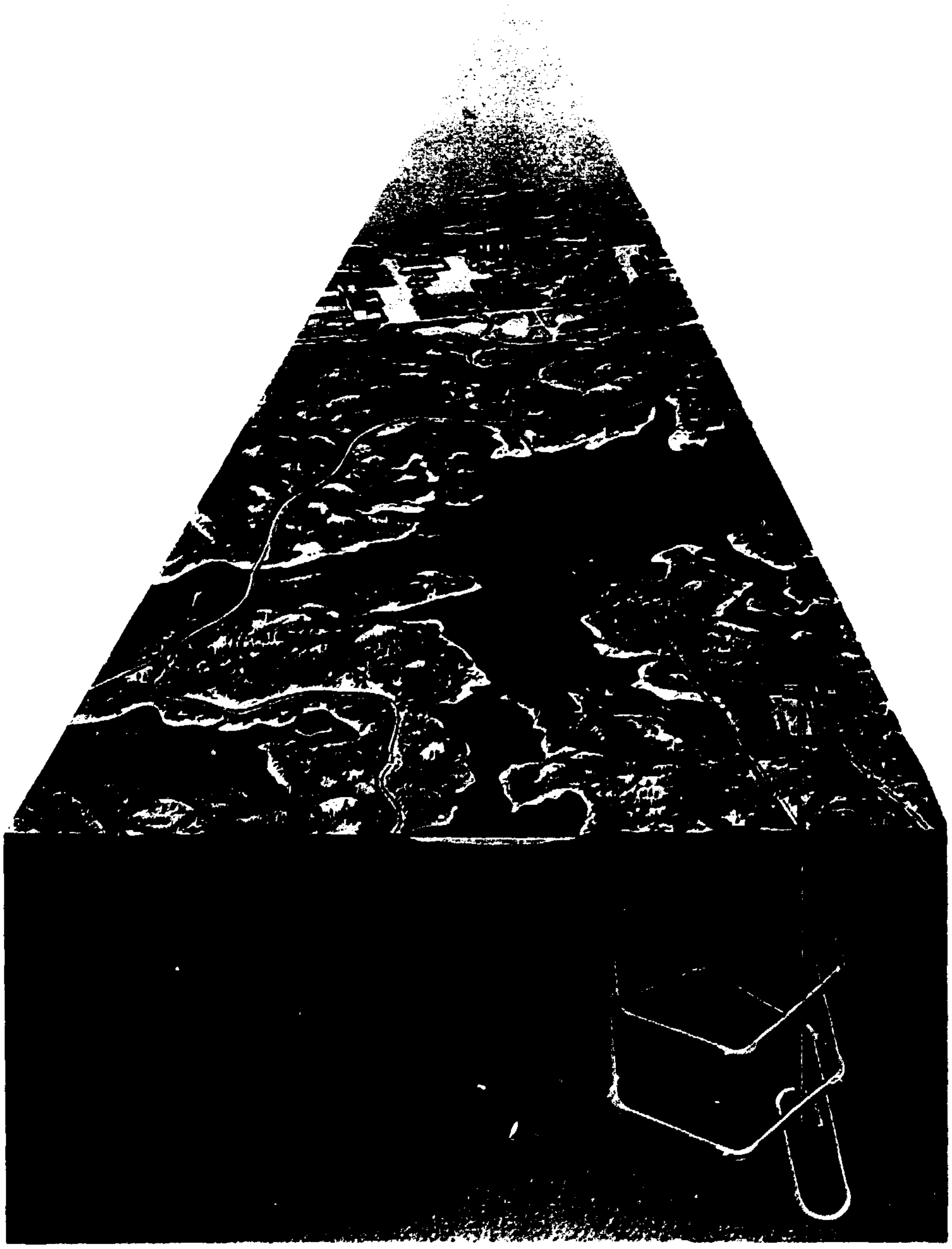
Too little has, however, happened in the field of public opinion and attitudes in relation to nuclear waste and the way laymen see the possibilities for safe disposal. Despite some improvements very much remains today the same as during the 70's.

The nature of nuclear waste

For several reasons the nuclear waste has got an established role as one of the most difficult waste problems in society. Today we can conclude that this is in many ways undeserved – it is however very difficult to change the picture.

I will not for a moment underestimate the problems connected to nuclear waste; they are difficult and they need correct handling. However, in addition to this we must consider the role nuclear waste plays as a very efficient political instrument and as symbol for a lot of worries in our society.

One shall not underestimate the role that nuclear waste has as a representative for a new type of complicated problems in today's society. The nuclear waste is often looked upon as a pilot case. In this context results from our research would surely give a positive "spin off" to other sectors.



The sketch shows the planned excavations for the Äspö Hard Rock Laboratory. The access ramp, c. 4000 metres in length, will give access to rock for research and development at a depth of 500 metres below the surface.

Most people, not involved in nuclear waste work, have a vague understanding in what way nuclear waste could be a risk to them. Despite this fact quite a number of those persons often participate in the debate and have strong opinions in spite of the limited knowledge.

Everyone in Sweden is, however, conscious of the existence of waste and that we must take care of it – but it is also a fact that we need to communicate much more facts to large groups in order to get a reasonably objective and good discussion during the localization of the repository.

The state of the art

From a scientific point of view I would like to limit myself to three questions where I believe we have reached important knowledge – a) time needed for isolation – b) requirements on the rockmass, c) when do we know enough to start design and construction of a repository?

Time horizons

Concerning the time aspects I would like to part the future in three, namely the time period when handling and disposing of waste to 2060, the disposal period some hundreds up to 1000 years ahead and a third period the time after up to around one hundred thousand years.

Encapsulation, handling, and disposal are difficult operations but no more difficult than today's operation of our nuclear power plants. Consequently, no one sees any particular problems related to these activities besides cautious and correct handling.

One can note that very much happened in relation to toxicity during a time period up to 1000 years. More than 99.9% of the original radioactivity of the spent fuel will disappear and also very much of the more difficult parts connected to for instance the fission products.

The remaining risks are connected to elements such as uranium, plutonium, americium, neptunium, and some other very long-lived substances but with a risk of different nature.

They are low active and one needs to have an intake in order to be exposed to a risk. At the same time they are extremely hard to dissolve in any quantities in the Swedish groundwater conditions.

Furthermore, I think it is true to say that between experts there is no disagreement that a well designed repository will certainly completely isolate the waste for at least one thousand years. If this view is combined with the fact that most of the radioactivity will be reduced after some hundred years we can understand that experts do not see any large problems for the main bulk of the waste and the time period when the potential risk is high.

Thus, our remaining problem concerns a small share of the original toxicity and its potential risks for a time period between one thousand years up to around 100,000 years. After this time the repository can be from a risk point of view compared with a rich uranium ore deposit – we have closed the circle.

According to climatologists Sweden will for a large part of this time be covered with thick ice.

Barriers

The extremely slow geological processes down in the earth crust mean that a hundred-thousand-year perspective is a short time. One can be convinced of stable and consistent conditions. This in turn means that the technical barriers – the copper canister and the bentonite clay – will stay intact and completely isolate the waste during this long time period.

The fuel which is extremely corrosion resistant and the rock mass inclusive of its possibilities for sorbtion of radionuclides are certainly also very qualified barriers in addition to the engineered ones. It might, however, turn out that we can encounter problems to quantitatively show the safety because of this – the safety of the long-lived technical barriers will certainly be more easy to show convincingly.

The most important task for the rock mass is then to create favourable surroundings for the technical barriers. Particularly important are the questions connected to the groundwater chemistry.

The existence of rock joints is less important but we will of course try to avoid larger zones of joints or faults and look for rock plinths where we can expect a small groundwater flow.

Hence, our judgement is that the requirements for the bedrock are modest and can be satisfied at many places in Sweden.

The 90's

For the 90's we are planning as follows:

- choice of final disposal system
- site selection for encapsulation stations and final repository
- confirm the safety of the repository at selected site.

