Radioactive Waste Management

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Geological Repositories: Political and Technical Progress

Workshop Proceedings
Stockholm, Sweden
7-10 December 2003

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Hosted by
Svensk Kärnbränslehantering AB (SKB)

Jointly organised by
Svensk Kärnbränslehantering AB (SKB)
International Atomic Energy Agency (IAEA)
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NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1st February 1958 under the name of the OEEC European Nuclear Energy Agency. It received its present designation on 20th April 1972, when Japan became its first non-European full member. NEA membership today consists of 28 OECD member countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Portugal, Republic of Korea, the Slovak Republic, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The Commission of the European Communities also takes part in the work of the Agency.

The mission of the NEA is:

- to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes, as well as
- to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

FOREWORD

In November 1999 an international conference was held in Denver, Colorado (USA) on global efforts to dispose of radioactive materials in geological repositories. The conference was attended by 240 high-level decision makers from 20 countries. The second conference in the series was held in Stockholm on 8-10 December 2003 in order to examine progress made in both political and technical areas since the 1999 conference in Denver.

The 2003 conference in Stockholm reviewed global progress made as well as ongoing activities to develop geological repositories. It also served to strengthen international co-operation on waste management and disposal issues.

The Stockholm International Conference on Geological Repositories: Political and Technical Progress brought together more than 200 delegates from over 25 countries as well as international organisations. It was organised by Svensk Kärnbränslehantering AB (Swedish Nuclear Fuel Supply Company – SKB) and held in co-operation with the International Atomic Energy Agency (IAEA), the OECD Nuclear Energy Agency (OECD/NEA), the European Commission (EC) and the International Association for Environmentally Safe Disposal of Radioactive Materials (EDRAM).

The Programme Committee consisted of the following persons: Torsten Eng, OECD/NEA (chair); Alexander Erastov, Minatom; Renee Jackson, US DOE; Claudio Pescatore, OECD/NEA; Jan-Marie Potier, IAEA; Hans Riotte, OECD/NEA; Katsuaki Shibata, NUMO; Jacques Tamborini, Andra; and Derek Taylor, EC. Session organisers were: Saida Engström, SKB; Claudio Pescatore, OECD/NEA; Jan-Marie Potier, IAEA; Kirsti-Liisa Sjöblom, STUK; and Magnus Westerlind, SKI. The Conference Manager at SKB was Björn Strokirk.

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INTRODUCTORY SESSION

GEOLOGICAL REPOSITORIES: POLITICAL AND TECHNICAL PROGRESS

Claes Thegerström
President, SKB, Sweden

Ladies and gentlemen, daylight has finally come to Stockholm and I have the honour of welcoming you to, what will hopefully be, a rewarding conference on an important subject. Safe handling of nuclear waste is, as we all know, one of the key issues for long-term protection of the environment and for the use of nuclear energy.

Four years have now passed since the previous conference, of a similar type, was held in Denver, Colorado, U.S.A. I would like to start my address by looking back over those four years, and attempt to summarise what are, in my opinion, the most important events and trends of those years.

I think the trend towards *increased consensus* is clear:

- I see an increased consensus that what is required is *deep geological deposits*. There are certainly different opinions as to how long spent nuclear fuel or reprocessed nuclear fuel should be kept in intermediate storage. But I think there is increased consensus that, in the end, long term safety has to be obtained through deep geologic repositories. Those who work with advanced reprocessing and transmutation also stress that even in such a system, certain long-lived waste must be stored in deep geological formations.
- I see increased consensus on the *multi-barrier principle*. Different countries have different geological requirements, which in turn demand varying technical solutions. Despite this, there is an increased consensus that robust safety is a matter of deep geological storage, reinforced with several technical and natural barriers. The area will be illustrated further during Session 1 tomorrow.
- I see increased consensus on the importance of the *involvement of stakeholders*. Dialogue and transparency is necessary for a fair and successful decision process. This may be as much of an important and difficult task as the questions concerning geology and technology.
- I see increased consensus that *each country should take care of its own waste*. If one chooses to co-operate with other countries, this should be on a voluntary basis. I would like to emphasise here the IAEA's "Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management". It is there stressed that radioactive waste, provided that it is compatible with safety, should be put into final storage in the country in which it originated. In this convention it is further said that "any State has the right to ban import into its territory of foreign spent fuel and radioactive waste". The Convention came into force in June 2001.

- I see increased consensus that focused *efforts for implementation of long term safe disposal should not be postponed to future generations*. Even with present nuclear waste management plans, the work from construction of a nuclear reactor to a closed final repository will involve three generations.

- I see increased consensus, and I value it. For this reason I would like to emphasise the importance of the international exchange of information in all forms, not least during this conference. I am very happy that you have been able to give priority to a trip to Stockholm in these busy times, just before Christmas.

My opinion is thus, that more people are pulling in the same direction, which means that development is gathering pace.

I see positive trends and increased efforts. I would like to highlight the development of some crucial decisions on nuclear waste management. I must first of all stress the principal decision on deep disposal in Olkiluoto which had the support of the Finnish Parliament in 2001, the voting being 159 against 3. An important and very encouraging decision. The American site decision on Yucca Mountain should also be mentioned, as well as the Swedish decisions on site investigations in Forsmark and Oskarshamn – two decisions which have been taken with strong local support. The ongoing construction of a rock laboratory in France is a further example of progress.

But there have also been some drawbacks which need to be mentioned: Wellenberg in Switzerland, Gorleben in Germany, and Scanzano Jonico in Italy very recently. They all show, as I have just said, that stakeholder involvement, public consultation, transparency and openness are at least as difficult and important questions as the technical and geological questions that face us.

I see good progress in my own country. I started in 1974, as a young scientist, to work within the area of environmental sciences and nuclear waste management. I have had the pleasure of being part of the steady progress that has been made in our country and many other countries around the world.

Starting with basic research and conceptualisation of the KBS-system in the early 1980s in our country, work has progressed gradually through development of new technologies to present day in active demonstration in a full scale laboratory for encapsulation and an underground laboratory for RD&D on disposal technology.

Within the next few years we plan to be able to start the licensing of the deep disposal system in Sweden. High scientific quality has to continue to form the basis for our work combined with transparent and open interaction with all stakeholders, not least the communities and local population directly concerned with the siting issues of which you may hear more about in tomorrow's sessions.

I would therefore like to round off my introductory address by offering all of you a very warm welcome. I am convinced that we will hear interesting lectures and worthwhile discussions. I hope also, that you will enjoy being in the City of Stockholm, despite the winter darkness, and that we will have the pleasure of having you here again as our guests. Thank you and a warm welcome to the Stockholm International Conference on Geological Repositories, Political and Technical Progress. I wish you all a fruitful meeting.

GEOLOGICAL REPOSITORIES: THE LAST NUCLEAR FRONTIER

Mohamed ElBaradei
Director-General, IAEA

Few issues play so central a role in the public acceptance of nuclear technologies as the management and disposal of spent fuel and radioactive waste. In the current climate, geologic repositories have come to be viewed not as one option among many for completing the nuclear fuel cycle, but as the *only* sustainable solution achievable in the near term. But despite a longstanding agreement among experts that geologic disposal may be safe, technologically feasible and environmentally sound, a large part of the general public remains sceptical. It is in this context that I would like to share a few of my views on the challenges we face and how the International Atomic Energy Agency hopes to help in furthering progress.

1. Building public confidence: A key challenge

Many IAEA Member States consider deep underground disposal in suitable geological media to be the preferred option for the long term management of radioactive waste – repositories designed with a combination of natural barriers and engineered systems to provide waste containment. During the past decade or so, geologic disposal concepts have evolved considerably, enhancing our understanding of how deep geological systems will function over very long periods of time as well as our confidence in the safety of disposal. This progress is primarily due to the extensive work carried out in national programmes, often assisted and guided by the exchange of information at international forums such as this conference.

Since the 1999 Denver Conference on Geologic Repositories, a number of countries have made significant progress in the implementation of site selection programmes for deep repositories. Although, as expected, no geologic repository for high-level waste is yet in operation, repository projects in Finland, Sweden and the United States have advanced to a stage at which, technically speaking, decisions may be made to begin construction. In Europe, the European Commission is proposing a directive that would urge its Member States to decide on repository sites by 2008 and to have a site operational by 2018 – although it appears that some flexibility may be introduced into these deadlines.

Despite steady technological development, the greatest challenge to repository development is how to build confidence in geologic disposal among a wider interested and concerned audience. Consequently, national programmes, as well as international efforts, must give increasing focus not only to the scientific and technical issues, but also to societal, political, legal and economic aspects – many of which are country specific – that influence public perceptions of the safety and feasibility of implementing the geologic disposal concept. Some national programmes, such as that of Sweden, have chosen a staged approach to repository development, which allows more time and flexibility in decision making and increases public awareness of the implementation process. At recent IAEA conferences – such as the Córdoba Conference on the Safety of Radioactive Waste Management in March 2000, and the Vienna Conference on Issues and Trends in Radioactive Waste Management last December – the general consensus emerging from high-level panel discussions is that confidence building is the key remaining issue to facilitate the decision-making progress in geologic repository projects.

2. Current issues: Extended storage, retrievability and safeguards

Recent waste disposal discussions have witnessed the emergence of a number of new issues.

In June, at another IAEA conference in Vienna on the *Storage of Spent Fuel from Power Reactors*, a number of Agency Member States announced that they are considering the extension of spent fuel storage times to 100 years and longer. This approach is emerging for various reasons, including delays in repository disposal programmes; lack of resources; uncertainties about whether to consider spent fuel a waste or a resource; the lack of public acceptance of disposal; and the lack of political will for moving forward on repository siting and construction. If the new initiatives for "very long term storage" persist, they will require more advanced storage technologies, new assessments of their safety implications, considerable extensions of storage licences for existing facilities, and long term institutional frameworks. The latter factor – the need to maintain institutional controls – has long been considered a key safety issue with long term surface storage, because human interactions are inherently more vulnerable to failure than passive physical barriers, and institutional integrity is difficult to guarantee over the very long term.

Another identifiable trend is the increasing general acceptance of the idea that retrievability and reversibility should be built into repository designs, to increase flexibility by keeping options open for future societies, and to enable countries to make use of subsequent technical advances in waste management and materials technologies. However, there has been little research, and no experience, relevant to how such retrieval provisions would affect the design and development of geologic repositories. Preliminary safety and security considerations would indicate that some potential retrieval provisions – such as delaying the placement of repository isolation barriers – could have negative impacts.

Geologic repositories, after closure, are expected to achieve adequate long term safety without the need for reliance on continuing institutional controls. However, the need to meet IAEA safeguards requirements is likely to result in some long term monitoring and possibly other forms of institutional controls for disposal facilities, particularly those that contain spent fuel subject to safeguards. These controls must be sufficiently robust to address non-proliferation and security concerns, in a manner that enhances public confidence – and they must be adequate to ensure stability well into the future. The IAEA is currently developing site-specific safeguards requirements and long term surveillance and monitoring approaches.

3. International co-operation on waste management and disposal issues

While the procedures and methods adopted for geologic disposal will continue to be country and programme specific, it is clear that international co-operation – on exchange of information, establishment of safety standards and conventions and the development of new technological approaches – may substantially enhance the effectiveness of repository development.

The IAEA continues to revise its body of safety standards and to develop new standards in needed areas. Of particular relevance to this meeting are the requirements covering “geologic disposal of radioactive waste”, designed to ensure that geologic repositories are safely sited, designed, operated and closed. We expect final approval of the document next year. Worldwide acceptance and implementation of these safety requirements as a global reference for protecting people and the environment will contribute to building confidence in radioactive waste management.

These safety standards also are expected to provide the basic reference point for international peer review teams in the evaluation of waste disposal programmes, concepts and facilities. Recent reviews, such as those carried out in the Republic of Korea and the United States of America under the Agency’s Waste Management Assessment and Technical Review Programme, have been helpful in improving the technical approach to repository development and supporting the approval of repository programmes.

The *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management* provides a framework in which Member States commit to achieving and maintaining a high level of safety worldwide in this area. Last month, the first review meeting of the *Joint Convention* was held in Vienna. Contracting Parties concluded that the review process mechanism had already contributed to improving the safety of spent fuel and radioactive waste management – through countries’ self-assessments of their national programmes, the identification and dissemination of ‘good practices’ in national reports, and the discussions of weaknesses and gaps in national approaches during the review meeting itself.

The IAEA will continue to encourage international co-operation on all fronts related to waste disposal and the development of geologic repositories. In recent years, we have used technical co-operation projects, co-ordinated research projects and extra-budgetary funding from several Member States to establish what we call the “Network of Centres of Excellence”, which use underground research facilities in multiple countries to train and build capacity on geologic disposal technologies – particularly for Member States with less developed management programmes for high-level waste.

A relevant initiative that the IAEA has begun to study recently is the feasibility and merit of greater international co-operation on proliferation-sensitive portions of the nuclear fuel cycle – including consideration of multinational approaches to the management and disposal of spent fuel and radioactive waste. Not all countries have the appropriate conditions for geologic disposal – and, for many countries with small nuclear programmes for electricity generation or for research, the financial and human resource investment required for research, construction and operation of a geologic repository are daunting. Clearly, for many countries, the acceptance of externally generated waste would not be consistent with current national policies, which remain at the discretion of each State; however, some countries with the appropriate geology and infrastructure might welcome the associated economic and other incentives. Overall, considerable economic, safety, security and non-proliferation advantages could accrue from international co-operation on the construction and operation of nuclear fuel cycle facilities.

Conclusion

The challenges we face in some ways make up a “Catch 22” situation: on the one hand, the lack of public confidence in the management and disposal of spent fuel and high-level radioactive waste hampers the effectiveness and efficiency of national efforts to construct geologic repositories; on the other hand, in order to substantially increase public confidence, the nuclear community must have one or more operational geologic repositories in which waste disposal technologies may be successfully demonstrated. But despite this “Catch 22”, we may continue to make progress – and it is my view that, once the first country or countries have succeeded in placing a geologic repository in service, the road ahead for other countries will be made much easier. In the sense, all members of the international community have a stake in the success of those national programmes that are the most advanced.

I would like to conclude by expressing my appreciation to the Government of Sweden and to the Swedish Radioactive Waste Management Organization for convening this important conference. We expect that it will provide a fruitful forum for policy makers and technical experts to stimulate an exchange of views on geologic disposal and to update each other on technological and other progress. I would also hope that the findings and recommendations of the conference would be conveyed to the Agency, to be incorporated as appropriate into our relevant programme of activities.

INTRODUCTION TO THE CONFERENCE
FROM THE PERSPECTIVE OF THE OECD/NEA

Luis Echávarri
Director-General, OECD/NEA

Preamble

Four years ago, the United States Department of Energy (on initiative of the Energy Secretary Bill Richardson) convened in Denver an "International Conference on Geological Repositories for Disposal of Nuclear Materials". Attending and participating in the Conference were high-level government representatives from more than 20 countries. The Conference highlighted the global progress made on the management of nuclear materials and waste, and provided what is now proving to be an ongoing, high-level forum to discuss activities related to the development of geologic repositories and to addressing policy and decision making in this field. We are grateful that such opportunity was created and agreed to sponsor and co-organise this initiative, as it is important that a high-level, periodic a review of current national perspectives receive wide attention.

1. The perspective from the NEA

1.1 There is wide international agreement on engineered geologic disposal as an effective, feasible and promising waste management end-point

Radioactive waste is associated with all phases of the nuclear fuel cycle and with the use of radioactive materials in industrial, medical, military and research applications. All such waste must be managed safely. The most hazardous and long-lived waste, such as spent nuclear fuel and waste from fuel reprocessing, must be contained and isolated from humans and the environment for many thousands of years.

There is international agreement, now formalised in the *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management* that solutions are required that do not result in undue burden on future generations and whose reasonably predictable impacts are not greater than those permitted for the current generation [1]. In the spirit of the "The Rio Declaration" [2], the international community, and certainly the OECD countries, are adhering to the principle that those who generate the waste – as well as those who benefit of the primary sources – should also provide for the appropriate management means [3]. Amongst these means there is, at national level, the provision of appropriate policy and regulatory frameworks and relevant institutions.

Disposal of long-lived radioactive waste in engineered facilities, or repositories, located deep underground in suitable geological formations, that are ultimately closed and sealed, is being widely investigated and developed world wide as an option in order to protect humans and the environment both now and in the future. Repository programmes are underway or planned in such countries as

Belgium, China, Finland, France, Germany, Hungary, Japan, the Russian Federation, Sweden, Switzerland, and the United States, and I am sure I am missing others.

From our OECD/NEA studies, engineered geologic disposal is seen as a radioactive waste management end-point providing security and safety in a manner that does not necessarily require monitoring, maintenance and institutional controls and therefore is sustainable [4]. Engineered geologic disposal is also known to be technically feasible [5] and acceptable from an ethical and environmental viewpoint [3]. Finally; the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management confirms that engineered geologic disposal is accepted from an international legal perspective [1].

1.2 There is more to geologic disposal than just "geology" as far as safety is concerned

I have insisted on the word "engineered", besides "geologic disposal", for we want to recall that there is much more to disposal than geology. An engineered repository is not a geological "dump". This management option relies very much on the multi-barrier concept, whereby safety is assured by the concerted action of both the natural and man-made barriers that provide a number of mutually re-enforcing, and in some cases, redundant, safety functions. A large amount of studies have focused and continue to focus on:

- the quality of the waste matrix itself – such as glass or the irradiated fuel pellets – to ensure that they have an intrinsically high durability;
- long-lived containers that would, at the very minimum, help the repository go through the initial phases where the disturbance to the natural environment would be highest. In some designs, containers would be effective containment barriers for hundreds of thousands of years;
- the system of buffers and seals, that would assure a favourable hydrological and chemical environment, and
- emplacing these barriers in a way that would not impair long-term safety while still providing a certain degree of flexibility in timing the closure of a repository.

The repository depth and other engineered features, such as the compartmentalisation that is used in some waste emplacement designs, are additional pillars of safety.

Currently, large sums are being spent on engineering aspects in development work both above and below ground. Here in Sweden, the spent fuel encapsulation facility at Oskarshamn is an example of such investment.

The OECD/NEA, I am proud to say, is well placed to talk about safety, we are one of the most important providers of independent peer reviews of national, waste disposal studies. In the past two years we have organised, on request by the member governments, the peer review of the SAFIR-2 study in Belgium, the *Dossier Argile 2001* in France, the Safety Report of the Repository in Opalinus Clay in Switzerland.

1.3 The technical challenges are being met successfully

In general, the experience not only of international but also of national reviews, shows that a consensus exists today among experts in various countries that sites may be properly identified and characterised, that repositories may be designed so that no short-term detriment to populations will result from the waste disposal, and that an acceptable level of safety is provided for times far into the future. The technical challenges are thus being met. The international agencies such as the NEA, are giving an important to these developments. The fora provided by the NEA provide a valuable mechanism:

- for dialogue across several boundaries, small-large programmes, regulators-implementers, etc., and
- for common projects, allowing the state of the art to advance and reaching of shared views on waste-management strategic aspects.

A paper on the modern concept of the safety case for disposal, which was developed at the NEA, will be given tomorrow (Claudio Pescatore, Session 1) as well on practical aspects on how to handle time scales in safety assessments (Peter de Preter, Session 1).

1.4 Current main challenges lie in the societal arena. These challenges are also being met, but require important adaptation to evolving societal contexts

In 1999, at the Denver Conference, in the heel of a few setbacks to geologic disposal, we could see that, perhaps, the most important challenge to geologic disposal comes from meeting societal demands.

The context of long-term radioactive waste management is being shaped by the rapid changes that are occurring in modern society. These require new forms of risk governance in dealing with hazardous activities, including decision-making processes that involve a large number of stakeholders and, therefore, new forms of dialogue. The new dynamics of dialogue and decision-making process has been characterised as a shift from a more traditional "decide, announce and defend" model, focused on technical assurance, to one of "engage, interact and co-operate", for which both technical assurance and quality of the decision-making process are of comparable importance to a constructive outcome. Consequently, the scientific and engineering aspects of waste management safety are no longer of exclusive importance. Organisational ability to communicate and to adapt to the new context has emerged as a critical contributor to public confidence and decision making. The paper on the evolving image and role of the regulator, by Judith Melin later today, will show more clearly how institutions are adapting to this new environment. The paper by Yves Le Bars will do the same from an implementer viewpoint, I suspect.

1.5 There is a need for defining efficient but flexible decision-making procedures

In the new societal context, it has become clear that:

- any significant decisions regarding the long-term management of radioactive waste will be accompanied by a comprehensive public review with involvement of a diverse range of stakeholders;
- the public, and especially the local public, are not willing to commit irreversibly to technical choices on which they have insufficient familiarity and understanding; and
- any management options will take decades to be developed and implemented, which will involve stakeholders who have not yet been born.

Thus, a "decision" no longer means opting for, in one go and for all times, a complete package solution. Instead, a decision is one step in an overall, cautious process of examining and making choices that preserve the safety and well-being of the present generation and the coming ones while not needlessly depriving the latter of their right of choice. Consideration is thus increasingly being given to the better understanding of concepts such as "stepwise decision making" and "adaptive staging" in which the public, and especially the most affected local public, are meaningfully involved in the planning process.

The NEA is placing great attention to the issue of societal decision making. A paper on stepwise decision making developed within the context of the NEA Forum on Stakeholder Confidence will be presented tomorrow, as well as a paper on the general lessons learnt by the Forum (Session 2). The NEA Forum on Stakeholder Confidence is at the forefront of developments in these areas, and I invite you to listen to those two papers.

2. What are conclusions to be drawn for future challenges and for this conference?

Geologic disposal is a mature technology, based and embedded in exploration and mining technology. From a technical point of view, future developments will most probably be only incremental, evolutionary and almost calculable over the next decade. The world will change, however, much more rapidly and fundamentally. The "megatrends" of globalisation, deregulation, the firming-up of the global information society and the development of more pluralistic societies will lead to a drastically changed socio-economic and even cultural environment for waste disposal. This is happening in shorter time frames than envisaged for the opening of waste disposal facilities for long-lived waste in some countries. Waste management has to position itself in this changing environment.

Geologic disposal is a technical and social project over many decades. While the socio-political and administrative framework of modern societies seems to be well equipped to support long-lived institutions, there is limited experience with the planning and implementation of long-term projects. To make geologic disposal happen, a broader socio-political process is needed and the appropriate framework must be re-invented. To a large extent, this will challenge the classical, technically centred infrastructure "triangle" of implementers, regulators and decision-makers in waste management

Although the procedures and methods adopted will be nation- or programme-specific, they will be influenced by developments elsewhere. When the world becomes a global village, international co-operation becomes co-operation between neighbours. All national projects will influence each other, and the national programmes will be dependent from developments elsewhere. The development of procedures and methods, the training of staff and progress in repository development will be aided through the development of international contacts and the exchanging of experiences and viewpoints. International fora allowing cross-party dialogue and co-operative projects are thus likely to continue to play an important role in the future for all those involved in waste management.

Conclusion

To meet future challenges, effective communication is needed within the body of the experts and decision-makers from different national programmes, with different cultural settings and different constraints, across the "regulator-implementer boundary", and between experts and decision makers and the wider community.

The choice of the NEA is to foster this multi-faceted dialogue, confrontation – in some cases – and co-operation, in others, on neutral ground. It is in keeping with this spirit that we co-organised this Conference and we are glad to see you so numerous to review current national perspectives. Our NEA aim is to continue to strengthen international co-operation in the realisation of safe, secure and environmentally sound disposal of radioactive materials.

I would like to thank SKB, and its President Claes Thegerström for hosting this important conference, all the speakers that have accepted to share their views and experiences with us, the Mayor of Stockholm, Barry Andersson, for welcoming us as well as Mr. ElBaradei, IAEA, and State Secretary Claes Ånstrand.

I wish all of us a successful meeting.

REFERENCES

[1] IAEA, (1997), *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management,* INFCIRC/546, Vienna.

[2] In the spirit of "The Rio Declaration", A/CONF.151/26 (Vol. I), 12 August 1992, United Nations.

[3] NEA, (1995), *The Environmental and Ethical Basis of Geologic Disposal: A Collective Opinion of the NEA Radioactive Waste Management Committee,* OECD, Paris.

[4] NEA, (1999), *Geologic Disposal of Radioactive Waste: Review of Developments in the Last Decade,* OECD, Paris.

[5] NEA, (1999), *Progress Towards Geologic Disposal of Radioactive Waste: Where Do We Stand? An International Assessment,* OECD, Paris.

KEYNOTE ADDRESS

Claes Ånstrand
State Secretary, Ministry for Industry and Trade, Sweden

Dear Colleagues, Ladies and Gentlemen:

As a representative of the Swedish government I am pleased to get the opportunity to give the keynote address of this important conference on political and technical progress of geologic repositories.

The main theme of this conference is nuclear waste management. I would, however, like to start from a somewhat broader perspective and give some reflections on the importance of a safe, secure, efficient and environmental-friendly energy supply.

Energy is a key factor in promoting economic growth and sustainable development. At the same time, it is a great challenge to meet the sometimes conflicting goals of security of supply, environment and economic growth.

We all have a responsibility to implement the agreements reached at the Johannesburg World Summit on Sustainable Development. In a global perspective, substantial new investments will be needed to provide security of supply, to reduce growing energy-related greenhouse gas emissions and to overcome the problem of lack of access to electricity for more than a quarter of the world's population.

Let me underline that the establishment of free and open markets is fundamental for sustainable development. Markets, however, need to be provided with, and guided by, a relevant policy framework. Creating this framework is – of course – the main task of the political process.

Measures to increase renewables and to promote increased energy efficiency are also central in a strategy for sustainable development. The policy instruments that we use have to be cost effective. That is why Sweden, together with many other countries, is paying more and more attention to market-based instruments. Green certificates and emissions trading are two good examples.

International co-operation is one of the corner stones of the policy development. Today's conference is a good example of this! Events like this are very important to endorse mutual understanding between different stakeholders, countries and regions.

We, who are gathered here today, are representing various countries and organisations, and we all hold different views on the future energy scene. This is not least true for nuclear energy. Of course it is a matter for each country to decide on their nuclear programmes.

In Sweden, the role of nuclear energy has been highly debated for more than two decades. One reactor has been closed as a result of a political decision. The parliament has decided that the remaining 11 reactors shall be phased-out successively. However, no final date has been set for the close-down. At present, the government negotiates with the power industry. The purpose is to reach an agreement on a long-term and sustainable policy for the phasing-out of nuclear power and the continued realignment of the energy system.

Regardless of the future for nuclear energy, we have a responsibility for the management of nuclear waste.

In many aspects, nuclear energy is unique among the different sources of energy Nuclear energy generates a waste material which cannot, with today's available technologies, be destroyed or converted into harmless substances. Therefore nuclear policy has to involve waste management schemes taking full responsibility for future generations.

The international nuclear industry has been pioneering in responsible management of the very toxic waste. The results of 25 years of research and development programmes are very promising. They indicate that the highest environmental ambitions may be fulfilled without excessive costs. The technical solutions based on geologic repositories were unique when they were initiated. Today, however, other sectors are inspired by, and gain from, the development of nuclear waste management with deep geologic repositories.

The technology for capture and storage of the carbon dioxide generated from fossil fuels, has developed rapidly. The feasibility of deep geological storage of carbon dioxide separated from natural gas, is being verified in full industrial scale at the Sleipner gas field in Norway.

Sweden has recently established a new policy on mercury. Mercury is an extremely environmentally harmful element which cannot be accepted in products. Furthermore, waste containing mercury, shall be disposed of chemically stable in a deep geologic repository.

These are only a few examples of promising new technologies inspired by safety policies and technical development in the nuclear sector.

Principles for the management of spent nuclear fuel and radioactive waste have evolved over the years and have been discussed by the Swedish parliament. The allocation of responsibilities is reflected in the Swedish legislation. The principles may be summarised as follows:

1. the expenses for the disposal of spent nuclear fuel and nuclear waste are to be covered by fees on the production of energy that has resulted in these expenses;
2. it is the responsibility of the reactor owners to safely dispose of spent nuclear fuel and nuclear waste;
3. the State has the ultimate responsibility for spent nuclear fuel and nuclear waste, and
4. each country is to be responsible for the spent nuclear fuel and nuclear waste generated in that country. The disposal of spent nuclear fuel and nuclear waste from nuclear activities in another country may not occur in Sweden other than in an exceptional case.

The construction of a repository for final disposal of spent nuclear has an obvious local dimension. To create public confidence in the decision-making process Sweden has chosen to have the public involved in this process and to secure that this involvement also gives possibilities for real influence on the outcome. In practice this means that the general public, and particularly bodies that are generally considered as true representatives for the most concerned public, have a decisive say. For this to be possible, transparency is a key word.

The Swedish model contains co-operation between the government, the authorities, the local administrative entity in the municipalities and the Swedish Nuclear Fuel and Waste Management Company (*Svensk Kärnbränslehantering AB* – SKB), the company owned and commissioned by the Swedish nuclear power producers to carry out the owner's legal obligations.

The general public must also have confidence in the solution to the final disposal issue that the society has decided upon. This particularly applies to public groups that are most affected by the issue, namely those living in a region, municipality, neighbourhood or vicinity where it is intended that a repository should be built.

The *Act on Nuclear Activities,* the *Radiation Protection Act,* the *Act on the Financing of Future Expenses for Spent Nuclear Fuel etc.* and the *Environmental Code* are there to guide and help in the process. The Swedish Nuclear Power Inspectorate (*Stätens Kärnkraftinspektion* – SKI), the Swedish Radiation Protection Authority (*Statens strålskyddsinstitut* – SSI) and county administrative boards are the responsible authorities for ensuring compliance with the legislation. There is an open and generally constructive dialogue between the regulatory bodies and the license holders.

Reactor owners have to present a research and development programme to the government regularly and this programme is then subject to regulatory review.

Sweden has been active for many years in the international effort to enhance nuclear safety and radiation protection with regard to the operation of nuclear reactors. Sweden is part to the Convention on Nuclear Safety as well as the *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management*. At the first review meeting for the Joint Convention, held just a few weeks ago in Vienna, the Swedish national report received a lot of interest and appreciation.

By that, I would like to conclude my remarks. I do appreciate having been given the opportunity to meet with such a distinguished audience. I am pleased that Sweden has been given the honour to host this meeting and I would like to express my gratitude towards the organiser and host SKB, who has done a tremendous job in preparing this event.

I wish you all a successful and rewarding meeting.

Thank you.

PLENARY SESSION I

INTERNATIONAL PERSPECTIVES ON GEOLOGICAL DISPOSAL AND WASTE MANAGEMENT POLICIES

PART I

Chairperson: H. Issler, Nagra, Switzerland

GUIDELINES FOR A EUROPEAN UNION WASTE MANAGEMENT POLICY

Christian Waeterloos
Director, Nuclear Safety and Safeguards, European Commission

Nuclear power currently represents almost one third of the electricity produced and consumed in the European Union. It offers strengths in terms of energy dependence and climate protection. The nuclear option *should remain open* for the future to those Member States who would like it, but provided nuclear safety is guaranteed.

In the public debate following the publication, in 2000,[1] of the European Commission's Green Paper on security of energy supply, it became very clear that *nuclear safety* in an enlarged Europe remained a major concern.

The future of the nuclear industry in Europe, therefore, depends on finding and communicating clear answers to safety concerns.

In 2007, half a billion consumers will be able to choose their electricity supplier freely in Europe. Public opinion's confidence is essential for the security and diversification of electricity supply consumers need.

The acceptance of the nuclear option is conditioned by the public's perception of the safety when producing nuclear power and, in particular, in relation to the waste management issue.

Recent European public opinion surveys have shown that the public is very concerned about radioactive waste management and also feel poorly informed about it. Three particular points are worth noting:

- a very large majority of people want the present generation to manage its own waste and not leave it to the next generation;
- a majority of people think that the nuclear option should remain open if all waste may be safely managed. Among the 15 Members States, Austria was the only exception to this, and
- a significant majority of people in Europe would be reassured if the European Community legislated in the area of radioactive waste management. There was a majority in favour of the EU involvement in all Member States, including those with a high nuclear electricity production.

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1. COM(2000)769.

The Commission, therefore, believes that *a legally binding Community instrument* is the only option, which will give sufficient assurances to European citizens on a high level of nuclear safety. This is the justification of our legislative proposals in the areas of nuclear safety and waste or spent fuel management.

The first objective of the proposals is, therefore, *to guarantee a high level of nuclear safety*. The proposals will also enable the European nuclear industry to evolve within a stable legal framework. But also a similar framework for all power plant operators securing *fair competition* in a changing electricity market.

Our proposals confirm, the prime responsibilities – on nuclear safety – of operators under the jurisdiction of their national safety authorities.

Since the Chernobyl accident in 1986, the need for a common approach to nuclear safety had been stated several times by the European Council, but without any substantive results. The Treaties of Accession signed with Central and Eastern European Countries also include a provision on nuclear safety, which was, for the first time, properly evaluated by the EU Council of Ministers.

In addition, in a ruling on 10 December 2002, the Court of Justice of the EU stated that there were clear Community competencies in the area of nuclear safety that could serve as a base for Community legislation. The Legal Service of the Council has clearly endorsed this view.

The Court has ruled that there is Community competence in several areas:

- for the establishment of a legislative and regulatory framework to govern the safety of nuclear installations;
- for the implementation of measures relating to the assessment and verification of safety;
- for the emergency preparedness, and
- for the siting of a nuclear installation and the design, construction and operation of nuclear installations.

This ruling opened the path to faster harmonisation in the area of nuclear safety at the level of the European Union.

The Commission's proposals are, therefore, intended to give the strength of Community law to general principles unanimously accepted on the international scene and in particular within the International Atomic Energy Agency.

The European Commission, like the NEA and the IAEA, considers that *nuclear safety should be looked at as a whole*. All the civil nuclear facilities should be addressed, from their design to their end of lifetime, including the radioactive waste. Three fundamental topics for nuclear safety are consequently part of our proposals: the safety of nuclear facilities, the decommissioning of them at the end of their lifetime and the safe management of spent fuel and of radioactive waste.

The Directive on the safety of nuclear facilities supplements the responsibilities of operators and national safety authorities by a *peer review* at Community level, according to two complementary methods. On the one hand, a cross-check evaluation of national safety authorities within a Community framework. On the other hand, a report system and evaluation meetings similar to what exists in the international Convention on nuclear safety.

This process should result in an improvement of the transparency of the work of national safety authorities and a backing of the results they achieve.

Concerning financial resources for decommissioning, it is obvious that nuclear safety cannot be guaranteed in the long run, without adequate financial resources to be available when required. Provisions for decommissioning are most important, as they have to be collected before the decommissioning of a nuclear installation, with all the possible uncertainties on the industrial operators' durability in a changing electricity market. The costs associated with decommissioning operations are large, and may represent almost one fifth of the initial investment costs. The availability of the necessary financial resources has to be guaranteed, however within a fair competition environment in the EU internal electricity market.

On management of spent fuel and radioactive waste, many people do not realise that a high percentage of the radioactive waste produced in the European Union has already been disposed of – mainly in surface or near-surface repositories.

Unfortunately, up to now, none of the high-level waste or spent fuel has been disposed of in the EU and there are no repositories ready to accept such waste. Finland has chosen a site – subject to a successful outcome of further underground studies. Sweden will take a decision on its preferred site in the next two or three years. France, the U.K. and some other EU countries have a programme hopefully leading to the choice of a site in the coming years.

The safe long-term management of high-level and long-lived radioactive waste is the only stage in the nuclear fuel cycle that has not yet been really put into practice. It has become, therefore, a critical issue for safe nuclear energy production. Such waste needs to be isolated from human beings and their environment for decades or centuries. Because it has not been done yet, many people have the perception that it cannot be done. They believe that we are creating waste, out of control, and that we are unable to manage it.

Despite these concerns, after many years of study and detailed research, there is now an overwhelming consensus that geologic disposal is a safe and sustainable option for the long-term management of high-level and long-lived radioactive waste. In fact, in the view of many experts – a view shared by the Commission – it is the *only* safe and sustainable option available at present. The necessary technologies are all available. It may be done now and we should start to do it.

This is not to say that other options cannot be found in the future. Therefore, the Commission strongly advocates continuing research in the field. The research should be targeted at better understanding of the possible host rocks for geologic repositories, through studies in underground laboratories, but also focused at research into alternative technologies.

The proposed Waste Directive encourages progress on the safe management of all forms of radioactive waste, but clearly puts the emphasis on the need for greater progress on the safe long-term management of high-level waste and spent fuel. In particular, it urges Member States to develop repositories, in deep geological structures.

Therefore, the Waste Directive requires each Member State to establish a well-defined programme, with clear deadlines.

Programmes will require the selection of at least one site, the launching of the licensing procedure, the building of the repository and its entry into operation. Member States will have to report on this programme at regular intervals. The reports will be subject to peer reviews by national experts.

The Directive would also facilitate co-operation and collaboration on waste management between Member States. It would allow for the development of “common facilities” – but would in no way require any Member State to accept waste from any other country. Shipments of waste will be subject to agreements between all parties concerned under high safety requirements.

Whatever the solution adopted for the ultimate waste disposal, *it is essential to continue research programmes in the field of waste management*. The financial commitment has to be maintained, and even increased in certain Member States. More effective co-operation is also needed between the various programmes, since progress in this field is in the interest of all. Establishing a framework for improved co-operation and co-ordination in this field will increase the overall profitability of the efforts undertaken.

At a later stage, the Commission might propose the creation of a joint undertaking to pull together, manage and direct the research funds intended for the waste management into the most promising areas. This would also guarantee a sharing of the results achieved.

The debate on the Waste Management Directive is still ongoing within the EU Institutions. The European Parliament, while clearly supporting the need for European binding legislation in this area, is coming out strongly in favour of a “two step” approach, where each Member State defines its own programme – with deadlines – and submits them to an EU Peer Review.

The majority of Member States in the Council of Ministers also support European legislation in this area and show a strong preference for the approach that has been developed by the EU Presidency, based on the principle of national programmes, but under EU co-ordination. Only four Member States are still reluctant to accept such a binding approach.

Nevertheless, nearly all Member States regard geologic disposal as a safe and sustainable long-term management strategy. Many also support the continuation of research in this area.

Many people believe that the nuclear option should remain open – because it is needed for both, security and environmental reasons, including the reduction of CO_2 emissions.

What is now needed is for the EU to take the political responsibility – across an enlarged Europe – and make the progress required in order to meet the waste management issue. The adoption of the Waste Management Directive and its implementation in an enlarged EU would be a significant step into such a direction.

FROM ATOMS FOR PEACE TO THE NEXT NUCLEAR ERA: THE ROLE OF NATIONAL REPOSITORIES

Ambassador Kenneth C. Brill
U.S. Representative, U.S. Mission to International Organizations in Vienna

1. Nuclear waste disposal: The challenge for nuclear nations

Exactly 50 years ago today, President Eisenhower laid the foundation for the present global nuclear enterprise. In his 1953 "Atoms for Peace" speech at the United Nations, President Eisenhower offered nuclear technology to other nations as part of a broad nuclear arms control initiative. In the years that followed, nuclear power generation, nuclear medicine, and industrial capabilities developed by many nations helped create the conditions for economic development and contributed to the prosperity and opportunity of the modern world.

Over 40 countries have invested in nuclear energy, developing over 400 nuclear power reactors worldwide, and more than a dozen have some radioactive material production and export capabilities. Globally, nuclear power supplies approximately 16% of electricity needs. In the United States, nuclear reactors around the nation generate 20% of our electricity and are among the most reliable means of energy production. Some nations, such as France, have an energy profile that is substantially based on nuclear, while other nations, such as Germany, have made the decision to move away from nuclear energy over time. Finland has recently conducted negotiations to build a new nuclear power plant in that country, and we look with interest to China on their plans to substantially expand their nuclear power generation.

Despite this diversity, all the nuclear nations share an unavoidable challenge: the safe and permanent disposal of nuclear waste. While there are differences among nations, with some countries using reprocessing as a key element of the fuel cycle, ultimately the disposal issue is one we all must address.

Spent nuclear fuel must be managed over a very long time span to protect human health and the environment, and we must address immediate concerns about nuclear non-proliferation. In the United States, acceptance and permanent disposal of spent nuclear fuel has been a longstanding federal government responsibility, and the government has liability for failure to meet the original timetable for acceptance. Moreover, it is clear that past delays in developing a repository have affected decision-making within the nuclear industry, shaping our energy options for the future. The economic impacts of delay are profound, and we do not believe this burden should be passed to future generations.

The proper disposal of radioactive waste is essential for bringing to fruition the visionary approach for the peaceful uses of nuclear energy embodied in President Eisenhower's 1953 speech. In 1999, at the International Conference on Geological Repositories in Denver, Colorado, more than 20 participating nations affirmed a joint declaration, recognising the need for continuation of work on the safe and secure geologic disposal of radioactive waste. The Joint Declaration expressed the participants' intention to ensure that disposal of radioactive waste is conducted in a safe and environmentally sensitive manner; to work to achieve public understanding of technical and safety issues; to continue co-operation in the development and demonstration of advanced disposal technologies and underground research facilities; and to work together through international fora to exchange of information regarding geologic disposal.

Since the Denver conference, several nations have made significant progress toward meeting the disposal challenge. For example, Finland was the first nation to reach a national decision designating a permanent geologic repository site in 2001, and has been conducting intensive scientific investigations at that site. Sweden has implemented a monitored retrievable storage strategy. Italy has struggled with siting issues, but has made a vital commitment to move forward toward a permanent solution for securing its spent fuel and other radioactive waste. Russia has offered some significant ideas regarding cradle-to-grave nuclear export services that involve returning irradiated fuel to Russia for treatment and disposal. And, of course, we in the United States are proud of the milestone we reached in 2002 with the official designation, by the President and Congress, of a repository site at Yucca Mountain, Nevada.

2. U.S. programme overview

The deep geologic disposal programme in the United States began more than 20 years ago, in 1982, with the passage of the *Nuclear Waste Policy Act,* which set forth processes for characterising, recommending, selecting, and licensing sites for permanent geologic disposal of commercial spent nuclear fuel (resulting from electricity generation) and high-level radioactive waste (resulting from atomic energy defence activities). In 1987, the *Nuclear Waste Policy Act* was amended to limit characterisation to one site, Yucca Mountain, Nevada. While some of the original provisions and the timeline for waste acceptance have proved to be unworkable, the Nuclear Waste Policy Act has been the key element sustaining the momentum and viability of the U.S. disposal programme. The Act addressed all aspects of the repository programme – its funding, the responsible agencies, and the entire life-cycle from site investigation through licensing, construction and operation, to closure. The Act also defined a clear and equitable process for site recommendation and approval, which last year proceeded step-by-step as described in the Act. The comprehensive nature of the Nuclear Waste Policy Act has provided the direction and the authority to get the job done.

Spent nuclear fuel and high-level waste are currently stored at 129 sites in 39 States in the U.S. Consolidation and safe disposal of these materials at Yucca Mountain are vital to US national interests. Disposal in a geologic repository is necessary to maintain our energy options and national security, to advance the cleanup of weapons-production sites, to continue the operation of nuclear-powered ships and submarines, and to advance international non-proliferation goals.

As one example of the importance of our repository programme to national security and non-proliferation, our arms reduction agreements with Russia, which enable the consumption of excess weapons plutonium and enriched uranium, would be impossible if we could not close the fuel cycle. Like Russia, the United States' ability to offer to take back research reactor fuels that we originally supplied to other countries under the Atoms for Peace programme would be impossible if we were not actively pursuing the ultimate disposition of those materials.

3. Yucca Mountain update

In 2002, we completed nearly 20 years of site investigations of the natural processes that could affect the isolation of radionuclides from spent nuclear fuel and high-level radioactive waste. These investigations show that a repository at Yucca Mountain may provide the reasonable expectation required by the U.S. Nuclear Regulatory Commission that public health and safety and the environment will be protected. The underlying basis for these investigations and engineering designs has withstood many independent scientific peer reviews and thorough examination by national and international organisations.

In February 2002, the Secretary of Energy recommended the Yucca Mountain site to the President. After the State of Nevada exercised its ability, as provided by the *Nuclear Waste Policy Act,* to disapprove the recommended site, the U.S. Congress passed a joint resolution overriding that disapproval. The President signed the bill approving the site on 23 July 2002, thus completing the scientific site characterisation phase and allowing the programme to proceed toward licensing. Near-term efforts are now focused on seeking a license from the Nuclear Regulatory Commission to construct a repository and on developing a transportation system for shipping waste to the proposed repository.

The Yucca Mountain repository is critical to our vision of the future of nuclear energy in the United States, reaffirmed by the President in his 2001 Energy Plan. We know that inaction on the back end of the fuel cycle could lead to unacceptable consequences in the future. Therefore, hard decisions have been made, and will continue to be made, and plans that have evolved over the last three decades will no longer be deferred.

4. Global considerations

The President’s Energy Plan calls for continued reliance on nuclear power in the United States and the construction of new nuclear power plants in this decade. Looking to the future, we must develop and construct next-generation reactors that cost less to build and are as safe as current reactors. These reactors may be used to produce both electricity and hydrogen, which will reduce our dependence on hydrocarbon energy sources. They may also be used to generate significant amounts of fresh water, addressing water shortages that are expected to become an increasingly significant global problem over the next two decades.

The global implications of these potential opportunities are clear. It is likely that more countries, including those with no history of nuclear power generation, will look to nuclear power to meet rising energy demands and drive economic prosperity. It is not possible to turn back the clock, nor is it fair to attempt to deny to emerging nations the benefits that we have already enjoyed. Each nation must decide its own future and determine whether and how nuclear power is a part of that future, but, of course, they must do so in ways that are consistent with their obligations under the nuclear non-proliferation regime.

The delegates to the 1999 International Conference acknowledged in their Joint Declaration that the responsibility for safe and secure radioactive waste management within a country rests with that country. However, since 1999, we have all been brought to recognise that an isolated approach to security is inadequate in the modern world. We believe it is the responsibility of the United States, along with the other nuclear nations, to ensure that future growth in peaceful uses of nuclear energy and materials occurs in a safe, secure, and legitimate manner. Thus, those of us at this meeting face a choice: we may either enable the safe and peaceful use of nuclear energy and work to implement permanent disposal solutions, or continue to worry about an ever-expanding problem of spent fuel accumulation.

Several nations are working to develop and demonstrate the technology that will establish future world standards for reactor safety, proliferation prevention, and global nuclear materials management. These goals are laudable, but will not be achievable if the leading nations do not establish and support programmes, based in law and transparent to the public, for the long-term management of the back end of the fuel cycle, and work toward developing their respective repository infrastructures. We must also be open to collaborative approaches that may help enhance security across national borders.

The risks we face from terrorism and nuclear proliferation are immediate, and it is certainly appropriate for near-term nuclear waste management systems to be evaluated and strengthened where necessary in light of those risks. However, in virtually all cases, permanent geologic disposal, which provides the highest degree of safety and security, will take considerable time to implement. Disposal projects overlap multiple political administrations or regimes, and multiple economic cycles. The long time frame for a disposal project challenges us to establish policies and make decisions that will be effectively sustained throughout the duration of the project. Disposal projects are also susceptible to other pressing priorities – they lack a sense of urgency, and there is a temptation to defer a long-duration project – just a little bit longer. The risk is a loss of momentum, which may send the programme backwards and, probably more importantly, negatively affect public confidence.

I believe the participants at this conference may serve their countries at best by reaffirming the importance and value of moving forward with geologic disposal, and by specifically supporting the adoption of geologic disposal as national policy. It is important to recognise the necessary role of national governments in taking responsibility for nuclear waste management and disposal programmes. Only national governments may provide responsible long-term stewardship of nuclear materials from the cradle to the grave. National governments are uniquely situated to address issues of equity with regard to host communities, to implement a long-term funding structure, and to establish regulatory requirements and a scientific and technical framework to meet those requirements in a way that merits public confidence. While the path to opening and operating repositories may be a long one, and each nation must confront unique challenges along that path, a commitment among all nuclear nations to implement safe, secure, permanent geologic disposal will increase security and create momentum toward that goal around the globe.

Conclusion

I believe the nations and organisations gathered here recognise our responsibility. We, who have reaped the benefits of nuclear power, cannot leave an unsolved legacy to future generations. Regardless of what option is used to "close" the fuel cycle, a repository is required now and will always be required to deal with some waste materials. Our collaboration on resolving these issues and assuring the availability of future repositories will enable continued global growth in peaceful uses of nuclear energy for sustainable development, make the Atoms for Peace vision achievable, and provide continuity to the next nuclear era.

PRESENT SITUATION AND PERSPECTIVE OF CHINA'S GEOLOGICAL DISPOSAL OF HIGH-LEVEL RADIOACTIVE WASTE

Huazhu Zhang
Chairman, China Atomic Energy Authority, China

Mr. Chairman, Ladies and Gentlemen,

The theme of the conference, "Political and Technical Progress of Geologic Repositories", has drawn world-wide attention and remains a challenging topic facing the nuclear industry. I am delighted to attend this important conference and have the opportunity to state our views. And I would like to express my gratitude to our host – Sweden – and IAEA.

The development of nuclear science and technology and the peaceful uses of nuclear energy is one of the greatest achievements of the mankind in the 20th century. The development and progress of nuclear technology, from application of fission energy to the exploration of fusion energy, embodies the mankind's expectation to the future. It will be the major energy of final settlement of the issue of global sustainable development. The safe and effective treatment and disposal of nuclear waste are of vital importance to the peaceful uses of nuclear energy and technology. The most dangerous and long-lived waste has to be contained and isolated from the human living environment. Construction of geologic repository in appropriate geological formation for radioactive waste disposal is being accepted as a suitable solution and being studied widely. In the International Conference on Geological Repositories held in Denver, U.S.A., in November 1999, senior governmental representatives from more than 20 countries stated related policies and decisions of their respective countries, which caught world-wide attention. I am convinced that this conference, an event about geologic repository following the Denver conference, will produce positive results for the safe and effective disposal of nuclear waste.

Now I would like to take this opportunity to brief you on China's current situation and perspectives of geologic disposal of high-level radioactive waste.

1. Current situation of nuclear facilities and waste production

China's nuclear energy development and HLW disposal policies. China's nuclear industry started in the 1950s, and a comprehensive nuclear industrial system has been set up with decades of efforts. The introduction of the policy of reform and opening-up in the 1980s ushered in a new era of development for China's economy and its nuclear industry represented by nuclear power as well. With more than two decades' efforts, we now have eight nuclear power reactor units, and three units under construction which are to be put into commercial operation by 2005. By that time, China's total nuclear power installed capacity will reach 9 000 MW, about 2.3% of the country's total installed capacity. China's nuclear power must make further development to meet the increasing demands of

China's economic development on electricity. According to tentative ideas, the nuclear power installed capacity of China will reach 32 000 MW by 2020.

With the development of nuclear power, China's spent fuel will accumulate to 1 000 t by 2010. It is estimated that about 1 000 t of spent fuel will be unloaded annually beyond 2020. Spent fuel is reprocessed for recovery of uranium and plutonium to have a closed fuel cycle and make full use of the uranium resources. China's reprocessing pilot plant for spent fuel has been under construction and will be commissioned in 2005. With growing amount of HLW produced through reprocessing, China will face increasing pressure, and therefore has to find a proper solution.

The Chinese Government attaches great importance to the safe management and disposal of HLW, and promulgated relevant regulations. The Law of the People's Republic of China on Prevention of Radioactive Pollution adopted on 28 June 2003 provides that "centralised deep geologic disposal shall be applied to solid high-level radioactive waste, and deep geologic disposal to radioactive solid waste". Feasibility studies of more than a decade have made progress to ensure the safe disposal of HLW. China will refer to the solutions generally accepted in the world to apply deep geologic disposal to HLW. HLW will be buried in geological formation 500-1 000 m underground, to be isolated effectively from the living environment of the mankind for a long period.

The China Atomic Energy Authority, the competent authorities for administration of China's nuclear industry, will continue its work of organising and implementing geologic disposal of HLW, and international co-operation and exchange in this aspect to promote the development of nuclear energy.

2. Progress of studies on the geologic disposal of HLW

Geologic disposal started in 1985 in China. Efforts have been made on siting for HLW repositories, preliminary characterisation of potential candidate sites, laboratory research on radio-nuclide migration and researches on backfill materials. Beishan of Gansu Province, Northwest China has been primarily selected as the potential candidate site for HLW geologic repository and bentonite from Inner Mongolia is the preliminary choice for backfill material.

2.1 Progress of site selection

Work for site selection for HLW geologic repository has lasted for about 20 years, in three stages: selection of region, area and site. Social and natural factors have been taken into account in the process.

In the last 10 years or so, work for siting was carried out mainly in Northwest China. We studied crustal stability and structure, seismic and geological characteristics, hydro-geological conditions and engineering geological conditions. Preliminary findings show that Beishan of Gansu Province near to the Gobi desert is a prospective site for final disposal of HLW as it is scarcely populated, with integrated and stable crust structure, and suitable geological and hydro-geological conditions.

2.2 Progress of site evaluation

Preliminary site characterisation has been conducted in three key areas in Beishan, Gansu since 1999, including surface geological mapping, hydrogeological survey and geophysical survey. Through the four deep bore holes in 2 areas for geological research, hydrogeological experiments and other *in-situ* geostress measurement, rock and groundwater samples and deep geological environment parameters have been obtained. The suitability of the region was evaluated through a series of site characterisation methods, the effectiveness of which has been proved. This provided reference to similar work and formulation of standards in the future. Good experiences have been accumulated to evaluate sites in fracture granite media in arid area.

2.3 Progress of studies on backfill materials

Backfill material is placed between the waste containers and host rocks as an engineered, hydrological and chemical barrier, as well as a heat conducting media. After the studies on the mineralogical, hydraulic and geomechanical features of bentonite, and its features of absorption and diffusion of nuclides, bentonite was selected as the backfill material for China's HLW repository. The GMZ bentonite from Inner Mongolia is the most suitable backfill material.

3. China's preliminary plan for HLW geologic disposal

Based on other countries' experience and the practical local situation, China plans to complete the construction of HLW geologic repository by the middle of the century, in the following three stages:

- Up to 2015, efforts will be focused on site selection and site evaluation. Site evaluation technology will be verified through the geological survey and research. The site for underground research laboratory will be confirmed by 2015.
- From 2015 to 2035, the underground research laboratory will be established in the selected site for evaluation of deep geological environment and in situ tests.
- The third stage is the construction of repository on the basis of the completion of the experiment in the underground research laboratory.

The key to our plan is the selection of an appropriate site and the detailed and sufficient characterisation of the potential site.

4. Prospects of international co-operation

The safe disposal of HLW is a common concern of the public and has been given great importance by all governments. Safe and effective disposal of HLW is one of the key factors for sustainable development of nuclear energy and is the challenge facing the nuclear energy sector of the world. International co-operation plays an important role in settling the issue. And China is willing to strengthen international co-operation in this aspect.

China, in co-operation with IAEA, has successfully completed a technical co-operation project entitled "Siting and site characterisation studies for HLW Repository in China" from 1999 to 2001. This project has been focusing on China's key candidate sites and has achieved good results.

The IAEA and China co-sponsored an international seminar on HLW geologic disposal in Beijing in May 2002 with the participation of more than 60 experts from the United States, France, Switzerland, Republic of Korea, Canada and China for discussion and exchange on important technological issues.

China has established cooperative relations with the United States, France and Republic of Korea in this field. Experts' exchange enhanced the development of related technology.

The *Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management* formulated with the support of IAEA produces positive influence to the issue of safe management of spent fuel and radioactive waste around the world. China has been actively participated in the formulation of the convention, and is under going the domestic approval procedures. China will further support IAEA in its efforts for promoting safe uses of nuclear energy and effective disposal of radioactive waste.

China expects to have broader co-operation with other countries in the management and disposal of radioactive waste and is willing to share our experience and achievements, in the form of international conference or joint research. The priority fields for co-operation and exchange at present are site selection, the technology and methods for site characterisation, construction and studies for underground research laboratory, and drafting of relevant regulations and standards. China hopes to join hands with other countries to make contribution to the realisation of safe and effective disposal of radioactive waste.

Thank you.

PLENARY SESSION II

INTERNATIONAL PERSPECTIVES ON GEOLOGICAL DISPOSAL AND WASTE MANAGEMENT POLICIES

PART II

Chairperson: D.M. Taylor, European Commission

NEW ELEMENTS IN THE GERMAN RADIOACTIVE WASTE MANAGEMENT

Wolfgang Renneberg
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, Germany

Ladies and Gentlemen,

As you know, the Federal Republic of Germany has carried out a very pronounced change in its energy policy since the year 1998. The key feature of this change is the phase-out of nuclear power for commercial electricity generation. Since the preceding conference organised by the Department of Energy four years ago in Denver, essential cornerstones of this new policy have been laid down in a consensual agreement between the Federal government and the major utility companies in June 2000. This consensual agreement served as a basis for the amendment of the Atomic Energy Act, which became effective on 27 April 2002 and which provides the legal basis for the new policy.

The phase-out provisions within the Atomic Act concern both nuclear power plants and the reprocessing of spent fuel:

- nuclear power plants' operation is terminated by law as soon as fixed residual amounts of electricity have been generated, and
- transport of spent fuel elements to reprocessing plants is legally forbidden after 30 June 2005. Moreover, as long as reprocessing of spent fuels takes place, it has become mandatory for licensees to prove to the regulator on an annual basis that all reprocessed plutonium will be reused in the form of MOX fuel elements in nuclear power plants.

1. What are the consequences of this new regulation?

- phasing out means that *no further plutonium is generated*;
- the effect of restricting spent fuel management to direct disposal is that *no further plutonium is separated* by reprocessing; and
- reusing the large amounts of separated plutonium means that at the end of the operation of nuclear power plants in Germany there will be no any legacy of separated plutonium.

Germany considers these steps as an important contribution to limit the generation and processing of weapon-usable material – as has been recently required by IAEA Director General, Mr. ElBaradei. Exiting the business of plutonium production, plutonium separation and transports by phasing out definitely terminates the principle risk of access of illegitimate would-be-users to fissile material, and thereby contributes substantially to meeting non-proliferation requirements

2. What are the key elements in the new German concept for radioactive waste management in the framework of nuclear phase-out?

- Operators of nuclear power plants are legally obliged to provide and operate dry interim storage facilities either onsite or in the vicinity of their plants. Fuel elements remain where they have been used until a final repository becomes available. As consequence termination of reprocessing and on-site storage of spent fuel both lead to a minimisation of spent fuel transport. In particular, it became possible to refrain entirely from transports of spent fuel rods to regional storage facilities at Gorleben and Ahaus.
- With respect to radioactive waste disposal we have decided that alternative repository sites in different host rock formations have to be investigated for their suitability. The final repository site is to be selected as result of a comparison between those alternative sites. The German government aims at the construction and operation of a single repository for all types of radioactive waste in deep geological formations by the year 2030. However, the boundary conditions for realisation of the single-repository approach still have to be clarified.
- In accordance with this new radioactive waste management concept we have initiated the development of a comprehensive national waste management plan to handle the legacy of our radioactive residues. This plan includes the flow of all kinds of radioactive waste, planned actions and time frames for the management of nuclear residues. The plan will be completed within this legislative period. In the future it will periodically be updated and presented to the German parliament once in each legislative period.

3. Where do we stand today?

The operators of nuclear power plants have stepped forward with respect to providing dry interim storage facilities at the reactor sites. To date, 12 applications have been filed to initiate licensing procedures for the construction and operation. Nine of those twelve interim storage facilities have already been licensed. The storage capacities range between 800 and 2 250 t of heavy metal. It is expected, that the remaining licenses will be issued soon, and operation of all new interim storage facilities may be expected by the year 2005. The interim storage time is not to exceed a time period of 40 years, for interim storage facilities are not final repositories.

Germany also has two large central storage facilities at Gorleben and Ahaus, which have storage capacities of 3 800 tons and 3 960 t of heavy metal, respectively, and 420 container positions each. The Gorleben storage facility will mainly be used to accept the radioactive waste obtained from the reprocessing of spent fuel elements while, among others, fuel elements from research reactors are stored in Ahaus.

In addition to the aforementioned interim and regional storage facilities there are 11 regional State collecting facilities operated by the Federal States. They collect radioactive waste from research, industry and medicine. The waste amount being delivered annually to these facilities amounts to only about 3% of the total waste generated on an annual basis.

The present state of the existing German repository projects may be summarised as follows.

- The abandoned Konrad iron ore mine in the Federal State of Lower Saxony has been investigated since 1975 for disposal of radioactive waste with negligible heat generation at a depth ranging from 800 to about 1 300 m. The application for the license was issued in June last year for the emplacement of 300 000 m^3 waste packages with a total activity in the order of 1,018 Bq and an alpha emitter activity of about 1,017 Bq. Presently, court decisions on several ongoing legal proceedings against the license have to be awaited. This process is expected to take a number of years.

- The Gorleben salt dome in the north-east of Lower Saxony has been investigated since the late seventies for its suitability to host, at depths between 840 and 1 200 meters, a repository for all types of radioactive waste, mainly for spent fuel elements and heat-generating waste originating from reprocessing The exploration of the Gorleben salt dome was interrupted in October 2000 for at least three, but not more than 10 years. Last and least there is the Morsleben repository, an abandoned salt mine located in the Federal State of Saxony-Anhalt which holds about 37 000 m^3 of low- and intermediate-level waste. This repository was designed and commissioned in the former German Democratic Republic. With the German reunification it acquired the status of a federal repository, however disposal was terminated in 1998. The actual backfilling and sealing measures, which are designed to stabilise the mine and to seal the emplaced waste are expected to take some 20 years.

We are all aware of the situation that, several decades after the installation of nuclear power plants, no repository is available worldwide where spent fuels from these plants or high-level waste from reprocessing could be disposed of, it has become increasingly clear during the last years that technically advanced approaches to radioactive waste disposal are not sufficient to solve the problem. More specifically, in Germany we do no longer consider it appropriate, particularly for high-level waste and spent fuel disposal, to rely on just one option in just one (salt) formation – as Gorleben is – whose selection may not be traced in a transparent way nor was based on public participation.

The new approach to radioactive waste disposal is consequently based on a site selection process which is independent on any predetermination of host rock formations. An approach that is based on sound criteria fixed well in advance of the selection process, that does not exclude nor favour beforehand any site or region, and that involves the public from the very beginning.

In February 1999, the Federal Minister for the Environment set up an expert group with the task to develop a procedure and criteria for site selection. Already during the development phase, the committee discussed results of its findings with national and international experts, with interested segments of the general public, and with politicians. Three big workshops were organised on an annual basis showing remarkable public attention and extensive positive media coverage. After some four years of work, the committee handed over its final report to the Minister in December last year.

The site-selection procedure recommended by the committee consists of a stepwise approach and essentially comprises two elements. The first element consists of selection criteria that comply with the international state of the art in science and technology. The second element consists of a concept of involvement of the general public in all stages of the search and selection procedure. Round table groups are envisaged to prepare a regional development plan with concepts of long-term prosperity of the site regions. The selection procedure shall be organised in a comprehensible, transparent way and shall be carried out under continuous public control. But at the end of this process there must be a solution and there must be one site. There is no doubt.

It is our impression that this approach to site selection is in good agreement with several other countries' programmes to find sustainable and accepted solutions to the waste problem. We particularly follow with high interest the progress in Japan where a principally similar site selection procedure has been started recently. The farer progressed programmes in Finland and Sweden encourage us in our hope that disposal sites may eventually be identified which are both safe and accepted.

Our next step is the political and legal fixation of the selection procedure and its financing by the waste producers, based on a broad societal and political consensus. It is our goal to set into force the necessary legal amendments of the atomic energy and other acts within this legislative period, that is, before mid-2006. Only after the fixation of the selection procedure and the corresponding criteria the site selection will begin. It is intended that the Gorleben salt dome will then be included into the selection process and evaluated against the same criteria as potential alternative sites.

The present safety criteria for the disposal of radioactive waste were issued back in the early eighties. They describe the basic aspects which have to be complied with to be able to achieve the protection goals of disposal. Regarding the tremendous progress in the field over the last 20 years, these safety criteria urgently needed revision. A new draft version has been worked out and submitted last year for a first review by the German radiation safety commission and reactor safety commission. Some work is still required, but we are confident that the revised safety criteria will also be issued during the course of this legislative period.

I believe that we have made considerable progress in radioactive waste management since the Denver conference. We have developed a selection procedure for repository sites that may stand up to international practices in this field. The features of public participation in the selection process in Germany will be one necessary condition to site a repository in accordance with the requirements of civil society. Another perhaps specific German condition for public acceptance of a disposal site will be that people may trust in the fact that the amount of waste will stay limited and the disposal site will not serve as justification for further and unlimited use of nuclear energy and unlimited production of more radioactive waste.

In this context, I would like to just briefly address one aspect of the so called "Nuclear package" of the European Commission. The deadlines which were suggested by the Commission to begin operation of nuclear disposal are incompatible with time frames required for necessary public participation and decision processes. This aspect and the scientific and technological challenges involved make it impossible to accept such constraints.

Let me close my presentation with pointing out that the quest for a responsible approach to nuclear disposal shows the need to work together and – as it is in matters of nuclear safety – leads together all countries with nuclear programmes quite the same whether they pursue the production of nuclear energy or phase out this technology.

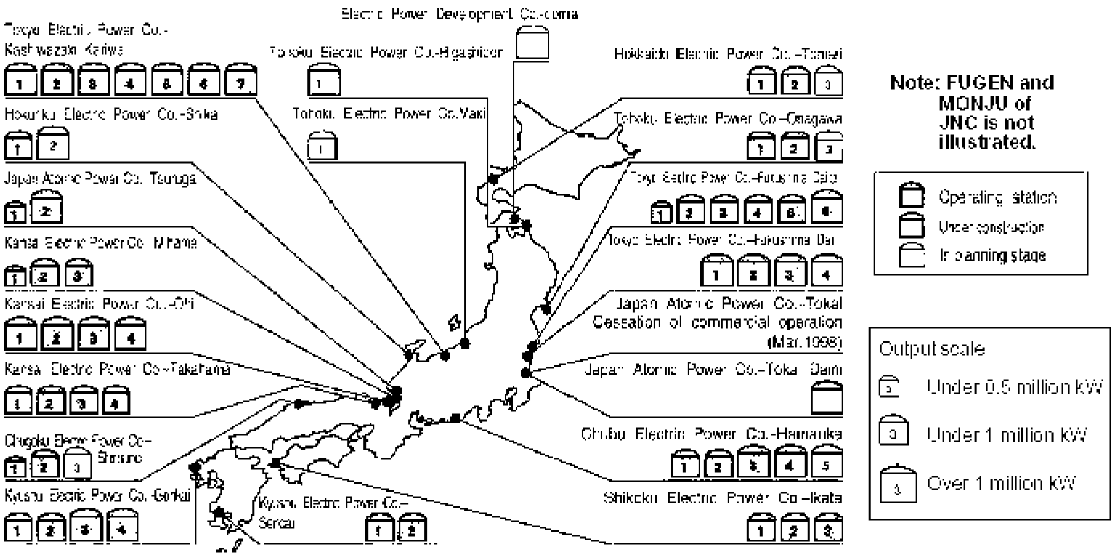
Thank you for your attention.

PERSPECTIVES ON GEOLOGICAL DISPOSAL AND WASTE MANAGEMENT IN JAPAN

Akio Morishima
Atomic Energy Commission (JAEC), Japan

Figure 1. Nuclear Power Generation in Japan

Number of nuclear units in operation	Nuclear electricity capacity (kW)	Capacity utilisation rate (%)	Nuclear percentage of total electricity supply
52	46 million	73	31



31 March 2003

Figure 2. Nuclear Waste in Japan

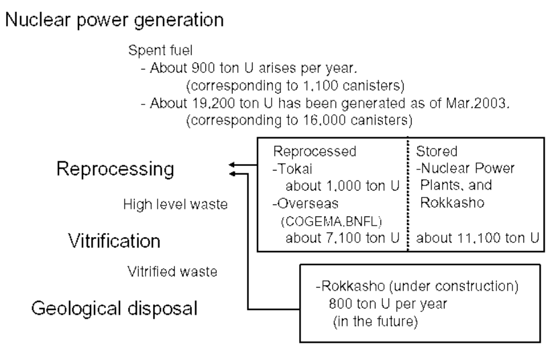


Figure 3. Development of Japanese HLW Disposal

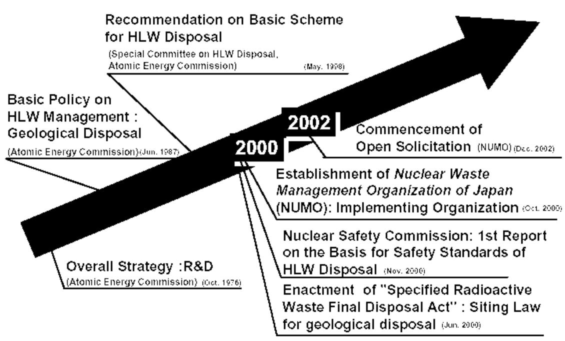


Figure 4. Framework of Implementation
"Specified Radioactive Waste Final Disposal Act (7 June 2000)"

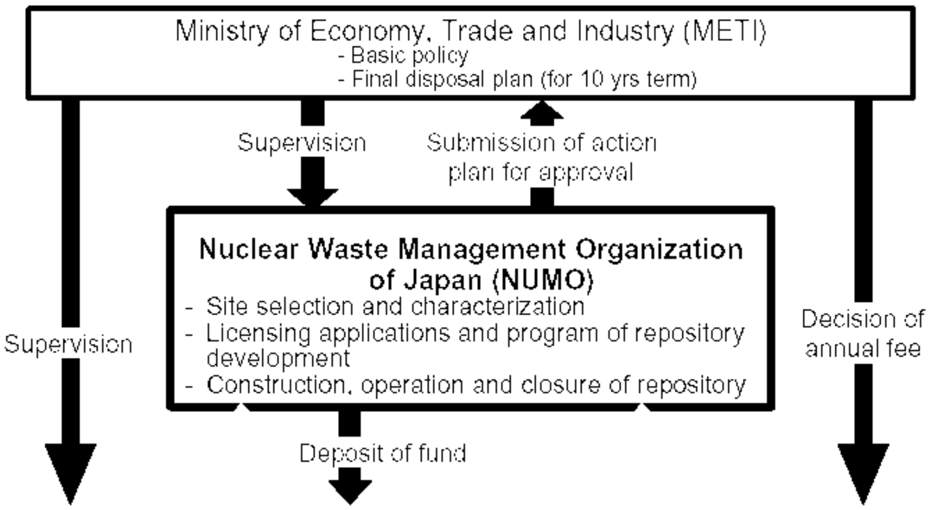
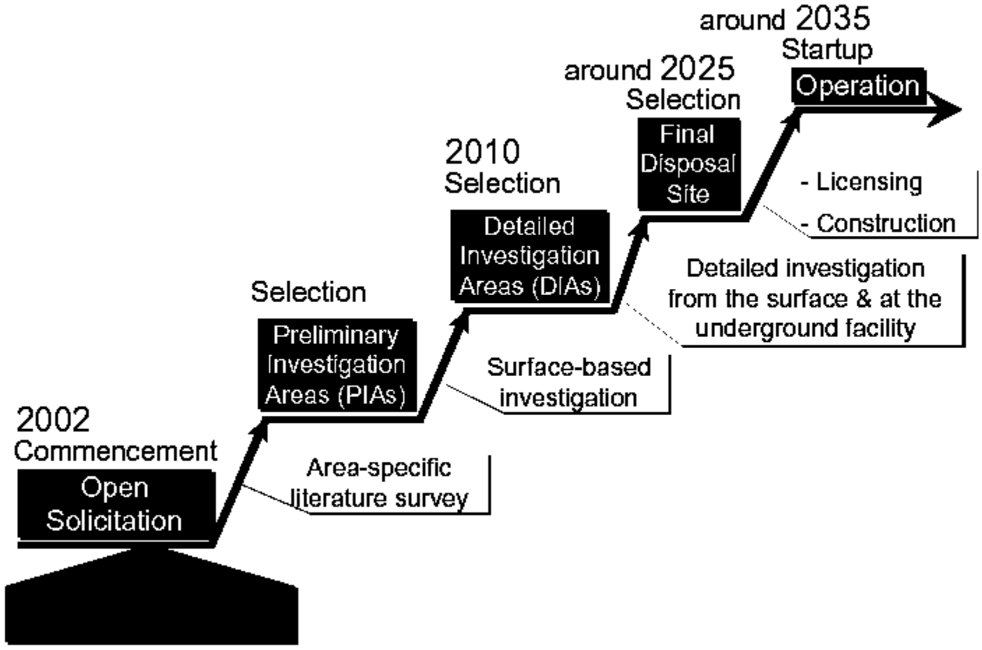


Figure 5. Stepwise Approach for Siting
"Specified Radioactive Waste Final Disposal Act (7 June 2000)"



GEOLOGICAL DISPOSAL OF NUCLEAR WASTE MANAGEMENT POLICIES
French Perspectives

Bernard Frois
Ministry of Research and New Technologies, France

Figure 1. French energy mix

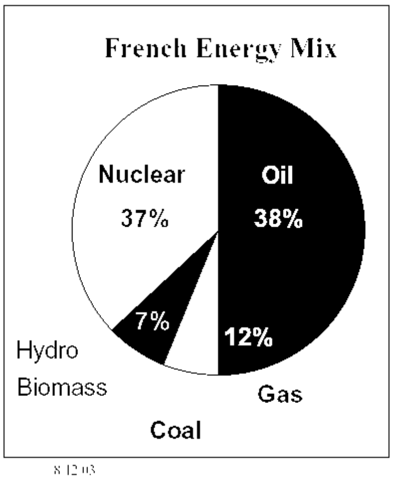


Figure 2. CO_2 emissions in France

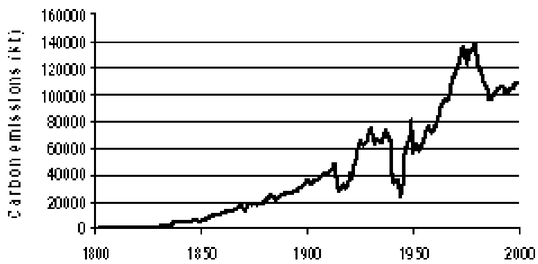


Figure 3. Greenhouse-gas emissions

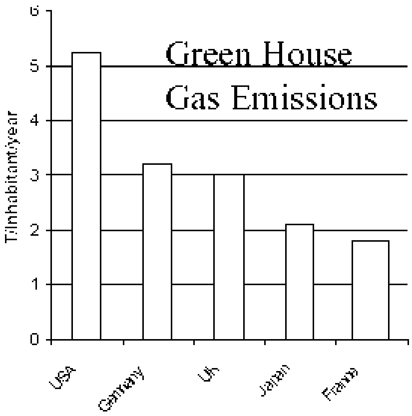
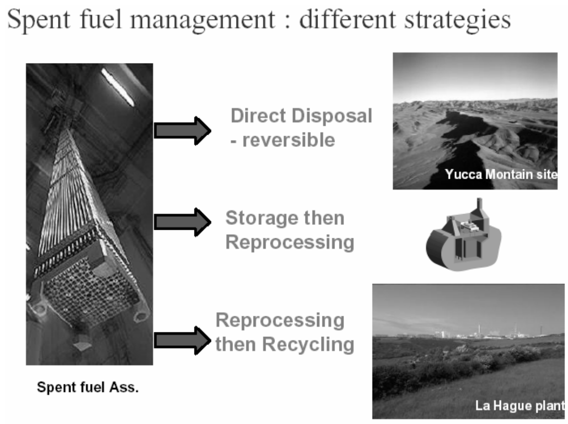


Figure 4. Spent fuel management: Different strategies



The 1991 Law on Nuclear Waste

- A political answer to public concerns.
- A specific legal framework for the management of high-level and long-lived intermediate-level waste.
- Research on HLLLW is conducted in France under the terms of the 1991 Waste Act (Bataille Law).
- The law provides a framework for a social, political and scientific debate.

Three major research areas will be carried out up to 2006

- Partitioning and transmutation of long-lived radioactive elements.
- Experimental study of deep geological underground.

  The law requests the construction of underground laboratories.
- Conditioning and long term storage.

  Reversibility is a key issue.

Clearly defined responsibilities

- CEA is responsible for partition/transmutation and long-term storage research.
- Andra is in charge of long-term waste management and responsible for deep geological storage research.
- The Ministry of Research co-ordinates the strategy and research programmes.
- The National Review Board (*Commission nationale d'évaluation* – CNE) continuously assesses the results obtained by the different actors and presents its annual reports to the Parliament.

Government public dialogue

- Local consultation before any siting decision of an URL.
- Well-defined legal frame to authorise and URL.
- Local commissions provide exchanges of information at the local level between government and stakeholders.
- Long process of public enquiry required before implementing any nuclear facility.

Assessing progress

- Annual review of the Ministry of Research with the participation of the Ministries of Industry and Environment, the Nuclear Safety Authority, CEA, Andra, Cogema, Framatome, EDF.
- Annual report of the CNE.
- Safety analysis assessment by the Nuclear Safety Authority.
- Peer review by OECD/NEA.

A comprehensive document

A complete overview published every year and presented to the CNE.

Ministère de la Recherche Direction de la technologie
Stratégie et programmes de recherches **sur la gestion des déchets radioactifs** **à haute activité et à vie longue** (au titre de l'article L542 du *Code de l'environnement*, issu de la Lois du 30 décembre 1991)

Research expenses since 1991

2003 Budget	**272 M€**
1992-2002	**1 957 M€**

Research area	**Organisation**	**2002**	**Total**
Area 1	CEA	63.3	551.2
	CNRS	7.9	35.3
	COGEMA	0.0	21.0
	EDF	1.5	14.1
	Framatome ANP	1.1	4.1
Total area 1		73.8	625.7
Area 2	Andra	83.3	580.7
	CEA	8.4	143.4
	CNRS	7.3	26.5
	COGEMA	0.6	2.9
	EDF	5.6	30.8
	Framatome ANP		0.2
Total area 2		105.2	784.5
Area 3	CEA	59.6	513.0
	CNRS	4.8	9.9
	COGEMA	1.7	6.6
	EDF	2.7	14.6
	Framatome ANP	0.3	2.4
Total area 3		69.0	546.5

Figure 5. R&D for enhanced partitioning

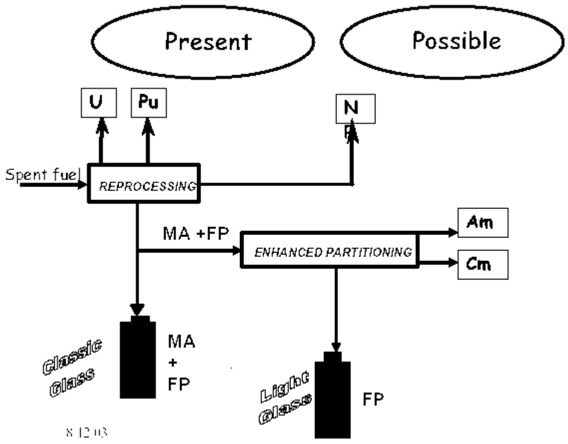
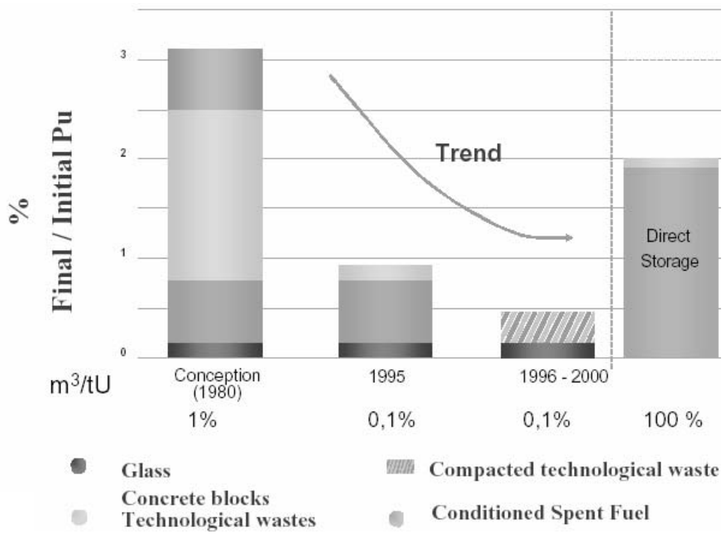


Figure 6. CEA/Marcoule Atalante Lot Lab

Results: Partitioning and transmutation

- Success of enhanced partitioning in Atalante: from 9 to 99% according to actinides species.
- Studies of possible transmutation scenarios have defined the possible gains as a function of the type of fuel cycle. PHENIX transmutation research programme in progress.
- International studies completed: OECD/NEA, 5th and 6th EU framework programmes.