Strategy for the future

I believe we all agree that the system we have built in Sweden is an advantage for the country and can be seen as a sign that we have taken the responsibility of the generation utilizing the electricity from the nuclear power.

For the future work of the final repository there exists a number of strategic possibilities.

With the interim storage in operation we are not in a hurry. Theoretically and technically we could now sit down and await the development leaving much of the problem to the future and our children.

As mentioned by Mr Carl-Erik Nyquist the Swedish approach up till now has been the opposite, we have used the possibilities available in order to solve the problem as soon as practical. This is also the strategy for the future.

Choice of system

The important question connected to choice of system is "when do we know enough to start a more significant work in order to design an construct a repository?".

After more than twenty years of research there exists an international consensus that the time has now come to leave the general research for a more site specific one. Naturally there exists no reason to force the work. One must be well prepared in all respects but a concentration on the most promising alternative will certainly contribute to an increased quality and progress of the work.

Besides, I also believe that this focusing on research is necessary regarding available future scientific resources.

In addition to this we foresee some research in parallel on alternatives and it is important to be open for new knowledge and possibilities. From the SKB side we, however, judge that there will not be drastical technical break-throughs within a foreseeable future.

With our interim storage in operation I am of the opinion that this way of working can be well defended. The only risk for society could be a delay if the authorities do not find our work completely satisfying and we have to take a step back and start again. If new alternatives and knowledge will appear it is in our interest to integrate that into our work.

Localization

The planning comprises a proposal of three possible sites before 1995 followed by detailed shaft investigations of the two most suitable sites in the period 1995–2000. A complete licensing application based on site specific data from one site is planned to be submitted some years after the turn of the century in order to enable construction work to start around 2010 and to have a facility in operation around 2020.

Äspö Hard Rock Laboratory

The Äspö Hard Rock Laboratory plays an important role concerning the preparation for the actual repository and in demonstrating and explaining results.

The normal case for underground construction is that tests and investigations are carried out, expecially test tunnels and chambers, in connection with the actual excavation.

The Äspö Laboratory allows us to lift this job out of the operation to show on beforehand:

- that the results from site investigation methods are correct
- that our modelling and calculations are correct and data acquisition can be made
- the most appropriate design of technical elements.

In agreement

One of the most important prerequisites for our localization is success in our job to communicate facts on the final disposal to opinion formers, decision-makers, and the general public. There is no reason at all to force the technical work if we had not gained enough tolerance in our surroundings.

The Äspö Hard Rock Laboratory will also here play an important role. The possibility to come and see will certainly be one of the more important tasks for the laboratory.

From the SKB side we will do our utmost to reach an agreement with the candidate communities for the repository. We are optimistic - our experience is that we can find communities which will not only see the negative sides of the repository and we will certainly work very hard to use existing possibilities to make the localization as positive as possible for the community.

Thank you very much!

U.S. Department of Energy Perspectives on the Benefits of International Technical Collaboration

Thomas H. Isaacs, Director
Office of Strategic Planning and International Programs
Office of Civilian Radioactive Waste Management
U.S. Department of Energy

Introduction

It is a pleasure to be here to take part in this important occasion. The Swedish radioactive waste management program has historically served as a successful model for other countries to follow and this new research facility at Äspö will help keep Oskarshamn and Sweden on the international map. To date, some of the most current underground research activities in other nations have been based on information learned through the international Stripa Project. For this reason, the work being initiated here today in Sweden's new Hard Rock Laboratory is considered by all countries with high-level radioactive waste management programs to be an important step in the advancement of technology associated with the safe handling and disposal of spent nuclear fuels and high-level radioactive wastes, and the U.S. remains interested in exploring the benefits of potential collaboration. I consider it an honour to have been invited to present U.S. perspectives on the benefits of international technical collaboration.

A "global" undertaking

The U.S. Department of Energy's Office of Civilian Radioactive Waste Management (OCRWM) is responsible for the permanent disposal of U.S. spent nuclear fuels and high-level wastes from civilian nuclear power and defense nuclear activities. These responsibilities include: selecting and determining the suitability of a site for a deep geologic repository; interim storing of the wastes at a federal facility; transporting spent nuclear fuel and high-level wastes to a federal storage facility and/or to the repository; final packaging of spent nuclear fuel and high-level wastes for disposal; assuring the safety of the repository, and seeking and obtaining a license for the repository; designing, building, operating, and closing a repository; and carrying out the necessary research and development to support all these activities.

Similar responsibilities have been assigned to governmental agencies and industrial consortia in a number of countries with a nuclear power generation program, and the nations that have nuclear programs circle the globe. All the countries that are proceeding to implement deep geologic disposal of spent fuels and high-level radioactive wastes are working in new technical and institutional arenas, and are advancing the state of related technology. In addition, the activities of any of these countries in this field will affect the remaining countries in a number of ways. Hence, the disposal of high level nuclear waste and spent nuclear fuel is a "global" undertaking.

A unique, unprecedented undertaking

The development of a deep geological repository for high-level wastes involves activities for which there are scientific and engineering precedents. However, there are many new issues involved in deep geological disposal, as well. Because of the unique undertaking, research and development is needed in a number of engineering areas. Some of these engineering research areas are:

- demonstrating satisfactory repository performance over thousands of years,

- mining in deep geologic formations to minimize impacts on the geologic environment.

- building highly competent engineered structures below ground that must withstand heating by the waste and the potentials for future activities by man.

- design and manufacture of waste packages that are competent for very long time periods.

- identifying or controlling movement of groundwater to repositories.

- providing careful and substantial ventilation and cooling of repositories during waste emplacement.

- shielding of workers during all aspects of waste handling, and

- providing highly competent and long-lasting backfilling and sealing of repository openings.

The primary scientific objective of the repository business is unprecedented in the history of human science and engineering: the need to assure, with a high degree of confidence, that radiological risks to society from deep geological disposal of a hazardous materia are acceptable for many thousands of years into the future.

The characterization, technical evaluation and engineering of a candidate site for a deep geological repository is a major new challenge to the geological and other physical sciences and engineering disciplines. The satisfactory completion of this long term "safety case" is a completely unprecedented activity.

International collaboration for the "Safety case"

Constructing the long-term "safety case" for a deep geological repository requires a detailed geoscientific characterization of a site, and conceptual design of a repository system. The design of the system includes definition of the waste forms (i.e., spent nuclear fuels, solidified high-level wastes), definition of the containers surrounding the waste form, and definition of engineered components surrounding the waste containers (e.g., buffers, backfills). The "safety case" requires the ability to predict the behavior of the combined site/repository system over very long periods of time.

The long-term "safety case" uses the results of measurements of parameters defined in the geological sciences, results of detailed engineering design and in-situ behavior studies, and informed estimations of likely future events and processes that can affect natural states. For the "safety case", these technical measurements, scientific principles, and other results are encoded into mathematical expressions that are used to predict future system behavior. The credibility and defensibility of these future predictions depend on the competency, appropriateness, and completeness of: geologic and engineered system state descriptions; understanding of all important interactions; the assumptions and simplifications of modelling; and assumptions regarding future states. Present geologic state and future state descriptions, in turn, depend on the geologic characterization providing information that describes the present state of the natural system, and are useful in predicting future states.

The basis for predicting the in-situ behavior of engineered systems depends on appropriate use of scientific principles, credible experimentation, and accelerated in-situ and laboratory analogue testing.

The basis for predicting the future evolution of geologic processes affecting behavior of a repository system and/or for predicting the occurrence of natural or human disruptions of the system, is understanding of the geology and geologic history of the natural system, appreciating potential changes that may affect the site, and postulating the boundaries of human motivations and behaviors with respect to the human exploration of deep geological formations in the future.

These information-gathering and future prediction endeavors are costly, complex, highly subject to technical challenge, and global in the same sense that the high-level nuclear waste disposal challenge is global. Multinational cooperation can be employed to leverage the resources of each country with the same radioactive waste disposal need, and to put the best minds in the world to work on finding solutions to these unprecedented problems.

Benefits of international technical collaboration

Financial. The most obvious benefit of multinational cooperation is financial. For example, those countries contributing one eighth of the resources needed for the Stripa underground research program received access to technology developments and experience representing an eight-fold return on their investment. International collaboration is good business.

Synergism. International collaborative efforts allow participants to work with technical peers independently engaged in accomplishing similar tasks. For example, an expert in working on groundwater transport modelling is not only in touch with other experts in this field, but is in touch with other experts trying to solve similar problems (and likely with different perspectives). The result is synergy among the participants. A body of collective knowledge becomes available to all participants through the small insights and contributions of individual participants.

An excellent example of synergy is the technical contributions being made through the HYDROCOIN (Hydrological Code Intercomparison, Verification and Validation exercises) and INTRAVAL (Hydrological and Solute Transport Code Validation) efforts on defining what can be done in terms of validation of models for hydrological transport. No single participant could technically tackle this vital subject as successfully as through these two collaborative efforts. They have been and are still defining and advancing the state of the art in using field and experimental work in supporting and evaluating complex modelling. This example typifies how international collaboration disseminates the best thought and techniques throughout the participating community.

Experience. The needs of site characterization are pushing the state of the art in geosciences and related technologies. Beyond the advanced technologies and scientific knowledge being used, the competence and experience of the technical "operator" is often as important as the technology itself. The important job of characterizing a potential repository site should employ key persons with below-ground experience with the techniques they are employing at the site. This experience is valuable in avoiding downtime or delays, reducing repeated efforts, obtaining valid information, preventing accidents, and preventing the need to modify or replace the technology after the start of characterization.

International collaborative efforts on in-situ work in an underground laboratory, and characterizing a natural analogue site that addresses the techniques and designs of site investigation activities can help provide valuable experience for staff in carrying out the site evaluation activities for their national program, and doing them quickly, economically and right the first time.

Credibility. One of the less tangible, but no less important benefits of international collaboration is to develop credibility in national programs. International collaboration provides inherent peer review. It can help establish that scientists and engineers sent to represent general approaches are truly peers of those representing other national programs or international organizations. Those having to validate a program's credibility will often look to the international community for validation.

Consensus. The idea that each country can be totally independent in defining its environmental protection goals and its technical approach to meeting the requirements of the "safety case" is erroneous. Although there will always be differences in the specific features of regulations in different countries, the overall technical basis for the goal of protecting present and future human populations and the environment is a matter of international consensus.

The basic approach to "safety cases" from a number of countries was presented in the 1989 Symposium on Safety Assessment of Radioactive Waste Repositories in Paris, France. These presentations showed there was a commonality in approach to the building of credible "safety cases." The 1989 Symposium led to an international consensus on the building of a credible "safety case"; that consensus is the Collective Opinion on Long-Term Safety Assessment published by the NEA. While there remain generic issues associated with the "safety case" (e.g., defining lists of unanticipated, low-probability events and human intrusions, defining bases for modelling global climate change impacts on local areas, predicting the frequency and types of human intrusions, etc.) international cooperation leading to common views and consensus is needed.

Goodwill. Cooperation creates goodwill among the participating countries, which is important. Countries can affect each others' environments, and environmental attitudes; the technical competence of the participating countries' scientists and engineers is enhanced; public feeling may be positively affected if there is international review and acceptance of a nation's approach; and public feeling may be positively affected if it is known that other countries are proceeding with similar disposal approaches. In other words, international collaboration can build competence within a nation's repository program, and thereby build confidence in its public and in neighboring countries.

Issues in selective participation in international collaboration

Not every international technical collaboration activity in geologic repository development is going to yield the benefits enumerated above to every participant. To some extent this depends on the applicability of the work done to the particular situation of a given participating country. Countries decide on their participation from the international collaboration opportunities available using a variety of reasons. These can include the applicability of the proposed work, the current national economic and/or political situations, and the respective schedules of their national program and the collaborative effort.

Development, testing, and demonstration of repository site characterization and engineering technologies in a collaborative program that may not be directly applicable to a given candidate repository location or concept, however, may still be of value to a country's program. The collaborative program may provide a practical illustration of a successful, engineering problem-solving approach, or as a general builder of experience in in-situ testing, or as a source of unanticipated insight into the characterizing of complex geologic systems, or as a source of information on a future unanticipated issue in a country's geologic disposal program.

The characterization and modelling of long-term geologic processes at natural analogue sites not directly analogous to a given candidate repository site may be of value to the candidate site. For example, it could show that large geological systems can be understood and described; it could enhance national modelling capability; it could demonstrate that modelling of geologic processes over geologic times is possible and technically credible.

In other words, international collaboration in projects not directly applicable to a country's repository site may still provide benefits in building experience and credibility, and other unexpected secondary benefits that accompany almost all cooperative efforts.

Summary

In summary, I would like to make the point that development of deep geologic disposal systems for spent nuclear fuels and high-level radioactive wastes is in a way, a global undertaking; that is, we are all affected by each other's activities.

The characterization of a candidate repository site and engineering of a deep geological repository is a significant challenge to the geological sciences and engineering disciplines. The construction and satisfaction of the long-term safety case is an unprecedented activity.

Potential benefits of international collaboration on deep geological repositories vary with each program and each country. Some of the benefits to national programs include: reducing costs, having access to improved technologies and knowledge throughout the community, providing practical experience, providing pier review and credibility for a national program, providing international consensus on approaches, and contributing goodwill and competence to other countries. International collaboration in repository related projects not directly applicable to a country's program can still benefit a country.

The United States has benefitted immensely from its international collaboration in geological repository development, and will continue to do so in the future.

Again, I am pleased to be able to participate in this important occasion, and appreciate the opportunity to talk to you today. I wish you great success in your Hard Rock Laboratory endeavors and in your overall repository program.

The Status of the Canadian Concept

C.J. Allan, Vice President
Environmental Sciences & Waste Management,
Atomic Energy of Canada Limited (AECL) Research,
Whiteshell Laboratories, Canada

In responsible industrial societies nuclear fuel waste management has been handled with a degree of care and attention, and consideration for protection of human health and the environment, not generally applied to other wastes. This is a consequence of the hazardous nature of the waste itself, and of the awareness, of the industry and the public, of the hazard.

In Canada, in common with many other countries with a nuclear power industry, we are carrying out a wide-ranging research program to develop means to safely dispose of nuclear fuel wastes. Based on our understanding of the behaviour of nuclear fuel waste under anticipated disposal conditions, we have developed a concept for isolating that waste from the environment, and methods to assess the performance of our chosen solution far into the future. Our Concept is about to be evaluated, and decisions made on how, and when, to proceed with disposal in Canada. Today I will provide you with an overview of the steps leading to the establishment of the Canadian program, its current status, and the review process that is underway.

In 1977 Energy, Mines and Resources, the federal government department responsible for the nuclear industry, commissioned a study led by Prof. Kenneth Hare, of the University of Toronto, to identify options for disposal of used nuclear fuel in Canada. After consideration of a wide range of possible options, including surface, seabed, or polar ice sheet disposal, this study recommended that disposal deep in the stable plutonic rock of the Canadian shield be investigated. A Royal Commission, established by the government of Ontario to examine electrical power planning, concluded that the existing methods of used fuel storage were safe and effective, but that a permanent method of disposal should be developed.

The Canadian Nuclear Fuel Waste Management Program was launched in 1978 as a joint initiative by the governments of Canada and Ontario. AECL, a federal Crown Corporation, was given responsibility for assessing the disposal concept and for developing and demonstrating the associated technologies. The provincial utility, Ontario Hydro, the largest operator of CANDU nuclear power stations, was to continue to develop the technologies for interim storage and transportation of used fuel. In executing the program AECL has contributed some scope and work to Ontario Hydro. Ontario Hydro contributes direct financial support to AECL's research programs.