Figure 7. Volume of final waste after conditioning at La Hague is considerably reduced



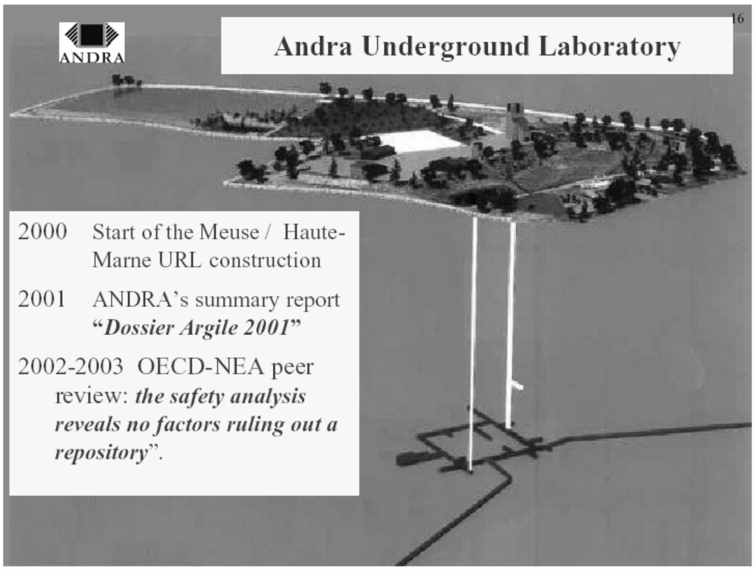
Results: Long-term interim storage

- Scientific feasibility of specific packages for separated radionuclides.
- Comprehensive report on different long-term interim storage systems published in 2001.
- Research planned 2004-2006:
  - Industrial feasibility of a long-term interim storage;
  - Technical and economic analysis of the long-term interim storage option.

Figure 8. Demonstrators of containers

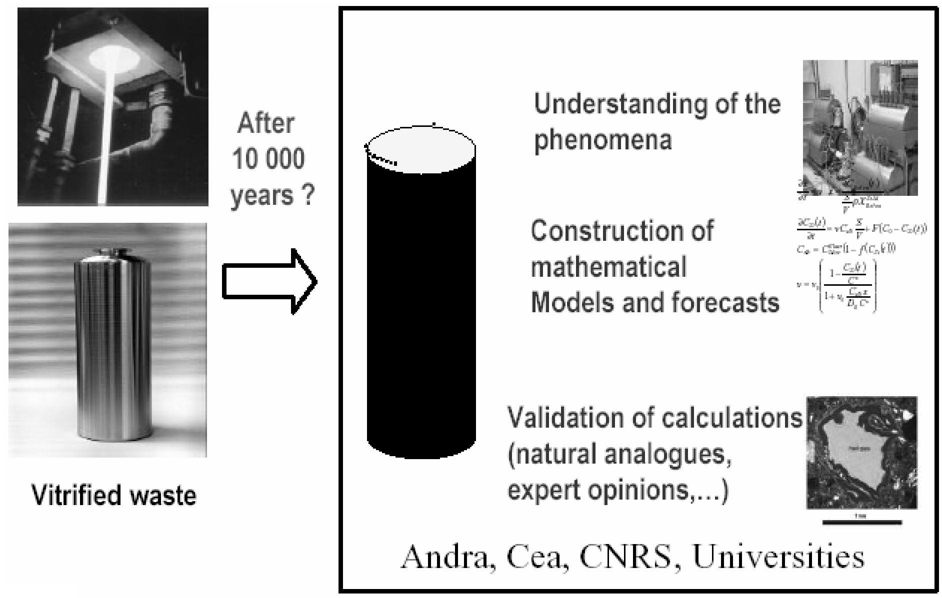
Agreement between EDF, CEA and Andra to study a deep geological storage container (design to be completed in 2003.)

Figure 9. Andra Underground Laboratory



2000	**Start of the Meuse/Haute-Marne URL construction**
2001	**Andra's summary report *Dossier Argile 2001*.**
2002-2003	**OECD/NEA peer review: "The safety analysis reveals no factors ruling out a repository".**

Figure 10. Strong collaborations: Increased confidence in deep geologic disposal
Long-term durability of vitrified waste, alteration by water



National (and international) consensus solutions do exist…

The safest range of possible solutions are based on multi-barrier confinement together with deep geological underground storage.

Long-term storage in safe conditions is feasible but needs continuous surveillance and maintenance.

Considerable activity to prepare 2006

- Synthesis of the results obtained by 15 years of technological research in France and abroad (ministry and research).
- The parliament will audition all the actors in 2004.
- Multi-criterion analysis (Ministry of Industry).
- A National Plan for Nuclear Waste management is prepared by the National Safety Authority.

Conclusions

- The French legal framework has generated a coherent and powerful research programme.
- Strong national and international collaborations.
- Results are important and concrete. Progress is considerable.
- Deep geological storage is the preferred solution (National Evaluation Commission).
- In principle no surprises expected in 2006, but…
- Decisions will be taken only in 2006.

FINAL DISPOSAL OF SPENT FUEL IN FINLAND

Jussi Manninen
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Ministry of Trade and Industry, Finland

Introduction

In accordance with the organisers' request, this presentation should provide a broad view of the development, after the 1999 Denver Conference, in the nuclear waste management field in Finland and of the future perspectives. Because this request effectively excludes the past, and since the final disposal activities of low- and intermediate-level waste have started in Finland already a decade ago and proceed on a routine basis and since the two former experimental uranium mine sites have already been rehabilitated, this presentation is directed towards the management of spent nuclear fuel. And since the Finnish legislation effectively prevents any reprocessing of spent fuel, its focus will consequently be on the direct disposal of the fuel.

1. Decision-in-principle – An important milestone

Without doubt, an important milestone was reached when the Government of Finland in December 2000 adopted a positive Decision-in-principle concerning a final disposal facility for spent nuclear fuel and this decision was, after an extensive debate, endorsed by Parliament in May 2001. This kind of positive Decision-in-principle is required, according to the *Nuclear Energy Act,* before detailed development of any major nuclear facility project may start. Unlike many people seem to think, a Decision-in-principle is not a construction licence, but a kind of political green light for the prospective developer to go on with the project. In this case, the construction licence stage will be reached around 2012.

A Decision-in-principle is always preceded by a wide environmental impact assessment and public consultation process. The requirements written in the law guarantee a minimum level of consultation, but actually, also in this case, much more important has been the interaction between the company, responsible for the project, and various stakeholder groups, especially the inhabitants of the municipality in question and local decision makers.

The content of a Decision-in-principle is simply "that the construction project is in line with the overall good of society". At the same time, the decision fixes certain main characteristics of the project. These form a framework within which the project must remain or otherwise a new decision is required. One of these characteristics is the developer, in this case Posiva Oy, a joint company owned by the Finnish nuclear power companies. Another characteristic, fixed by the decision, is the final disposal concept, i.e., geologic disposal in canisters at the depth of 400 to 700 m in bedrock. The decision also covers an encapsulation plant on the same site. The site, which the decision also fixes, is on the Olkiluoto Island, in the vicinity of one of the existing nuclear power plants. It is worth mentioning that the *Nuclear Energy Act* gave the municipality in question an absolute right to veto the whole project, but this possibility was not used. Actually, it turned out that also another municipality would have been willing to accept the facility.

The Decision-in-principle also limits the size of the future disposal facility to that required by "the current assessed needs of the existing Finnish nuclear power plants". In other words, it limits the size to that needed to cover the past spent fuel arisings and also those estimated on the basis of the current operating licenses of those power plants. When the operating licenses are renewed, the maximum allowed size also increases. The reason for this limitation is simply to eliminate the possibility to have extra capacity to be built for foreign spent fuel. Recently this Decision-in-principle was amended to cover also the fifth nuclear power unit to be built in Finland.

2. Current spent fuel strategy and key players in its implementation

The Decision-in-principle is an important milestone, but it represents only one of those established by the overall spent fuel strategy of Finland. The essential features of this strategy go back to the year 1983, i.e., to the very first years of operation by the Finnish nuclear power plants. It reflects in its own way a well-developed sense of responsibility towards the future generations. At the same time, it also reflects the realisation that it is better to have at least one useful solution to be worked out as long as the nuclear power companies still have something to lose.

The strategy was originally devised to guide the R&D activities, but has, in practice, over time transformed to a concrete roadmap for the spent fuel management. The strategy, in its present form, is based on on-site intermediate storage and geologic disposal in Finland. The timetable set by the strategy consists, after the site selection in 2000, of having the necessary material for the construction license application ready in 2012 and of having the final disposal facility in operation around 2020.

In parallel with this strategy, also a system for collecting funds for future nuclear waste management costs was established.

The strategy is obviously a common national undertaking with many players implementing it. Four key players have their respective roles defined by the Nuclear Energy Act. The most central player or players are the *nuclear waste producers*, i.e., the nuclear power companies Fortum Power and Heat Oy (FPH) and Teollisuuden Voima Oy (TVO). The Nuclear Energy Act gives them the primary responsibility for all nuclear waste management measures and also for their costs. In order to jointly carry out an important part of this responsibility, these companies formed, in the middle of the 1990's, Posiva Oy to take care of the final disposal of their spent fuel arisings. It is to be noted that the Decision-in-principle is valid only for Posiva Oy's project.

According to the Nuclear Energy Act, it is up to the Ministry of Trade and Industry to decide on the principles for waste management, in other words on the strategy. The Ministry also formalises any changes in the strategy. Thus, its role is to guide the waste producers in fulfilling their responsibility for waste management. The Act provides the Ministry also with a "stick", even "a whip", to be used if need arises, but no use has been made of it, so far.

A third key player is the *national regulatory authority*, STUK Its role is, according to the *Nuclear Energy Act,* to make the safety assessment of the future facility. However, it has also a role to play in the development of the strategy and its implementation through opinions given to the Ministry.

Finally, one should mention the *Government*, i.e. the Ministers together who must, sometimes around 2013, take the decision whether or not issue a construction license for the future disposal facility.

Two other important players have to be mentioned, even if they have no statutory role in the remaining phases of the implementation of the strategy. The research community is, of course, all the time producing a firmer and firmer base for the decisions of all the four key players. And even if the municipality in question may no longer exercise its veto right, it is important to continuously secure its positive attitude to the project.

3. Preparations made by the key players for the building-permit application

Posiva Oy is presently making preparations for building an underground rock characterisation facility, ONKALO. It will be built so that it may be used as a part of the future facility. Among the objectives of constructing this facility are: to get confirmation for the current results obtained from the surface; to provide data for designing the future facility; and to gather data for the safety analysis.

In parallel, Posiva Oy is further refining the technical concept that formed the basis for the Decision-in-principle. ONKALO is naturally very much a domestic project while in the development of the technical concept the company is making use of intensive international co-operation. Finalising, together with SKB, the encapsulation concept, selecting the filling material and developing, together with SKB and also in connection with the EU framework programmes, and the safety analysis are among the components of this work programme.

Already in 1999, STUK finalised a draft Decree on the safety of disposal of spent nuclear fuel. The Decree was, in the same year, formally adopted by the Government. This event passed almost unnoticed both in Finland and abroad, even if such a decree may be considered an important achievement also from the global perspective. The Decree is, undeniably, of a rather general nature, listing mostly different aspects to be taken into account and defining procedures for submitting information on these aspects, but even as such it considerably contributed to the subsequent adoption of the Decision-in-principle. Partly this was due to the fact that it contains a requirement for retrievability. What this requirement means in practice is still an open question. STUK is now in the process of producing, together with an advisory commission formed by outside experts, various implementing guides (YVL Guides) to further define how the Decree should be implemented.

At the same time, STUK is addressing a much neglected aspect of the final disposal. Together with the IAEA it is developing a nuclear safeguard concept for the future final disposal facility.

Continuous surveillance of the construction work of the ONKALO facility will also form an important part of STUK's work during the next ten years. This surveillance will be based on voluntary arrangements between Posiva Oy and STUK, since the Nuclear Energy Act gives STUK powers to control the activities on a site only after the construction license has been issued. Posiva Oy's motive to agree to these arrangements is, of course, the wish to facilitate a speedy handling of the future building-permit application.

The Ministry of Trade and Industry, on the other hand, is closely following that the nuclear power companies and particularly Posiva Oy are making, in an orderly and realistic way, progress in implementing the requirements of the strategy. The surveillance is based mostly on plans and reports submitted regularly for approval to the Ministry. The Ministry also recently made a decision to defer one of the remaining milestones of the strategy to a later date. The necessary material for a construction license application has now to be ready for submission in 2012 instead of 2010. The reasoning behind this change was simply that a rock characterisation facility, a step not envisaged in 1983, will greatly enhance the knowledge base for assessing the safety of the facility simultaneously allowing the actual construction time to be shortened.

4. Future prospects

The Director-General of the IAEA has characterised the global situation of the spent nuclear fuel management as a Catch-22 situation: one cannot make people to believe in the safety of the geologic disposal solution, because its feasibility has not been demonstrated, and its feasibility cannot be demonstrated otherwise than by building a facility. We in Finland are trying to break this Catch-22 situation.

The future perspectives of the spent nuclear fuel management in Finland may be summarised, in the light of the current strategy, as follows. The construction license for a final disposal facility will be issued around 2013. The facility will be in operation around 2020. And the operation of the facility will continue, as matters stand, to some distant future.

Everything seems to be proceeding fine, but there are also clouds in the horizon. These clouds are the ideas, being floated around, of regional disposal facilities. We in Finland are very afraid that the, if not exactly favourable but at least tolerable, attitude towards building a national final disposal 4 facility could suddenly change if a perception of a threat of transforming this facility into a regional “waste dump” would gain ground.

THE EVOLVING IMAGE AND ROLE OF THE REGULATOR FOR IMPLEMENTING REPOSITORIES FOR NUCLEAR WASTE AND SPENT NUCLEAR FUEL

Judith Melin
Director General, Swedish Nuclear Power Inspectorate, Sweden

A country introducing nuclear power in their energy strategy has a life long obligation. The obligation is not mainly a question of energy production. It is an obligation to maintain safety during the phase of construction, energy production and decommissioning as well as to take care of all the waste streams from nuclear installations.

I believe that one of the most controversial siting projects in the society is a waste repository for spent nuclear fuel. Competence, available funds and a clear responsibility between the stakeholders as well as the trust of the public is indispensable to obtain a good result. The Swedish programme for managing nuclear waste and spent nuclear fuel has been in progress for more than 25 years.

The pre-licensing process of a repository for spent nuclear fuel is much alike a pre-licensing process for the first nuclear power plant in a country. You need a clear political will, you have to involve the nuclear regulator without jeopardising his integrity and you need the money to perform research and make the investments. The enthusiasm of politicians and industry may however differ between these two projects.

1. A stepwise process is needed

Looking at the process so far it is obvious that finding a method and a site for a repository for spent nuclear fuel has to be a stepwise process comprising decisions made by the parliament, the government, the central authorities, the industry and the local governments. Starting with a broad approach with several options which will narrow down as experience and knowledge is evolving.

Let me give you an example how this stepwise process developed in Sweden.

1.1 Parliament and governmental decisions

- In *1972* the first commercial reactor was taken into operation. Nuclear industry took on the duty to rapidly find a solution for final disposal for spent nuclear fuel.
- In *1977* the parliament required that a condition taking additional nuclear power plants into operation was that industry presented a complete safe method for the final disposal of spent nuclear fuel-the “Stipulation Act”.

- In *1984* parliament launched a new act (the Act on Nuclear Activities). With the act four important decisions were taken:
  - The requirement "complete safe method" was changed into a "method acceptable with respect to safety and radiation protection".
  - The industry has to present a programme for research, development and demonstration (RDD). The government must every third year take a decision on the content of the RDD.
  - The industry should estimate the funds needed and also make funds available now and in the future for the final disposal for spent nuclear fuel. Funds needed have to be evaluated by SKI and are controlled by the government.
  - The complete responsibility for financing and finding a method and site for the spent nuclear fuel lies with the producer/permit holders of nuclear power.

The transfer of any burden to future generations should be prevented in the Swedish strategy for waste management. The government decided this goal.

The act from 1984 and the goal preventing any burden for future generations set the frame wherein the stakeholders should carry out their work.

1.2 Method

Since the mid-80s the nuclear industry's main strategy for managing the spent fuel is direct disposal in the bedrock. However it was first a few years ago, the Swedish Nuclear Power Inspectorate, (SKI) and the Swedish Radiation Protection Authority (SSI) as well as the government declared its believe that the method now developed by industry, the KBS-3 method, will be able to meet the regulatory requirements.

1.3 Selection of sites

It is by the Nuclear Act a clear responsibility for a permit holder of nuclear facilities to take all measures that are required for ensuring the safe handling and final storage of nuclear waste arising in the activities. Of course, the act will not by itself make the public accept a site for spent nuclear fuel. It is easy to realise that in a democratic regime a voluntary commitment is a necessary condition in the site selection process.

Consequently in order to fulfil their responsibility the nuclear industry in the shape of a jointly owned company, Swedish Nuclear Fuel Waste Management Co (SKB) in 1992 invited Swedish municipalities (about 90) to participate in the siting process. In total SKB has since 1992 been conducting feasibility studies in eight municipalities. Two of them decided on an early stage to terminate their participation. In the end of 2001 SKB proposed on the bases of the feasibility studies three sites for further investigations. SKI reviewed the feasibility studies and the government decided in accordance with the proposal of SKI that site investigations could proceed. After the review by regulatory bodies and after the government's decision, two of the municipalities accepted to participate in the further site investigations.

During the 10-year period, the municipalities involved have given their consent to each stage of the industries investigation programme. The need for consultation and involvement by the stakeholders (including the municipalities) did become apparent with the ongoing site selection process. The industry as well as the regulators factual statements has to be evaluated by the public. The responsible authorities, the Swedish Nuclear Power Inspectorate and the Swedish Radiation Protection Authority have during these ten years prioritised the task to support and engage in the dialogue with the municipalities. At the same time there was an increased request by the municipalities for the authorities to take an active role in the environmental impact assessment as the people's expert and at the same time maintaining the integrity as licensing authorities.

1.4 Safety and radiation protection requirements

Some years ago general regulations were elaborated on safety and radiation protection, as follows:

- *The technical solution should comprise several passive barriers*. The safety may never depend on one single barrier. The barriers in the Swedish KBS-3 concept comprise the fuel, the canister, the bentonite and the rock.
- *Leakage out of the barriers should not exceed the radiation protection requirements*. These requirements are quite firm: The repository should only give an insignificant addition to the doses received by the population from nuclear power today.
- *The construction must withstand external events* such as earthquakes, glaciation periods and human activities.
- The safety analyses should also, beside some of above topics, comprise *uncertainties in estimates and lack of knowledge* in certain areas.
- Environmental impact assessments have to be carried out.

These are general requirements. More specific requirements will be elaborated as the construction and licensing process evolves.

2. Four challenges

This brings me to the four challenges the society has to face relating to the stepwise process during the process leading up to the licensing of a repository for spent nuclear fuel.

2.1 Economic challenge

Funds should be made available to cover all costs for research, development, construction and operation for a final repository for spent nuclear fuel. In Sweden these costs are internalised – that is, the costs are included in the costs for the production of nuclear energy. A fee based on energy production builds up the fund. A governmental body administrates the fund. Based on plans and calculations submitted by the industry it is the task of SKI to verify the industries calculations for the future costs for research, development, construction and operation. On basis of these estimations the government propose the size of the fee. The fund was established in 1992 and amounted in the year of 2003 to 30 billion Swedish Crowns (about 3 billion euros). Each reactor pays a fee for 25 years. This means that the fees will be paid until the year of 2010 when the latest constructed reactor taken into operation has reached the age of 25 years.

2.2 Safety challenge

Technical solutions and the methods to develop them have to have the necessary quality to fulfil the regulators requirements in the safety analyses, evidently a task for the regulator.

2.3 Scientific challenge

To identify all possible factors to be considered in the safety, radiation protection and environmental analyses of the repository. This could for instance mean the influence of the chemical and biological environment on the repository. In Sweden this is the task for the licensees. The regulatory bodies evaluate the results. There must therefore be a substantive research programme to identify the scientific challenges and give answers to all the questions raised. According to the Swedish Nuclear Act the industry has to report every third year to the government on their programme and findings with respect to research, development and demonstration for a repository for spent nuclear fuel. The regulatory bodies, prior any decision taken by the government, evaluate the programme.

2.4 Democratic challenge

It is essential to involve all stakeholders. This is not only a matter of information; it is a matter of education and communication. The decision-making process must be transparent and it must involve the public concerned as well as the politicians on all levels. It is essential that municipalities who are prepared to take part in the siting process are able to receive all the answers they need in order to make a decision whether to accept or not to accept a repository for disposal of spent nuclear fuel. In addition the municipalities must have the competence to understand the safety assessment reviewed by the regulatory bodies on proposals submitted by the licensee. It is important that the regulators are prepared to support the municipalities as independent actors on behalf of the public.

We must remember that we as Nuclear Safety Regulators have a mission in the service of the public. We are by the public seen as guarantor for the safety of nuclear installations in our countries. Our aim must be that the public trusts our work and judgments.

2.4.1 Trust means an investment in expertise, independence and communication

I would like to stress that trust may only be obtained by demonstrating expertise, independence and by a good communication with the public.

It is easy to realise that one pre requirement for the public to trust our actions and policies to maintain and improve safety is the openness with respect to our decisions and considerations.

2.4.2 Openness means to be active

We have to realise that the right of insight into the documentation of the authorities or the government is only one part of openness. Openness is also a question of being active in informing about our decisions, our policy our oversight strategy or other questions related to safety. Openness is also a matter of being prepared to answer questions, to discuss and to exchange views with the public or organisations. The importance for us (SKI) as a regulator to communicate has been stressed by the

Swedish government by stating, in the letter of Appropriation, that one of our (SKI's) main objectives should be to report and inform.

One question which might arise is weather openness is improving safety at Nuclear installations. I would say that this is the case. You may see the public as inspectors of decisions and considerations we make as authorities. We must remember that a continuous discussion with stakeholders on issues related to safety will most certainly enhance quality in our decisions and increase knowledge and experience. However it is important to be realistic and realise that openness towards the public may not be introduced from one day to another. It takes years before it will have an influence on trust. In Sweden we have by Law a "transparent government" for more than 200 years.

2.4.3 Investing in trust

Trust means that you have to invest in an independent regulator, with an open attitude and with the capacity and competence to review the safety assessment done by industry. You have also to invest in the regulators' ability to act as the people's expert in stretching industry. At the same time the regulator must be open to be stretched by stakeholders and the public at large. You have also to invest in a legal framework, which clearly state the responsibility between industry and the regulatory bodies.

When we are able to meet all these challenges and with that also involve industry, regulators and the public, we will have a good chance to find an acceptable site and a method for a repository for spent nuclear fuel.

CHALLENGES TO A SUCCESSFUL WASTE MANAGEMENT PROGRAMME

Yves Le Bars
Chairman of the Board, Andra, Chairman of EDRAM, Chairman of the FSC (OECD/NEA)

I have chosen to testify about my personal experience as a practitioner in the development and implementation of sensitive public policies and about some of the lessons I have learnt in various related fields. Those fields do not only include Andra, but also the exchanges from which I benefit within EDRAM, the club (that I currently chair) of agency directors responsible for those programmes, as well as within the Forum for Stakeholder Confidence (FSC) of the OECD/NEA. Last but not least, I would also introduce some lessons from my previous activities in the city planning, and in the management of water projects.

In order to succeed, a sound policy relating to a sustainable radioactive-waste management must be able to take up a certain number of challenges. Three of those challenges seem essential to me:

- combining the technical and social aspects of the issue;
- organising a suitable context in which the definition and the implementation of the policy will take place; and
- achieving a solid implementation locally.

1. Combining the technical and the societal aspects

For the long-term management of the most radioactive waste the first challenge is probably the most difficult one: to merge the technological rationale with the societal frame of mind.

For technicians such as most of us are, waste appears basically as a technical issue: we know how to describe it, how to characterise it, how to categorise it and even explain how we take over responsibility for it. However, experience has taught us that waste is also perceived as a social issue to which public opinion often links some forms of risk that we do not always understand. We know that it is actually hard for engineers, who work directly on the subject, to accept the fact that the reality of an object depends primarily on the way people perceive it.

Understanding and accepting such a reversal of values is the first major turning point to pass. It is not natural for an engineer like me not only to see things as they are perceived rather than how they really are, and also to consider the little confidence we inspire.

1.1 What is the situation today?

From a technical standpoint, it is fair to mention that the results of the R&D programmes have proven increasingly positive in several countries in confirming the feasibility of a waste repository in a deep geological formation. We see, for example, the progress achieved by Finland, the United States, Sweden and France in their programmes on specific sites. Such feasibility is even demonstrated in a reversibility rationale, as it is the case in French research and development projects.

From a societal standpoint, it is important to note a high level of reluctance. In a public-opinion survey, 76% of French citizens felt that "the management of radioactive waste remains an unresolved issue" (BVA IRSN 1999), while 46% of Europeans even believe that "no solution really exists" (Eurobarometer 2001). 65% of the French agree with the statement that "they are not being told the whole truth about the hazards of radioactive waste".

1.2 What shall we do then?

First and foremost, we have to make better attempts at grasping what lies behind that difference of approach between technologists and society.

Let us start by eliminating the adjective "irrational" from our vocabulary when qualifying the attitude of the public. It is not because we don't understand how people perceive the hazards associated with high-level long-lived radioactive waste that it automatically makes their behaviour irrational. Caution would be most advisable in this case especially when a word such as "irrational" enters into the debate, because it may increase the feeling among the public that we are unable or unwilling to understand what the public truly feels. Such responses on our part may even contribute in the end to widen the misunderstanding. Conversely, let's also recognise our own irrational behaviour, which is far from absent from discussions: are we 100% sure of the rationality of all our arguments? Are we using specific comparisons only for reassuring people, notably when we refer to the small volume of radioactive waste "that would fit within an Olympic swimming pool".

We must spend more time at understanding why waste is such a particular issue, how it is perceived by the population, and what symbols it conveys. Such efforts call for qualitative analyses, such as the one undertaken by Andra with the French Research Centre for the Study and Observation of Living Conditions (known as *Crédoc*) and a certain number of personalities. A brochure written in French was published recently; if it were to be translated into English, its title would sound something like *Should we be afraid of radioactive waste?*

Another particular observation is worthy of mention: for the first time, it has been recognised that society is not in a position anymore to ignore those items that are not degradable either biologically or technologically, irrespective of the hopes invested in the transmutation of certain radionuclides. However, our societies seem to rely on oblivion as some form of therapy to maintain their mental stability, and the 20th century is full of examples of that collective forgetfulness. In the case of radioactive waste, such behaviour is no longer considered to be tolerable.

1.3 Is it possible for public opinion to evolve?

Oblivion is unacceptable as a solution; that form of rejection is often used by people who even refuse to discuss the matter, so much so that nuclear operators work in relative isolation from public opinion.

However, I am pretty sure that the same public opinion is also able to evolve.

During the 1970s, I had the opportunity to work on the implementation of a tramway system in a medium-size French town. At that time, people considered that means of transport as an outdated, noisy and dangerous reminiscence of an obsolete and long-rid past. Today, tramway cars appear on the cover page of many brochures celebrating the quality of life in communities using them for public transport: they have become a symbol of modernity.

Time is needed to allow each individual to discover his or her true interests in life, a path that is not always that obvious, since each and everyone of us is torn between contradictory attitudes one must reconcile at all times.

Time is needed to allow each individual to evolve from "a rejecting attitude simply to ignore a problem" to that of a citizen who assumes full responsibility for the impact of his or her activities as a consumer.

The credibility of technologists in the eyes of the public – in comparison to their technical expertise – is a key factor in the potential evolution of public opinion.

From it derive:

- the required freedom of thought and speech that each expert must have in response to economical and social challenges: let's then avoid to provide any suspicious grounds for the public to think that we are trying to please or spare anybody in our conclusions; and
- the need not only to mobilise a broad diversity of experts and research teams, but also to develop a wider outreach to public criticism.

Consequently, we are invited to a dual set of activities in our capacities as operators, policy makers and other stakeholders: a reflection on ourselves and a joint effort with public opinion.

Each time we succeed, we contribute to the solution of a more general and crucial question, that is, the place of experts in society. Even if the nuclear issue served as a catalyst in this case, the issue also concerns the climate, the food-processing industry, medicine, and everything else pertaining to public health and the environment, or to sum it up briefly, all long-term and very-long-term effects.

I shall be a little briefer on the next two challenges: the organisation of the context of an effective public dialogue and the success of local implementations.

2. Organising a suitable context

The second challenge involves the setting up of the necessary technical and social framework to develop a public policy, in other words, the stage or the platform for public participation and policy making.

Each society has it own decision-making process based on its history, its culture and the confidence of its stakeholders in all the different actors involved. It is obvious that matters are not handled the same way in Washington, Stockholm or Beijing.

However, the different past experiences in radioactive waste management all agree on one point: with the Forum on Stakeholder Confidence, we say that it is essential to structure that long-term process, to define its responsible actors and to demand transparency in their behaviour.

Such a stepwise procedure, with firm deadlines, proposes and reviews various alternatives, includes the selection of sites, mobilises research, calls upon an independent assessment and provides debate platforms with a view to promoting a mutual apprenticeship among the different partners. It also authorises any concerned party to be involved in the project.

The process is divided in several steps, also known as "adaptive staging" in the United States.

The definition of that process and of its actors does not simply come out of the blue: it must be negotiated. It is not an easy task when influential stakeholders, such as anti-nuclear associations, are not convinced that it is necessary to go forward.

However, a new idea is slowly taking shape that the long-term management of radioactive waste must be successful irrespective of future energy choices. The waste exists, and that is a given fact; since our generation produced the waste, it must therefore assume responsibility for it. 80% of European citizens have said that "the nuclear-waste issue is the responsibility of the generation that benefited from nuclear power" (see Eurobarometer). The fact that countries with different energy policies actually follow the same common approach is a valid demonstration of that concept.

Simply look at the situation in Sweden, Finland, France and Germany. The structure of the nuclear actors and their responsibilities were first defined according to a post-war context, where there was basically only one actor. Today, such a rationale is totally obsolete to address the social dimension of the waste issue.

If we succeed in taking up the challenge to structure a suitable platform for public participation in the process of defining and implementing a sensitive public policy, we will have contributed to the resolution of at least one key issue of our times, that is the broad relationship between science and society, and in practical terms, an efficient method to make "democratic" choices on technical matters. Such an approach would also be beneficial to the definition of other public policies, such as GMOs, information technologies, biotechnologies, climate actions, etc.

3. Achieving a solid implementation locally

The third challenge brings us in direct contact with the people that will be ultimately concerned, that is, at the local level. It constitutes a key aspect of the process that several programmes have failed to resolve because it is not easy to initiate a local debate when an overall feeling of rejection prevails among the population.

The way to address that opposition is always very delicate and the history of each programme is a determining factor. However, by drawing upon the experience of several successful people, one may derive the following conclusions:

- the important thing to do before even approaching any potential implementation area is to hold guarantees on three essential subjects: health and safety, local development and possibility of an open debate; and
- the second element is how should the definition of potential sites be oriented: where to go, which communities to contact first?

3.1 Three guarantees

3.1.1 Health and safety

The first guarantee in any local endeavour is to ensure health and safety at any given time, whether the short term, the medium term or the long term is concerned. The existence of a national consensus on the relevant means to ensure health and safety would certainly facilitate the definition of the sites to be investigated and the selection of the final implementation site. That is already the case in Sweden and Finland with the KBS III concept.

In France and in the United States, safety authorities have prepared and published the principles to be taken into consideration under the various specific geological conditions of a potential repository.

3.1.2 Local development

The second guarantee concerns the recognition that deserves any community accepting to host a facility. That means more particularly that – from the very moment that health and safety have been recognised as the main priority – development opportunities must be offered to all local and regional authorities agreeing to involve themselves in the process.

In France, the Law of 1991 prescribes the creation of a specific public interest group in each department concerned and run by the department itself, in order to distribute two yearly subsidies of 1.5 M€. In an effort to compensate for the concerns associated with the negative aspects of waste management, Canada, for example, is offering a compensation if the real-estate value of buildings were to drop in a community hosting a waste disposal facility. In the United States, the WIPP facility where military waste is disposed of, provides 25% of employment for the local town of Carlsbad and close to 30% of its resources. In France, the surface disposal facility located in the Aube Department was quite instrumental in the development of the local community, compared to the decline of the population observed in the vicinity.

3.1.3 Open debate

The third and last guarantee consists in providing an opportunity for all those who feel concerned and wish to participate in the process to voice their views and their questions.

In order to achieve that goal, the existence of a permanent platform, such as the Local Information and Follow-up Committee associated with the Underground Laboratory in Bure, in France, may prove useful.

International outreach may also prove very fruitful for the different stakeholders. The promotion of bilateral exchanges through European projects, such as COWAM, or within the OECD/NEA Forum for Stakeholder Confidence (FSC), is in line with that approach. It also improves the quality of the local debate in each country.

As a matter of fact, a constant care has been observed in all countries to respect the role of local elected officials. They must be involved very early in the process in order to have the opportunity to organise discussions on the assessment of the projects. Certain countries provide a formal veto right to their local communities (such as Finland, and also Switzerland until recently), but such a right is often informal, as in Sweden or in France.

Another observation to take into account is that, during difficult discussions, some people simply shift their responsibility for their denial of radioactive waste in their vicinity or their refusal to make a decision on the organisation in charge of the waste. That organisation then becomes a scapegoat protecting the peace of mind of its opponents. That type of situation does exist in France, but other agencies have also experienced it or are still doing so.

An effort of scientific culture is useful at the local level in order for the different local stakeholders to acquire sufficient information to understand the safety factors at stake. A programme of scientific and technical culture, not restricted to radioactive waste or nuclear energy, but encompassing all natural and industrial hazards is contemplated in the Meuse Department.

3.2 Selection of potential sites

However, once those three guarantees have been recognised and granted, how should the definition of potential sites be oriented? There is actually no universal rule, but some factors seem to facilitate the approach. Let me propose three:

- Since there is no consensus on the risks associated with artificial radioactivity, it is much easier to discuss with local communities that already have some experience of radioactivity because they are already hosting a nuclear facility and have learnt to live with it. Such is the case in Sweden, Finland and the United States.
- It is better to aim at the most widespread geological formation in the country, if only to facilitate the selection of the safest disposal concepts before searching for a suitable site. Such is the case in France and in Germany.
- It is appropriate to minimise conflicts in the use of the territory, but to allow for local authorities to submit applications during the process with a view to showing their interest in hosting a radioactive-waste repository. Local communities should be put in a position to appreciate the advantages of volunteer applications.

Conclusion

In conclusion, let me simply summarise the three challenges I wanted to highlight to you today:

- a reflection effort on ourselves with the support of public opinion in order to take into account the joint social and technical aspects of the issue, seeking to overcome the current misunderstanding and to act upon the factors of our credibility;
- the negotiated implementation of stable processes, the “setting-up of a suitable platform” to discuss the issue of radioactive-waste management and to investigate alternatives with a consistent structure of actors; and
- lastly, a successful local implementation through relevant preparatory work in order not only to provide suitable guarantees to local populations with regard to health and safety, local development and openness of debate, but also to orient our efforts towards those communities that already have shown a minimum level of understanding to the proposed approach.

If we succeed in those endeavours, we shall have resolved the sensitive issue of managing the radioactive waste resulting from the production of electricity.

Furthermore, beyond our current concern, we shall have shown the way towards the solution of the most difficult problem of our developed societies, that of identifying specific activities perceived as hazardous.

SUMMARY OF DAY 1 – INTERNATIONAL PERSPECTIVES

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The interest of this first session was to have presentations by genuine policy makers, i.e., by people directly involved in the political process by which society deals with its technological challenges. There was general agreement that progress is continuously being made, to the point that technological aspects of geologic disposal may be considered to have been solved.

Although further progress will surely be made, no major breakthrough is expected in this area and many consider the technology to be mature.

This is only one side of the waste disposal issue however. The other side, which covers socio-political issues, is far from having been resolved. Progress has been made, in the sense that technologists accept that they need help from other, non technical groups in society. This is a complex issue because whereas technology, like science, is universal and easily lends itself to international co-operation, socio-political issues are closely connected to the continuous evolution of one particular national society. Here, international co-operation may mean following what others are doing, but not necessarily copying their approach.

All national societies may draw technical help from a common international pool of knowledge, but each one will weave it into its national fabric, in its own specific way.

As one example, the so-called "Swedish model" for geologic disposal cannot necessarily be directly transposed to other countries.

Little was said in presentations about "the future" except for the fact that because of the very long lead times that are usual in this field (20 to 50 years) there may exist a trend to believe that the future, 20 or 30 years from now will be a continuation of the present.

This is a plausible assumption for technologies, but need not be true for socio-political developments. We cannot predict the future but we should not assume that we know what it will look like. In our policies we must therefore not only have a clear idea of where we want to go, but also favour flexible approaches that we may modify if required. Above all, we must never loose from sight that our ultimate goal is to ensure the safety of geological waste disposal.

PLENARY SESSION

RISK IN TECHNICAL AND SCIENTIFIC STUDIES: GENERAL INTRODUCTION TO UNCERTAINTY MANAGEMENT AND THE CONCEPT OF RISK

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The management of uncertainty has always been of concern to nuclear reactor designers and regulators. Before Probabilistic Safety Assessment (PSA), uncertainties in the frequencies of accidents could not be quantified and the nuclear community developed the concept of defense-in-depth to assure that these frequencies were very low. After PSA (roughly, after 1975), some of the frequencies could be quantified and, in addition, the major accident sequences could be identified.

A comparison of the pre-PSA and post-PSA thinking provides useful insights regarding the value of the systems approach that PSA takes. Before PSA, the situation was as follows:

1. The core damage frequency (CDF) was not quantified but was thought to be very low.
2. The accident consequences were thought to be disastrous [1]. To keep a very low CDF, a precautionary attitude prevailed leading to:
   i) Conservatives designs and operations.
   ii) The defense-in-depth philosophy.
   iii) Large safety margins.