In 1981 the two governments reaffirmed their commitment to the program, but stated that selection of a nuclear fuel waste disposal site would not proceed until the "Concept" had been reviewed and assessed. Thus the Concept assessment that we are undertaking is generic rather than site specific.

The need for development of a well researched and understood method for permanent disposal of radioactive wastes has been repeatedly reemphasised throughout the last decade. In 1988, a parliamentary Standing Committee on Environment and Forestry published a report calling for a moratorium on further construction of nuclear power plants in Canada until a permanent disposal method for used fuel was demonstrated. While this recommendation was rejected by the government it reflected a public concern consistent with the results of public opinion polling. Later in 1988 the Tenth Report of the Parliamentary Standing Committee on Energy Mines and Resources issued a report which was favourable towards the nuclear option but which recommended acceleration of the concept assessment process to respond to public concerns.

During 1990 the Ontario Hydro Demand Supply Option Study was completed. This study examined the province's electricity needs for the next 25 years. It recommended a significant increase in nuclear capacity. If implemented, the result would be an increase in the quantity of used fuel generated. This plan is now the subject of an environmental review in Ontario and disposal of nuclear fuel waste could become an issue.

The Canadian Concept, for nuclear fuel waste disposal, is based on disposal in the plutonic rock of the Canadian shield which extends through a large part of Canada, from western Quebec to Saskatchewan. In common with approaches in other countries, the fuel will be isolated from the biosphere by a series of engineered and natural barriers; these include the waste form, container, buffer and backfill materials, and the host rock. During the past ten years we have carried out detailed studies on each component of this barrier system. This has enabled us to develop a robust concept permitting a choice of materials and designs for the components of the system. If the Concept is endorsed and the decision made to site a facility the components will be optimised based on their applicability to the site actually chosen.

In seeking endorsement of the concept AECL intends to show that:

1) that criteria exist that can be used to assess the safety and reliability of the disposal facility,

2) that the technology exists to site design, build, construct, operate, decommission and close a disposal facility that meets the safety and environmental criteria,

3) that a methodology exists to evaluate the performance of a disposal facility against the safety and environmental criteria, particularly in the long-term and

4) that suitable sites in plutonic rock are likely to exist that, when combined with a suitably designed facility, would meet the safety criteria.

Safety and performance criteria have been established by the Atomic Energy Control Board (AECB), the Federal agency which regulates the Canadian nuclear industry. The AECB has issued three regulatory documents which describe its policy on nuclear fuel waste disposal and provide guidance on its requirements. Two of the documents list requirements regarding the assessment of the Concept and its documentation, and conditions that must be met by a geologic repository. The third document provides guidelines for the objectives of radioactive waste disposal. These objectives seek to limit the burden placed on future generations by calling for a repository design which does not rely on long-term institutional controls.

AECL's R&D program has been directed towards establishing that the latter three criteria can be met. It covers a broad spectrum of activities. Processes in the geosphere, the biosphere and the performance of engineered systems are being investigated. The research includes underlying investigations, engineering scale studies, large-scale integrated effects tests, analogue studies, and model development. A major component of the program is the Underground Research Laboratory (URL) that has been constructed to perform large-scale, in situ experiments in plutonic rock. This laboratory has been built in a rock body of the type expected to be suitable for disposal. It was the first such test facility to be built below the water table in previously undisturbed granitic rock. Disturbance to pre-existing conditions caused by construction have been continuously monitored throughout its development. The work in the URL, and in an extensive borehole network surrounding it, has assisted in the development of methodology for geologic characterisation, and the results from the surface characterisation and construction phases of the program are important components of the documentation for concept assessment.

The underground construction phase was completed early in 1990. The shaft has been sunk to 445 metres below the surface, and experimental rooms have been built at the 240 and 420 metre levels. The URL is now entering the Operating Phase and a program of operating phase experiments has been selected.

These include:

- An investigation of solute transport in zones of moderately and highly fractured rock.
- An engineering demonstration of the grouting of a fracture zone.
- A demonstration of the engineering aspects of borehole emplacement.
- A study of materials and emplacement methods for shaft sealing.
- The Mine-by Experiment, a study of the material properties and response of an intact volume of highly stressed rock to excavation.
- A multicomponent experiment to study many aspects of the disposal concept including buffer emplacement and room backfilling and sealing, to gather a database on performance of a fully backfilled room.

Work is well advanced on the full scale buffer/container experiment, simulating a container of used fuel in a disposal borehole. The borehole has been excavated and preliminary monitoring of the rock characteristics is taking place. The main experiment will start in early summer. Work is also underway on the instrument tunnels for the Mine-by Experiment. Instrumentation boreholes will be located off the tunnels to monitor the response of the rock to the excavation of the last section.

Discussions are nearly completed with our colleagues in the French waste management agency (ANDRA) for a blasting experiment to be carried out in the URL. As part of the effort to establish that methodologies exist to site, characterise, operate, close and assess the long-term performance of a nuclear waste repository, we have carried out two extensive case studies on aspects of the Concept. One study is a conceptual design for a disposal centre, "the Used-Fuel Disposal Centre", UFDC, which is based on a particular set of reference specifications for all disposal system components and activities. The design uses present day technology or easily achievable extensions to that technology. The hypothetical site conditions used are based on information derived from our field research areas in the Whiteshell Research Area. This study has enabled us to assess the engineering feasibility, costs, safety and potential environmental impact of disposal. It is expected that such a facility could not be operational before about 2025 and would operate for about 40 years.

A second case study has been carried out to analyze the long-term environmental impact and safety of a disposal facility following closure of the vault. The case study is used to explain and demonstrate the methodology for performing environmental and safety assessments, and for using this methodology to establish design and operating constraints on a disposal facility.

The disposal Concept has been referred for review under the Canadian Environmental Assessment and Review Process. AECL is the "Proponent" for this review and will submit an Environmental Impact Statement (EIS) describing the Concept. The final scope of the EIS will be determined by the Environmental Assessment Panel responsible for carrying out the review. The Panel has appointed a Scientific Review Group, (SRG), of 15 eminent scientists from a variety of relevant disciplines to assist in judging the technical validity and acceptability of the disposal Concept. We anticipate that the Panel will issue its guidelines for the EIS later this year. These guidelines are likely to incorporate extensive comments from the SRG on scientific and technological issues that must be addressed.

The EIS will summarize the results of our R&D programs and will describe:

- the technology developed and acquired in the program for siting of a nuclear fuel waste disposal facility.
- the engineering technology for containers, seals, and other engineered barriers
- the conceptual design for the UFDC.
- the models used in the long-term environmental and safety assessment and their scientific basis.

The Panel will review AECL's Concept along with a broad range of nuclear fuel waste management issues. These issues include the criteria for determining safety and acceptability; the approaches used in handling wastes, both in Canada and other countries; the potential social, economic and environmental effects of waste disposal; and the potential impact of recycling and other processes on waste volume. A general review of other aspects of the nuclear industry, such as energy policy and reactor operation and safety, is specifically excluded from the panels review. During hearings to review the EIS, members of the public will have an opportunity to make presentations to the Panel and to question the proponent, AECL. In addition, the government expects that all departments with a relevant regulatory interest, e.g. the departments of Health and Welfare, Environment, Transport, will provide a written response to the EIS. At the end of the review the Panel will make its recommendations on the acceptability of the Concept and for future action on nuclear fuel waste disposal leading to government decisions on the acceptability of the disposal Concept, and the next steps to be taken.

Public hearings to assist the Panel in determining the scope of the EIS, took place in the fall of 1990. These Scoping hearings provided the first opportunity for interested parties, not directly connected with the nuclear industry or with the scientific review process, to become involved with the program as "intervenors". In total, 130 intervenors made presentations: they included government departments, scientific and business organisations, special interest groups, and private individuals. A number of major issues were raised. These included the scope of the Panel arguments for and against storage as opposed to disposal, the adequacy of the regulatory criteria and issues of monitoring and retrievability, etc. Aboriginal land claims affect much of the land where there are potential sites and the concerns of aboriginals were raised. In response, an aboriginal representative has now been appointed to the Panel.

The social and ethical issues associated with the management of nuclear fuel wastes were of considerable concern to the intervenors during the Scoping Hearings. AECL conducted a workshop earlier this year with eight ethicists (including an aboriginal leader) selected for their interest in, or experience with, the ethics of science and technology, and radioactive waste management. Dr. Camilla Odhnoff, Chairwoman of the Swedish National Council for Nuclear Waste participated in the workshop.

The workshop was highly successful and the discussions were constructive and informative. The recommendations, broadly stated, were that the generation which benefits from nuclear power must take responsibility for disposing of the nuclear fuel waste. Disposal was regarded as preferable to storage, but that future generations should have the option to retrieve and to repair, if necessary. In principle these options exist within our Concept. It was regarded as most important that arrangements for handling waste should be based on informed consent amongst the affected publics, and that developing informed consent should be clearly recognised as distinguished from persuasion. A report on the proceedings of the workshop is in preparation.

We believe that we have been able to develop a robust and flexible Concept for disposal of nuclear fuel waste. We have now entered the environmental review process and await its outcome.

In developing an concept we have benefitted from interaction with our colleagues in the international waste management community. It is important that this collaboration continue. Extensive peer review of our work, and comparison with the programs of other countries is of direct benefit to all of us and it provides governments and the general public with added confidence in our efforts.

It is a distinct pleasure to be here today and to participate in this seminar marking the opening of this new and important facility.

HRL Project Start, 14th May, 1991

Yoshikazu Hashimoto, Executive Director
Power Reactor and Nuclear Fuel Development Co. (PNC), Japan

Good morning Ladies and Gentleman!

It is my pleasure and indeed a distinct honor to be here this morning and have some words on this significant project.

I am sure that this project will greatly contribute to achieving success in establishing technologies for geological disposal of High Level Radioactive Waste Management which is a common and an important issue for all of us.

As Mr. Nyquist has mentioned in his talk earlier this morning, PNC has officially signed on an agreement to participate in the HRL Project prior to this ceremony.

I am very proud of the fact that our organization had the honor to participate in this important project at its earlier stage.

In addition, we appreciate SKB's decision to open the door to the unknown and to provide opportunity for its overseas colleagues to challenge together.

I am convinced that we will be able to acquire important knowledges and to encounter surprises on various characteristics of geological environment which will improve the certainty and the credibility on the long-term performance of the geological disposal system.

I believe that it is a great thing for researchers from many countries to get together here and cooperate in order to achieve the mutual goal without being restricted by national boundaries which only exist on the earth's surface.

It is expected that our efforts in such a direction will also lead to a higher degree of public acceptance of the geological disposal option.

Last of all, I would like to give my best wishes to all the people concerned in this project and hope that this project will provide us with valuable opportunity for international collaboration in the field of High Level Radioactive Waste Management.

Thank you for your attention.

Äspö Hard Rock Laboratory-High-Lights

Göran Bäckblom, Mr, Project Manager Äspö HRL
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The evolution of the project

The Äspö Hard Rock Laboratory was launched 1986 for the main purpose of providing an opportunity for research, development and demonstration in a realistic and previously undisturbed underground rock environment down to the depth planned for the future final repository of long-lived nuclear waste. Regional site characterization started late 1986. After target area investigations, the south part of Äspö was selected by SKB 1988 as the site for the laboratory. Comprehensive pre-construction characterization was made in order to set up predictive models of the rock, models that will be checked and updated during the construction of the laboratory. An access ramp will be excavated down to a depth of 500 m below surface where experiments will commence in 1994. The excavation work started in October 1990 after decision by SKB board and after obtaining permits from pertinent authorities. As of May 1, about 650 m of the access ramp, area 25 m^2, has been excavated. An outline of the project can be found in /1/. In the following some high-lights during the course of the project are discussed.

Major decisions

The final repository for spent fuel will utilize the principle of a multi-barriers, natural and engineered. Evaluation of the KBS-3 disposal concept showed that a very high safety was feasible. The safety was in principle assured by the geochemical conditions at depth, the long-lived copper canister, the low solubility of the waste and the stable conditions in the bedrock. A new underground laboratory was deemed to be the most efficient way to increase the knowledge of the rock as a barrier, knowledge needed in order to perform more realistic safety analyses. The need to test technology for detailed site characterization and the need for pilot-tests and demonstration was as well anticipated. The proposal 1986 to construct an underground laboratory received a favourable reception by the reviewers.

The Äspö area has the proper infrastructure for such a research facility and the island provide access, within a geographically limited area, to the different geological and hydrological conditions required for the planned research, development and demonstration programme. The composition of the groundwater is representative of Swedish coastal rock. Establishment of the site office was preceeded by permits by authorities. On April 19, 1990 the government decided that the siting of the laboratory on south of Äspö was permissible according to Act on Conservation of Natural resources. The Development Plan accordingly to Building and Planning Act was approved by the Oskarshamn County. The decision was appealed but finally adopted by the Government in September 1990. The Water Rights Court handed down their ruling in September 1990.

The layout of the laboratory

Two options for access to the 500 m level were considered, either a exploratory shaft or an access ramp. The alternatives were compared on four different grounds, collection of data (ramp preferrable), methods and knowledge for numerical modelling and validation (alternatives equal), time, method development, costs (alternatives equal) and operation of the facility (ramp preferrable). The choice of the ramp 1987 due to its higher degree of flexibility proved to be wise. The government decided in August 1989 that the siting of the laboratory should be reviewed under the Act on the Conservation of Natural Resources. In connection herewith, SKB decided to make certain changes in the layout of the laboratory to reduce the environmental impact. In the new layout the access ramp was located on the Simpevarp peninsula, 1.5 km from Äspö, instead of on Äspö as was earlier planned. This change had not been possible with an exploratory shaft, thus jeopardizing the permit for Äspö.

The approach to site characterization

The site characterization performed so far has many unique aspects. It is in many ways comprehensive with respect to methods. During the pre-investigations a huge bulk of data has been collected at a cost of approximately 100 MSEK. The need for a general approach to allow for interpretation, integration and evaluation of all data was early anticipated.

Predictive models of the geology, groundwater flow, groundwater chemistry, transport of solutes and mechanical stability were selected as tools to push the evaluations. The site characterization is treated as an iterative process, where the predictive models will be more refined in steps. This iterative approach must be recognized as well when the real repository is constructed.

To facilitate the evaluation of the site characterization, it has been divided into stages and different geometrical scales with respect to designated key issues. The adopted approach has so far been very useful and it is deemed that the approach will be highly valuable in the planned detailed investigations that will start on two sites in Sweden in the mid 90's.

Development of technology

New technology has been developed and applied in the course of the project. Specific improvements are on drilling technology, hydraulic testing and numerical modelling.

Hole diameter for the cored holes is 155 mm in the uppermost 100 m of the hole and 56 mm for levels below. This design made it possible to integrate hydrotesting with sampling of the groundwater chemistry. The amount of drilling water pushed into the formation during the drilling was minimized. The design also facilitated hydraulic interference testing, measurement of ambient groundwater flow and monitoring of groundwater head and salinity. The design also made it possible to do "spinner" surveys, thereby rapidly finding out where all conductive structures are within some meter accuracy.

The tools for calculation have been enhanced to a degree that was not anticipated a few years ago. The threedimensional groundwater code, PHOENICS, now take into account the density contrast of the water. Fracture zones can be fed into or out of the model without the formidable task of changing the internal mesh for calculation, saving manmonths of work. The model as well allow for the complex geometry of the facility with a high resolution (2m) close to the excavation. The calculations do not need supercomputers but can be run on a working station.

Concluding remarks

An overall ambition for the Äspö Hard Rock Laboratory is that it shall be a leading centre of research and development regarding the construction of final repositories for high-level waste. Efforts are made to test and verify all the appropriate methodology and techniques that may be required. The project has so far received considerable international interest and it is envisaged that the international participation will be of great value in carrying out the planned programme.