Defense in depth was the cornerstone of the safety philosophy. It was formally defined much later (in 1999) by the US Nuclear Regulatory Commission (USNRC) as: "Defense-in-Depth is an element of the Nuclear Regulatory Commission's safety philosophy that employs successive compensatory measures to prevent accidents or mitigate damage if a malfunction, accident, or naturally caused event occurs at a nuclear facility."

The publication of the Reactor Safety Study (RSS) in 1975 and subsequent PSAs performed worldwide changed the approach to safety. The plants were analysed as integrated socio-technical systems. This new approach revealed that:

1. There were important contributors to risk (e.g., interfacing systems LOCA) that were previously unknown.
2. CDF estimates were higher than previously believed.
3. Accident consequences were significantly smaller.
4. Many regulatory requirements that had been imposed in the name of defense-in-depth did not contribute significantly to safety.

This comparison leads to the following insights:

1. Beliefs based on "deterministic" analyses without a risk assessment can be wrong.
2. Precautionary (defense-in-depth) measures are not always conservative – some important failure modes were missed.
3. In some instances, unnecessary regulatory burden was imposed on the licensees wasting valuable resources.

Since PSA provides quantitative estimates of accident frequencies, both industry and regulators have focused on the uncertainties in these estimates. A systematic way to deal with these uncertainties is provided by the subjectivistic theory of probability [2]. The application of this theory to PSA proceeds as follows [3] [4]: The "model of the world" (MOW) is the mathematical model that is constructed for the physical situation of interest, such as the occurrence and impact on a system of a physical phenomenon. The "world" is defined as "the object about which the person is concerned [5]." There are two types of models of the world: deterministic and probabilistic. Examples of deterministic MOWs are the various mechanistic codes that we use, e.g., thermal-hydraulic codes. However, many important phenomena cannot be modelled by deterministic expressions. For example, the occurrences of earthquakes exhibit variability that we cannot eliminate; it is impossible for us to predict when the next earthquake will occur. We, then, construct models of the world that include this uncertainty. A simple example is the Poisson model for the probability of occurrence of k events in a period of time (0, t), i.e.

$$\Pr[k / \lambda, H] = \frac{e^{-\lambda t}(\lambda t)^k}{k\,!}, \quad k = 0, 1, 2,... \qquad (1)$$

The argument of this expression shows explicitly that this probability is conditional on our knowing the numerical value of a parameter, namely, the occurrence rate λ, as well as on our accepting the assumption H = {the times between successive events are independent}. As with all probabilities, it is understood that this probability is also conditional on the totality of our knowledge and experience.The uncertainty described by the model of the world is sometimes referred to as "randomness," or "stochastic uncertainty." Because these terms are used in other contexts also, these models have recently been called *aleatory* models.

As stated above, each model of the world is conditional on the validity of its assumptions, H, and on the numerical values of its parameters, e.g. λ. Since there may be uncertainty associated with these conditions, we introduce the *epistemic* probability model, which represents our knowledge regarding the numerical values of the parameters and the validity of the model assumptions. Uncertainties in assumptions are usually handled via sensitivity analyses or by eliciting expert opinions. Parameter uncertainties are reflected on appropriate probability distributions. For example, for the Poisson rate: $\pi(\lambda)d\lambda$ = Pr (the rate has a value in dλ about λ). We note that the distinction between aleatory and epistemic uncertainties is introduced for modelling purposes and communication. This distinction is not always clear in practice. Conceptually, there is no difference (there is only one interpretation of probability, that of degree-of-belief) [6].

PSA is a scenario-based approach. It is useful to think of it as a set of triplets [7]:

$$R = \{< s_i, \pi_i(\varphi_i), c_i >\} \qquad (2)$$

where

s_i: scenario i, i = 1,…,N

φ_i: frequency of s_i (aleatory uncertainty)

π_i: probability density function (pdf) of φ_i (epistemic uncertainty)

c_i : consequence i

All modern PSAs for technological systems identify scenarios and rank them according to their frequencies.

Equation (2) can be the basis for a discussion on uncertainties by asking the following questions:

- Is the scenario list complete? (Incompleteness uncertainty).
- Are the models in the scenarios accepted as being reasonable? (Model uncertainty).
- Are the epistemic pdfs of the scenario frequencies representative of the current state of knowledge of the community? (Parameter uncertainty).

As stated above, uncertainties in assumptions are usually handled via sensitivity analyses or by eliciting expert opinions [8] [9]. Since the PSAs are usually performed to help a government agency to make decisions, they should represent the views of the wider expert community and not just the experts who were involved in the study.

The consequences of these uncertainties are:

1. Decision making must be risk-informed, not risk-based.
2. Traditional safety methods, such as defense-in-depth, have a role to play.
3. It is difficult to assess how much defense-in-depth is sufficient.

Regarding defense-in-depth (DID), two interpretations have been proposed [10]. The structuralist interpretation asserts that DID is embodied in the structure of regulations and in the design of the facilities built to comply with those regulations. The designers continually ask the question: "What if this barrier or safety feature fails?" The rationalist interpretation asserts that DID is the aggregate of provisions made to compensate for uncertainty in our knowledge of accident initiation and progression. They both deal with uncertainty; however, the structuralist does not need a PSA, while the rationalist does.

Both interpretations have weaknesses. Arbitrary appeals to the structuralist interpretation of defense-in-depth might diminish the benefits of risk-informed regulation, such as the avoidance of unnecessary regulations. On the other hand, strict implementation of risk-informed regulation (the rationalist interpretation of DID) without appropriate consideration of the structuralist defense-in-depth could undermine the historical benefits, i.e., protection against unexpected events. The structuralist interpretation is more appropriate when large uncertainties due to scenario incompleteness and model inadequacy are present.

Reference 10 proposes a "pragmatic" approach, i.e., apply defense-in-depth (the structuralist approach) at a high level, and implement the rationalist approach at lower levels, except when PSA models are incomplete, in which case one should revert to the structuralist approach.

The USNRC is now risk-informing its regulations [11]. Risk-informed decisions use epistemic mean values from the PSA to compare with various goals. When the mean value of a risk metric approaches the goal, the USNRC staff warns that there will be "increased management attention," which means that the analysis will undergo significant scrutiny.

Although the appropriate framework for analysing uncertainties is in place, formal guidance as to how these uncertainties should be taken into account in risk-informed decision making is not available at this time.

References

[1] Beckjord, E.S., M.C. Cunningham and J.A. Murphy (1993), "Probabilistic Safety Assessment Development in the United States 1972-1990," *Reliability Engineering and System Safety*, 39 pp. 159-170.

[2] De Finetti B (1974), *Theory of Probability,* Vols. 1 and 2, Wiley, New York.

[3] Apostolakis G. (1990), "The Concept of Probability in Safety Assessments of Technological Systems," *Science*, 250, pp. 1359-1364.

[4] Apostolakis G.E. (1994), "A Commentary on Model Uncertainty," in: *Proceedings of Workshop on Model Uncertainty: Its Characterization and Quantification*, Report NUREG/CP-0138, US Nuclear Regulatory Commission, Washington, DC.

[5] Savage L.J. (1972), *The Foundations of Statistics,* Dover Publications, New York.

[6] Winkler R.L. (1996), "Uncertainty in Probabilistic Risk Assessment," *Reliability Engineering and System Safety,* 54, pp. 127.

[7] Kaplan S. and B.J. Garrick (1981), "On the Quantitative Definition of Risk," *Risk Analysis* 1, p. 11.

[8] Budnitz R.J., G. Apostolakis, D.M. Boore, L.S. Cluff, K.J. Coppersmith, C.A. Cornell, and P.A. Morris (1998), "Use of Technical Expert Panels: Applications to Probabilistic Seismic Hazard Analysis," *Risk Analysis*, 18, pp. 463-469.

[9] Zio E. and G.E. Apostolakis (1996), "Two Methods for the Structured Assessment of Model Uncertainty by Experts in Performance Assessments of Radioactive Waste Repositories," *Reliability Engineering and System Safety*, 54, pp. 225-241.

[10] Sorensen J.N., G.E. Apostolakis, T.S. Kress, and D.A. Powers (1999), "On the Role of Defense-in-Depth in Risk-Informed Regulation," *Proceedings of PSA '99, International Topical Meeting on Probabilistic Safety Assessment*, pp. 408-413, Washington, DC, August 22-26, American Nuclear Society, La Grange Park, Illinois.

[11] Caruso M.A., M.C. Cheok, M.A. Cunningham, G.M. Holahan, T.L. King, G.W. Parry, A.M. Ramey-Smith, M.P. Rubin and A.C. Thadani (1998), "An Approach for using Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis," Reliability Engineering and System Safety, 63, pp. 231-242 (also known as Regulatory Guide 1.174).

RISK PERCEPTION AS A FACTOR IN POLICY AND DECISION MAKING

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Abstract

Risk perception is often believed to be an important factor in policy decision making, when it comes to the management of hazardous technology. Research on risk perception by the public since the 1970s has purportedly shown that such perception is emotional and based on ignorance. Experts, on the other hand, have been claimed to be objective and correct in their risk assessments. The present paper reviews a large body of research which has led to a quite different conclusions, viz. that emotions play only a marginal role in risk perception, which is mainly driven by ideological concerns and attitudes. The methodological shortcomings of the prevailing view of risk perception as emotional and simply misinformed are described.

Key words: risk perception, risk management, hazardous technology, attitude, emotion

Policy making in matters associated with risk is often difficult. The siting of nuclear waste repositories is one of the most dramatic examples. In many countries, such siting has run into what seems like almost intractable difficulties, due to local or national opposition. More generally, political decisions in matters of risk tend to be overly responsive to what is believed to be the public demands, resulting in skew allocations of resources to various safety programs [1-4]. This is so in spite of indications that people do not really demand, or accept, very skew resource allocations [5]. Politicians have, however, at times erroneous views of the public's beliefs and attitudes regarding risk [6].

Why should risk be important? We have repeatedly found risks to be more important than benefits [7, 8]. In related work, we found that people are more easily sensitised to risk than to safety [9]. Mood states have been found to be more influenced by negative expectations (risk) than by positive ones [10]. Tversky and Kahneman's Prospect Theory of decision making posits that monetary losses are more abhorred than corresponding gains are desired [11]. People seem to be more eager to avoid risks than to pursue chances.

In the case of nuclear waste, arguments voiced against proposed repository siting tend to center on risk, especially health risks of ionising radiation [9, 12, 13]. Such health concerns cannot be met with economic arguments about new jobs or other types of economic compensation, at least not in all cultures and countries where the problem arises. However, some studies have found that the most affected sub-populations, those living closest to a proposed site, may be positive while those living in the same larger region are negative [14]. It is possible that such differences reflect the effects of economic factors, as well as – in some cases – familiarity with nuclear facilities and job experience in the nuclear industry [8].

The opposition to a siting project may take different routes to exert political influence on the process. Regional opposition, as reflected for example in state level decisions in the USA, may be very strong in spite of local up-backing of a project. At the national level, we see in Sweden that politicians currently assume a very low profile, arguing that the matter is for local authorities to decide [15]. This is, of course, only part of the truth because a possibility of over-ruling a local veto exists, as a final measure [16-18].

In addition, the whole siting issue is intimately connected to national energy policy. It remains to be seen how national policy will be developed in the coming years, when some very hard decisions have to be taken. Earlier experience, from the 1970s, shows that many voters were likely to change their traditional political preferences on the basis of energy policy options. The political situation was de-stabilised due to the nuclear power controversy, resulting in a change of government in 1976, the break-up of a coalition government in 1978 and a nuclear referendum in 1980, following the TMI accident in the USA. Temporary opinion changes have later been observed, and new political turbulence has resulted, such as the events following the Chernobyl accident in 1986 [19]. Much of contemporary political thinking seems to be governed by the belief that a new nuclear disaster, somewhere in the world, will lead to new political demands for the fast phasing out of nuclear power.

Research basis of policy beliefs

Hence, policy making in matters of risk and hazard is very hard and it is to some extent governed by beliefs about the public's fear and volatility of beliefs, driven by such external events as foreign nuclear accidents and disasters. These political beliefs have been backed up by social and behavioural research on the public's risk perception, carried out mainly in the USA, since the end of the 1970's. There are two major approaches, called Cultural Theory of Risk Perception, and the Psychometric Paradigm.

In 1982, Mary Douglas and Aaron Wildavsky published their book "Risk and Culture" [20], where they suggested a complicated theory of risk perception, termed the Cultural Theory of Risk Perception. Briefly, it amounted to a typology where people were regarded as egalitarians, individualists, hierarchists and fatalists. Membership in any of these categories was socially functional. These groups were said to "choose" different hazards to be concerned about, suggesting that risk beliefs were little reality oriented, and mostly socially motivated. Empirical data published by Wildavsky and Dake seemed to support the theory [21].

The theoretical background and formulation of Cultural Theory was criticised by Boholm [22]. Empirical work on the theory was critically assessed by Sjöberg [23]. Although culture is a broad concept covering important factors, the work by Douglas and Wildavsky treats culture only in a very limited, speculative and highly restrained manner. Later work by anthropologists such as Åsa Boholm [24, 25] is more promising but has not yet reached a stage where more definite statements can be made.

More extensive work on risk perception was carried out by an American group led by Baruch Fischhoff and Paul Slovic, both of them psychologists. This work is often summarised under the heading "The Psychometric Paradigm". Fischhoff and Slovic claimed that "dread" is the main factor driving attitudes to hazardous technology such as the nuclear one [26-29]. Another important factor according to them was novelty of a risk, and ignorance of it. A two-dimensional system (Dread vs. New Risk) was used to describe a large number of hazards, and nuclear technology was found to be extreme in both respects: highly dreaded and new and unknown. Parallel to this work, social trust has been claimed to be another important determinant of perceived risk [30].

In the original work, and much of the later one as well, no risk target was specified. It is clear, however, that risks are judged differently when pertaining to one's own person (personal risk) or to others (general risk). In most cases, personal risk is judged as smaller than general risk, a finding related to the unrealistic optimism affecting health related beliefs, as documented by Weinstein [31, 32]. The two types of risk also have different correlates, general risk being related to policy attitudes especially for lifestyle hazards (smoking, drinking alcohol, etc). When no target is specified, people seem to judge general rather than personal risks [33, 34].

Slovic and other researchers went on to formulate, in the 1980's, a "stigma theory" which posits that hazardous facilities create a stigma of an area, leading to loss of economic opportunities and also to people living there being ostracised in the wider society [35]. The most recent work in the Psychometric Paradigm claims that "affect" is important in driving perceived risk [36, 37].

Experts have also been investigated, to a limited extent [38, 39]. On the basis of a very small sample of risk analysts (N=12), it was concluded that experts make "objective" risk judgments, unaffected by factors which were found to be important in the case of the public (dread, novelty). This early work was critically assessed only recently [40, 41]. Apart from the sample being very small, the studied risk analysts could not have had expertise in the many and very varied topics investigated, from nuclear power plants to mountain climbing. In this work, it seemed that experts made correct risk judgments, and that they were not affected by such factors as emotions or ignorance.

Summing up, risk perception work appeared to imply that the public reacts emotionally, and out of ignorance, with regard to their risk perceptions. Experts are, in contrast to the public, objective and correct in their risk perceptions, which are not contaminated by emotions and other biasing factors. Trust in experts could re-establish the gap between the experts and the public, trust being a very important factor in perceived risk.

This work has enjoyed a wide-spread credibility, in spite of serious weaknesses which I now briefly review.

Assessment of the prevailing views of risk perception

Nine critical points will be made here:

1. The models proposed seemed to be very powerful in accounting for perceived risk and risk acceptance, but that was an illusion, based on misleading data analysis [42]. Mean values were used in regression analyses. When raw data and individual differences were analysed, amount of explained variance dropped from about 80 to 20 percent [43]. Considerable improvement has been achieved by introducing new factors in the original model, such as Interfering with Nature [44]. Another important factor, related to Interfering with Nature, is that of moral value [45]. Man-made disasters are reacted to very differently from natural disasters, in part because there is nobody to blame for natural disasters.

2. The original work on "dread" did not measure only emotion, but mainly judgments of the severity of consequences of an accident [46]. The dread item has turned out to have less explanatory value than the items measuring severity of consequences. Only recently, more emotion items have been introduced in the models [47].

3. The notion that "new risk" is very important in accounting for perceived risk has not been supported in current research [48, 49]. Novelty of a risk is a very marginal factor in risk perception. Besides, nuclear technology is hardly a new technology to-day, as it may have

seemed to be in the 1970's when the notion of novelty as a factor in risk perception was introduced.

4. "Stigma" has never been established as a factor, except as a *post hoc* explanation of a few cases. Stigma theory cannot be used to predict events, nor can it explain the large prevalence of non-stigma cases (the vast majority with regard to nuclear facilities) [50, 51].

5. Current beliefs that "affect" (emotion) is an important factor in risk perception are mainly based on the fact, well known in other literature [52, 53], that attitude tends to be strongly correlated with perceived risk. Researchers within the Psychometric Paradigm chose to use the word affect for what is more appropriately called attitude, thus giving rise to the erroneous belief that they had shown that emotions influenced risk perceptions [54].

6. The belief that risk policy attitudes are based on perceived risk misses at least two important qualifications. First, policy attitudes are based on perceived or expected consequences of e.g. an accident, not its risk (which is mainly interpreted as probability) [55, 56]. Probability tends to be ignored [57]. Second, attitude to a technology is largely based on beliefs regarding its benefits and whether it is indispensable or not, if viable alternatives exist [46, 58].

7. Social trust is fairly marginal when it comes to accounting for perceived risk [59, 60]. Trust in the value of science is more important. People may well think that experts are honest and competent, yet that their scientific basis is insufficiently well developed [61, 62], as Drottz-Sjöberg found in her work on attitudes, following the two local repository referenda that have been held in Sweden. More research is needed, in the eyes of many, or they even reject the value of science and opt for other notions of knowledge, such as those offered by New Age proponents. In studies especially oriented towards New Age beliefs and world views, it was found that such beliefs account for some 10-15 percent of the variance of risk perception [63, 64].

8. While experts tend to give lower risks estimates than the public, in their own area of expertise and responsibility, the structure of their risk perceptions is similar to that of the public's [41].

9. Cultural theory has failed to account for more than a tiny fraction of the variance of perceived risk [23, 64]. Small correlations between perceived risk and dimensions of Cultural Theory around 0.10 were termed "strong" by some researchers [65], but the explanatory power is just a few percent of the variance of perceived risk. The fact that there may be a practical use to some independent variables with such weak relationships to criteria, does not imply that they are useful in theoretical work [64].

Conclusion

Misconceptions based on the psychometric paradigm have indeed penetrated very far. Jasanoff [66] put the matter quite well in the following citation:

> *"The psychometric paradigm, in particular, has been instrumental in preserving a sharp dualism between lay and expert perceptions of risk, together with an asymmetrical emphasis on investigating and correcting distortions in lay people's assessments of environmental and health hazards. In policy settings, psychometric research has provided the scientific basis for a realist model of decision making that seeks to insulate*

supposedly rational expert judgments from contamination by irrational public fears". (p. 98).

The simple diagram, reproduced many times (see e.g. Slovic [27]), of the factors Dread and Novelty, seemed to show convincingly that people oppose nuclear power because they were emotional and ignorant. And, as Jasanoff points out, experts were widely held to be rational and objective in their risk perceptions. The widespread notion that policy decisions should ignore the public's perceived risk probably has some of its roots or at least considerable support in these conclusions from the psychometric model. It disregards the simple fact that the views of the public cannot and should not be ignored in a democracy [67, 68].

In our research, briefly summarised above, we have found a quite different picture of the risk perceiver, be he or she an expert or not. The dominating factors in risk perception are of an ideological character, such as attitude or beliefs that a technology is interfering with Nature. Three points need to be stressed in particular:

- Attitude is a very important factor. In the case of nuclear risk, attitude to nuclear technology is an important explanatory construct.
- Moral issues, intimately connected with notions about Nature, account for a large share of risk perceptions and attitudes.
- Trust in science emerges as a factor of great importance. The belief that the development of technology involves unknown dangers is very important, and it seems no less rational than not believing that such is the case. Science does develop all the time and risks we do not know about today will be discovered tomorrow. If experts say "there is no risk" this usually means "no risks have yet been discovered".

The dualism pointed to by Jasan off in the citation above takes on a very different meaning in the light of these new research results. The driving factor behind risk perceptions and attitudes is not emotion, nor is it ignorance, but ideology and related epistemological beliefs. Risk managers and risk communicators may become more successful than hitherto, if they take this image of the risk perceiver into account.

References

[1] Morrall, J.F. (1986), III, *A review of the record.* Regulation, (Nov/Dec): pp. 25-34.

[2] Tengs, O.T., *et al.* (1995), *Five-hundred life saving interventions and their cost effectiveness.* Risk Analysis. 15: pp. 369-390.

[3] Ramsberg, J. and L. Sjöberg (1997), *The cost-effectiveness of life saving interventions in Sweden.* Risk Analysis. 17: pp. 467-478.

[4] Sunstein, C.R. (2002), *Risk and reason. Safety, law, and the environment.* Cambridge University Press, Cambridge, United Kingdom.

[5] Ramsberg, J. and L. Sjöberg (1998), *The importance of cost and risk characteristics for attitudes towards lifesaving interventions.* Risk - Health, Safety & Environment. 9: pp. 271-290.

[6] Sjöberg, L. (1996), *Risk perceptions by politicians and the public*. Center for Risk Research, Stockholm.

[7] Sjöberg, L. (1999), *Risk perception in Western Europe.* Ambio. 28: pp. 543-549.

[8] Sjöberg, L., *Local acceptance of a high-level nuclear waste repository.* Risk Analysis, in press.

[9] Sjöberg, L. and B.-M. Drottz-Sjöberg (1993), *Attitudes to nuclear waste*. Center for Risk Research, Stockholm.

[10] Sjöberg, L. (1989), *Mood and expectation*, in *Cognition in individual and social contexts*, A.F. Bennett and K.M. McConkey, Editors. Elsevier, Amsterdam, pp. 337-348.

[11] Kahneman, D. and A. Tversky (1979), *Prospect theory: An analysis of decisions under risk.* Econometrica, 47: pp. 263-291.

[12] Sjöberg, L. and B.-M. Drottz-Sjöberg (1994), *Risk perception of nuclear waste: experts and the public*, Center for Risk Research, Stockholm School of Economics.

[13] Sjöberg, L. and B.-M. Drottz-Sjöberg (2001), *Fairness, risk and risk tolerance in the siting of a nuclear waste repository,* Journal of Risk Research, 4: pp. 75-102.

[14] Dunlap, R.E., M.E. Kraft, and E.A. Rosa (1993), eds. *Public reactions to nuclear waste*. Public reactions to nuclear waste, ed. R.E. Dunlap, M.E. Kraft, and E.A. Rosa., Duke University Press, Durham.

[15] Sjöberg, L., M. Viklund, and J. Truedsson (1999), *Attitudes and opposition in siting a high level nuclear waste repository*, in *Facility Siting: Issues and Perspectives*. Academia Sinica: Columbia Earthscape Research.

[16] Särskilde rådgivaren inom kärnavfallsområdet, *Plats för slutförvaring av kärnavfall? Förstudier i åtta kommuner. (A site for a final nuclear waste repository? Pilot studies in eight municipalities).* SOU. Vol. SOU 2002:46, 2002, Stockholm: Regeringskansliet.

[17] National Council for Nuclear Waste (KASAM) (2001), *Feasibility study municipalities in dialogue with the public: The examples of Nyköping, Oskarshamn and Tierp.* SOU 2001: 35, Stockholm: Government Printing Office.

[18] Sundqvist (2002), G., *The bedrock of opinion. Science, technology and society in the siting of high-level nuclear waste*. Dordrecht, the Netherlands: Kluwer.

[19] Sjöberg, L. and B.-M. Drottz (1987), "Psychological reactions to cancer risks after the Chernobyl accident". Medical Oncology and Tumor Pharmacotherapy, 4: pp. 259-271.

[20] Douglas, M. and A. Wildavsky (1982), *Risk and culture*. Berkeley, CA: University of California Press.

[21] Wildavsky, A. and K. Dake (1990), "Theories of risk perception: Who fears what and why?*"* in Daedalu*s*, pp. 41-60.

[22] Boholm (1996), Å. *The cultural theory of risk: an anthropological critique.* Ethnos, 61: pp. 64-84.

[23] Sjöberg (1997), L., *Explaining risk perception: An empirical and quantitative evaluation of cultural theory.* Risk Decision and Policy, 2: pp. 113-130.

[24.] Boholm (1998), Å. *Visual images and risk messages: commemorating Chernobyl.* Risk Decision and Policy, 3: pp. 125-143.

[25.] Boholm (2003), Å. *The cultural nature of risk: Can there be an anthropology of uncertainty?* Ethnos, 68(2): pp. 159-178.

[26.] Fischhoff (1978), B., et al., *How safe is safe enough? A psychometric study of attitudes towards technological risks and benefits.* Policy Sciences, 9: pp. 127-152.

[27.] Slovic (1987), P., *Perception of risk.* Science, 236: pp. 280-285.

[28.] Slovic (1991), P., J.H. Flynn, and M. Layman, *Perceived risk, trust, and the politics of nuclear waste.* Science, 254: pp. 1603-1607.

[29] Slovic, P. (2000), ed. *The perception of risk*, Earthscan, London.

[30] Flynn, J., *et al.* (1992), *Trust as a determinant of opposition to a high-level radioactive waste repository: Analysis of a structural model.* Risk Analysis, 12: pp. 417-429.

[31] Weinstein, N.D. (1989), *Optimistic biases about personal risks.* Science, 185: pp. 1232-1233.

[32] Weinstein, N.D. (1980), *Unrealistic optimism about future life events.* Journal of Personality and Social Psychology, 39: pp. 806-820.

[33] Sjöberg, L. (2000), *The different dynamics of personal and general risk*, in *Foresight and precaution. Volume 1*, M.P. Cottam, *et al*., Editors, A. A. Balkema: Rotterdam. pp. 1149-1155.

[34] Sjöberg, L. (2003), *The different dynamics of personal and general risk.* Risk Management: An International Journal, 5: pp. 19-34.

[35] Flynn, J., P. Slovic, and H. Kunreuther (2001), eds. *Risk, media, and stigma. Understanding public challenges to modern science and technology*, Earthscan: London.

[36] Loewenstein, G.F. (2001), *et al.*, *Risk as feelings.* Psychological Bulletin, 127: pp. 267-286.

[37] Finucane, M.L., *et al.* (2000), *The affect heuristic in judgments of risks and benefits.* Journal of Behavioral Decision Making, 13: pp. 1-17.

[38] Slovic, P., B. Fischhoff, and S. Lichtenstein (1979), *Rating the risks.* Environment, 21(3): pp. 14-20, 36-39.

[39] Fischhoff, B., P. Slovic, and S. Lichtenstein (1982), *Lay foibles and expert fables in judgments about risk.* American Statistician, 36: pp. 240-255.

[40] Rowe, G. and G. Wright (2001), *Differences in expert and lay judgments of risk: myth or reality?* Risk Analysis, 21: pp. 341-356.

[41] Sjöberg, L. (2002), *The allegedly simple structure of experts' risk perception: An urban legend in risk research.* Science, Technology and Human Values, 27: pp. 443-459.

[42] Sjöberg, L. (2002), *Are received risk perception models alive and well?* Risk Analysis, 22: pp. 665-670.

[43] Gardner, G.T. and L.C. Gould (1989), *Public perceptions of the risk and benefits of technology.* Risk Analysis, 9: pp. 225-242.

[44] Sjöberg, L. (2000), *Perceived risk and tampering with nature.* Journal of Risk Research, 3: pp. 353-367.

[45] Sjöberg, L. and E. Winroth (1986), *Risk, moral value of actions, and mood.* Scandinavian Journal of Psychology, 27: pp. 191-208.

[46] Sjöberg, L. (2003), *Risk perception, emotion, and policy: The case of nuclear technology.* European Review, 11: pp. 109-128.

[47] Lerner, J.S., *et al.* (2003), *Effects of fear and anger on perceived risks of terrorism: A national field experiment.* Psychological Science, 14: pp. 144-150.

[48] Sjöberg, L., *Explaining individual risk perception: the case of nuclear waste.* Risk Management: An International Journal, in press.

[49] Sjöberg, L., *The perceived risk of terrorism.* Risk Analysis, in press.

[50] Bassett, J., G. W. and R.C. Hemphill (1991), *Comments on "Perceived risk, stigma, and potential economic impact of a high-level nuclear waste repository in Nevada"*. Risk Analysis,. 11: pp. 697-700.

[51] Broström, L., et al. (2002), *Psykosociala effekter av ett djupförvar för använt kärnbränsle. Litterturöversikt och intervjuer med Uppsalabor. (Psychosocial effects of a depth repository for spent nuclear fuel. Literature review and interviews with residents of Uppsala)*, SKB: Stockholm.

[52] Sjöberg, L. (2000), *Factors in risk perception.* Risk Analysis, 20: pp. 1-11.

[53] Sjöberg, L. (2000), *Specifying factors in radiation risk perception.* Scandinavian Journal of Psychology, 41: pp. 169-174.

[54] Sjöberg, L., *Will the real meaning of affect please stand up?* Journal of Risk Research, in press.

[55] Sjöberg, L. (1999), *Consequences of perceived risk: Demand for mitigation.* Journal of Risk Research, 2: pp. 129-149.

[56] Sjöberg, L. (2000), *Consequences matter, "risk" is marginal.* Journal of Risk Research, 3: pp. 287-295.

[57] Sunstein, C.R. (2003), *Terrorism and probability neglect.* Journal of Risk and Uncertainty, 26: pp. 121-136.

[58] Sjöberg, L. (2002), *Attitudes to technology and risk: Going beyond what is immediately given.* Policy Sciences, 35: pp. 379-400.

[59] Sjöberg, L. (1999), *Perceived competence and motivation in industry and government as factors in risk perception*, in *Social trust and the management of risk*, G. Cvetkovich and R.E. Löfstedt, Editors, Earthscan: London. pp. 89-99.

[60] Viklund, M. (2003), *Trust and risk perception: a West European cross-national study.* Risk Analysis, 23: pp. 727-738.

[61] Drottz-Sjöberg, B.-M. (1996), *Stämningar i Storuman efter folkomröstningen om ett djupförvar. (Moods in Storuman after the repository referendum)*, SKB: Stockholm.

[62] Drottz-Sjöberg, B.-M. (1998), *Stämningar i Malå efter folkomröstningen 1997. (Moods in Malå after the 1997 referendum)*. SKB: Stockholm.

[63] Sjöberg, L. and A. af Wåhlberg (2002), *New Age and risk perception.* Risk Analysis, 22: pp. 751-764.

[64] Sjöberg, L. (2003), *Distal factors in risk perception.* Journal of Risk Research, 6: pp. 187-212.

[65] Peters, E. and P. Slovic (1996), *The role of affect and worldviews as orienting dispositions in the perception and acceptance of nuclear power.* Journal of Applied Social Psychology, 26: pp. 1427-1453.

[66] Jasanoff, S. (1998), *The political science of risk perception.* Reliability Engineering and System Safety, 59: pp. 91-99.

[67] Sjöberg, L. (2001), *Political decisions and public risk perception.* Reliability Engineering and Systems Safety, 72: pp. 115-124.

[68] Sjöberg, L. (2001), *Whose risk perception should influence decisions?* Reliability Engineering and Systems Safety, 72: pp. 149-152.

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THE COLLECTION OF EXPERT JUDGEMENTS FOR ENVIRONMENTAL RISK STUDIES

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Analyses of the environment are inherently complex and require the specification of many parameters and relationships. Often these analyses are implemented as computer simulation models which allow for various scenarios to develop and facilitate expressing uncertainty about the models predictions. This uncertainty is driven by the uncertainty in the models, the relationships, and the parameters employed in the analysis. The focus of this presentation is on capturing the uncertainty in parameters so that it may be realistically propagated through the analysis.

When available, data from experiments or the field can be used in this quantification. But often, these sources of data are not fully adequate because the situation under which the data are gathered and the situation represented by the model differ. For example, it may be necessary to scale up from a lab experiment to a field setting or a safe analog may have been substituted for a dangerous material. Moreover, there may be conflicting pieces of evidence that require interpretation and reconciliation. It is also common for risk models to produce estimates of uncertainty in risk and well as point estimates of risk. For all these reasons, expert human judgements have played a role in quantification of risk models.

Human judgements can enter a risk study in various ways. An analyst may need to provide a value for a parameter and therefore searches for information to support the quantification. Suppose that the analyst encounters several, perhaps disparate, sources of information. The analyst might choose to select one source of information as being primary and use a value suggested by that study. Conversely, the analyst may decide that all sources of information are relevant and decide to take an average or integrate the results by some other means. But what about the uncertainty that is present in the original studies and the uncertainty that is introduced by the analyst's choice? How is this uncertainty to be expressed? It may be that the uncertainty is just ignored or a rule of thumb such as using an error factor is used. What has become a poor representation of uncertainty may become worse because the methodology and rationales for decisions may not be documented. Traceability is lost and the meaning of the risk estimates obtained become cloudy.

Alternatively, the inclusion of human judgements, judgements based on evidence, can be based on a more structured and more scrutable set of procedures. Over the last thirty years, a knowledge base for the collection and processing of such judgements has emerged from the fields of psychology, statistics, and decision and risk analysis. From this data base an approach has evolved has been termed Formal Elicitation [Bonano *et al.* 1989, Cooke 1991]. It entails a structured approach to obtaining the judgements from one more experts and processing those judgements to produce probability distributions for uncertain parameters. The formal structure treats:

- Selection and specification of quantities to be assessed.
- Qualification and selection of experts.

- Organisation of the experts.
- Elicitation of individual judgements.
- Reconciling and combining judgements.
- Documentation of the process and expert rationales.

Formal Elicitation has been used for a number of risk studies [USNRC 1990, Kotra *et al.* 1996, HARPER *et al.* 1994, Trauth, Hora and Guzowski 1994. Rechard *et al.* 1993, Trauth, Hora, and Rechard, 1993, Wheeler, Hora, Unwin, and Cramond. 1988]. It provides a reasoned approach to incorporating judgements into studies and is particularly valuable where a process is needed that will stand up to public scrutiny and legal challenges.

Ever since the landmark WASH-1400 Reactor Safety Study [USNRC 1975], there has been an awareness in the risk analysis community that the quantification of uncertainty distributions cannot always be made directly from the data at hand. In such instances, experts have been employed to interpret the available data and express their interpretations in the form of probabilities of events and probability distributions for quantities.

Some situations that favour the use of experts include:

- Conflicting data sources.
- Data collected using laboratory scale experiments where the uncertainty is on a field scale.
- Unverified models or measuring procedures.
- Analog chemicals and tracer elements.
- Limited evidence.
- Data insufficient to internally estimate uncertainty.

Formal elicitation programmes are not without their drawbacks, however. The formal structure means that more time and resources must be applied. Often multiple external experts are employed and these experts must be compensated. Using formal methods to treat every uncertain value in an analysis is therefore unwarranted. These resource intensive methods should be used for those key parameters and uncertainties that are seen to be most important in shaping the estimates of risk and uncertainty.

Next, we describe the essential elements of a formal elicitation process. There are options with each of these elements, but each element needs to be considered in building a process.

Selecting issues and specifying questions

As mentioned earlier, not all uncertainties should be treated using a formal process. The parameters should be, first, important contributors to risk and uncertainty. This is normally determined through preliminary sensitivity studies. Second, the task of quantification should not be trivial. If there is strong evidence that all would agree upon and that evidence leads to a relatively unambiguous distribution, why bother to bring in experts? Third, there must be an available pool of expertise. If you can not find experts to address the issue or if there is not evidential basis for making the judgements, the product of the effort will not stand up to scrutiny.

Perhaps the most unacknowledged difficulty in obtaining expert judgements is the specification of the explicit issues to be addressed. It seems as this would be a simple a matter, but often the interpretations of issues differ among the experts and between the study staff and the external experts. Questions should not be asked about parameters and values that are specific to a model. The questions should be about quantities whose values can be, at least theoretically, be ascertained in the environment.

Another difficulty that sometimes presents itself is sorting out the sources of uncertainty that should be included in the experts' assessments. For example, if the experts were provide uncertainty distributions for the amount of radioactivity left in the surface soil in grassland, should the length of grass, the precipitation, etc. be included as factors causing uncertainty or should these values be specified as conditions for the assessment?

Selecting the experts

There are several issues here:

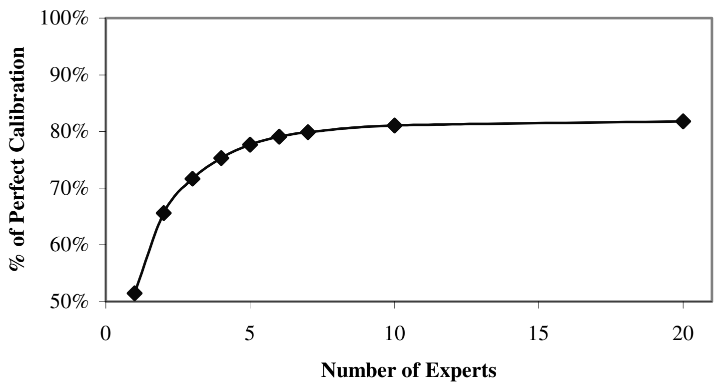
- How does one qualify experts?
- How should the expert be selected?
- How many experts should be selected?

The qualification of experts should be based on some documented criteria. These criteria can include measures of expertise such as degrees, publications, positions, etc. Additionally, the experts should be free from "motivational biases". A motivational bias is a real or perceived circumstance that could lead an expert to provide answer that are not neutral from a scientific basis. A person with strong political view either for or against a project may intentionally or unintentionally provide a biased opinion. Similarly, a person with an economic stake in the outcome of a study (such as the employee of an operating company) may be swayed. The perception, as well as the reality, of a motivational bias should be guarded against.

The selection of the experts may be done by the study staff or it can be "out-sourced" to an advisory group. This may be a good tactic in circumstances where the subject is under intense public debate.

The question of how many experts should be selected depends in part upon the breadth of the issues and the method of organising the experts. When experts are organised as teams, each team normally provides a single assessment. When experts work individually, each expert provides an assessment. What ever the form of organisation, there appears to be growing evidence that the number of assessments should be between three and six. Figure 1 shows a graph of the calibration of varying size groups of experts participating in training exercises for the NUREG-1150 study [Hora 2003]. The vertical axis is scaled from 0% to 100% and reflects how faithful the assessments are in the following sense: 100X% of the actual values on training questions should be found in the lower X-probability tails of the respective distributions. The graph shows that the calibration improves rapidly from one to five or six experts but only a little after six.

Figure 1. **Average calibration score of expert groups**



Organising the experts

We have already mentioned that experts can be organised in teams or they can work individually. Teams are useful when the issues addressed span several different disciplines. Each team member takes the lead in their own area of expertise. In designing markers for nuclear waste disposal, a team might be composed of a linguist, a materials scientist, an architect or mechanical engineer, and an archaeologist [Trauth, Hora and Guzowski, 1992].

More often, the experts work individually but with the possibility of interaction. In some studies the experts have worked in total isolation, in others they are required to meet and exchange views. Isolated experts are more independent (good) but perhaps less knowledgeable (bad). It is our opinion that the experts should interact but be required to make their assessments independently. The appears to be real advantage in having some redundancy otherwise the expressed uncertainty is likely to be less that the uncertainty that is really there.