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The International Stripa Project – Some Conclusions

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The International Stripa Project was organized in 1980, under the auspices of OECD/NEA, for the purpose of developing technology for the geologic disposal of nuclear waste. Phase I was initiated in 1980 and was followed by Phase II, beginning in 1984, and Phase III, beginning in 1986. For the most part, the field tests dealing with characterization methods, ground-water flow and solute transport, and engineered barriers have been conducted in the granite rock in the Stripa Mine. All testing in the Stripa Mine will be terminated by June 30, 1991, and, apart from the completion of the final overview reports and the last Stripa Symposium, the investigative activities of the Stripa Project will be concluded by the end of 1991.

Phase III had two principal objectives dealing with (1) the application of characterization, testing, and modelling techniques for the prediction and validation of ground-water flow and solute transport in a previously "undisturbed" mass of the Stripa granite; and (2) the sealing of water-conducting zones of fractured rock in the Stripa granite with injections of bentonite and cement, with attendant laboratory studies of the longevity characteristics of these sealing materials. To accomplish these objectives, three programs were established: (1) the site characterization and validation (SCV) program, which included the characterization and testing activities in the Stripa Mine and the associated modelling predictions of ground-water flow and solute transport; (2) the site assessment concepts (SAC) program, which included further development of the techniques for rock characterization and fracture-flow modelling, along with a study of the channelling phenomenon; and (3) the sealing program, which included sealing of fractured rock around emplacement holes and in the "disturbed" zone around a drift, and a water-bearing fracture zone in the Stripa Mine, as well as extensive evaluation of the longevity characteristics of bentonite-based and cement-based sealing materials in the laboratory and by geochemical modelling.

Based on the results that are available at this point in time from the three programs, the following preliminary conclusions can be made:

– The geologic structure and hydrologic features of a granitic rock mass, with a volume on the order of one million cubic meters, can be characterized quite well by means of data obtained from a few strategically placed boreholes through the integrated use of core logs, borehole photography, and single-hole and crosshole testing with radar, seismic, and hydraulic techniques.

– The ground-water flow and head distribution within a volume of granitic rock, as cited above, can be described reasonably well by a combination of fracture-flow and equivalent-porous-media models that make use of the characterization data mentioned above.

– The redistribution of stress around an excavated drift can reduce the expected groundwater inflow into the drift, based on borehole inflows, by almost an order of magnitude.

– Rock fractures with small apertures can be effectively sealed against circulating ground-water by injections of bentonite and cement grouts, and these grouts can be expected to maintain their sealing effectiveness for thousands of years or longer.

In 1992, overview reports will be prepared on the basis of the results obtained from the three programs in Phase III, as well as from the results obtained in Phases I and II. These reports are expected to evaluate the applicability of the characterization, modelling, and sealing techniques to other rock types and geohydrologic conditions.

Modelling the Underground – Experiences from Stripa and Äspö

Gunnar Gustafsson, Professor of Geology
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Models of the underground

We know less of the underground than of many other things. One reason for sure is our limited ability to see into the rock by direct means, but there is probably a psychological component also since what we once have swept under the carpet we also hope will stay there forever.

In the case of nuclear waste disposal nothing must be swept under the carpet, which stresses the need to understand the subsurface, to analyse and determine its properties, and to predict its future behaviour. In all these cases models come in as important and versatile tools.

By a model in the context above, we mean the concepts behind the processes we are to analyse or predict, the structure in which the process acts and the computer code with which calculations are performed. They are all different aspects of the same model.

A historical note

With the dawn of numerical flow models in the beginning of the 1970's, I and many with me believed that with proper pre-investigations and a sufficiently large computer everything could be solved. The reality was however more complicated. Numerous efforts with limited success made us understand that the great inhomogeneity of a fractured crystalline rock introduces scale effects that necessitates different approaches depending on what we want to model, in what scale and for what purpose. The dream of a grand unified groundwater model for a site, where all answers can be obtained is thus at present out of sight.

The Stripa experience

The research work in Stripa started in the 1970's. Already from the beginning numerical models were applied. The so called Mine Model, a FEM-model of the mine area and its surroundings, was set up by John Gale (Ohlsson et al, 1989) and is still used in a refined version in the final phase of the Stripa research program.

The Site Characterisation and Validation (SCV) Project is a major effort to investigate a rock volume by different methods, to analyse the data and to predict flow and transport to an excavated drift in the examined rock volume. One of the objectives of the project is to apply Discrete Fracture Flow (DFF) models and validate their use. Modelling is made by three different groups with different approaches: AEA Harwell (Herbert et al), Golder Associates (Dershowitz et al) and Lawrence Berkeley Laboratory (Long et al) and with conventional FEM-modelling as a reference (Gale). Of these, the two first groups make forward modelling based on analyses of fracture mapping, hydraulic tests, geophysical data etc. The LBL approach is different since they use an inverse technique, simulated annealing, that automatically calibrates the model to hydraulic cross-hole data (Long et al, 1990)

The SCV modelling effort is right now run more than half way through. The DFF-approach has proven useful and feasible for the SCV-drift experiment, and the experience has been possible to implement in the Äspö project.

Modelling for the Äspö Hard Rock Laboratory

Hydraulic modelling has been a vital part of the project from the very beginning. It is also reflected in the main goals, that flow and transport modelling shall be successfully applied before it is over.

Initially, when very little field data were available some generic modelling of the lay-out (Axelsson et al, 1987) and the saline interface under the island (Hemström and Svensson, 1988) was made. The latter made use of a stochastic continuum approach, that later was pursued all the way to the final site-scale model of the drawdowns and inflows to the laboratory tunnel.

A major part of our work has been the analysis and reduction of field data to model structure and parametres. A great effort has been put in finding correlations between geological, geophysical and hydrological features. The results are, however, not too good, and the main conclusion is that the great inhomogeneity makes the correlation weak. The inhomogeneity also implies that different conductivity distributions are obtained in different scales. A large effort has also been put into transient interference pumptests in order to define the geometry and properties of the main conductors in the laboratory volume.

The first site specific numerical models were based on field data from Äspö and three surrounding areas which were involved in investigations for the site selection. These were still somewhat generic and concerned mainly the hydrologic influence from the laboratory.

In the next stage an abundance of field data were available. This meant that a FEM-model and a stochastic continuum model could be calibrated to several cross-hole tests and used to predict drawdowns and flows at a long-term pump test. From this excercise we conceived that the conceptual model needed improvement, and that the conductivity distribution of the cells in the stochastic continuum should be better defined.

The effective hydraulic conductivity was studied in a DFF-model, where data from fracture mapping and hydraulic tests were put in. However, the results were not conclusive since a substantial part of the modelled 50m blocks were not connected (Axelsson et al, 1990). For the laboratory model an empirical distribution based on test data was used. Finally a laboratory model based on three years of investigations was set up (Svensson, 1991). It is a stochastic continuum finite difference model calibrated towards several cross-hole tests. With this model the predictions of what will happen when the tunnel is excavated are made (Wikberg et al, 1991).

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Spent Fuel – A Matter of Waste, Hard to Dissolve

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Spent fuel characteristics

Uranium dioxide is a ceramic material and when used as reactor fuel, it has been sintered into cylindrical pellets. However, after irradiation, the physical appearance of the pellet has been altered. Due to thermal stresses, the pellet is cracked radially as well as circumferentially. After higher burnup, the build-up of transuranium elements, particularly fissile plutonium, in the outer rim of the fuel leads to an increased fission rate in that region. This is manifested as higher porosity and higher concentrations of fissions products as well as alpha emitters at the fuel rim. Thus, this region has an increased surface area, as well as an increased radioactivity. It is therefore reasonable to assume that, when contacted with water, the rim is more reactive than the rest of the fuel and that any corrosion attack should be most manifested in this region. This is also confirmed experimentally, where a further increased porosity has been found at the rim after prolonged exposure to water. Other parts of the fuel show no signs of corrosion, which is not unexpected, considering the very low rate at which spent nuclear fuel corrode in groundwater.