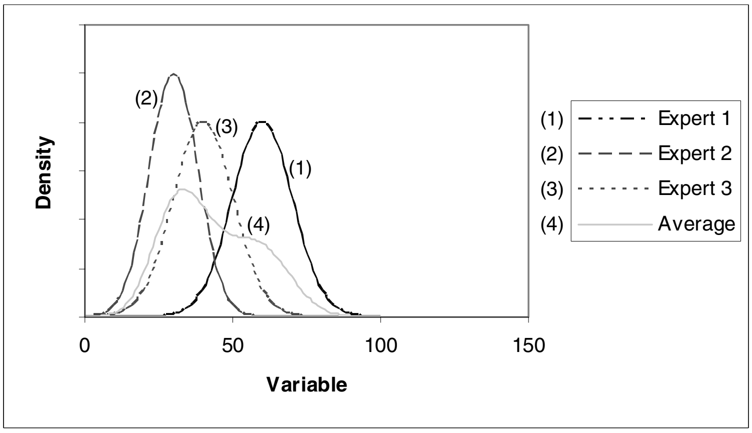
Several studies in the United States have used a multiple meeting format [see USNRC 1990, Bonano *et al.* 1989, Kotra *et al.* 1996 for references]. The experts have an initial meeting, participate in probability training and exercises, and openly discuss the issues, the methods, and the data relevant to the problem. The experts then disperse and study the problem by examining data sources, running analyses, etc. They return after, perhaps, one month and again exchange views. This exchange is followed by formal probability elicitation conducted by a team of specialists individually with each expert.

Reconciling and combining judgements

The expression of uncertainty about a quantity is usually accomplished by asking the expert to given certain cumulative probabilities – for example the 0%, 5%, 25%, 50%, 75%, 95%, and 100% points on a distribution function [Hora, Hora, and Dodd 1992]. These values give a good indication of the location and shape of the uncertainty distribution but they do not completely specify the distribution. This is usually accomplished by interpolating between the points. In those instances where the 0% and/or 100% points have not been obtained it may be necessary to extrapolate to obtain the tails of the distribution. Extrapolation is much more difficult than interpolation and it is better not to get into this situation.

We have earlier made the case for redundancy among the experts. Redundancy is important in that it allows us to capture the differences among the experts' judgements as well as the internal uncertainty expressed in each individual judgement. Figure 2 shows the hypothetical distributions provided by each of three experts and then an aggregated distribution that is simple the average of the three component distributions. The spread of the aggregated distribution is clearly greater because it incorporates both sources of uncertainty – intra- and inter-expert.

Figure 2. **Averaging three densities**



The simple averaging aggregation rule employed in Figure 2 is perhaps the most widely used aggregation rule for multiple experts. This method is well received for several practical reasons:

- It is robust.
- It is transparent and easily comprehended.
- It preserves the total uncertainty expressed by multiple judges.
- It avoids differentially weighting experts.

Genest and Zidek (1992), and Clemen and Winkler (1997) provide extensive discussions of combining experts. Also see Cooke (1990).

Documentation of the process and expert rationales

While the numerical results of a probability elicitation exercise provide the data to be input in computer codes for the evaluation of risks, the numbers by themselves are not sufficient to make a case. The rationales the experts used to reach their judgements, the models and data sources, the places where they agree and disagree must be documented in order to provide a base of support for the values. This is an important step in concluding the process and should not be ignored.

It is also important to document the process and procedures used in the exercise. For example, sometimes more attention is paid to how the experts were selected than to the judgements the experts have provided.

References

Bonano, E.J., S.C. Hora, R.L. Keeney, and D. von Winterfeldt (1989), *Elicitation and Use of Expert Judgement in Performance Assessment for High-level Radioactive Waste Repositories,* U.S. Nuclear Regulatory Commission, NUREG/CR-5411.

Clemen, R.T. and R.L. Winkler (1997), "Combining Probability Distributions from Experts in Risk Analysis" *Risk Analysis,* 19, pp. 187-203.

Cooke, R.M (1991), *Experts in Uncertainty,* Oxford University Press, Oxford.

Genest, C. and J.V. Zidek (1986), "Combining Probability Distributions: A Critique and Annotated Bibliography". *Statistical Science,* 1, 114-48.

Harper, F.T., S.C. Hora, M.L. Young, L.A. Miller, C.H. Lui, M.D. Mckay, J.C. Helton., L.H.J. Goossens, R.M. Cooke, J.P¨Asler-Sauer, B. Kraan, J.A. Jones (1994), *Probability Accident Consequence Uncertainty Analysis*, Nureg/Cr-6244 Eur 15855en Sand94-1453.

Hora, S.C (2003), Probability Judgements for Continuous Quantities: Linear Combinations and Calibration, in review.

Hora, S.C., Hora, J.A., Dodd, N.G. (1992), "Assessment of Probability Distributions for Continuous Random Variables: A Comparison of the Bisection and Fixed Value Methods", *Organizational Behavior and Human Decision Processes,* 51, 133-155.

Juslin, P. (1994), "The overconfidence phenomenon as a consequence of informal experimenter-guided selection of almanac items". *Organizational Behavior & Human Decision Processes,* 57(2), Feb 1994, 226-246.

Kotra, J.P., M.P. Lee, N.A. Eisenberg, and A.R. DeWispelare (1996), *Branch Technical Position on the Use of Expert Elicitation in the High-level Radioactive Waste Program,* U.S. Nuclear Regulatory Commission, NUREG-1563.

Rechard, R.P., K, Trauth, J.S. Rath, R.V. Guzowski, S.C. Hora and M.S. Tierny (1993), *The Use of Formal and Informal Expert Judgements when Interpreting Data for Performance Assessments* SAND92-1148, Sandia National Laboratories.

Trauth, K. S.C. Hora, and R.P. Rechard (1993), *Expert Judgement as Input to Waste Isolation Pilot Plant Performance-Assessment Calculations*, SAND91-0625, Sandia National Laboratories.

Trauth, K., S.C. Hora and R.V. Guzowski (1992), *Expert Judgement on Markers to Deter Inadvertent Human Intrusion into the Waste Isolation Pilot Plant*, SAND92-1382, Sandia National Laboratories.

Trauth, K., S.C. Hora and R.V. Guzowski. (1994), *A Formal Expert Judgement Procedure for Performance Assessments of the Waste Isolation Pilot Plant,* SAND93-2450, Sandia National Laboratories.

Trauth, K., S.C. Hora and R.V. Guzowski (1994), *A Formal Expert Judgement Procedure for Performance Assessments of the Waste Isolation Pilot Plant*, SAND93-2450, Sandia National Laboratories.

U. S. Nuclear Regulatory Commission (1990), *NUREG-1150: Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants, Vols. 1-3, Final Report.*

U.S. Nuclear Regulatory Commission (1975), *Reactor Safety Study: WASH-1400,* NUREG-751014.

Wheeler, T., S.C. Hora, S. Unwin, and W. Cramond (1998), *Results of the Expert Opinion Elicitation of Internal Event Front-End Issues for NUREG 1150: Expert Panels* NUREG/CR-5116 Vol 1 and Sand 88-0642, Sandia National Laboratories.

SURVEY OF THE ROLE OF UNCERTAINTY AND RISK IN CURRENT REGULATIONS[1]

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Introduction

This paper provides an overview of the different standards adopted by regulators in different countries for determining the safety of radioactive waste facilities, and of the different approaches adopted by regulators for determining how uncertainties are treated in safety cases for such facilities.

The aim of the paper is to identify both common approaches and differences between regulations and guidance in different countries. It is also intended that the paper should act as an introduction to the issues to be discussed at the Workshop.

Regulations and guidance include two broad categories of criteria: numerical and qualitative. Numerical criteria are both relatively easy to compare between different regulations and also to use simplistically in assessing a safety case. In the same way that numerical criteria should not provide the sole basis for determining safety, they are not the only type of standard for which a comparison is useful. There are many qualitative requirements in regulations and guidance, including transparency and traceability, quality assurance, sound science and engineering, and optimisation. However, this paper is limited to a comparison of the ways in which different regulations address the issue of uncertainty.

Regulatory standards

In a discussion of regulatory standards for determining the safety of radioactive waste facilities, it is useful to distinguish between three levels of standards:

- Limits. A limit provides a value (e.g., for effective dose) that must not be exceeded.
- Constraints. A constraint provides a value (e.g., for site-related or source-related dose) that should not be exceeded.
- Targets. A target provides a numerical criterion against which information can be assessed. A target is sometimes termed an optimisation level.

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1. The work reported in this paper has been funded by SKI, and the support of Eva Simic (SKI) is acknowledged.

Different levels may be specified within the same regulations. Within Europe for example, the Basic Safety Standards specify a dose limit to the public of 1 mSv/year for all man-made sources of radiation (excluding medical sources). Because individuals may be exposed to more than one exposure source but must remain within this overall limit, different countries then apply constraints and/or targets for site- or source-related exposure.

For example:

- in the Netherlands a dose constraint of 0.1 mSv/yr applies to waste management facilities and there is also a target or first optimisation goal of 0.04 mSv/yr;
- in the UK, there is a change from a dose constraint of 0.3 mSv/yr for a single new source to a risk target of 10^{-6}/yr at the time when control is withdrawn from the site;
- in Switzerland, a dose constraint of 0.1 mSv/yr applies to an average member of the population group most at risk for scenarios representative of the more likely future evolution scenarios. There is also a risk constraint of 10^{-6}/yr applicable to the sum of scenarios not considered in the comparison with the dose constraint.

In almost all cases, regulatory standards take the form of numerical criteria. Exceptionally a qualitative standard may be set. For example, in France a criteria based on the ALARA[2] principle has been established for the disposal of low-level radioactive waste. In this case, the proponent has proposed a dose constraint of 0.25 mSv/yr for the normal evolution scenario or any abnormal situation with a high probability of occurrence.

The numerical criteria in general use in regulations and guidance applicable to radioactive waste management are dose and risk. Within those regulations specifying a risk criterion, there is general agreement that a risk of 10^{-6} per year of suffering a serious health effect is an appropriate level as a regulatory constraint or target. There are differences relating to who is protected at this level, and also as to what constitutes a serious health effect. These differences are discussed in the following sections.

Within those regulations specifying a dose criterion, there is slightly less consistency concerning an appropriate value. Dose constraints typically range between 0.1 and 0.5 mSv/yr. As with risk criteria, there are also differences as to who is protected, but all the dose criteria are based on an annual individual dose.[3]

Serious health effects

A key element of any quantitative assessment of risk, be it probabilistic or deterministic, is accounting for the stochastic element of the response to any given dose. At dose rates below about 0.5 Sv/yr, not everyone exposed to a given dose will suffer a detectable health effect, and a dose to risk conversion factor is used to take account of this uncertainty. Some regulations state the factor to be used or require use of an appropriate ICRP value. Different values apply depending on the consequence considered. In the UK, for example, the guidance includes reference to a value of 0.06 per Sv, established by ICRP for the:

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2. ALARA – As Low As Reasonably Achievable.
3. Where regulations are more specific in terms of the dose to be calculated, they generally refer to an annual individual effective dose (i.e., the summation of the equivalent doses to the individual tissues of the body, weighted by the appropriate tissue weighting factor).

"… purpose of assessing the frequency of induction of fatal cancer and serious hereditary effects in a general population of all ages."

In Sweden, however, the recommended factor is 0.073 per Sv, which is the value established by ICRP to take account of cancer (fatal and non-fatal) as well as hereditary effects.

The corollary of this difference in factors is that a risk of 10^{-6} per year corresponds to a dose of 13.7 μSv/yr or 16.7 μSv/yr depending on whether non-fatal cancers are included in the definition of health effects. A 20% difference is small in comparison with some of the other uncertainties inherent in assessments, but it highlights the importance of clarity when making and documenting all the assumptions in a safety case.

Values for the dose to risk factor are based on epidemiological information, which is periodically re-assessed, particularly as estimates of exposure to past sources of radiation are revised. Over time, therefore, the same level of exposure may be assessed as giving rise to a different level of risk. Conversely, dose criteria may need to be changed periodically to ensure a consistent level of protection in terms of actual consequences (e.g. numbers of people suffering a serious health effect).

For most stakeholders, a value of dose has no implicit meaning and must be compared to some other dose (e.g., from background radiation) or otherwise converted to a consequence that can be interpreted from experience. The dose to risk factor or a similar conversion may therefore also be relevant if the regulatory end-point is dose.

Protected individuals

Regulations need to specify to whom the dose or risk criteria apply. There are two principal approaches; a representative member of an exposed group, or a reasonably maximally exposed individual (RMEI). The approach based on a representative member of a group is an extension of the critical group concept used in regulating routine releases from operating plants. In the UK, the guidance adopts the term potentially exposed group (PEG) to clarify that there is uncertainty regarding the location of any release. Other regulations and guidance based on the same concept do not apply the same terminology, but there is generally a requirement to consider a number of groups so as to identify the most significant in terms of dose or risk.

The extent to which regulations specify the groups or activities to be considered varies. Some guidance is generally provided on the extent to which human intrusion should be considered. Typical activities that may be prescribed include subsistence farming, and groundwater abstraction for drinking and irrigation. Regulations and guidance may also specifically exclude activities from regulatory concern. No regulations currently require consideration of deliberate intrusion and certain other types of human activity may also be excluded.

ICRP provides guidance on the identification of the critical group that can, by extension, be applied to the definition of exposed groups. However, since the exposed group does not comprise specific individuals with particular characteristics and patterns of behaviour, the range of characteristics from which a representative member is identified is a modelling assumption, rather than an observation. In fact, for most assessment approaches, the range is unimportant and the only purpose of applying protection standards to a group is to ensure that extreme individual behaviour does not drive decision making. This leads to the alternative approach of protecting the RMEI as required, for example, by the regulations promulgated for Yucca Mountain. Again, extreme individual behaviour is avoided by requiring that the protected individual's behaviour and characteristics are "reasonable".

In the case of deterministic calculations, there may be little difference between results for an exposed group or the RMEI. Probabilistic evaluations may result in some calculated differences depending on the extent to which the location and characteristics of the exposed group are treated probabilistically.

Other numerical criteria

As an alternative to dose or risk, some regulations specify fluxes or release rates at particular points or boundaries, either as supplementary criteria to dose or risk or as a "surrogate" for such measures. In the USA, for example, cumulative releases over a period of 10 000 years is used as a regulatory standard for the WIPP site. In Finland, STUK has established a set of nuclide-specific activity release constraints for fluxes at the geosphere-biosphere boundary.

A further example of supplementary criteria is radionuclide concentration: maximum radionuclide concentrations are specified in the groundwater protection standards for both the WIPP and Yucca Mountain. A recent IAEA report[4] discusses other measures that could be developed into supplementary numerical criteria.

A perceived benefit of these supplementary criteria is that they avoid the need to make assumptions concerning the biosphere and protected individuals. However, in order to set numerical values for this type of criteria, the significance of fluxes, release rates or concentrations must be assessed and this can only be done by making assumptions about receptors. The key difference, therefore, is that it is the regulator who is required to make assumptions about the biosphere and protected individuals rather than the developer. Since regulations are normally established in advance of site selection, this approach also means that these assumptions are likely to be generic rather than site-specific.

Some regulations and guidance include limits on the timescales to be considered in assessments. These could be regarded as numerical criteria, but such limits are generally set so as to take account of varying levels of uncertainty so they are discussed in the following section.

Treatment of uncertainty

In general terms, regulators can adopt three different approaches to determining how uncertainties are treated in safety case for radioactive waste facilities:

- Prescriptive regulations could be promulgated to require the developer to consider particular types of uncertainty in a particular manner.
- Regulatory guidance could be issued to ensure that the developer is aware of the issues of concern to the regulator and, in appropriate circumstances, indicate specific approaches or methods that the regulator would like to be used or followed.
- Regulatory review of methodologies and approaches developed by the proponent. This review may be supported by independent calculations, but these do not constrain the approach used by the proponent.

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4. IAEA, 2003. Safety indicators for the safety assessment of radioactive waste disposal. IAEA-TECDOC-1372. Vienna, IAEA.

The choice between these various regulatory responses is related as much to the established style of regulation in a particular country as it is to the different types of uncertainties to be considered. There are overlaps between these approaches, and the majority of regulations and guidance are based on a combination of the last two approaches. The USA provides the key examples of the first approach, with the regulations applicable to the WIPP and Yucca Mountain both including prescriptive elements that require the developer to consider particular scenarios and human intrusion activities and to adopt a particular assessment approach. The regulatory end-point for the WIPP, for example, requires the use of probabilistic calculations. The regulations for Yucca Mountain expect the use of probabilistic methods for calculating dose.

Two key areas of uncertainty that are addressed in the majority of regulations and guidance are timescales and scenarios. The various approaches adopted for these topics are outlined below.

Timescales

A key source of uncertainty in assessments of long-term performance is time-dependent changes in the natural environment and in the properties of barrier systems. These uncertainties increase with time and there is a general acknowledgement that different levels of detail are appropriate for different assessments over different timescales.

Irreducible uncertainties about the natural environment limit the timescales over which quantitative assessments can be applied. Over longer timescales, many regulations expect alternative approaches to assuring safety, generally based on qualitative arguments. Conversely, some regulations expect more detailed assessments for the relative short-term after closure. Whatever the regulatory requirements and expectations concerning the level of detail in assessments, no examples were found in which the regulatory criteria change with the timescale considered.

The following specific examples illustrate the differences in the extent to which regulations prescribe the timescales to be considered:

- WIPP – the principal regulatory criterion is based on cumulative releases over 10 000 years.
- Yucca Mt – the individual and groundwater protection criteria apply for 10 000 years. The safety case must consider human intrusion for the same period or until the time that degraded waste packages would no longer be recognised during drilling.
- Sweden – The regulations consider it feasible to model system evolution for the first 1 000 years after closure. Beyond this time, assessments of system evolution are expected to be based on a series of different scenarios.
- Finland – The importance of scenarios that cannot be assessed through quantitative analyses should be examined through complementary considerations such as bounding analyses and comparison with natural analogues. The importance of such considerations increases as the assessment period increases. Judgements of safety beyond 1 million years can be based mainly on complementary considerations.
- UK – The regulatory guidance does not prescribe an overall timescale for assessments. Assessments are expected to cover the period over which models and data can be demonstrated to have validity. Performance over longer timescales may be based on scoping calculations and qualitative information.

Scenarios

The evolution of a radioactive waste disposal system, including both constructed barriers and the natural environment, is dependent on a wide variety of features, events and processes (FEPs). Groups of such FEPs, taken together, form scenarios that describe in broad terms the patterns of influence to be considered in assessments. Regulations and guidance are variable in the extent to which they specify the scenarios to be considered in a safety case.

A normal evolution scenario, including the events and processes expected to occur, is implicitly or explicitly required in all regulations. An assessment of human intrusion is also required in all cases, although the results of this assessment are not necessarily required to be integrated with other scenarios or compared against the same criteria as the normal evolution scenario.

Most regulations require the consideration of variant scenarios, although generally only broad descriptions of the events and processes to be considered are provided. For example, Finnish guidance requires consideration of variant scenarios based on declined performance of single barriers or, where the behaviour of barriers is coupled, multiple barriers. The French safety rules require consideration of a reference scenario that includes gradual degradation of the barriers and highly probable natural events. Variant scenarios must be considered for highly uncertain events or likely events of exceptional magnitude.

Regulations may also exclude specific events or processes from assessment calculations. For example, Swiss Protection Objectives exclude scenarios with more serious non-radiological consequences or with extremely low probability. In France, an Appendix to the safety rule describes various mining and similar activities applicable to different rock types and notes those that can be excluded from assessment calculations. In the USA, the regulations for the WIPP site describe the scope and extent of mining operations to be considered in the assessment and specifically exclude other mining operations and similar activities.

Conclusions

This paper has examined a range of regulations and guidance relevant to the authorisation of facilities for the disposal of radioactive waste. There are broad similarities between the requirements included in regulations that have a risk criterion. Regulations with dose criteria show a wider range, particularly in the value of the numerical criteria, but also in other aspects of the treatment of uncertainty such as the extent of variant scenarios to be considered.

Key issues include the practical significance of constraints and targets for dose and risk rather than site- or source-related limits. A related issue is the importance of numerical compliance versus the fulfilling of qualitative criteria. Differences between the dose constraints may give rise to questions from stakeholders in particular countries. Questions may also be raised by some stakeholders about the basis and justification for the apparent addition of an extra level of protection when a risk criterion is adopted.

MANAGEMENT OF UNCERTAINTIES AND THE ROLE OF RISK IN ANDRA'S PROGRAMME

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This paper aims at presenting some aspects of the management of uncertainties in the programmes of Andra for the study of a deep geological repository for high level, long-lived wastes. After presenting very briefly the context of risk-management in the French safety rules, it will discuss how Andra has attempted to link the notions of uncertainties and risk in its "Dossier 2001" for the clay medium, how this could be made compatible with a deterministic safety approach, what feedback it got from this first exercise, and what are the perspectives for future work.

The French regulation and standards require safety analysis for repositories to be performed in a deterministic manner. In terms of design, it relies on the concept of "defense-in-depth", that requires to define multiple lines of defense, or multiple safety functions, so as to reduce risk as reasonably as possible, regardless of the probability of each identified risk. In terms of quantitative evaluations for the long term, the Basic Safety Rule III.2.f. recommends the use of a limited number of scenarios (both "normal evolution" and "altered evolutions") to represent the various situations that can occur in the repository, and to evaluate them in terms of effective dose. The normal evolution is characterised by an (implicit) reference to probability, as the Basic Rule states that is should correspond to *"the foreseeable evolution of the repository as regards certain or very probable events*". As regards altered evolutions, the acceptability of their impacts should be assessed "*with allowance made for the nature of the situations taken into consideration, the duration and the nature of the transfers of radioactive substances to the biosphere, the properties of the pathways by which man can be affected and the sizes of the groups exposed*". The use of risk, meaning the product of a probability by an exposure, is envisioned as a possible complementary indicator. However, the RFS expresses doubts about the use of such an indicator, since it "*may imply a debatable equivalence between reducing the probability and reducing the exposure*". Such a notion is, in practice, rarely used in an explicit manner in safety assessments performed on French repositories.

Andra has tried to implement methods for the management of uncertainties in all steps of its research programme for the study of a repository in clay. Risk was used as a tool in the context of the dossier 2001. First of all, it is important to give an overview of the various meanings of "risk" as used in the Andra's practice:

- "risk" is defined, inside Andra, as the characterisation of a potential danger in terms of probability and gravity. The product of both is rarely considered. Therefore, such expressions as "the probability of a risk" or "the gravity of a risk" refer to two independent variables.
- "risk", in such expressions as "risk analysis", refer to the methods used in the field of both nuclear and non-nuclear industry, to identify potential sources of danger and hierarchise them. A "risk" analysis does not always imply the characterisation of the various sources of

danger by a risk indicator, though their classification always imply some notion, even qualitative, of the relative likelihood and gravity of each individual source.

At the stage of the dossier 2001, the aim was to address uncertainties throughout the safety evaluation, by referring to notions of risk analysis. Various types of uncertainties were addressed, that could roughly be categorised into three different types. Those were uncertainties in the understanding of the phenomenology of the repository, uncertainties in the way its evolution is modelled and predicted, uncertainties in the occurrence of future events (such as boreholes, earthquakes, climate changes, etc.). This simple categorisation did not intend to cover exhaustively all types of potential uncertainties. It could be refined if needed; for example, uncertainties on the understanding of the phenomenology might be due to the lack of data, to the variability through time and space of the data, to the limited understanding of a phenomenon that can be accessible at a given time, to the long timescales involved.

The idea behind the analysis of uncertainties in the "dossier 2001" was to treat them, especially phenomenological uncertainties and uncertainties on future events, as "risks" for the repository not to behave as expected. This analogy between uncertainty and risk allowed the use of methods of risk management commonly employed in other fields of industry to perform the management of uncertainties. These methods use the concept of gravity and probability to rank the various sources of danger; such an approach had to be adapted in the context of long term safety. This process was called "qualitative safety analysis" (AQS).

The principle of the AQS was to identify the events, features and processes, both internal and external to the repository system, that could result in a malfunction of the repository. A malfunction was defined by reference to the functional analysis of the repository, that displayed a list of all the safety functions to be performed within the repository system. External events were identified by reference to national regulation or international FEP's databases (earthquake, glaciation, etc.). Relevant internal events and processes were derived from the uncertainties on the phenomenology identified in the scientific reports. Each uncertainty was converted into a possible malfunction of the repository system, and the relative ranking (equivalent, in terms of method, to a relative "probability" or "likelihood", but not used as such) of the corresponding event was derived from the level of uncertainty. This means that a possible malfunction was ranked higher (compared to others) if the underlying phenomenology was judged to be more uncertain. For example, at the stage of dossier 2001, the uncertainties on the geomechanical behaviour of the host rock lead to regard the development of an EDZ, potentially able to short-circuit the sealings, as "of a higher rank" than other types of dysfunctional processes.

The idea of the "ranking by expert judgement" was not to assess a "probability" of each event or process, but to give a sense of the relative importance of events, features, and processes, by laying more emphasis on those that were judged the more likely *or* the least characterised.

This process allowed to select sequences of events or processes that could be detrimental to the repository, in terms of effect on the various safety functions. Those that were equally detrimental, as regards safety functions, could be ranked if needed thanks to the ranking of individual uncertainties. These results were used both to hierarchise the situations, and to inform priorities for the future research programme (the higher the ranking of a particular sequence of events or processes, the more critical the underlying uncertainties). It was considered that the hierarchy of detrimental events could be related to the definition of scenarios, though this was not performed thoroughly at the stage of the dossier 2001.

Other uncertainties, essentially the uncertainties on models and parameters, were treated directly by the use of a quality assurance procedure. This required the choices of parameters to be presented in a pre-designed format, that displayed the various possible choices ("best estimate, conservative, maximum physically possible…"). Uncertainties were then treated by the choice of a "cautious but reasonable" value for each parameter. A later comparison with a probabilistic calculation showed the coherence between a deterministic and a probabilistic approach as long as they rely on the same underlying assumptions. However, the results of a probabilistic calculation, such as a distribution of expected dose, is difficult to use in a context where it is expected that the results of the calculation should be compared to a pre-defined threshold.

Feedback from this methodology was positive in the sense that it proved important to have a pre-defined strategy for the management of uncertainties. The exercise was also instrumental in underlying some difficulties in the application of procedures, or when explaining the methodologies to various evaluators. In particular, methods of risk management appeared to be complex as communication tools. Their adaptation to the context of management of uncertainties over long time-scales and progressive processes proved difficult, though not impossible in principle. Moreover, the notion of "likelihood" of events or "ranking" of uncertainties was difficult to use in the context of a deterministic safety approach.

The perspectives for future work will focus on trying to integrate more the different types of uncertainties. For this aim, an important part will be given to "scientific integration", i.e. the presentation and modelling of the evolution of the repository, both expected and altered, in a global and coherent manner. A unit dedicated to this particular objective was created inside the scientific division of Andra, as a feedback from the organisation of the production of dossier 2001. The quality assurance procedures governing the choice of data will be both strengthened and simplified.

The analogy between uncertainties and risks will be maintained in the next dossier, but Andra's aim is to treat them in a different way. AQS will attempt to analyse each uncertainty systematically through design, modelling and evaluation of residual risk. First of all, for each uncertainty, the analysis will evaluate if the design of the repository manages to reduce the probability or the gravity of the underlying "risk". If it appears possible, then the remaining uncertainty will be considered as part of the normal evolution of the repository and represented within the models dedicated to the safety assessment. If not, either because the potential gravity is significant (for example: a deep borehole in the repository) or because it prevents the performance of an important safety function (for example: uncertainties on the reliability of sealings) the "residual risk" will be evaluated by reference to one of the altered scenarios that will be specifically assessed. Methods for the formalisation of these three stages of the analysis are under development.

This leaves aside the question of how to evaluate the gravity of a residual risk, when there is little reference in the French regulation to dose constraints under altered evolutions, other than a request that the impact should "*be maintained well below levels liable to give rise to deterministic effects*". This is made all the more difficult since a scenario is not always meant to represent a plausible situation, but is designed to encompass various situations that are sufficiently similar. If the probability of a particular situation can be defined, if not always calculated, it can be much more difficult for a whole scenario. "What if" scenarios, not meant to represent a realistic situation but meant to test the robustness of the design, pose a similar problem. In spite of these difficulties, some idea of the likelihood of the corresponding situations will have to be obtained in order to evaluate the relative gravity of a scenario.

Probabilistic calculations, using in particular Monte Carlo distributions, will be performed for the sensitivity calculations of at least the normal evolution scenario. They will not aim at evaluating risk as an indicator, but at gaining access to the relative importance of parameters in a given situation. Those calculations will be performed for the first time in Andra in the context of a safety assessment; the deterministic nature of the safety evaluation as a whole will nevertheless be preserved.

TREATMENT OF UNCERTAINTY IN THE US DEPARTMENT OF ENERGY'S YUCCA MOUNTAIN REPOSITORY TOTAL SYSTEM PERFORMANCE ASSESSMENT (TSPA)

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Abstract:

The regulatory requirements being addressed in the US geological repository programme for spent nuclear fuel and high-level waste specify that performance assessment is to be used to address probabilistically defined mean-value dose constraints. Dose was chosen as the preferred performance measure because an acceptable dose limit could be selected through the regulation-setting process, based on a defined acceptable risk. By setting a dose limit, arguments about the conversion of a potential dose to a potential risk was taken off the table as a potential licensing issue. However, the probabilistic approach called for actually delivers a "risk of a dose," a risk of a potential given dose value to a hypothetical person living at a set distance from the repository, with a set lifestyle, between the time of permanent closure and 10 000 years. Analyses must also be shown for the peak dose if it occurs after 10 000 years, essentially to a million years. For uncertain parameters that are important to system performance, the goal is to present an analysis that, in accord with applicable regulation, focuses on the mean value of the performance measure but also explores the "full range of defensible and reasonable parameter distributions". . . . System performance evaluations should not be unduly influenced by . . . "extreme physical situations and parameter values." These disclosure requirements are to be met by showing a range of potential outcomes and designating the mean value within that range.

Introduction

Uncertainty in a regulatory context

In its review of US Department of Energy (DOE) work leading up to the License Application (LA) that requests authorisation to construct a repository, the US Nuclear Regulatory Commission (NRC) has identified issues that need to be addressed by the DOE before and in the LA. These issues are documented in an Issue Resolution Status Report published by the NRC [1] using Key Technical Issues as organisational categories with sub-issues attached to them. Each Key Technical Issue sub-issue was evaluated by the NRC in terms of information needed to reach closure. Where additional information was needed to allow closure, agreement was reached between the DOE and the NRC regarding the nature of that information to be provided. Appendix A of [1] gives a complete listing of these agreements. There are five agreements relating to Total System Performance Assessment (TSPA) uncertainty (issues TSPAI 3.38, 3.39, 3.40, 3.41, and 4.01). Collectively, as summarised in [2], these issues call for the DOE to:

1. Develop guidance for a systematic approach to developing and documenting conceptual models, model abstractions, and parameter uncertainty.

2. Implement the guidance leading to an improved and consistent treatment of alternative conceptual models, model abstractions, and parameter uncertainty.
3. Write TSPA-LA documentation that reflects the written guidance.

"Uncertainty in a probabilistic context

The reason for using a probabilistic safety assessment approach is to allow the evaluation of a complex system over ranges of independently and dependently varying parameter space. It is also to allow the safety evaluation to include not only those varying parameter spaces, but to also include alternative models, in some cases, and uncertain initiating events that can lead to changes in conditions and pull in new models and varying data sets.

Probabilistic approaches provide a convenient way to evaluate all of the above. Such evaluations are not easily approachable using non-probabilistic methods if the system is very complex. Apostolakis [3] also adds that a benefit of using the probabilistic approach properly is to identify and thus be able to evaluate, "the complex interactions between events/systems/operators."

"Operators" is a specific reference to the subject at hand in Apostolakis' paper, which is the safety of reactor and other active systems. But the equivalent of the operator in the case of a repository may be the preclosure errors in manufacturing of waste packages and package emplacement that can have consequences after system closure. An example of including postclosure consequences from such preclosure errors will be given below."

Apostolakis reminds readers that the integration needed for a probabilistic risk assessment to be meaningful is a good thing, and that its focus is on the inclusion of uncertainty in a quantitative manner. The results should be carefully and also independently reviewed, and may then be used to judge the relative importance of features, events and processes that contribute significantly to risk.

One of the main purposes of a TSPA is to provide decision makers with a meaningful display of the impacts of uncertainty on our understanding of the future behaviour of the system. It is widely understood that uncertainty is unavoidable, but it must be understood and managed.

Because TSPA supports regulatory analyses, decisions about the treatments of accuracy and uncertainty have a regulatory component. In fact, in the US, regulations require the safety assessment to be probabilistic. According to the NRC, TSPA "estimates the dose incurred by the reasonably maximally exposed individual, including the associated uncertainties, as a result of releases … weighted by the probability of their occurrence" (10 CFR 63.2). [4]

Uncertainty and recent TSPA reviews

Internal [5] and external [6,7,8,9] (including international [10] and regulatory [1,11]) reviews have suggested there was inconsistent treatment of uncertainties across disciplines feeding into the TSPA supporting the Site Recommendation. As part of the response to the suggestions made, especially those made by the Nuclear Regulatory Commission (NRC), an "Uncertainty Analysis and Strategy" [11] document was prepared, and it, in turn, was followed by a "Guidelines" [2] document. These guidelines are currently being implemented as part of the preparation of the License Application (LA).

A criticism from several reviewers of the TSPA approach, in addition to but also related to the uncertainty-treatment criticisms, has been its conservative nature. One way to manage uncertainty is to assume bounding values and evaluate the system using those values. This allows demonstration of compliance with post-closure performance requirements. However, it can interfere with an evaluation of the level and the likelihood of risk, and thus allows no quantification of a safety margin. Although a safety margin is a desirable quantity to understand, it is not required by the applicable regulations.

The external reviewers who suggested there was undue conservatism in the TSPA supporting the Site Recommendation were not making a surprising statement. When preparing a TSPA, analysts are faced with competing and contradictory demands. In principle, conservatism is incompatible with a full uncertainty analysis because it obscures understanding. Hence, it should be avoided. In practice, however, the use of conservative or bounding approaches is a normal reaction to the absence of definitive information. Conservatism is a recognised approach to dealing with uncertainty.

The TSPA analysts may be asked to make conservative assumptions, even if more realistic understanding is potentially available, in order to simplify tests, models, or analyses. This, of course, is related to reducing cost (and schedule, which has a direct impact on costs). It can be said that if a conservative analysis shows safety, there is an enhancement of confidence in the likelihood of safety. So, reality steps into the ideal world and conservatism will be part of any complex system analysis, and may therefore obscure and perhaps even skew uncertainty analysis results. This makes it incumbent on the analysts to evaluate the impacts of conservatism. These impacts should be understood and explained.

Partly in response to these and other external and internal criticisms, the goal for TSPA for several years has been to deliver a more realistic, less bounding, analysis. Conservatism that remains must be identified and evaluated in terms of its basis and importance. A more realistic treatment of uncertainty in the TSPA is not the same thing as obtaining a full understanding of realistic performance, however. Full understanding where large spatial and time scales are involved for a complex system may be forever out of reach, but the goal is to provide a ‘reasonable expectation’ of safety, not complete certainty.

Progress has been made in changing several dozen conservative, fixed-value data points into simplified models that are being used and evaluated. Scientists and performance assessment analysts are organised to work together as teams to incorporate, propagate and evaluate uncertainty in models and parameter distributions.

Documentation is required to give a clear, traceable explanation of what was done. Documentation alone cannot explain a process, however, the process itself must be outlined and demonstrably followed to assure consistency in approach. The process for selecting parameter values and distributions for TSPA is a formal one that uses specialty teams to strongly integrate scientists, designers, engineers, and performance assessment analysts.

Responses to reviews: Uncertainty strategy and guidelines

Summary of uncertainty analyses and strategy document [11]

The strategy, it almost goes without saying, is to develop a TSPA that meets the regulatory intent of providing the basis for a finding of a “reasonable expectation” of safety by the regulator. This requires the TSPA to document the quantified uncertainties in inputs to the performance assessment. In order to meet this requirement, however, there must be a clearly defined process in place that encourages the quantification of uncertainties and gains concurrence on the process approaches with the NRC.

The technical basis for all uncertainty assessments must be provided, addressing conceptual model as well as parameter and initiating event uncertainty. The use of "bounds" and "conservative" estimates is unavoidable, but should be clearly identified, explained and evaluated. The purpose is to develop and communicate uncertainty information that can be used by decision-makers.

In order to assure this strategy is properly implemented, the DOE developed detailed guidelines for implementation.

Uncertainty strategy guidelines [2]

The strategic goal is an analysis approaching realism. Pragmatically, however, some conservatisms must remain. The documentation needs to be clear about where they are, what their basis is, and what their impacts are.

The focus of the assessments should be on providing a realistic treatment of uncertainty, which is not the same as a full understanding of realistic performance. Simplified models are acceptable in the TSPA, and are not necessarily conservative, though they may be.

Broad uncertainties need to be justified and explained, and analyses need to show they do not contribute to an unwarranted risk dilution [10]. Risk dilution may occur when, in order to capture incomplete understanding, analysts broaden probability-density-functions (pdfs) unduly to assure they are being conservative. When overly broad pdfs are sampled in a complex probabilistic analysis, however, they can introduce unduly small (or unduly large) numbers into the performance-measure averaging process, and they can affect the time of the occurrence of releases for the regulatory performance measure. The net effect may be non-conservative, and needs evaluation. Scientists and analysts must work together to properly and defensibly incorporate uncertainty in TSPA models and parameter distributions. In their documentation they must focus on clear explanations of what was done in their mathematical and conceptual descriptions. Traceability, meaning a transparent linking to the supporting technical basis, has to be provided.

Status of guidelines implementation

The guidelines document addresses the consistent treatment of abstractions in TSPA, of alternative conceptual model uncertainty, and of parameter uncertainty. It also addresses the propagation of risk through the abstraction processes that lead to simplified models.

The guidelines document addresses Nuclear Regulatory Commission (NRC) Key Technical Issue agreements related to uncertainties, point for point.

Implementation is to be documented in Analysis and Model Reports (AMRs) currently being updated for License Application (LA) that is to be submitted late in 2004.

Approach to consistency for implementation of uncertainty guidelines

As Apostolakis [3] noted, human errors, whether they occur in software or hardware production, is an issue not easily treated in a probabilistic risk assessment. The Quality Assurance programme has rigorous reviews of the software and configuration management issues, but a problem arises when a complex organisation integrates itself to produce an integrated safety assessment. It turns out when scientists and engineers meet to feed the TSPA modellers that: (1) definitions were not interpreted the same way and measures and uncertainties generated are not compatible with the needs of the analysts, (2) assumptions that bridge disciplines were incompatible, (3) uncertainty propagation, even where uncertainties were properly treated, is not easy. To bridge this set of potential gaps before it becomes a last minute emergency, the guidelines document, not unlike a Quality Assurance procedure, identifies those who are responsible for seeing that these things are prevented to the extent practicable, or handled expeditiously when they occur.

The following individuals are identified in the document, with their duties:

1. Parameter Team Lead (PTL) – Leads the process for ensuring the consistent treatment and documentation of parameter values, parameter distributions, and parameter uncertainty.
2. Abstraction Team Lead (ATL) – Leads the process for ensuring the consistent treatment and documentation of alternative conceptual models and model abstractions.
3. Subject Matter Expert (SME) – Identifies and develops alternative conceptual models, model abstractions, and parameters consistent with guidelines (personnel most knowledgeable about individual process models and uncertain parameters).
4. Process Modeller – Assists the SME in developing and implementing process models and abstractions (where appropriate) for use in the TSPA-LA.
5. TSPA Analyst – Integrates alternative conceptual models and model abstractions in the TSPA-LA model.