Spent fuel corrosion

Uranium dioxide fuel has been chosen as light water reactor fuel among other things because of its excellent corrosion resistance in water. Under anoxic conditions, the uranium dioxide is stable. However, if oxygen is present, the transformation to U(VI) compounds will occur. Generally, U(VI) compounds have a much higher solubility than U(IV) compounds in neutral or slightly basic water solutions. While this corrosion of UO_2 proceeds, soluble elements may be released at the rate of corrosion. Sparingly soluble elements may, of course, be solubility limited and released to the near-field at a lower rate than determined by the fuel corrosion rate.

Experimental results, oxidizing conditions actinides

Experiments performed in Sweden and elsewhere have shown that the actinides rapidly attain constant concentrations. For U the steady state concentrations for oxic conditions in groundwater are in the range 5 to 50 nM. The corresponding value for Pu is about 0.5 nM after prolonged exposure. For Np, only a few measurements have been performed so far, but available data indicate level comparable to what is found for Pu, i e about 1 nM.

Cesium

Cesium segregates under irradiation from the fuel gains and grain boundaries and a fraction of the inventory, typically c. 1 %, migrates to the gap between the fuel pellet and the cladding hull. This fraction is rapidly released when the fuel is contacted with water. After this initial release, the release rate is considerably slower and, within the experimental time frame, decreases with time.

Strontium

Strontium is believed to remain within the fuel grains throughout the irradiation cycle. However, at this point, some segregation to grain boundaries cannot be excluded. Certain observation in the experiments seem to indicate some segregation. However, this has not been confirmed by observations of the fuel itself. Lacking this confirmation, it is assumed that all the strontium released is associated with corrosion or alteration of the fuel grains or grain boundaries. After prolonged contact with groundwater (several years), the fraction release rate of strontium is in the range of 10^{-7} per day of the total strontium inventory. This is then the upper limit for the fuel corrosion rate, assuming that all the strontium is released through oxidative alteration of the fuel pellet.

Experimental results, reducing conditions

The conditions in the repository are expected to be reducing, i e completely oxygen free. Under these conditions, there is no supply of oxidants externally and, as was mentioned above, the UO_2 fuel will be stable and only subject to chemical dissolution. Under the conditions at hand in the repository, this is an extremely slow process and the fuel will remain as deposited virtually for ever. However, due to the radiation field, primary α- and ß-radiation, radiolytic decomposition of the water may result in locally oxidizing conditions at the fuel surface and, hence, some potential for oxidative dissolution of the fuel. Spent fuel alteration under reducing condition has also been studied in the laboratory. The results are significantly different from what is obtained under oxidizing conditions. The steady state uranium concentrations drop at least three orders of magnitude to below the current detection limit for the analyses. A drop in plutonium concentration to below the detection limit is also noticed. However, the influence on the plutonium concentrations is probably less dramatic than what was the case for uranium. If the fuel matrix solubility is controlling the plutonium release, as would be expected for reducing conditions, the drop in plutonium concentration would be one to two orders of magnitude.

The influence of the reducing conditions on the strontium release rate is a reduction of about a factor of ten. This corresponds to a fractional release rate of about 10^{-8} per day of the total strontium inventory. At present, it is still unclear if this corresponds the release from areas enriched in strontium or if this is an actual measure of the oxidative effect of radiolysis from fresh irradiated fuel. If it is release from segregations, it is not connected to the fuel matrix alteration, which must then be lower than indicated by the strontium release. Even if there is a contribution from segregated strontium, the rates measured under reducing conditions give an upper limit for the possible effect of radiolysis on the fuel alteration.

Conclusions

Generally, the results from the experimental studies show that the fuel will last for a very long time. In the most pessimistic case, at least 5 million years with canister failure after 1000 years. In a more realistic case with pessimistic assumptions regarding the rate of radiolytic oxidation, at least 50 million years. In the case when radiolytic effects can be neglected, the fuel will last for ever with a minimum of release of radioactivity.

How Can We Provide and Demonstrate Safety?

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Key questions in developing disposal facilities

Provision and demonstration of safety are two key technical issues which govern approaches worldwide to the planning and implementation of radioactive waste disposal. A third important task, which is closely related to these but which goes beyond purely technical considerations, is to present our work to a broad audience in an understandable way which can encourage the public consensus needed to achieve acceptance of disposal facilities. Today, I will concentrate on technical questions and try to summarize the principal features of safety systems in waste disposal and to highlight the unusually intensive efforts which are devoted in our field to providing a transparent and convincing demonstration of achievable safety levels.

Strict requirements on safety for very long times

For many years there has been a high public awareness of and technical interest in the potential hazards of radiation. Attitudes have been based partly on the early experiences of military applications and partly are rooted in current widespread reservations or worries with respect to major new technologies such as nuclear power production. One result of these attitudes has been the setting of very strict standards for radiation protection. In few, if any, areas of toxicology are acceptable exposures to man so far below natural levels of occurrence or below those levels clearly shown to be hazardous to health. In radioactive waste disposal, typical dose limits are around 0.1 mSv/year which is not only far below exposures due to natural radiation but even below the variations in such exposures caused by differences in our living habits and locations. In radioactive waste disposal, a further unusually strict requirement is that the very low allowable dose or risk limits must be shown to be adhered to over extremely long time periods. For high-level waste disposal, the timescales considered in analyses of safety range **upwards** from 10 000 years. The explicit consideration of such timescales is not a consequence of the known long hazardous lifetimes (some chemical wastes are permanently toxic), but is rather a specific new feature which has been introduced into the radioactive waste disposal field – and will certainly spread to safety analyses of other technologies.

Safety based on confinement by multiple-barrier systems

To be balanced against the above-mentioned demanding requirements on safety are various characteristics of radioactive wastes which can greatly ease the problems of implementing their safe disposal. In particular, the wastes are mostly confined (for example inside the spent-fuel matrix) from the moment of their production onwards, their physical behaviour is well understood, their volumes are relatively small, and consequently the specific costs for disposal can be high without unacceptable adverse financial effects on the nuclear fuel cycle.

The common principle for safe disposal of high-level radioactive wastes involves confinement and isolation from the environment for very long periods which allow decay of most radioactivity. Thereafter, releases must never occur at rates which could lead to unacceptable radionuclide concentrations in the biosphere. For high-level and long-lived wastes, the generally accepted method of isolation today involves disposal in mined repository systems in continental geologic formations. The repositories are designed to provide safety by passive means over long times without any necessity for monitoring or maintenance.

The isolation is based on a system of natural and engineered safety barriers which are partly complementary and partly redundant. The specific choice of these barriers and their relative contributions to overall system safety can vary. In Swedish concepts, the waste matrix is the uranium oxide of the spent-fuel, the engineered barriers are a copper canister and a bentonite backfill, the geologic barrier is the granitic bedrock. The pioneering work on waste disposal carried out in Sweden during the last 15 years has led to this concept becoming something of a standard internationally. In some other countries, however, glass is the waste matrix, corrosion-resistant alloys or steel form the canister material, local clays or cement are used as backfill and a large variety of rock types are considered. The specific configuration chosen for the safety barrier concept will depend upon many factors, such as the technical experience and capabilities available in a country or the available range of geologic media at appropriate depths and in potentially suitable siting areas. Over the last 10 years, a range of diverse repository safety analyses produced in various countries – with Sweden amongst those at the top of the list – have illustrated that extremely high levels of safety are indeed achievable for deep geologic repositories.

A further important consideration governing the choice of repository system is, however, the ameanability of the chosen system to a convincing demonstration that the high level of safety in the design will, in fact, be achieved in practice. This key issue has been the driving force behind many years of development efforts in the planning of radioactive waste disposal.