Types of uncertainty, and approaches to their evaluation and management

Parameter uncertainty

Formal processes are used for selecting parameter values and distributions for TSPA. The effort involves identification and categorisation of the TSPA parameters. For uncertain parameters that are important to system performance, the goal is to represent, as the regulations require, rightfully: the "full range of defensible and reasonable parameter distributions rather than only upon extreme physical situations and parameter values."

Uncertainty distributions are developed considering available data. The use of the parameter in the TSPA model (e.g., scaling issues, variability, application in model) is considered in developing descriptions of uncertainty. Distributions are developed jointly by subject matter expert, PA analyst, and a statistician. Parameter distributions that fold in the agreed on uncertainties are implemented in TSPA through a controlled database.

Alternative conceptual models (ACMs)

For each process of interest, an attempt is made to identify ACMs (if any) consistent with the available information. If only one conceptual model is consistent with all information, ACM uncertainty is not significant. The approach for identified multiple ACMs is to evaluate impacts of alternatives on the appropriate subsystem or component performance. If ACMs result in the same subsystem performance, ACM uncertainty is not significant.

If two or more ACMs show different subsystem performance, then the principal investigators must develop abstractions for both and deliver the to the TSPA analysts.

If abstractions for ACMs are not straightforward, conservatism is an option. TSPA evaluates system-level impact of ACMs. If impacts are significant, options are to carry multiple ACMs in TSPA with weighting, or to consider a conservative choice between ACMs. The latter has typically been the approach to dealing with ACMs in Yucca Mountain TSPAs.

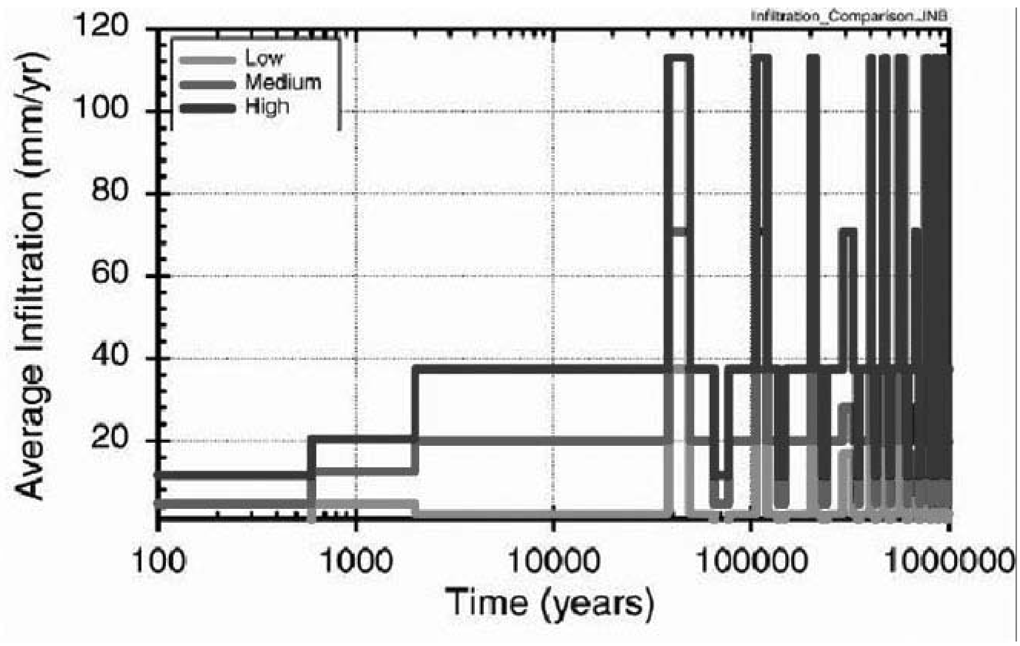
Abstraction

The key to the proper incorporation of process-level uncertainties lies in the formulation of the abstractions. Their goal is to capture aspects of process model important to system interactions, with appropriate representation of uncertainty. They are developed by subject matter experts, and reviewed by TSPA analysts.

Various forms of abstraction to capture the salient features of the process-level models are acceptable; e.g., simplified numerical models, simple functions, response surfaces, and parameter distributions. The abstracted models are implemented by TSPA analysts, and again reviewed by subject matter experts.

An example of an abstraction that also illustrates parameter and ACM uncertainty treatment is the use of a stylised step-wise introduction of successive climate states that are, admittedly, conservatively selected from the potential progression into the future. Infiltration uncertainty is then added realisation by realisation by sampling from three possible infiltration ranges for each climate state: a low range that has a 17% likelihood, a medium range that occupies 48% of the probability space, and a high case that may occur 35% of the time. The outcome is a set of flow-fields illustrated in Figure 1. Given a certain point in time, the climate-state is fixed, however, the water infiltration rate may vary widely, reflecting the uncertainty obtained from field, laboratory and analogue studies. The result is shown in Figure 1.

Figure 1. **Unsaturated Zone Flow Fields: 13 distinct flow fields account for uncertainty in future climate states and infiltration into the mountain (using 3 climate states before 10 000 years, and 4 after, all overlain with three infiltration-rate states indicated by the three colors, both alternative conceptual model and parameter uncertainty are addressed) [12]**



Initiating Event Probability Uncertainty

A probabilistic analysis allows the incorporation of events that are unlikely and may lead the TSPA to reach for sub-models not used if the event does not occur. The key to selecting this other set of sub-models is the frequency or likelihood of occurrence. Such likelihoods are usually, and properly, determined through internal or external expert judgement based on the analysis of analogous systems, or on formal expert elicitation using internal, external, or both types of experts.

An example of expert-judgement based designation of an event probability, and a formal expert-elicitation based evaluation of another probability, will be illustrated below.

Premature Waste Package Failure Example

A non-mechanistic (expert-judgement based) early (at emplacement) waste package failure probability was included in the model to avoid the non-conservative choice of not addressing the probability of such failures for lack of a mechanistic model. The experts consulted the failure rates of roughly comparable manufactured entities and came up with the following failure probabilities for use in TSPA. Note that the expected case has from zero to two failures.

Figure 2. **Expert-judgement based estimates of failure-at-emplacement probability for waste packages [13]**

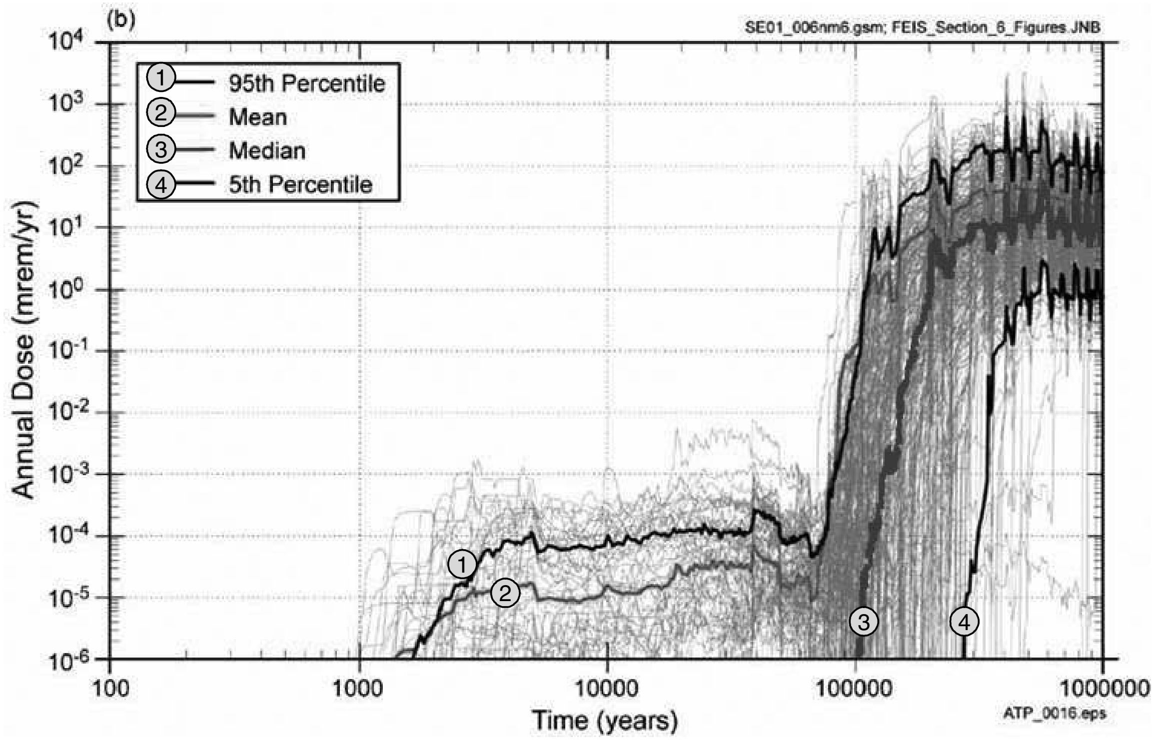
Number of Packages	Probability
0	0.77
1	0.2
2	0.027
3	2.30E-03
4	1.50E-04
5	8.00E-06

The results are shown in Figure 3. Prior to incorporating these early failures, there was no dose consequence above 10^{-6} mrem/year during the first 80 000 years.

Probabilistic Volcanic Hazard Analysis (PVHA) Example

The PVHA study was done to develop a defensible assessment of the volcanic hazard at Yucca Mountain, with quantification of uncertainties [14]. It utilised eight experts, seven of them external to the project, in a formal expert elicitation. Twenty years of geologic exploration work provided a basis for each expert making quantitative estimates of model and parameter uncertainty. Expert elicitation, in turn, allows the quantitative assessment and incorporation of alternative models and parameter values suggested by these experts.

Figure 3. **Example preliminary TSPA results with premature waste package failures probabilistically included [13]**



The types of alternative models considered for an igneous event were both temporal (when) and spatial (where) models. There were two alternative temporal models: (1) homogeneous Poisson models, and (2) several non-homogeneous models, namely, volume-predictable, waxing or waning models.

Similarly there were alternative spatial models of the homogeneous and non-homogeneous type. The homogeneous models were locally homogeneous "source zones," defined by observed volcanoes, structural control, geochemical affinities, tectonic provinces, etc.

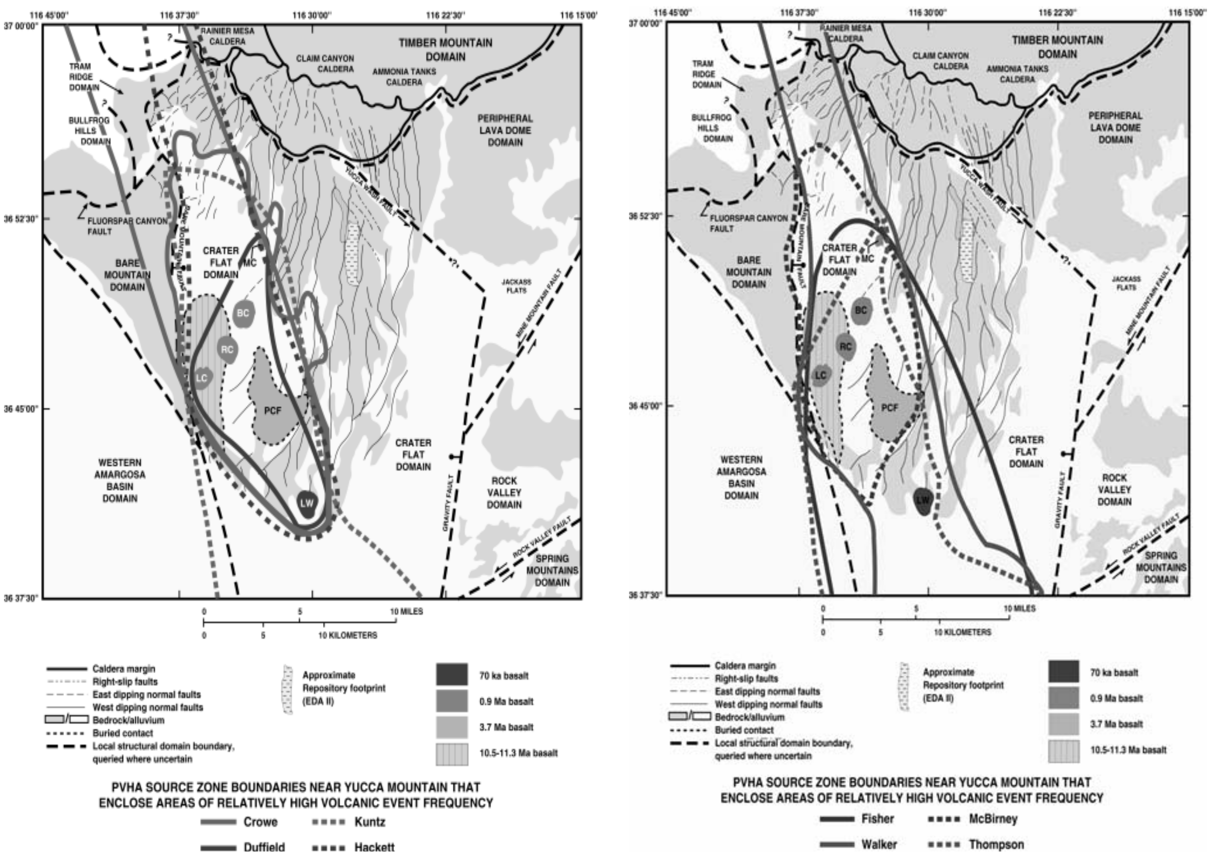
The non-homogeneous models were either parametric (bivariate Gaussian distribution for the field) or nonparametric (kernel density function and smoothing operator).

The point being that the alternative models and data ranges associated with them were treated, through the mathematics of the expert-elicitation process, in such a way as to allow for one distribution of annual frequencies of a dike intersecting the repository.

The experts each drew contours on a map suggesting where they believed the zones of higher potential eruptive frequency were. The next two illustrations (Figures 4 a and b) give the results of that exercise.

Figure 4: **Eight experts' interpretations of the zone boundaries near Yucca Mountain with relatively high volcanic event frequency [14]**

(a) **(b)**



The uncertainty in the frequency of potential eruptions in the repository area were evaluated using an event tree (Figure 5). The report in which these results are presented [14] explains the logic and mathematics underlying this event tree. The important point to be made here is that the uncertainty attributed to models and parameters by the experts was propagated through this tree to result in estimates of a dike intersecting a repository. One conceptual model (Figure 6) was used to allow each expert to calculate the frequency of dike propagation leading to an intersection with the repository in terms that would be compatible with the results of every other expert's calculation. This allowed acknowledged and quantified uncertainty to be propagated forward to the final result to be supplied to the TSPA analysts (Figure 7).

Figure 5. **Event tree used to incorporate conceptual model and parameter uncertainty into the probability of a dike intersecting the repository [14]**

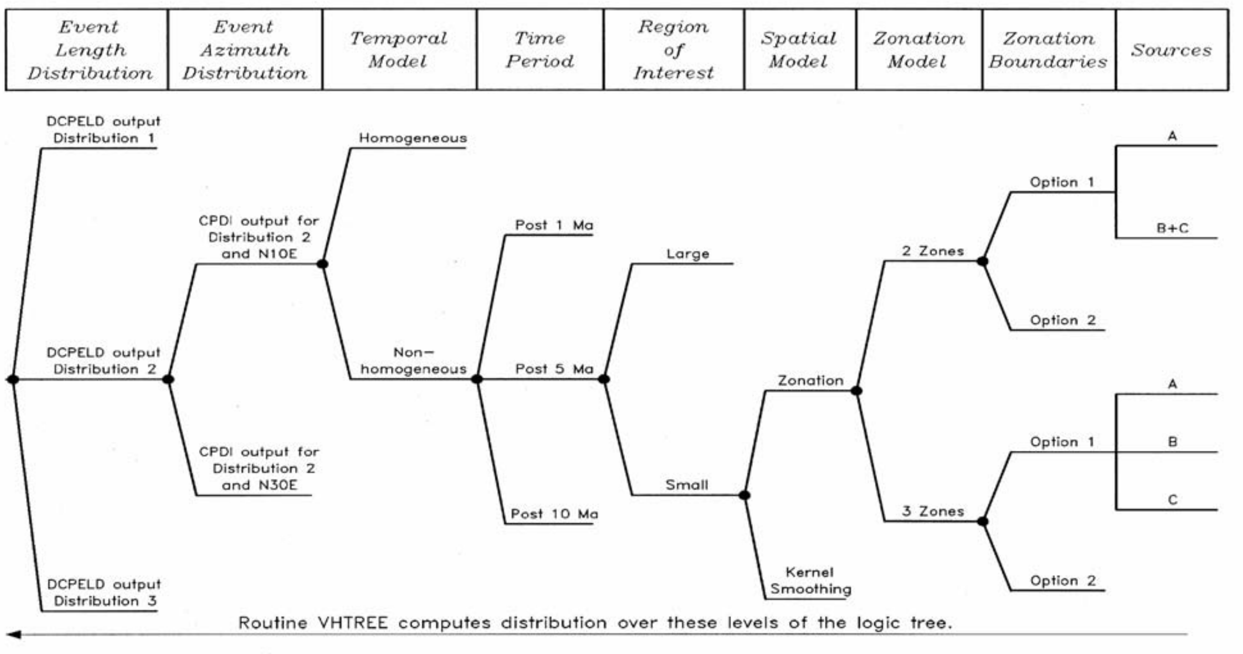


Figure 6. **Model for calculating probability of propagating dike intersecting with repository [14]**

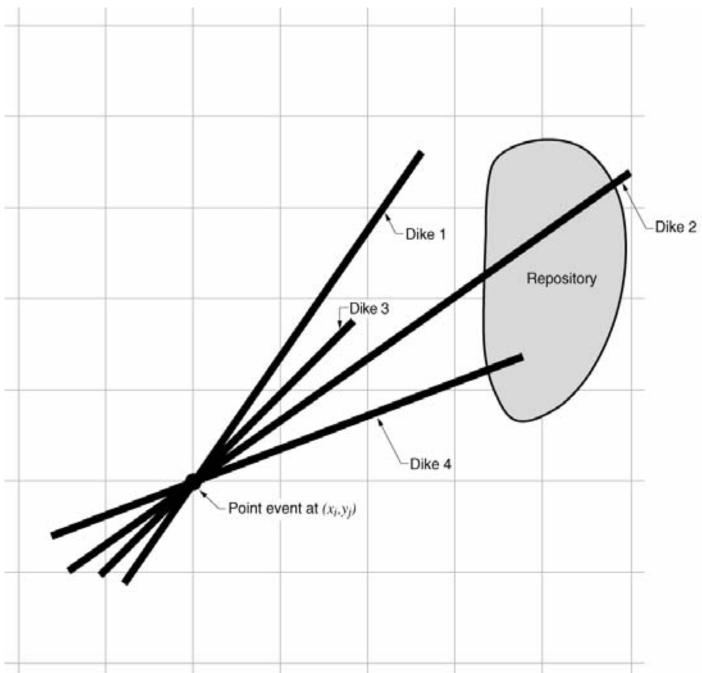
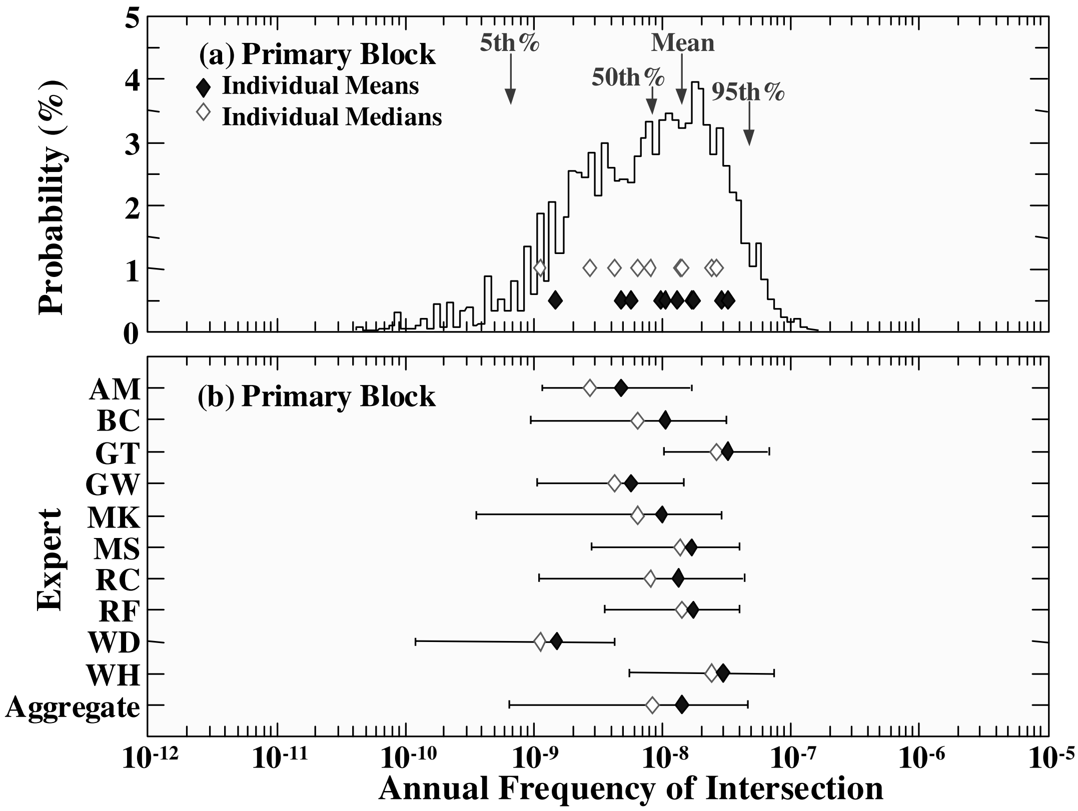


Figure 7. **Annual frequency of intersection results of PVHA used as input to the TSPA analysis [14]**



The PVHA expert elicitation was conducted to assess the volcanic hazard, with particular focus on quantifying uncertainties in the frequency of a dike intersecting the repository. This is a requirement if one is to estimate a probability-weighted dose as a decision-aiding performance measure.

The full range of temporal and spatial probability models was used to characterise potential future volcanic occurrences. The PVHA output provided hazard frequencies and event descriptions that served as inputs to consequence models. The consequence models, in turn, were able to propagate the uncertainty from the PVHA along with uncertainties in the consequence models themselves. The output of such an analysis is given in Figure 8. This result is from was an older analysis, since superceded. Hence it is not a reflection of what is expected for the TSPA-LA

Figure 8 shows 500 out of 5 000 TSPA realisations. It highlights the 95th, 50th, and 5th percentiles and the mean annual dose, weighted by probability. The initial, smoother portion of the curve rises and then falls. It rises with the increasing number of realisations that include a dike intrusion, which increases with time. After about 400 years the curve falls because of radioactive decay, which offsets the rise in probability-weighted doses from intrusions. Where the graph becomes more uncertain is where groundwater radionuclide transport from waste packages disrupted by the magma begins to arrive at the biosphere. Note that some of the very high potential dose values skew the mean to temporarily rise above the 95th percentile.

Figure 8. **Uncertainty in TSPA probability-weighted dose results from igneous events resulting in dikes intersecting the Yucca Mountain repository [12]**

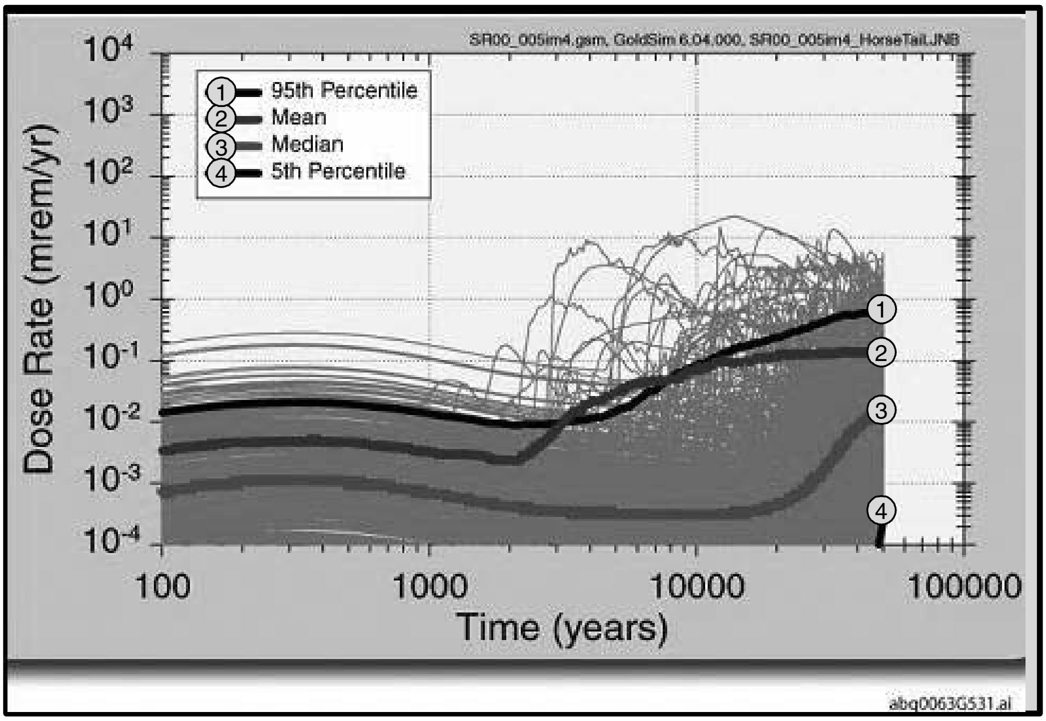
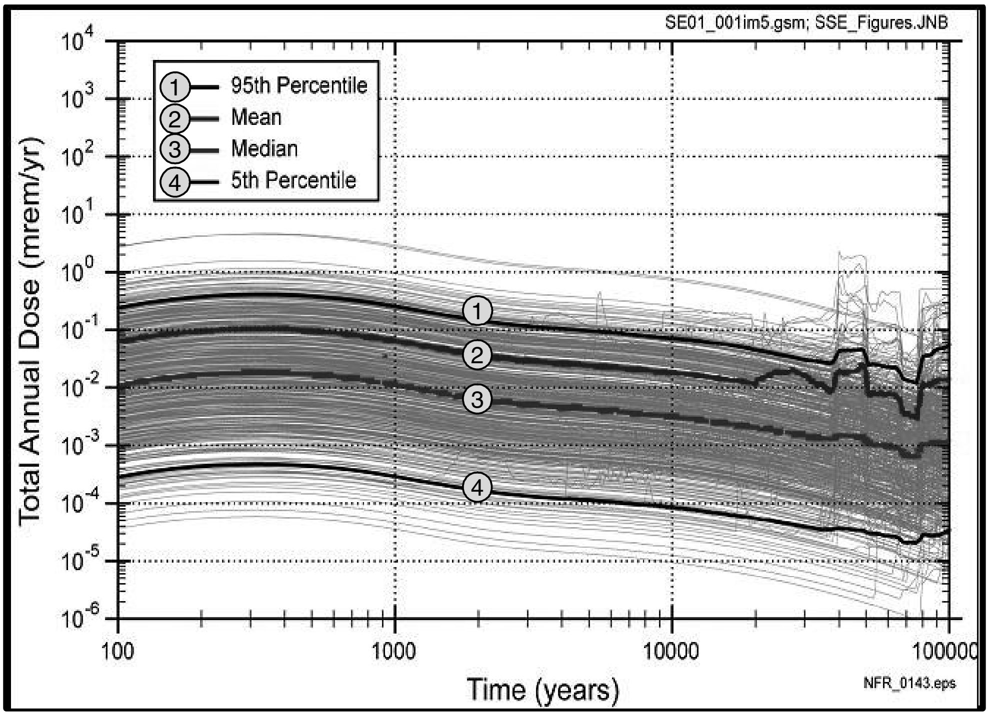


Figure 9. **Recalculation of potential probability-weighted doses from dike intersections with a potential repository at Yucca Mountain (change in consequence model, not probability model) [15]**



A difficulty in explaining this type of result to a non-specialist audience lies in the use of a probability-weighted, rather than a disaggregated, dose. The difficulty in explaining a disaggregated dose, however, lies in the natural discounting of the very low probability and focusing instead on the high potential-dose consequence.

Figure 9 shows a recalculation, using the same PVHA frequency-of-intersection input, but using a refined consequence model. The point of importance to this discussion is that the final judgement of safety, whichever model is selected for that crucial calculation, needs to be supported by a thorough analysis of uncertainties, their sources, and propagation.

Conclusions

Confidence in the treatment of uncertainty in TSPA comes from understanding uncertainty in underlying data, models, and parameters. Therefore, analyses such as those just illustrated need to be accompanied by documentation of the propagation of uncertainty through the TSPA.

Importance of specific uncertainties in underlying information depends on the measure of interest. Sensitivity analyses show that many uncertainties don't really matter to system performance. Regulations focus on mean performance, and therefore on accuracy of the estimate of mean performance. Uncertainty in model results is readily quantified once models and input distributions are complete, and provides insight into model behaviour and system understanding.

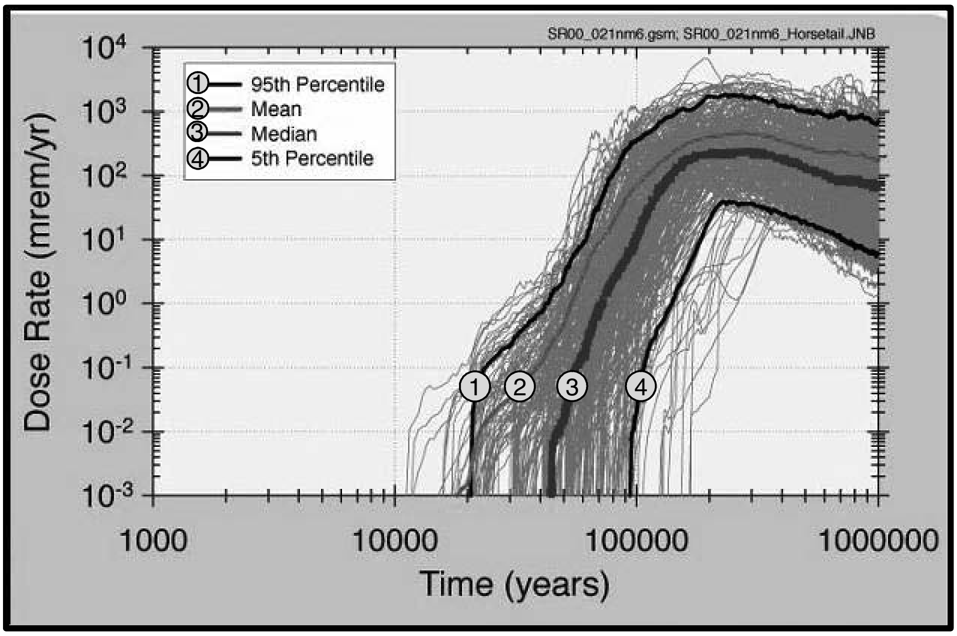
A final observation: does uncertainty always increase over time? No, not always for all systems.

For some systems, such as the older analysis illustrated in Figure 10, uncertainty will reach a maximum and then decrease as the occurrence of the controlling processes (e.g., waste package degradation in this example) becomes more certain. After that point in time, however, it is to be expected that remaining natural system processes do become more uncertain over time.

This is illustrated in figure 10 for uncertainty in a system not disturbed by igneous events. Please note that Figure 10 is an earlier analysis than that shown in Figure 3, and includes differences in assumptions, models and data. It is being used here to illustrate a point about uncertainty over time only. The quantified uncertainty is reflected in the vertical extent of the "horsetail" plot at any given point in time. Results become less uncertain as engineered system containment is lost, which is highly uncertain in this analysis. Thereafter, uncertainty increases again.

The engineered system uncertainty is coupled with natural system uncertainty on the left side of the diagram, with engineered system uncertainty dominating, until about 200 000 years. Thereafter, it is natural system uncertainty that is reflected in the results from 200 000 years to a million years, and that uncertainty expands gradually over time as is to be expected. One reason the engineered system uncertainty is large is that it is a transient system, it changes in important ways over time. By contrast, the natural system is modelled as a series of steady states. Transient system uncertainties tend to be larger than steady-state uncertainties, especially when plotted on a log scale versus time.

Figure 10. **A preliminary "horse-tail" plot folding in all quantified uncertainties for a preliminary Yucca Mountain repository TSPA in which disruptive events were not included [12]**



References

[1] USNRC (2002), *Integrated Issue resolution Status Report,* NUREG-1762, Washington, D.C., U.S. Nuclear Regulatory Commission.

[2] BSC (Bechtel SAIC Company) (2002), *Guidelines for Developing and Documenting Alternative Conceptual Models, Model Abstractions, and Parameter Uncertainty in the Total System Performance Assessment for the License Application.* TDR-WIS-PA-000008 REV 00 ICN 01, Las Vegas, Nevada.

[3] Apostolakis, G.A. (2003), "How Useful is Quantitative Risk Assessment?" Massachusetts Institute of Technology, Engineering Systems Division, Working Paper Series ESD-WP-2003-05, available at http://esd.mit.edu/WPS/wp-2003-05.pdf.

[4] USNRC (2002), *Disposal of High-Level Radioactive Wastes in a Proposed Geologic Repository at Yucca Mountain, NV.* 10 CFR Part 63, Washington, D.C., U.S. Nuclear Regulatory Commission.

[5] YMP (Yucca Mountain Site Characterisation Project) (2001), *Evaluation of Uncertainty Treatment in the Technical Documents Supporting TSPA-SR*, Las Vegas, Nevada.

[6] Budnitz, B., R.C. Ewing; D.W. Moeller, J. Payer, C. Whipple and P.A. Witherspoon (1999), *Peer Review of the Total System Performance Assessment-Viability Assessment Final Report.* Las Vegas, Nevada: Total System Performance Assessment Peer Review Panel.

[7] Hornberger, G.M. (2001), "Documented Findings of the Advisory Committee on Nuclear Waste's (ACNW's) Vertical Slice Review of the TSPA-SR." Letter from G.M. Hornberger (U.S. Nuclear Regulatory Commission) to R.A. Meserve (U.S. Nuclear Regulatory Commission), September 18, 2001.

[8] NWTRB (U.S. Nuclear Waste Technical Review Board) (2001), *Report to the U.S. Congress and the Secretary of Energy, January to December 2000.* Arlington, Virginia.

[9] Cohen S. & Associates (1999), *Review of Total System Performance Assessment in the U.S. Department of Energy Viability Assessment for the Yucca Mountain Site.* [Las Vegas, Nevada]: Clark County, Nevada, Department of Comprehensive Planning.

[10] OECD/NEA-IAEA (2002), *Joint International Peer Review of the Yucca Mountain Site Characterization Project's Total System Performance Assessment Supporting the Site Recommendation Process*. Paris, France: Nuclear Energy Agency.

[11] BSC (Bechtel SAIC Company) (2001), *Uncertainty Analyses and Strategy.* SA011481M4 REV 00. Las Vegas, Nevada.

[12] CRWMS M&O (2000), *Total System Performance Assessment for the Site Recommendation.* TDR-WIS-PA-000001 REV 00 ICN 01. Las Vegas, Nevada.

[13] DOE (U.S. Department of Energy) (2001), *Yucca Mountain Science and Engineering Report.* DOE/RW-0539. Washington, D.C., U.S. Department of Energy, Office of Civilian Radioactive Waste Management.

[14] CRWMS M&O (1996), *Probabilistic Volcanic Hazard Analysis for Yucca Mountain, Nevada.* BA0000000-01717-2200-00082 REV 0, Las Vegas, Nevada.

[15] BSC (Bechtel SAIC Company) (2001), *Total System Performance Assessment – Analyses for Disposal of Commercial and DOE Waste Inventories at Yucca Mountain – Input to Final Environmental Impact Statement and Site Suitability Evaluation*. REV 00 ICN 01, Las Vegas, Nevada.

INDIVIDUAL SESSIONS

SESSION 1

THE LONG-TERM SAFETY AND SECURITY OF GEOLOGICAL DISPOSAL

Chair: Martin Virgilio, Nuclear Regulatory Commission, U.S.A.

Objectives

This technical session examines the progress made and of some the main lessons learnt over the past four years dealing with both safety and security. Four years ago, the Denver Conference on "Geologic Repositories: Facing Common Challenges", highlighted the global progress made on the management of nuclear materials and waste, and provided a forum to discuss ongoing and planned activities to develop geologic repositories. In 1999 the concept of a long-term "safety case" – vis-à-vis performance assessment – of disposal facilities was put forward,[1] which was accepted internationally and further developed thereafter. Since then a few, major safety studies have been finalised, international peer review of these studies have taken place as well as many workshops and other initiatives regarding the long-term safety case. The international community is also embarking on formulating requirements[2] for geologic disposal to be promulgated, in due course, under the aegis of both the IAEA and the OECD/NEA. In 1999 a definition was also given linking geologic disposal to both security and safety,[3] but the security aspects were not taken up in international and legal instruments, e.g., in the Joint Convention. Since 1999, the aspect of guaranteeing long-term security have also been brought to the fore and are playing an important role in decision making for waste management, including disposal.

Issues that will be examined

- Do we observe significant progress in safety cases for disposal? Can we confirm that we can do them? What are the major issues?

- Are the principles in favour or against geologic disposal sufficiently clear? What is an agreeable hierarchy of principles?

- Is security, besides safety, an important concern? Should the current international definition of "disposal" be amended to indicate that it is a management solution that is also meant to provide security?

1. *Confidence in the Long-Term Safety of Deep Geologic Repositories*, OECD/NEA, 1999.
2. See Session on International Instruments; this conference.
3. "Disposal represents the radioactive waste management end-point providing security and safety in a manner that does not require monitoring, maintenance, and institutional controls" in *Geologic Disposal of Radioactive Waste – Review of Developments in the Last Decade*, (p. 33), OECD/NEA, 1999.

Programme

Chair: **Martin Virgilio**, Nuclear Regulatory Commission, U.S.A.

Michael Aebersold, BFE, Switzerland

Thomas L. Sanders, Sandia National Laboratories, U.S.A.

Panel-led discussion*: **Thomas Isaacs**, LLNL, U.S.A., **Michael Aebersold,** BFE, Switzerland

Moderator: **Martin Virgilio,** Nuclear Regulatory Commission, U.S.A.

Are the principles in favour or against geologic disposal sufficiently clear? Which is an agreeable hierarchy of principles? Is security, besides safety, an important concern? Should the current international definition of "disposal" be amended to indicate that it is a management solution that is also meant to provide security?

Peter De Preter, ONDRAF/NIRAS

Claudio Pescatore, OECD/NEA

L.P. Sukhanov, A.A. Bochvar (All-Russian Scientific Research Institute of Inorganic Materials, Russian Federation)

Panel-led discussion*: **P. De Preter, J. Vira,** Posiva, Finland

Moderator: **Martin Virgilio**

Do we observe significant progress in safety cases for disposal? Can we confirm that we can do them? Which are the major issues?

Closing remarks: **Martin Virgilio**

* The panelists will give their view on the questions asked in the programme. The moderator will then open the floor to further discussion with the audience.

LONG-TERM SAFETY AND SECURITY, THE RIGHTS OF FUTURE GENERATIONS: THE RESULT OF EKRA STUDIES ON CHOICES FOR THE LONG-TERM MANAGEMENT OF RADIOACTIVE WASTE

Dr. Michael Aebersold
Federal Office of Energy (BFE), Switzerland

Overview

1. Management of radioactive waste in Switzerland
2. Review of disposal concepts
3. Social expectations
4. The concept of monitored long-term geologic disposal
5. EKRA-conclusions and recommendations

1. Management of radioactive waste in Switzerland

Radioactive waste in Switzerland originates from five nuclear power plants generating 3 GW electrical energy which amounts for about 40% of the electrical energy consumed in Switzerland. Radioactive waste also originates from application in medicine, industry and research.

Nuclear waste management has a long history in Switzerland. In 1957 the first article on atomic energy was inscribed in the Constitution. The National Cooperative for the Disposal of Radioactive Waste (Nagra) was created in 1972. Since then a comprehensive waste management programme was pursued.

Today Switzerland has two disposal programmes: one for low- and intermediate-level waste and one for spent fuel, high-level and long-lived intermediate-level waste.

However, as in many countries the implementation of waste disposal facilities meets with strong opposition. Following political discussions in the 1990, the Federal Department of Environment, Traffic, Energy and Communication set up the Expert Group on Disposal Concepts for Radioactive Waste (EKRA) in June 1999.

2. Review of disposal concepts

EKRA was responsible for providing the basis for comparison of different concepts of radioactive waste disposal. In particular it considered and compared the concepts of surface based interim storage, indefinite deep storage and geologic disposal in the light of active and passive safety, monitoring and control as well as retrievability of waste and finally developed the new concept of monitored long-term geologic disposal.

The safety of radioactive waste disposal has to be ensured by a system of multiple natural and engineered barriers (passive safety system) and by measures (active safety system).

The natural barriers consist of the geosphere and the host rock. The engineered barriers include the waste matrix and containers as well as the backfilling of the cavities. Measures involve technical, organisational and administrative tasks and therefore place high demands on social institutions.

3. Social expectations

For a long time it was assumed that the management of radioactive waste was a matter purely for technical experts. In recent years, however, there has been an increased call for society as a whole to be involved in the decision-making process. Questions on democratic decision making in a pluralistic society, including a diversity of opinions, the value of expert opinion and Stakeholder involvement became high priority.

Social expectations are oriented towards the principle of reversibility. Retrievability of waste may be required for various reasons: Safety, test operations, alternative waste treatment or re-using of waste, availability of new, safer disposal facilities and conflicts of interest due to alternative uses of the underground. Allowing for retrievability in the design of the repository thus enhances the options of future generations to handle the waste problem.

EKRA investigated the scientific and technical aspects of safe waste disposal, taking into account sustainable development as well as socio-political aspects.

The paramount objective and value of every radioactive waste management concept has to be the safety of man and the environment. Once a sufficient level of safety has been assured, then fairness takes on a central role. Fairness means that as long as radioactive waste represents a risk to man, future generations have the right to the same level of safety as people living today.

Compared to safety and fairness, the criterion of acceptance is of secondary importance because it clearly favours the present generation and may be the immediately following generations. Last but not least the "producer-pay principle" has to be fulfilled.

4. Monitored long-term geologic disposal

According to EKRA, safety has top priority as evaluation criteria when comparing various radioactive waste disposal concepts.

The basic idea of monitored long-term geologic disposal was to combine the advantages of passive safety provided by geologic disposal with the possibility of implementing additional active safety measures like retrievability, monitoring and control.

A repository for monitored long-term geologic disposal consists of a test facility, a main facility and a pilot facility. All the facilities will be constructed in a suitable host rock, such as Opalinus clay currently under investigation for high-level waste disposal in Switzerland.

The test facility serves as a rock laboratory for site specific studies. It is built as the first element. Investigations are targeted to provide the necessary information for a concession application for the repository.

The main part of the waste will be disposed in the main facility. It should be constructed in such a way that retrievability is possible and straightforward.

However, for safety reasons, the cavities should be backfilled as soon as they are filled with the waste. Access and service tunnels will remain open as long as there is no formal decision for repository closure.

A representative portion of the waste will be disposed in the pilot facility. The purpose of the pilot facility is to monitor the long-term evolution of the engineered barriers and the near field. It will thus allow detecting signs of premature repository failure. It will also allow the verification of models used to predict the long term behaviour of the repository.

5. EKRA conclusions and recommendations

EKRA drew the following conclusions:

- interim storage facilities, surface waste disposal facilities and deep open facilities fail to meet the long-term safety criteria;
- geologic disposal is the only safe method to isolate radioactive waste in the long term;
- social demands concerning waste disposal are oriented towards the principle of reversibility; and
- the new concept of monitored long-term geologic disposal includes the following advantages:
  - possible enhancement of safety as a result of gained knowledge and technical advances;
  - early recognition of unexpected and undesirable developments; and
  - easy retrieval of the waste or, if necessary, repair of the facility.

In its final report, EKRA made the following recommendation to the government:

- Public and political debate on the issue of nuclear waste management is to be encouraged and intensified.
- Geologic disposal of all waste types should be stipulated in the legislation. The waste management programme should be financially independent of the nuclear power plant operators.
- LL/ILW: The Wellenberg project should be followed up and as a next step an exploratory shift should be built.
- After the negative outcome of a public referendum in the canton of Nidwalden in September 2002 a new site evaluation is necessary.
- HLW: The host rock currently under investigation – Opalinus Clay – looks suitable for both, geologic disposal as well as monitored long-term geologic disposal. Once the feasibility has been demonstrated, the site characterisation should move forward.

- A time schedule for both programmes should be prepared and progress should be controlled at regular intervals.

Some of EKRA’s proposals were subsequently implemented and the new concept was adopted in the new Nuclear Energy Law which will most likely enter into force at the beginning of 2005.

However, technical and institutional questions remained open and the Federal Department of the Environment, Transport, Energy and Communication requested EKRA to prepare an additional report to address these issues.

In the second report, EKRA expresses its views on the legal boundary conditions, the waste management programme, dialogue and participation, research and the organisation and financing of waste management activities.

EKRA II made among others the following recommendations:

- authorisations in the area of geologic disposal should be made exclusively on a federal level;
- the federal government should specify binding time targets for the start of operation of geologic repositories and should set up a system for controlling the waste management programmes;
- the waste management organisations should formulate an implementation programme that ties in with the specified objectives;
- the principles for setting up a Waste Management Council, drawing on experience both in Switzerland and abroad, should be defined, and
- a programme of interdisciplinary, independent basic research and specific research on implementation of the new concept should be initiated and its financing be secured.

OPPORTUNITIES FOR NATIONAL REPOSITORITES TO RESOLVE SECURITY CHALLENGES OF PAST, PRESENT AND FUTURE NUCLEAR ERAS

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Background

Since the beginning of the first nuclear era, the objective of nonproliferation policy (including safeguards and security) has always been to ensure that access to the beneficial uses of nuclear energy does not increase the risk of the spread of nuclear weapons. Today, the world has changed dramatically. There are now 32 countries with 444 nuclear power reactors with ~30 more under construction. There are also ~250 research reactors in 60 countries around the world. The anticipated worldwide growth in nuclear energy and nuclear technology applications will go a long way toward providing sustainable energy but it brings with it concerns over the possible increased access to nuclear materials suitable for nuclear weapons.

In the past, diverting materials from civilian nuclear fuel cycles has proven to be a highly unattractive route for nuclear-proliferant states to follow. Despite this fact, the specter of nuclear weapons proliferation has influenced nuclear policy, technology development and international relations since the dawn of the nuclear age. Because information on the design of a crude nuclear weapon is widely available, denial of access to nuclear material has been the principal barrier to nations and renegade organizations having illicit proliferation aspirations. Since 11 September 2001, there has been a new terrorism concern – dispersal of highly radioactive material by a conventional explosion of a designed munition, or by conventional or unconventional attack on an operating element of a nuclear fuel cycle such as a spent fuel storage site.

As so eloquently noted in an earlier paper by Ambassador Brill, on behalf of the Undersecretary, the importance of the U.S. repository in accomplishing U.S. national security goals has added additional drivers for moving on toward near-term licensing of the Yucca Mountain Repository. Energy Secretary Spencer Abraham noted these in his letter to President Bush recommending Yucca Mountain:[1]

> "I have considered whether sound science supports the determination that the Yucca Mountain site is scientifically and technically suitable for the development of a repository. I am convinced that it does. The results of this extensive investigation and the external technical reviews of this body of scientific work gives me confidence for the conclusion, based on sound scientific principles, that a repository at Yucca Mountain will be able to protect the health and safety of the public when evaluated against the radiological protection standards adopted by the Environmental Protection Agency and implemented by the Nuclear Regulatory Commission."

The Secretary went on to say that there are also compelling national interests that require the development of a repository including energy and national security, homeland security, nuclear nonproliferation policy, secure disposal of nuclear waste, and ongoing efforts to clean up the environment at former nuclear weapons production sites. Specific drivers mentioned are the following:

- advance nonproliferation goals by providing secure disposal of waste and products from decommissioning unneeded nuclear weapons;
- ensure effective operations of the nuclear Navy by providing a secure place to dispose of its spent nuclear fuel;
- consolidate nuclear waste (129 sites in 31 states) at one underground location to enhance protection against terrorist attacks;
- protect the environment by cleaning up defense waste sites permanently;
- dispose of commercial spent nuclear fuel to ensure that nuclear power remains an important part of the domestic energy production.

In addressing homeland security, the Secretary said:

> "More than l6l million people live within 75 miles of one or more of these sites. The facilities housing these materials were intended to do so on a temporary basis. They should be able to withstand current terrorist threats, but that may not remain the case in the future. These materials would be far better secured in a deep underground repository at Yucca Mountain."

> "Yucca Mountain is a geologically stable site, positioned in a closed groundwater basin, isolated on federally controlled land, housed approximately 1 000 feet underground, and located farther from any metropolitan area than the great majority of less secure, temporary nuclear waste storage sites that exist today."

The Secretary of Energy recommended the site to the President in February 2002, and on 9 July 2002, Congress passed a joint resolution approving Yucca Mountain as a suitable site for repository development. The recommendation was based on over 20 years of research and analysis, at a cost of approximately $4 billion, encompassing:

- 36 million hours of labour;
- 1 136 227 records of detailed analyses;
- 40 129 academic references;
- 22 062 program references;
- 75 000 feet of core samples;
- 18 000 geologic and waste samples.

The President signed the bill approving the site on 23 July 2002 (P.L. 107-200) thus completing the site characterization phase. Near-term efforts are now focused on seeking a license from the USNRC to construct a repository and develop a transportation system for shipping waste to the proposed repository.

Opportunity

As noted, the Yucca Mountain repository is not only critical to the vision of the future of nuclear energy in the U.S., reaffirmed by the President in his 2001 Energy Plan, but also to numerous other national security goals that were not understood very well when the original Nuclear Waste Policy Act was written.[2]

Our arms reduction agreements with Russia that enable the consumption of excess weapons plutonium and enriched uranium, would be impossible if we don't reach closure on the repository end of this cycle. Similarly, like Russia, our ability to offer to take back research reactor fuels that we originally supplied to other countries under the Atoms for Peace Program would be impossible if we were not actively pursuing the ultimate disposition of those materials. Disposing of these and other more dangerous or, more attractive materials from a theft perspective, give rise to additional security challenges that must be addressed in the design of the repository.

In particular, dealing with these additional issues may require a new nuclear materials management regime that involves tracking and controlling not just uranium and plutonium, but all materials in the nuclear fuel cycle, including those destined for geological storage and disposal.

To address all such issues, new technologies are needed in the areas of the global management of nuclear materials, advanced monitoring and control systems for improved operations, and enhanced safeguards to provide high levels of external observability, protection, and information management. As a first step, metrics must be established for security risks that include theft and sabotage and technical approaches must be developed to achieve appropriate reduction in these risks.[3]

An effective management strategy must integrate several complementary approaches to assuring safe, secure, and legitimate use and disposal of nuclear materials. Institutional measures, such as international treaties and independent oversight, will continue to provide the backbone of the nonproliferation framework. In fact, one of the original goals of Dwight Eisenhower's Atoms for Peace Initiative – international fuel cycle centers capable of cradle-to-grave supply – is being revisited by Russia and IAEA.

Preparation for such a 21st century nuclear nonproliferation regime should be included at the earliest stage of planning for all elements of a future fuel cycle and the earliest elements arising are the repositories we are discussing here. A good starting point would be to develop a consensus risk assessment methodology to help evaluate technology tradeoffs and identify steps that require stronger extrinsic barriers to theft, sabotage, and proliferation. It will be important in developing this consensus to explore establishing quantitative measures where possible so that approaches can be compared and the most cost-effective methods identified.

Unfortunately, until recently, an international (or national) consensus on how to perform a relative risk comparison between concepts and what standards of acceptability to use was never developed and applied to "cradle-to-grave" material cycles. However, there is considerable experience worldwide on the application of Probabilistic Risk Evaluation Methodologies for comparing the "Relative Risk" of various safety and security options for nuclear material life cycles. A specific "repository" example is illustrated by Figure 1. My goal here is not to recommend a particular solution but rather, to illustrate some of the tradeoffs. In keeping with past U.S. policies that material processing is not desirable or necessary, certain fuel types in the U.S. are now destined for the repository that in principle have attributes that make these fuel types much more "attractive" in comparison to civilian LWR irradiated fuel. As illustrated, either the fuel must be processed to reduce attractiveness, or in the case of minimizing "theft," the protective features of the repository must be enhanced.

The way we have automated and used information systems in high consequence processes such as advanced manufacturing enterprises has substantially changed the human risk of hazardous material operation. If such advanced features could be incorporated into the operational design characteristics of future waste management systems, not only would vast improvements in worker safety be achieved, but also the likelihood of undetected illegitimate material diversion or access by human intervention would be also significantly reduced to as low as reasonably achievable.

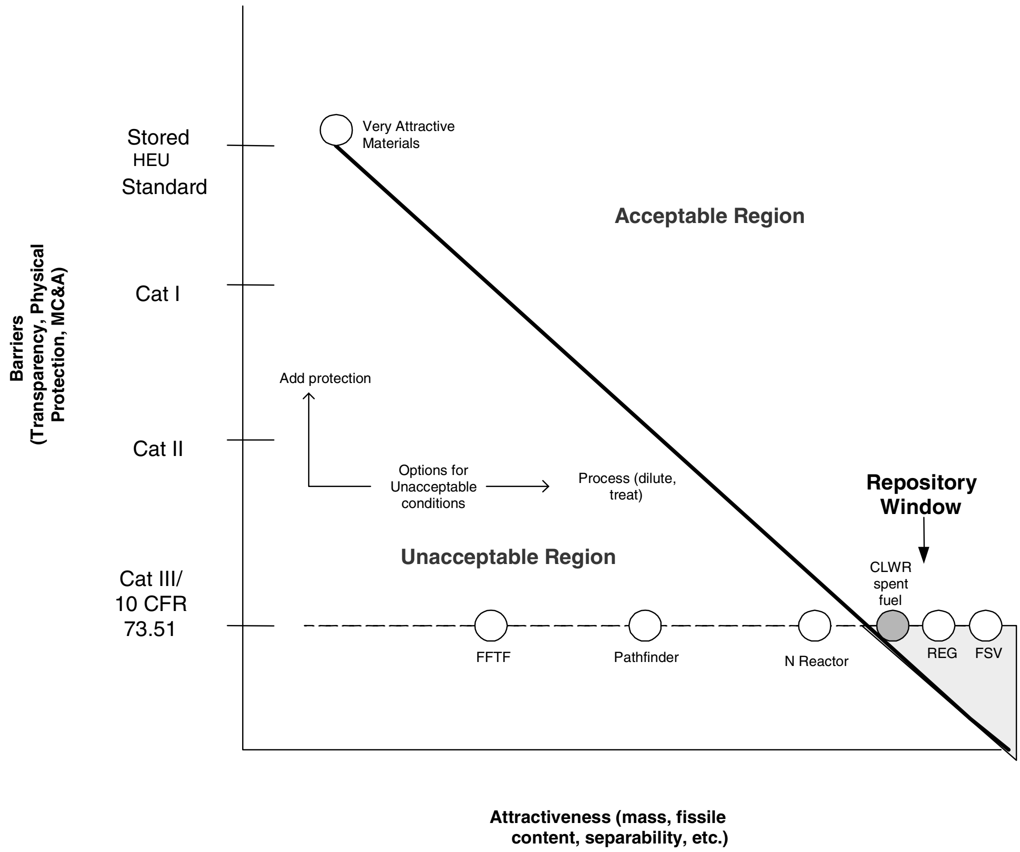
Capitalizing on the substantial progress that has been made in sensor technology in the past decades, modern monitoring systems should be integrated into new fuel cycle facilities and transportation systems starting with the earliest conceptual design of repository facilities. The new management scheme should also encompass radioactive materials that are not weapons-usable, but that could be dangerous in the hands of terrorists.

Summary

With the global nuclear picture becoming even more complex, the role of repositories in accomplishing arms control, homeland security, and proliferation prevention goals has moved to front and center. Evolving repository infrastructures offer outstanding opportunities for illustrating advanced approaches for managing these risks.

The traditional defense-in-depth concepts used to manage fuel cycle safety and protect nuclear materials in the U.S. and other countries could also be established as a framework for developing hardened, secure, and proliferation resistant material infrastructures including disposal systems. This analysis concept has been effective in establishing the safety basis for nuclear fuel cycles, reactors, and nuclear waste repositories. The concept results in the balanced use of multiple, diverse barriers to prevent the occurrence of undesired events such as radioactive releases from a safety perspective, or materials theft from a physical protection perspective.

Figure 1. A simple comparison to illustrate "security risk management"



REFERENCES

[1] Letter from Secretary of Energy Spencer Abraham to U.S. President G.W. Bush, February 2002.

[2] National Energy Policy, Report of the NEPDG, by letter to President Bush from Vice President Dick Cheney, May 16, 2001.

[3] *Nuclear Energy: Power for the 21st Century*, ANL-03/12, SAND2003-1545P, J.F. Kotek, T.R. Allen, H.F. McFarlane, H.P. Planchon, J.I. Sackett, H.S. Khalil, and D.C. Wade (ANL); J.A. Lake and J.S. Herring (INEL); R.J. Eagan and T.L. Sanders (SNL); G.E. Michaels and D.J. Hill (ORNL); E.D. Arthur (LANL); D. Christensen, W.G. Halsey, J.A. Blink (LLNL), May 2003.

HANDLING LONG TIMESCALES: APPROACHES AND ISSUES IN THE CONTEXT OF GEOLOGICAL DISPOSAL

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Introduction and context

Geologic repositories are sited, designed and operated to protect humans and the environment from the hazards associated with radioactive waste. Most challengingly, they are required to provide protection after their closure and over timescales that are considerably in excess of those commonly considered in most engineering projects, often up to several thousand or even a million years. This requirement is laid down in international guidance and in many national regulations.

Various processes and events will drive the evolution of a repository and its environment, and hence could affect the containment and lead to possible release of radioactive substances from the repository and their migration to the surface. These processes and events are characterised by timescales ranging from a few tens or hundreds of years for transient processes associated with, for example, the resaturation of the repository and its immediate surroundings following closure, to perhaps millions of years for changes in the geological environment.

Safety assessments must consider consequences of releases of radioactive substances and verify that targets set by regulation are complied with. In order to evaluate compliance with dose or risk criteria, assumptions must be made regarding the habits of potentially exposed groups (e.g., diet, lifestyle and land use), and these may change over timescales of just a few years.

The need to deal with such a wide range of timescales gives rise to a range of issues related to the methods and presentation of safety assessments and of safety cases. In particular:

- Is it really necessary to argue a case for safety over timescales of a million years or more?
- If so, how predictable is the evolution of the repository and its environment over these timescales?
- What types of arguments are available that take account of the inevitable changes and uncertainties associated with long timescales?

- How may the very limited predictability of human habits and the evolution of the surface environment over relatively short timescales be dealt with?
- How may public concerns affect the emphasis given to different types of argument at different times?

These issues are of concern to all national geologic disposal programmes and provided the motivation for the IGSC (Integration Group for the Safety Case, set up by the Radioactive Waste Management Committee of the OECD Nuclear Energy Agency) to launch in 2001 an *Ad-hoc* group on the timescales issue. The first activity of this group was the organisation of a workshop entitled "Handling of timescales in assessing post-closure safety". The workshop was held in Paris on 16-18 April 2002 and was hosted by the French Institute for Radiological Protection and Nuclear Safety (IRSN). The NEA prepared a synthesis of the workshop, which was published in the proceedings [1]. The main findings may be summarised as follows.

1. The timescales over which a safety case needs to be made

The long timescales addressed in safety assessments arise from the long half lives of some of the isotopes in the waste and the high degree of effectiveness with which deep geologic disposal facilities are expected to contain radioactivity – safety studies for deep geologic repositories tend to focus on the distant times when releases eventually occur. There are no ethical arguments that justify imposing a definite limit to the period addressed by safety assessments, in spite of the technical difficulties that this may present to those conducting such assessments. It is an ethical principle that the level of protection for humans and the environment that is applicable today should also be afforded to humans and the environment in the future, and this implies that the safety implications of a repository need to be assessed for as long as the waste presents a hazard. In view of the way in which uncertainties generally increase with time, or simply for practical reasons, some cut-off time is inevitably applied to calculations of dose or risk. There is, however, generally no cut-off time for the period to be addressed *in some way* in safety assessment, which is seen as a wider activity involving the development of a range of arguments for safety.

2. Intrinsic quality of the site and the design and limits to predictability

An important line of argument in safety assessments relates to the intrinsic quality of the site and the design. The safety of any repository depends primarily on the favourable characteristics of the engineered materials and the geological environment – including their predictability over prolonged periods – and these characteristics need to be stressed in safety cases. As regards the geological environment, evidence for stability and other favourable characteristics often comes from *in situ* observations and measurements. More generally, thermodynamic, kinetic, mass balance and palaeohydrogeological arguments may play a role. Arguments for the feasibility, in principle, of safe geologic disposal may also be made based on the existence of natural analogues and, in particular, natural uranium deposits.

In order to maintain credibility within the scientific community as well as with other stakeholders, it is important to acknowledge the limits of predictability of the repository and its environment in both regulations and in safety cases. Well-supported statements regarding radiological consequences can be made that cover a prolonged period provided a repository is well designed and a suitable, geologically stable site is selected. At times when the stability of the geological environment can no longer be assured, a more qualitative assessment of radiological consequences is likely to be adequate, because of the strongly decreased radiological toxicity of the waste that is expected at these times.

3. Arguments for safety in different time frames

Multiple lines of argument are useful for building a convincing safety case. Some lines of argument are more qualitative in nature than others, and there may be an emphasis on different types of argument and different indicators of performance and safety in different time frames. Safety assessments are increasingly taking into account the full range of arguments for safety that is available, as well as the safety and performance indicators that may be used to complement dose and risk, and regulations are increasingly providing guidance regarding their use. When discussing different time frames, it is important to bear in mind the decrease with time of the hazard presented by the waste.

4. Stylised approaches

Given that changes in human society, technology and the surface environment are likely, and are largely unpredictable over the time period of interest in safety assessments, there is international consensus that radiological doses and risks calculated for hypothetical human groups dwelling in the future, but with habits and technology similar to those of the present day, are appropriate as indicators of repository safety. The doses and risks calculated for critical groups in stylised situations are not interpreted as measures of expected health detriments and risks to future individuals, but rather as illustrations based on agreed sets of assumptions, and this needs to be stressed in the presentation of safety assessment results. Adoption of such a stylised approach avoids open-ended speculation on issues such as future human habits for which uncertainties are large and irreducible.

5. Complementary safety and performance indicators

The use of safety and performance indicators other than dose and risk may give indications of safety independent of both the limited predictability of the surface environment and, on a far longer timescale, the limited predictability of the geological environment. They provide useful complementary arguments for safety if accepted reference values or criteria for comparison may be agreed upon. Possible starting points for the definition of reference values are considerations of either acceptable hazard (as for dose and risk) or negligible disturbance of nature. There are, however, some problems concerning:

- the temporal and spatial scale at which observations of natural systems need to be made;
- the fact that natural conditions are not necessarily “harmless”; and
- how to deal with radionuclides that are not found in nature.

Arguments based on complementary indicators require careful explanation and a sound strategy regarding the choice and utilisation of indicators needs to be developed and communicated. The use of complementary indicators, their weighting in different time frames, as well as reference values for comparison, are issues that may well deserve further regulatory guidance.

6. Addressing public concerns

Documents aimed at the public should focus on arguments that may be understood without reference to detailed technical analyses for all timescales that are addressed. The presentation of safety cases for the period of a few hundred years following emplacement of the waste may, however, deserve particular attention, with greater emphasis in documents aimed at the public on the fact that, for most repository concepts, zero release of radioactivity is expected in this period. Monitoring in the operational and immediate post-closure period may potentially contribute to public confidence.

Reference

[1] NEA, (2002), *The Handling of Timescales in Assessing Post-closure Safety of Deep Geologic Repositories*. Workshop Proceedings, Paris, France, 16-18 April 2002. OECD: Paris.

Acknowledgements

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INTERNATIONAL PROGRESS IN PERFORMING LONG-TERM SAFETY ANALYSES

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Background

- NEA
  - industrialised countries;
  - platforms for info exchange and co-operative projects;
  - across institutional boundaries;
  - one platform dedicated to Safety Case [SC] for geologic disposal *[technical managers from R&D, Regulatory Agencies, implementing organisations]*.

Sources

- IPAG series of initiatives (1995 – 2001):
  - Contents of "PAs"; regulatory review issues; confidence arguments.
  - Data base of all major geologic disposal studies and their reviews in the 90s.
- Confidence report of 1999:
  - Formulation of modern concept of Safety Case for deep disposal.
- International Peer Reviews:
  - Sweden (3); Japan (1); USA (2); UK (1);
  - Belgium R&D; France R&D;
  - Switzerland (*in progress*).
- Integration Group for the Safety Case (2000-…).

In the 90s

- Is it really "PERFORMANCE" Assessment (PA) that we are after?
  - "Science tells us that" attitude …
  - Implication of prediction of performance *per se* [no strong link to decision making].
  - Reduced space for dialogue.
  - Easily challenged: **no validation = no reproducibility = no full scientific product.**
- Regarding reproducibility
  - Best that can be done is a PA that is simple, traceable and transparent enough to allow reviewers to redo analyses and calculations if they wish.
  - This was the Finnish approach.
- To keep in mind:
  - Repository development proceeds in stages, and the depth of understanding and technical information available to support decisions will vary from stage to stage.
    - Within each stage, understanding is also acquired incrementally.
  - Both the provider and the reviewer should state the reasons for their confidence, concerning the decision at hand.
    - Dialogue, accountability become more prominent.
- Shift from Performance Assessment to Safety Case, because:
  1. When it comes to long-term predictions we leave the scientific domain in the strict sense. A mixture of quantitative and qualitative analyses will have to be provided; a host of safety/protection/performance indicators will be used.
  2. A safety study is performed explicitly to enable a decision; not in the absolute.
  3. Decision making requires only that:

     (i) A transparent description of the system and its possible evolutions has been compiled giving adequate confidence to support the decision at hand,

     > *"A safety case is a collection of arguments, at a given stage of repository development, in support of the long-term safety of the repository. A safety case comprises the findings of a safety assessment and a statement of confidence in these findings."*

(ii) A strategy, in which there is confidence, exists to deal at later stages with any remaining uncertainties that have the potential to compromise safety.

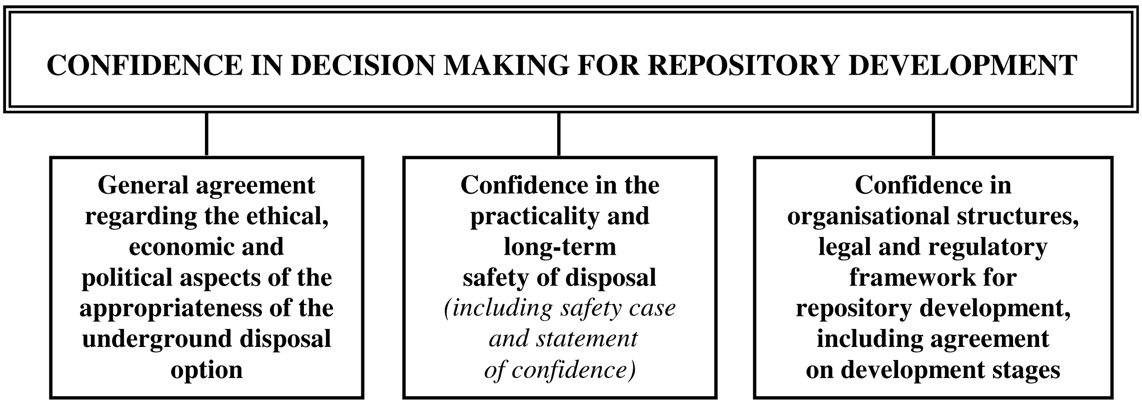
> *"It should acknowledge the existence of any unresolved issues and provide guidance for work to resolve these issues in future development stages."*

Conclusions from the 90s

- Society is more interested in safety than in performance.
- A safety case is what society wants for making decisions at each stage.
  - Most likely along the principles to be exposed here.
- A safety case is a platform for dialogue for a multiplicity of actors.

What is needed to respond to those demands?

- Support for decision making.
- Support for dialogue.
- What are the apparent obstacles?
  - UNCERTAINTY;
  - issues of CONFIDENCE.

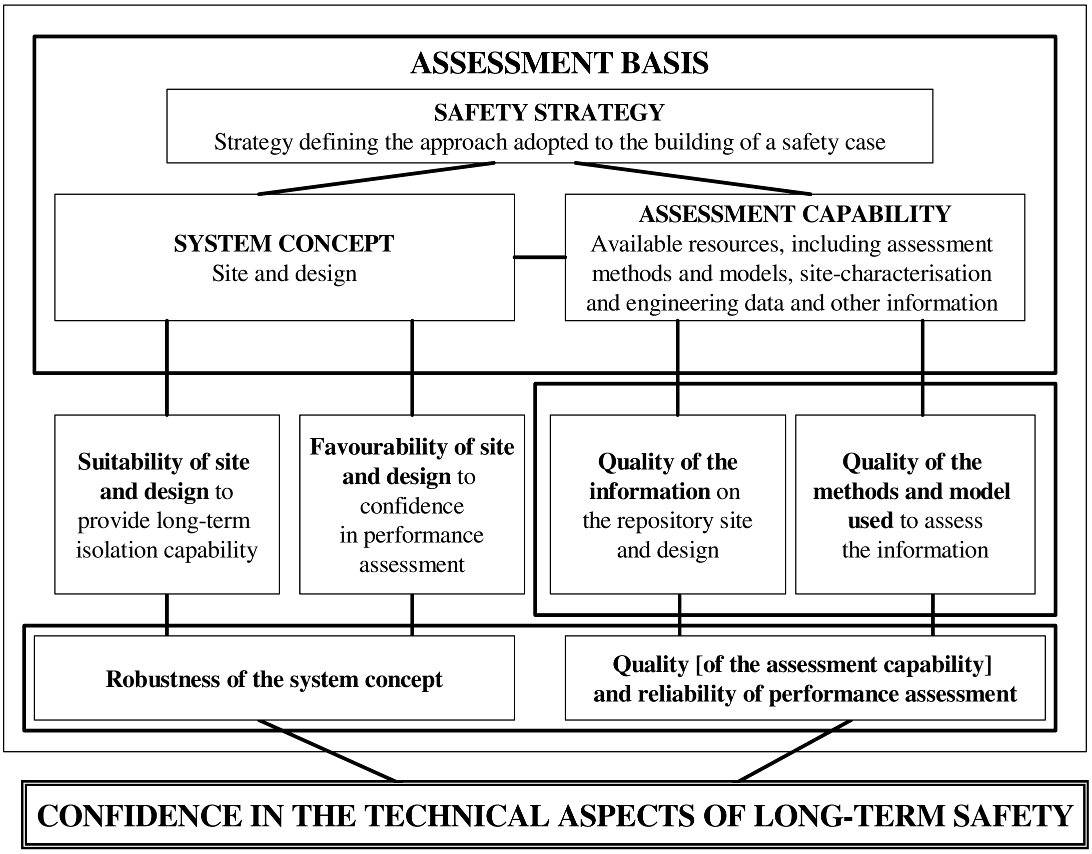


Confidence vs uncertainty

- Uncertainty will exist in any human endeavour. Decision making has always to take uncertainty into account. The real issue for decision making is that of confidence.
- Decision making is hardly ever based on numerical values for uncertainty:
  - Even if probabilistic assessments of safety of NPPs have been in use for many years, no NPP has ever been licensed on the result of only a probabilistic assessment.
- Confidence does require a demonstration that "uncertainties" have been dealt with.
- There are means to deal with scientific uncertainty, i.e. those typically applied in data analysis and model testing. They have to be implemented.
- When it comes to long-term predictions we leave the narrow scientific domain:
  - A mixture of quantitative and qualitative arguments will have to be provided and will need to engender confidence in both the provider and the reviewer.
  - The reasons for this confidence, in support of the decision at hand, should be stated to enable dialogue.

The concept of confidence

- … implies awareness …
- … awareness must rely on a deliberate set of actions/procedures meant to achieve confidence for taking a specific decision under a specified set of constraints.
- There must be a frame whereby confidence is sought and within which confidence can be **evaluated**, communicated and enhanced.
- … is more subjective than "validation", in that it is less amenable to quantification.
- …exposes the fact that the "reasonable expectation of bounded performance" is the standard.

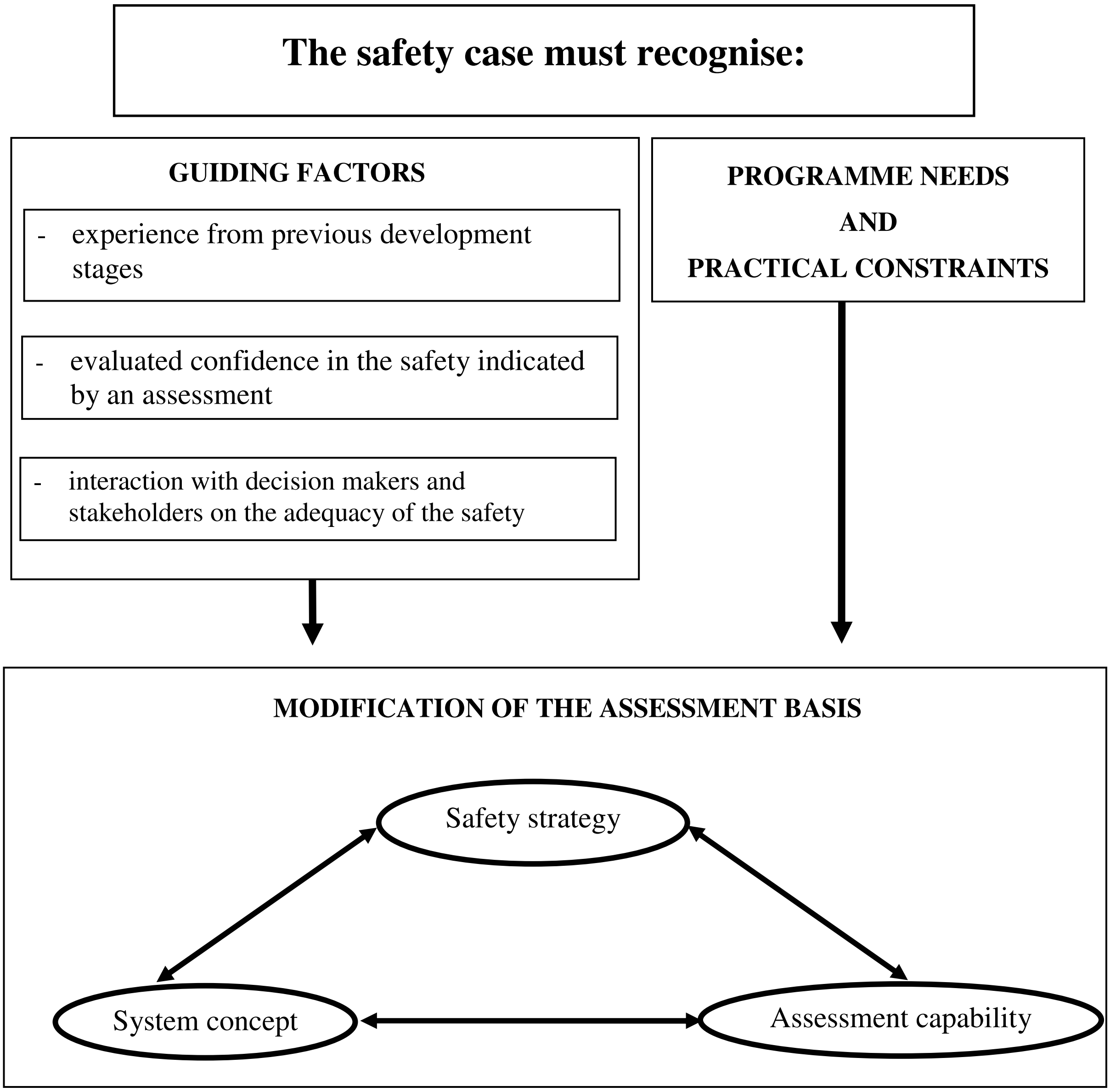


Comunication of strategy

- Strategy for achieving safety, i.e. a robust system concept:
  - Through the choice of site and design, avoiding or forcing to low probability or consequences most phenomena and uncertainties that could be detrimental to safety and to its evaluation.
- Strategy for "proving" safety, i.e. for arriving at a reliable performance assessment:
  - Acquisition of relevant information to the system concept.
  - Development and application of methods and models to assess this information. This includes the identification of assessment cases.

To provide confidence the SC should document

- Tests of the robustness of the system concept:
  - confirming that appropriate criteria and procedures have been observed;
  - using performance assessment as a test across a range of scenarios, in order to identify/exclude sensitivities.
- Quality of PA methods and models:
  - PA approach; level of understanding of safety relevant features events and processes; availability of the conceptual and computational tools.
- Quality of information on site and design:
  - Are data/models
    - Well supported?
    - Quality assured?
- Reliability of the application of methods, models, and data in PA:
  - QA procedures;
  - independent evidence;
  - demonstrate broad understanding through use of simplified models, etc.


The safety case must recognise:
GUIDING FACTORS
- experience from previous development stages
- evaluated confidence in the safety indicated by an assessment
- interaction with decision makers and stakeholders on the adequacy of the safety
PROGRAMME NEEDS
AND
PRACTICAL CONSTRAINTS
MODIFICATION OF THE ASSESSMENT BASIS
Safety strategy
System concept
Assessment capability

Key elements of a modern safety case
(from the NEA SC brochure, 2004)

Purpose and context of the safety case

↓

Safety case at a given stage in disposal system development

↓

Safety strategy
Siting and design
Management
Assessment

Assessment basis
System concept
Scientific and technical
Methods, models, codes, databases

↓

Evidence, analyses and arguments (examples)
Intrinsic quality of the site and design
Strategy to manage uncertainties, open questions

↓

Synthesis
Key findings and statement of confidence *vis a vis* purpose and context

What does the confidence statement communicate? (cf., NEA SC brochure, 2004)

- The confidence statement says that, within the context of the given programme stage:
  - principles, previous guidance, programme constraints and safety strategy have been respected;
  - all relevant data and info, and their uncertainty, were considered;
  - all models have been tested adequately;
  - a rational assessment procedure has been followed;
  - results are fully disclosed, subjected to QA and review procedures;
  - the safety strategy is appropriate to handle remaining, not-fully resolved safety-related issues in future stages.
- The *rigour* and *discipline* implied are further factors of confidence in SC quality.

Conclusions

- There is no requirement to achieve the impossible in decision making for repository development.
- It is possible to make a safety case that supports decision making and, within in it, make confidence a tangible, overarching concern in the preparation of a safety case. This requires clarity of purpose and discipline.
- The move towards modern safety cases is underway:
  - IGSC topical sessions confirm trend in national programmes.
  - Joint IAEA-NEA safety requirements guide DS-164.
  - NEA safety case brochure (2004).
  - The latest safety study: Nagra’s Project Opalinus (Dec. 2002).