Demonstration of safety is based on predictive modelling

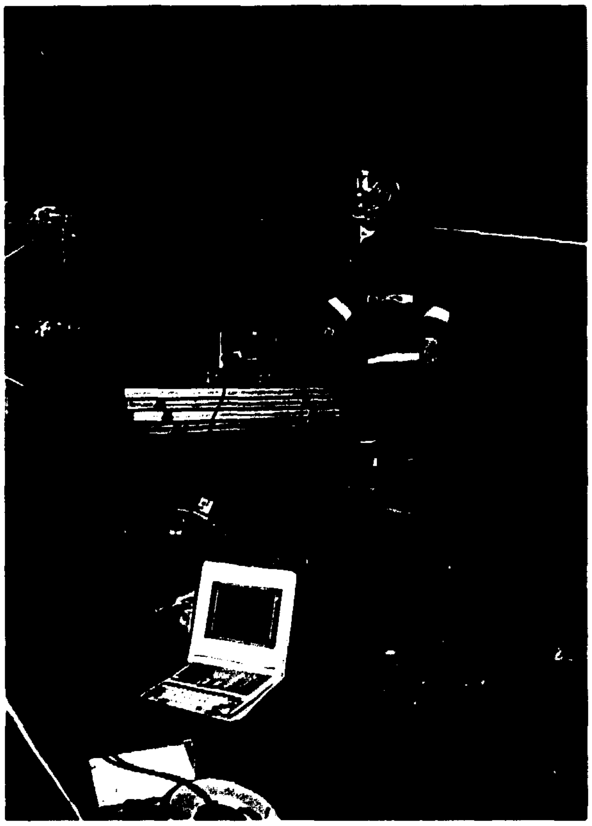
Clearly, the long timescales involved in judging the safety of waste repositories rule out a demonstration by direct observation. Accordingly, over more than 15 years the discipline of safety analysis or performance assessment has been developed, with intensive interaction at an international level. Safety analyses require a sufficiently correct and complete conceptual understanding of the physical and chemical processes influencing system components, a quantitative formulation of this understanding in so-called calculational models, and the exercise of these models to predict actual or bounding behaviour of the repository system over long time periods.

The current technical consensus on the status of such modelling has been recently summarized in a joint statement by experts of the OECD–NEA, the IAEA and the CEC, entitled "Disposal of radioactive waste: Can long-term safety be evaluated?". This document confirms the collective opinion that adequate safety assessment methodology are available to evaluate the potential long-term impacts of a repository and to provide a suitable decision basis for repository acceptability. Emphasis is, however, placed upon the continuing need to increase the confidence of scientists, regulators and decision makers in the validity of the models upon which the safety analyses are based.

Data from the laboratory and the field enhance confidence in modelling

How can we be confident that our models correctly predict future repository performance – or at least that they do not underpredict potential consequences of radionuclide releases? A rigorous proof will seldom or never be possible. Instead, we must build up confidence by comparing the predictions of our models with measurements or with observations; these should be as many and as varied as possible whilst still retaining their relevance to the repository situation. This leads to experimental programmes in the laboratory on, for example, corrosion, rock/water interactions, and mass transport in buffer materials and rocks. Lars Werme has spoken of specific work on fuel dissolution. Further valuable data for comparison with model predictions can be obtained from the observation of natural analogue systems, as will be described by Jean-Claude Petit.

Some of the most critical data for assessing model validity must, however, be gathered in the underground. The earlier talks in this Symposium have illustrated the pioneering work which Sweden has led in this area in the scope of the International Stripa Project. It is a pleasure to observe how such work will be carried forward at the new Äspö site, where the opportunity to excavate at a virgin site allows new degrees of freedom in planning and execution of validation experiments. The technical programme at Äspö goes beyond such purely scientific experiments, however, and takes a significant step forward into the physical demonstration of the feasibility of disposal technology. This is a valuable additional, confidence-enhancing programme element from which not only Sweden, but also the entire international waste disposal community will certainly profit.



Various kinds of investigations are conducted in the access ramp in order to improve the descriptions of the rock.

Natural Analogues: What Can Be Learned?

Jean-Claude Petit, Dr, Geochemistry Specialist
Commissariat à l'Energie Atomique, France

The long-term safety of a radioactive waste disposal in a geological formation depends on the capacity of the different barriers, both technological and natural, to retard and limit the release of radioelements, which may eventually migrate towards human beings. The evaluation of this capacity can be difficult, because it is linked to complex and interdependent processes, which must be analysed over large time and dimension scales (typically more than 10.000 years and about one cubic kilometer). In addition, it should be done for radioelements normally absent from natural systems, such as plutonium, neptunium and americium. It has been recognized very quickly that long-term extrapolations concerning the safety of a radioactive waste disposal cannot be satisfactorily made on the sole basis of short-term laboratory investigations. Most nuclear countries have hence developed an hybrid scientific approach relying on a combination of laboratory and on-site experiments, modelling and natural analogues.

In this conference, it is firstly shown that the principal role of natural analogues in the research process is to increase the confidence that one may have that our current scientific knowledge is correct and that our predictions are valid. Notwithstanding our trust in experimental science, justified by its exceptional achievements, the use of natural analogues is based on a kind of "Nature-knows-best" principle which assumes that Nature should remain the ultimate arbiter of truth. It is then suggested that natural analogues help building a common understanding of what is likely to happen in a repository and to improve communication amongst specialists of varied disciplines as well as between scientists and non-scientists, thus allowing the formation of a consensus. Secondly, instances are given to illuminate the actual use of natural analogues for some relevant issues of the Swedish radioactive waste disposal concept: 1. What assurance do we have that the confinement of radioelements in geological formations is feasible? 2. What is the long-term durability of the spent fuel and of the copper container upon aqueous corrosion? 3. What are the processes that control the migration and/or retention (or even immobilisation) of radioelements in granite? For all these issues natural analogues have proved in recent years to offer valuable outputs for the development of conceptual models, the acquisition of data, the identification of boundary conditions and finally the validation of models.

Human Intrusion – a Threat or an Asset?

Claes Thegerström, Mr, Project Manager – Siting
Swedish Nuclear Fuel and Waste Management Co,
Sweden
(Previously Project Manager OECD/NEA, Paris)

It has been internationally recognised that the generation(s) benefitting from nuclear power and generating radioactive waste should:

– isolate the wastes from the human environment over long time-scales without relying on future generations to maintain the integrity of the disposal system, or imposing upon them significant constraints due to the existence of the repository (RESPONSIBILITY TO FUTURE GENERATIONS); and

– ensure the long-term radiological protection of humans and the environment in accordance with current internationally agreed radiation protection principles (RADIOLOGICAL SAFETY).

In the evaluation of radioactive waste disposal systems there is a need to also consider potential future human actions at the disposal site. Such actions could be of two types:

– **Intentional**, for example some future generation may decide to retrieve the waste because they want to make productive use of it.

– **Unintentional**, for example if society has partly or completely forgotten about the disposed waste, somebody may drill deep into the bedrock and destroy some of the barriers or even bring some waste to the surface.

Compared to most natural systems, such as the scandinavian crystalline rock formations, human beings and societies are highly dynamic and unpredictable. This is precisely why it is considered that the safety of a repository should not, in the long term, depend upon active human surveillance or intervention. On the other hand, some argue that it would be a positive value if future generations – should they so wish and consciously decide – have the possibility to retrieve the waste. Thus **intentional** intrusion should not be made unnecessarily difficult, as long as the objective of confinement and passive isolation of the waste can be fulfilled.

The likelihood of **unintentional** intrusion has to be kept as low as reasonably possible. The main means to fulfil this objective is to effectively **confine** (in a canister) and **isolate** (in a deep repository) the waste, so that any unintentional intrusion will be highly unlikely. In addition, well-organised and clear records should be kept about the waste and the repository.

In my talk, I will discuss the various aspects of human intrusion. I will indicate that our generation can deal with this issue in a responsible way even though we cannot predict what will happen in the future with human beings and society.

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