ECOLOGICAL ASPECTS OF THE RADIATION-MIGRATION EQUIVALENCE PRINCIPLE IN A CLOSED FUEL CYCLE AND ITS COMPARATIVE ASSESSMENT WITH THE ALARA PRINCIPLE

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The modern stage of the Russian nuclear industry is characterised by the following features [1]:

- the previous nuclear activities have resulted in accumulation of a large amount of high- and intermediate-level liquid radioactive waste (RW) formed upon reprocessing of spent nuclear fuel (SNF) and nuclear materials (radioactive waste continues to be formed during reprocessing of spent nuclear fuel at the operating RT-1 plant at the IU "Mayak");

- the strategy of the development of nuclear power engineering of our country in the first half of the 21st century is determined, according to which a twofold increase in the power on the basis of thermal and fast neutron reactors with coming nearer to the closing of a nuclear fuel cycle (see figure) is contemplated by the middle of the century;

- a wide application of fast liquid-metal cooled reactors using a uranium-plutonium fuel is intended; and

- the development of complex spent fuel management is determined, including the modernisation of the operating regeneration plant (RT-1 at the IU "Mayak"), the performance of scientific research on the design of a new regeneration plant (RT-2 at the MCC), and creation of a developed infrastructure of long-term SNF storage.

As regards the liquid radioactive waste formed during reprocessing at the operating radiochemical RT-1 plant, the technology of incorporating that waste into aluminophosphate glass with the use of direct Joule-heated melters was implemented on an industrial scale. In 2001, an EP-500/3 melter was put in operation. This melter operates continuously, and the composition of radioactive waste fed for vitrification is maintained constant. In order to provide the reprocessing of radioactive waste with different compositions, it is intended that a facility for immobilising liquid RW with the use of a cold crucible induction melter will be put in operation late in 2004 at the IU "Mayak". This facility will make it possible not only to reprocess RW of variable composition but also to produce various matrices (vitreous, glass-ceramic, and crystalline) involving waste radionuclides.

The creation of large-scale nuclear power engineering will lead to considerable increase in the amount of spent nuclear fuel, which will be stored and reprocessed in a greater volume. The currently used water extraction reprocessing leads to formation of large amounts of liquid radioactive waste. However, with the aim of substantially reducing RW, new technologies of reprocessing the spent nuclear fuel are under development. In any case, all fission fragments (or their large part) and minor actinides are intended to be removed from fuel upon reprocessing and may be treated as waste components.

It is of fundamental importance that the activity of these components is appreciably higher than the initial activity (prior to reactor) of fuel from which they are separated. Actually, the amount of fission fragments and minor actinides (in terms of mole fractions) formed in a reactor is considerably larger than the amount of the "burnt" fuel. At the same time, the half-life of fission products and minor actinides are short compared to those of ^{235}U ($T_{1/2} = 7.04 \times 10^8$ years) and ^{238}U ($T_{1/2} = 4.46 \times 10^9$ years). In view of these two circumstances, the total activity of fission products and minor actinides substantially exceeds the activity of the initial fuel and, apparently, will approach the latter activity with time comparable to the decay time of the longest lived radionuclides contained in waste.

As is known, a harmful effect of a particular radionuclide is determined by the type of the radioactive decay (and the corresponding radiation characteristics) and the decay rate. The fact that the waste activity is dominant over the activity of the initial fuel for a long time is responsible for the necessity of resolving the RW problem.

By contrast, when the waste activity and the activity of the corresponding fuel would be equal to each other (immediately or after a short time), we could speak about the absence of a harmful effect of waste, because, in this case, the radiation balance would be retained in nature, namely, the number of decays per unit time would remain unchanged when radioactive waste would be buried within a geological formation. The case in point would be the radiation equivalence of waste and initial natural fuel component. Unfortunately, this situation cannot be achieved. In this respect, the possibility equalising the radiological waste effect and the natural component is of considerable importance.

Over the recent 10-15 years, the problem of geologic disposal has attracted increased attention of specialists, technical experts, regulatory agencies, and national and international community. This is explained by the fact that the geologic disposal of radioactive waste and the justification of its safety by way of giving conclusive evidence remains a critical area of nuclear power engineering.

The position of Russia with respect to the geologic disposal of radioactive waste coincides with the international position stated on the level of the International Atomic Energy Agency (IAEA) and may be summarised as follows:

- the geologic disposal is the sole preferential means of long-term isolation of spent nuclear fuel and radioactive waste from the biosphere;

- the technology of disposal, building, and operation of burials in various rocks (salt, clay, crystalline rocks, tuff) is ready to be introduced;

- the results of research and development carried out at more than ten underground laboratories made it possible to obtain very valuable information for verifying mathematical models used to assess the disposal safety;

- the advanced mathematical models for justifying the safety of geologic disposal and the obtained computational data on the development of events and the behaviour of burial systems provided the basis for the technical examination and the assurance of specialists that SNF and (or) RAW may be safely buried into deep geological formations when the established principles, requirements, and criteria of disposal are satisfied;

- the assurance of technical experts is a necessary but not sufficient condition for the implementation of geologic disposal, because the disposal problem has not only technical but also ethical, social, and political aspects and infringes on interests of the society as a whole, future generations of peoples, and biosphere; and

- the disposal problem may be solved on the level of the society when the safety of burials will be supported by impressive evidence, and specialists bear the responsibility for the development of a reliable and safe solution of the problem and should be ready to defend this solution in open debate.

It is evident that the delay in the accomplishment of national programmes concerned with the RW disposal in different countries is explained not technical but social and political factors and by the presence of diverse sections of society that doubt the safety of disposal and the reliability of provided evidence. Therefore, efforts to continue the research and development programmes that are associated with the refinement of the data, models, and concepts dealing with the justification of long-term safety of disposal and also to continue the search for regions and specific sites suitable for building burials are encouraged on the national and international levels. Special attention should be focused on enlightening activity with the community in order to overcome a negative attitude to the disposal, because it is this community that plays a key role in the receipt of permission for burial building.

The scientific and technical basis of evidence for the feasibility of safe HLW disposal is provided by the results of predicting simulation that evaluates radiation and other impacts of burial over the course of a long time (up to 10^4-10^6 years). In that case, the obtained assessments should satisfy the safety requirements that are imposed by regulatory agencies of countries.

The international strategy of safety in the waste management is developed by the International Atomic Energy Agency, which focuses efforts to produce safety standards for the geologic disposal of waste. The initial conditions for the development of standards were general principles of safety whose formulations were discussed and refined in international debate organised by the International Atomic Energy Agency. Russia follows these principles and they are laid down in the “RW Management Concept of Minatom of Russia”. Those are:

1. the protection of public health;

2. environmental protection;

3. the assessment of possible actions on the health and environment outside national boundaries;

4. the protection of future generations of people;

5. the prevention of undue charges on future generations;

6. the development of the corresponding regulatory legal acts;

7. the minimisation of amounts of formed waste;

8. the estimation of interrelations between different stages of waste management, and

9. the safety in the operation of waste management facilities.

These principles are applied to the present and future time. At present, the principles are supported by the acting safety system, whereas the support the long-term safety (Principles 4, 5, 7) requires further development.

A routine approach to the assessment of the safety of a particular burial consists in constructing an integrated model involving a set of models of burial subsystems that are used to assess the long-term reliability and safety according to the scheme "scenario/models/codes/verification". The assessment is refined by the successive iterative procedure.

As is known, a tremendous effort should be made to construct the integrated model of disposal. It is necessary to develop and verify a number of specific models that include hundreds of models of disposal subsystems. There is a need of constructing the following models:

1. An integrated model of a site describing the geology of a region, including stratigraphy, rock properties, mineralogy, structure, etc.
2. A model describing water transfer in unsaturated zones above and below the burial horizon. This model also evaluates radionuclide transfer in an unsaturated zone below the burial.
3. A model of a near zone that describes how the thermal, hydrologic, mechanical, and chemical factors associated with the heat generated by waste affect rocks surrounding mine working.
4. A model describing processes that may lead to the failure of engineering barriers (waste packages and shields against moisture percolation) and related radionuclide migration through barriers.
5. A model of failure of waste containers, which describe processes that may result in the corrosion of protective shields and containers with waste.
6. A model of failure of waste matrix, including the expected action on the radionuclide mobility.
7. A model of water flows and radionuclide transfer in a saturated zone below disposal.
8. A biosphere model.
9. A model describing the action of catastrophic events (earthquakes, volcanic activity) on disposal.

Since the simulation is performed on the basis of thousands of initial variables and simplification of physicochemical, geological, and other phenomena, it is necessary to continue to refine the model in order to decrease uncertainties in the results of simulation of burial characteristics and to enhance the assurance that the burial may isolate waste during a required time interval.

When developing the regulatory basis for regulating the safety of geologic disposal, national agencies should use the radiation safety criteria recommended by international organisations, namely, the individual annual dose for any person and (or) the individual risk [2]. Numerical values of these criteria are imposed by regulatory body of Russia reasoning from the recommendations of the International Commission on Radiological Protection (ICRP). In turn, ICRP is guided by the ALARA principle[1] and provides new recommendations with allowance made for the last scientific radiological

1. The ALARA (as low as reasonably achievable) principle means that the radiation exposures must be reduced to the lowest level possible with due regard for the scientific, economic, and social factors.

data in the field of dosimetric effects and social regulations. Beginning in 1959, ICRP regularly has revised the individual annual doses and risks, so that the fulfilment of the ICRP recommendations should prevent all determinate (non-stochastic) effects and stochastic effects should remain within reasonable limits. According to the ALARA principle and new scientific knowledge, each next ICRP publication contains recommendations involving lower doses and risks [3].

In particular, in ICRP Publication 60 (1991) an individual annual dose of 1 mSv is recommended for members of the public, whereas, in ICRP publication 81 (1998), it is recommended to reduce this dose to 300 μSv for a normal evolution scenario of developing processes in disposal (without failure processes) [3].

It should be noted that, as applied to the geologic disposal, ICRP developed the policy and the corresponding recommendations in the following publications:

- Publication 77: *Radiological Protection Policy for the Disposal of Radioactive Waste,* and
- Publication 81: *Radiation Protection Recommendations as Applied to the Disposal of Long-lived Solid Radioactive Waste*.

These recommendations may be treated a starting point when considering the radiological protection of the underground disposal.

It should be noted that, as a result of the adoption of more rigid dose criteria for the radiation safety, it is necessary to justify the safety of geologic disposal of radioactive waste during longer time intervals through more complex calculations and simulation or to extract the ^{237}Np, ^{99}Tc, ^{124}I, and other longest lived radionuclides.

An alternative approach to the justification of the disposal safety (apart from the approach based on the calculation of the individual dose and/or risk for members of the public) consists in comparing different RW parameters (radioactivity, radiotoxicity, radiogenic heat release, chemical toxicity) with similar parameters of natural radionuclides or chemical hazardous compounds, for example, with the parameters of ore bodies of uranium deposits or uranium ores that may be extracted for producing a required amount of nuclear fuel. It is this comparison that underlies the radiation-migration equivalence (RME) principle in the RW management [4]. Actually, uranium ore is a raw material for the nuclear fuel in which a part of the natural component transforms into fission fragments and transuranium actinides due to the burning in a reactor. This implies that a certain amount of ore may be assigned to a certain amount of a particular fuel, which, for a given operating period, results in the formation of a fixed amount of fission fragments and actinides. Therefore, there is a one-to-one correspondence between the amount of the consumed natural fuel component and the amount of radioactive waste, which allows one to determine the specific amount of waste per unit mass of ore.

1. RME principle in RW management

It is essential that the protective action of a burial is ensured by a multi-barrier system, which includes a RW matrix, a package (a cane and a container), a filling material, and a geological medium. Each barrier retards the motion of radionuclides toward the biosphere. A combined effect of all the barriers (or even individual barriers, for example, the geological medium as most efficient) leads to a substantial decrease in the escape of radionuclides and a weakening of their radiological action. This action may be comparable to the radiological action of the uranium raw material used for producing the fuel, provided that the raw material is placed in the same geological medium (undeniably, a comparison with the uranium deposit from which the ore was mined is most adequate). In the case when the hazardous effect of waste never exceeds a similar effect of the ore, it is possible to tell about the radiation-migration equivalence [1] between the radioactive waste and the initial natural raw material. The radiation-migration equivalence may be attained not at once but after a lapse of time (due to the radioactive decay of particular nuclides). However, this time is appreciably shorter than the time of reaching the radiation equivalence of waste and raw materials. The radiation-migration equivalence may be more easily attained in the case of RW fractionation when a part of radionuclides is extracted and used in a particular way or is subjected to transmutation.

The RME principle in the RW management is the specific representation of one of the IAEA principles regarding waste minimisation: "it is necessary to provide the formation of radioactive waste at a minimum, practically achievable level".

It is originally assumed that the "natural safety of RW management is achieved if the RW activity equivalent with respect to the hazardous effect on a person upon final disposal does not exceed the activity of consumed uranium".

According to this assumption, the waste activity should be compared with the uranium activity. Apparently, this comparison is not quite correct taking into account the difference between the interference levels of nuclides and uranium, their mobilities, their sorption capacities, abilities of matrices to fix nuclides, etc. These factors should be included when formulating the RME principle. For each *ith* nuclide, the effective radiotoxicity is introduced in the following form:

$$r_i = \frac{A_i}{IL_i R_i}, \qquad (1)$$

where A_i is the activity of the *ith* radionuclide, *IL(i)* is the interference level, and R_i is the retardation factor for the nuclide motion with underground waters (R_i allows for the chemical form of a material involving nuclides and, correspondingly, included the coefficient of nuclide distribution among a solid rock and water due to the sorption and adsorption; the coefficient R_i is experimentally determined and tabulated). The effective activity r_u of natural uranium used for producing the fuel from which the waste was subsequently extracted is introduced in a similar way. Since radioactive waste contains a set of radionuclides, the synergetic effect is determined by the sum:

$$I = \sum \frac{r_i}{r_u}, \qquad (2)$$

which is the effective radiotoxicity index of radioactive waste (or, to put it differently, the RME index). It is evident that, if I is less than unity, the radiological effect of waste is less that that of the initial natural component. Here, it is persistent to make a number of comments. The index I is a function of the elapsed time from the RW disposal. If the index I at zero time is larger than unity, I decreases with time owing to the nuclide decay and becomes equal to unity at a certain instant of time. This is the time of achieving the radiation-migration equivalence between waste and uranium. This time is of crucial importance: the time T = 200 to 300 years may be considered reasonable, because the protection during this time interval may be provided by engineering means; on the other hand, the time T >1 000 years is long and the safety of RW disposal in this case is ensured only by the geological medium.

Let us consider a specific example. First, we estimate the radiotoxicities without regard for the migration mobility.

The radiotoxicity of 1 kg of natural uranium may be estimated as:

$$r_{0(U)} = 0,72 \cdot 10^{-2} \cdot \frac{10^3 g/kg}{238g} \cdot 6,02 \cdot 10^{23} \cdot \frac{2}{7,1 \cdot 10^8 \, year \cdot 3,15 \cdot 10^7 \frac{s}{year} \cdot 1,3 \frac{Bq}{kg}} = 0,5 \cdot 10^6$$

The radiotoxicities of the ^{90}Sr and ^{129}I isotopes in the spent nuclear fuel of a WWR-440 reactor (fuel, UO_2; enrichment in ^{235}U, 3.6%; stationary operating conditions, three years; burn-up, 30 GW/d/t) are as follows:

$$r_{0(Sr-90)} = 1.0 \cdot 10^{11}$$

$$r_{0(I-129)} = 0.72 \cdot 10^5$$

The interference levels of the ^{235}U, ^{90}Sr and ^{129}I isotopes upon entering with water for members of the public according to NRB-99 are equal to:

$$IL_{U-235} = 3.0 Bq/kg;$$

$$IL_{Sr-90} = 5.0 Bq/kg;$$

$$IL_{I-129} = 1.3 Bq/kg.$$

It is essential to account for the differences between the mobilities of various radionuclides and isotopes of natural uranium in underground water. These differences are characterised by the retardation factors R_i [see Formula (1)]. The normalising of the radiotoxicity of the ith isotope to the corresponding retardation factor gives the effective radiotoxicity:

$$r_i = r_{0(i)} / R_i.$$

The radiation action of fission fragments and actinides of spent nuclear fuel is equivalent to that of the initial natural component if the sum of the radiotoxicities of fission products and actinides of spent nuclear fuel does not exceed the radiotoxicity of natural uranium. However, this situation may be achieved after a lapse of long time intervals exceeding the half-lives of isotopes whose radiotoxicity is higher than that of uranium.

For example, for ^{90}Sr and ^{129}I (after storage for one year), we have:

$$I_{Sr-90} = 2 \cdot 10^4,$$

$$I_{I-129} = 0,06.$$

It may be seen that, the radiation-migration equivalence for ^{90}Sr cannot be achieved even within 300 years (10 $T_{1/2}$), whereas the equivalence condition for ^{129}I is met initially.

For the ^{90}Sr radioisotope, the values of $R_{Sr-90} / R_U = 4$ were taken from [4]. In this case, the radiation–migration equivalence is achieved for approximately 400 years.

The implementation of the RME principle dictates the following strategy of the SNF management: the spent nuclear fuel cannot be buried without reprocessing. In the absence of reprocessing, the radiation-migration equivalence may be achieved only after storage of the spent nuclear fuel for 70 000-500 000 years, which is evidently unrealistic.

The fulfilment of the principle dictates the "deep" reprocessing, i.e. not only the use of regenerated uranium and plutonium as raw materials but also the fractionation and subsequent burning of neptunium, americium, iodine, and, possibly, technetium as well as the extraction and long-term (up to 200 years) storage of caesium and strontium fractions. The implementation of the principle dictates the burning of curium after storage.

The retardation factors for the water transfer of radionuclides substantially depend on the composition of rocks, their permeability, and water composition (in particular, pH). The use of "mean" values of these characteristics is not representative and may be only illustrative. Certainly, when choosing specific sites and determining the conditions of a burial, it is necessary to use true parameters. This approach makes it possible to obtained the "weighted" effective radiotoxicity of radioactive waste with respect to the effective toxicity of initial natural uranium, as applied to local disposal conditions. Since the formulation includes the relative concentrations, the principle does not involve any limitations on absolute nuclide concentrations. It is reasonable to supplement the RME principle with restrictions on the concentration and total activity of waste radionuclides in comparison with the same parameters of uranium deposits.

The RME principle may be easily generalised with allowance made for the retention of radionuclides in the RW matrix, which provides a way of achieving the equivalence between waste and natural materials for appreciably shorter times. The retention of nuclides by the matrix plays a very important role.

2. Generalisation of RME principle with due regard to retention of nuclides in matrix

The waste to be buried should be incorporated into slightly soluble matrices whose dissolution rate is considerably lower than that of oxides of the majority of incorporated radionuclides. This permits one to reduce the radionuclide concentration in water being in equilibrium with the matrix by two or three orders of magnitude. Phosphate and borosilicate glasses are intended for use as RW matrices. In nature, volcanic glasses, namely, obsidians are stable for millions of years. Unfortunately, the data only on the short-term stability of radioactive glasses are available to date. This problem calls for further investigation. At present, in order to incorporate radioactive waste, synthetic, very poorly soluble materials each for a specific radionuclide fraction have been designed.

According to the RME principle, it is necessary to return the radioactivity to the Earth in the amount equivalent (in the hazardous effect on person) to that of uranium extracted from the earth. When very long-lived nuclides are returned to the Earth, their migration is the main hazard. The implementation of the concentration radiation-migration principle implies that these nuclides may be returned to the Earth in greater amounts as compared to those satisfying the radiation equivalence principle in the case when their migration throughout the storage period will be so low (owing to an extremely poor solubility) that it compensates for an increase in the amount. A long-term low solubility of the matrix is provided by a nature-like stability of its material.

The extraction of individual nuclides or groups of nuclides and the occurrence of dominate nuclides in the remaining radioactive waste enable one to design virtually individual matrices that ensure the stability and a low solubility.

The estimates demonstrate that the migration rate of dominant nuclides should be decreased by no more than two orders of magnitude. This may be easily achieved by incorporating nuclides into glasses. Other matrices are required for other nuclides. If for some reason, it is not expedient to burn technetium in reactors and the retention of caesium in a glass is complicated owing to its radioactivity, these radionuclides should be incorporated into special nature-like materials.

The rough data on the dissolution rates of materials used as matrices for radioactive waste are presented in Table 1 [4].

Table 1. Dissolution rates of matrix materials in water [4]

Material	**Dissolution rate, g/cm^2 day**
Spent nuclear fuel (rough data)	10^{-2}-10^{-3}
Cement (with additives), clay	10^{-4}
Glass	10^{-5}-10^{-6}
Mineral-like materials	10^{-6}-10^{-7}

These dissolution rates should be compared with the escape rates of uranium from natural minerals. For example, the escape rate of uranium from pitchblende at pH 7 is equal to 10^{-4} g/cm^2/d.

The chemical and electrochemical conditions of disposal, that is, the presence or absence of oxygen as an oxidising agent, pH of a medium (acidic, alkaline, neutral), the presence of reducing agents in a burial medium, including in the system of technogenic barriers, for example, metallic iron, also affects the burial stability.

The disposal depth (important not by itself) should prevent access to a burial for oxidising and acidic media from the weathering crust and the Earth surface. It is this formation of oxidising media that is responsible for the reduction and migration of uranium deposits. On this basis, uranium is mined by the acidic underground leaching method. The disposal at a depth of 600 m ensures the absence of oxidising media (unlike those occurring in surface Earth layers). These conditions provide a low migration rate of actinides.

Up to now, the RME factor has been determined using the effective radiotoxicity of uranium. However, it is also necessary to take into account the contribution from the products of decay of natural fuel components to the increase in their radiotoxicity [5].

3. Radiotoxicity of uranium with inclusion of daughter decay products

The natural uranium isotopes are characterised by the following decay chains:

$$^{235}U \underset{T_{1/2}=7{,}1\cdot 10^8\ year}{\longrightarrow} {}^{231}Pa \rightarrow {}^{227}Ac \rightarrow {}^{207}Pb_{stab} \qquad (3)$$

$$^{238}U \underset{T_{1/2}=4,5\cdot 10^9\ year}{\rightarrow} {}^{234}U \rightarrow {}^{230}Th \rightarrow {}^{226}Ra \rightarrow {}^{210}Pb \rightarrow {}^{206}Pb_{stab} \quad (4)$$

In deposits, uranium is at equilibrium with decay products. Let us determine the uranium radiotoxicity with allowance made for the decay products.

The nuclide radiotoxicity is calculated from Formula (1).

At equilibrium, the concentration N_i of the *ith* product meets the condition:

$$N_i = \frac{x_i}{T_{1/2}} N_4 , \quad (5)$$

where x_i is the half-life of the *ith* product, N_4 is the number of atoms of the corresponding uranium isotope, and $T_{1/2}$ is its half-life.

It is important that the activities of the products coincide with the activity of the parent isotope.

We have:

$$r_{(O)i} = \left(\frac{N_u}{2T_{1/2}} \right) : (IL_i) .$$

Making allowance for the synergetic effect of different isotopes, for the chain, we obtain:

$$r_{(o)set} = r_{(o)u} + \sum_i r_{(o)i} ,$$

where $r_{(0)u}$ is the radiotoxicity of the corresponding uranium isotope. Then, we arrive at the relationship:

$$r_{set} = r_{(o)u} \cdot \left[1 + \sum_i \frac{YB_u}{YB_i} \right] = r_{(o)u} \cdot K_{(o)set} , \quad (6)$$

where:

$$K_{(o)set} = 1 + \sum_i \frac{YB_u}{YB_i} . \quad (7)$$

The values of $K_{(o)set}$ for different uranium isotopes are calculated to be:

$$K_{(o)set} = 1 + 3\left(\frac{1}{0.2} + \frac{1}{0.13}\right) = 39,5 \text{ for } {}^{235}\text{U}$$

$$K_{(o)set} = 1 + 3\left(\frac{1}{2.9} + \frac{1}{0.66} + \frac{1}{0.5} + \frac{1}{0.2} \right) = 1 + 1 + 4.5 + 6 + 15 = 27.5 \text{ for } {}^{238}\text{U}.$$

The effective radiotoxicity of the nuclide accounts for the retardation of its migration due to the sorption and desorption and is related to the nuclide radiotoxicity by the expression:

$$r_i = r_{(o)i} : K_i$$

For uranium and the chain of the daughter isotopes, we found:

$$r_i = r_U \cdot K_{set}, \quad (8)$$

where:

$$K_{set} = 1 + \sum_i \frac{R_u \cdot IL_u}{R_i \cdot IL_i}. \quad (9)$$

Taking into account that $\frac{R_u}{R_i}>1$, we obtain $K_{set} > K_{(o)set}$.

Therefore, the inclusion of the hazardous effect of the daughter decay products of the natural fuel components leads to a substantial increase in the radiotoxicity of the fuel and, hence, to a decrease in the RME factor of the waste [4].

4. RME and ALARA principles

Thus, we may draw the following conclusion.

The errors and uncertainties arising in the determination of radionuclide escape from the RW burial require the use of extremely conservative estimates. In the limit, the nuclide concentrations in the waste may be used as estimates of their concentrations in underground waters. On this basis, it is possible to evaluate the corresponding radiotoxicities (by normalising to the interference levels) of individual components and radioactive waste as a whole or the effective radiotoxicities (by dividing the radionuclide radiotoxicities into the retardation factors for the nuclide transfer with underground waters). This completely coincides with the procedure of performing the limiting conservative estimate according to the traditional approach with the use of scenarios, escape models, and the corresponding codes.

A comparison of radiotoxicities for waste with those for natural uranium consumed for producing a required fuel results in the notion of radiation-migration equivalence for individual waste components and radioactive waste as a whole. Therefore, the radiation-migration equivalence corresponds to the limiting conservative estimate in the traditional approach to the determination of RW disposal safety in comparison with the radiotoxicity of natural uranium.

The amounts of radionuclides in fragments (and actinides) and the corresponding weight of heavy metal in the fuel are compared with due regard for the hazard (according to the NRB-99 standards), the nuclide mobility (through the sorption retardation factors), the retention of radioactive waste by the solid matrix, and the contribution from the chains of uranium fission products.

It was noted above that the RME principle is aimed at ensuring the radiological safety of the present and future generations and the environment through the minimisation of radioactive waste upon reprocessing. This is attended by reaching a reasonably achievable, low level of radiological action in the context of modern science, i.e. the ALARA principle. Economic factors are disregarded in constructing the RME principle (for example, the cost of SNF reprocessing to the corresponding depth). However, the RME principle may be demonstrated to broad sections of the public with achieving the necessary understanding, which is of crucial importance.

The ALARA principle is not reduced to the RME principle and is a more general programme into which the RME principle may be embedded. The ALARA principle covers all the stages of creating a burial, including the design, building, operation, and closing with the subsequent monitoring. This principle regulates the stages of burial building, the location of waste, the use of remote control and protected equipment for location of waste, environmental control, measures for a decrease in the probability of emergences and their consequences, which should provide the main aim – the control and a decrease in the dose load on staff and members of the public at all the stage of creating and operating the RW burial.

References

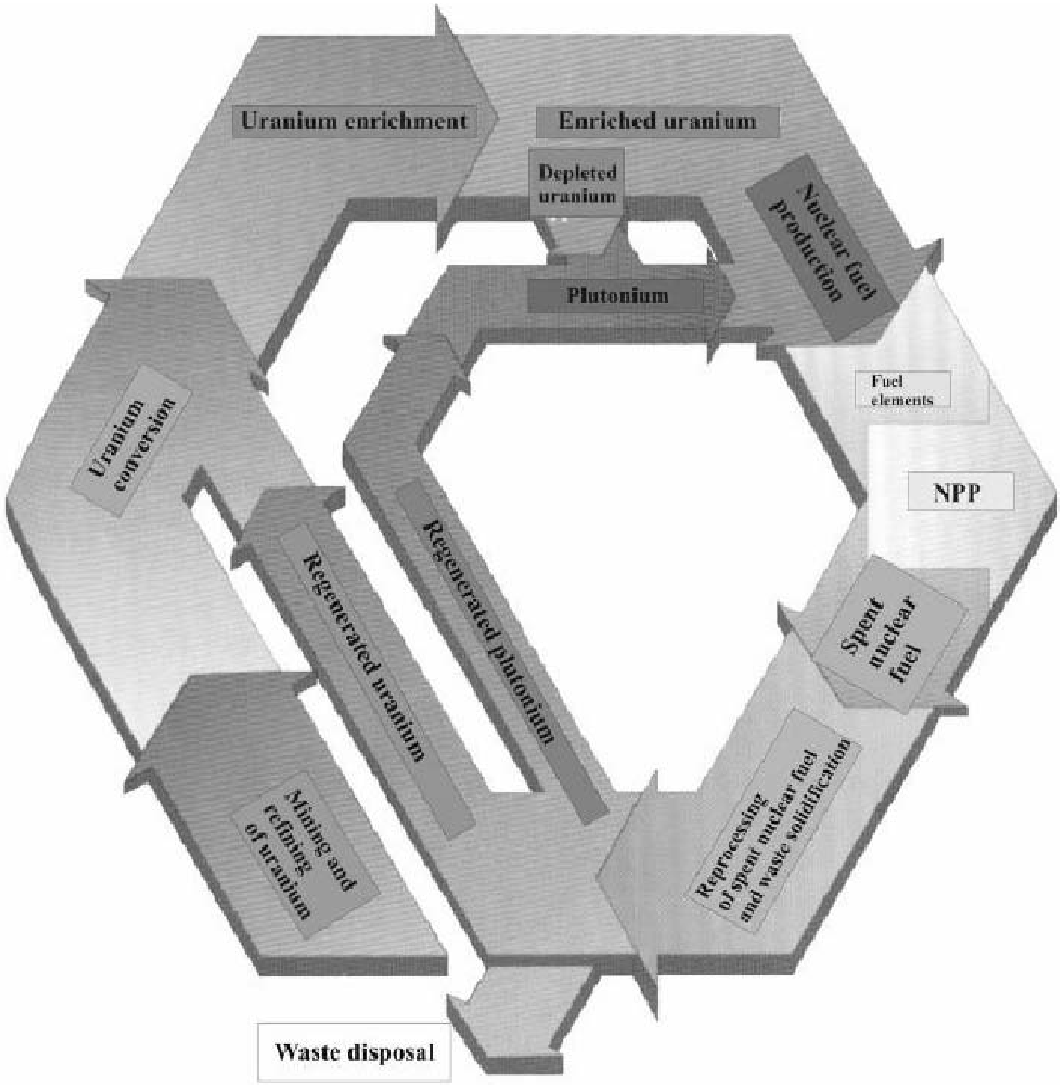
[1] A. S. Polyakov and M. I. Solonin, "Basic Directions of Research on RW Management in Russia", *Toplivno-Energ. Komplex,* 2002, No. 2, pp. 65-66.

[2] V. I. Velichkin, A. A. Stroganov, and R. B. Sharafutdinov, "Criteria for Long-Term Safety of Radioactive Waste and Spent Nuclear Fuel Burials", *Vestn. Gosatomnadzor Rus.,* 1999, No. 4(6), pp. 2-20.

[3] Publication ICRP 81: *Radiation Protection Recommendations as Applied to Disposal of Long-lived Solid Radioactive Waste,* 2000.

[4] B. V. Nikipelov, V. B. Ivanov, V. I. Velichkin, V. V. Grabovnikov, T. A. Gupalo, I. Kh. Ganev, V. A. Lebedev, A. V. Lopatkin, V. V. Orlov, M. I. Solonin, and V. V. Shatalov, "Radioactive Waste Management", *Byull. Obshchestv. Inf. At. Energ.,* 2000, No. 12, pp. 28-35.

[5] A. V. Lopatkin, V. I. Velichkin, and B. V. Nikipelov, "Radiation Equivalence and Nature Similarity in Radioactive Waste Management", *At. Energ.,* 2002, Vol. 92, No. 4.


Uranium enrichment
Enriched uranium
Depleted uranium
Nuclear fuel production
Plutonium
Fuel elements
NPP
Uranium conversion
Regenerated uranium
Regenerated plutonium
Spent nuclear fuel
Reprocessing of spent nuclear fuel and waste solidification
Mining and refining of uranium
Waste disposal

RISK CONSIDERATIONS IN THE DOMAINS OF PROTECTIONS AGAINST MAJOR ACCIDENTS IN COMPARISON WITH RISK CONTROL FOR NUCLEAR POWER PLANTS

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Abstract

Risk-based decision making in the control of major chemical hazards in Switzerland is presented and compared with new risk-based decision-making framework for Swiss nuclear power plants. The legal framework on which risk control of major chemical hazards is based in Switzerland is provided by article 10 of the "Law Relating to the Protection of the Environment" (LPE, 1983) which deals with protection against disasters. Enforcement is based on the Ordinance on "Protection against Major Accidents" (OMA, 1991) which was put into effect on April 1, 1991. OMA reflects well-established procedures in risk control, in particular those used in the Netherlands in the context of the environmental control policy. At the same time, OMA requires implementation of state-of-the-art safety technology in agreement with the German practice. It is compatible with the corresponding regulations of the European Union (EC Directive 96/82 [1996] and EC Directive 90/219 [1990]). Risk analysis and risk-informed decision making have a long tradition in the licensing and supervision of nuclear installations. Consequently, the new Swiss nuclear legislation that will come into force in 2005 makes explicit reference to risk. The Nuclear Energy Ordinance, the implementation rules for the Nuclear Energy Act, contains quantitative risk criteria for the safe operation of existing nuclear power plants and for the licensing of new ones. A preliminary outline of the decision-making scheme for risk control, to be published in the Regulatory Guides of the Swiss Nuclear Safety Inspectorate (HSK), is presented. The decision-making approach is then compared to the one used for the control of major chemical hazards. Finally, the paper contains some reflections on the use of risk-based regulatory approaches from the point of view of nuclear waste disposal.

The opinions expressed in this workshop paper are those of the authors.

Keyword

Risk control, decision making, quantitative risk criteria, chemical hazards, nuclear power plant

Introduction

The legal framework on which risk control is based in Switzerland is provided by article 10 of the "Law Relating to the Protection of the Environment" (LPE, 1983) which deals with protection against disasters. In the aftermath of the fire of November 1, 1986 in Schweizerhalle near Basel with the subsequent catastrophic pollution of the Rhine river, political pressure increased to improve provisions on protection against serious damage resulting from major accidents. As a consequence, the

Ordinance on “Protection against Major Accidents” (OMA, 1991) came into force on April 1, 1991. The issues of concern are the protection of the population, surface and ground water, soil and property. Other issues of concern may arise in special cases such as the protection of natural parks, livestock, recreational areas or ecosystems of particular value. The most important stakeholders took part in the process of creating the draft version of the OMA (chemicals industry, transportation companies, Swiss railways, future regulators etc.). In addition, before an ordinance becomes law, all affected stakeholders are consulted by the government department in charge.

Outline and scope of the OMA

The Ordinance reflects well-established procedures in risk control, in particular those used in the Netherlands in the context of the environmental control policy. At the same time, the OMA requires implementation of state-of-the-art safety technology in agreement with the German practice. The OMA applies to all facilities in which (i) the threshold quantities for a defined set of substances are exceeded (examples of threshold quantities are 200 kg of chlorine, 2 000 kg of ammonia, 20 000 kg of liquefied petroleum gas or 200 000 kg of petrol) or in which (ii) dangerous natural or genetically modified micro-organisms are being contained. Furthermore, OMA applies to (iii) transport routes used for the shipping of dangerous goods (railway lines, roads, and Rhine river).

Terminology

The OMA provides the following definition for “hazard potential” and “risk”:

- Hazard Potential means the sum of all the consequences which substances, products, special wastes, micro-organisms or dangerous goods could have as a result of their quantity and properties.
- Risk shall be determined by the extent of the possible damage to the population or the environment, caused by major accidents and by the probability of the latter occurring.

Note that risk is defined merely as a function of damage extent and probability of occurrence. The mathematical relationship between these two parameters is not specified.

Procedure

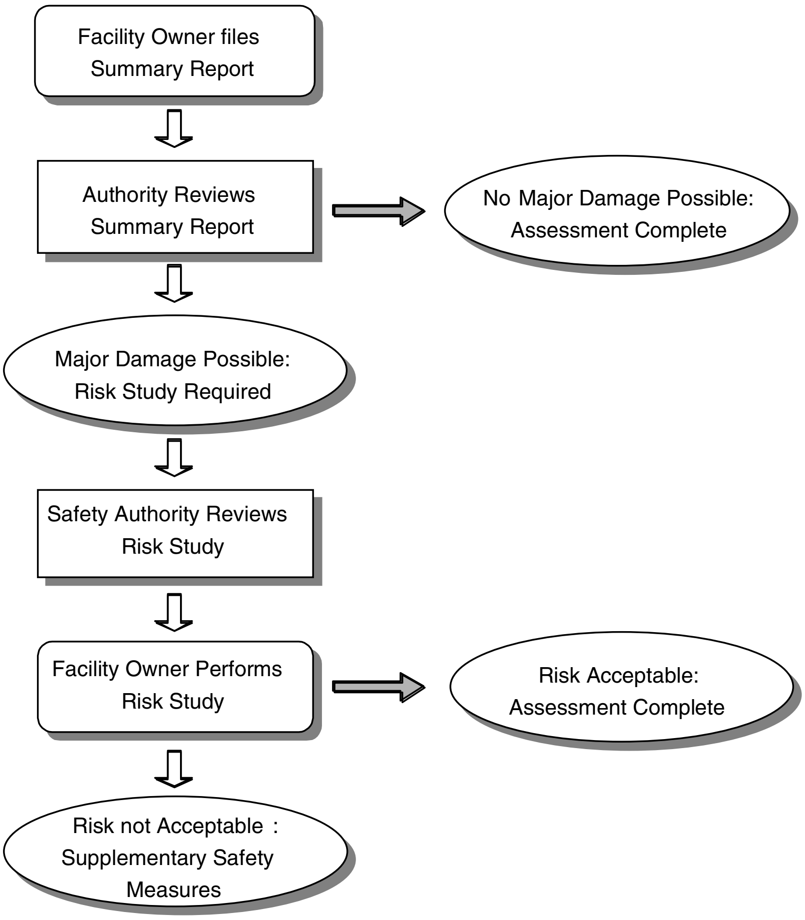
The procedure to control and assess relevant hazard potentials and risks consists of two steps (Figure 1).

In the first mandatory step, the owner of a facility submits a *summary report* containing an assessment of hazards. On the basis of the hazard assessment in the summary report, the enforcement authority decides whether, in a second step, a *quantitative risk assessment* has to be performed.

The summary report with the hazard assessment contains the following main items:

- A list with the maximum amount of any potentially hazardous substance kept at the facility at any given time and for which the threshold value specified by the OMA is exceeded.
- A detailed description of existing safety measures.
- An estimation of the extent of possible damage to the public and the environment resulting from major accidents at the facility, regardless of the (un-)likelihood of the accident(s) (maximum probable loss, see also section 3.3).

Figure 1. **Two-step Procedure for hazard and risk assessment for facilities and installations falling under the OMA (SAEFL, 1996a)**



If, in the first assessment step, the enforcement authority concludes that serious damage to the public or to the environment from major accidents must be expected, it orders a *quantitative risk assessment* to be performed. If serious damage is not to be expected, the assessment procedure is completed after the first step. In 1996, when the Swiss Agency for the Environment, Forests and Landscape (SAEFL) began its systematic data collection, some 2 477 facilities in Switzerland were recorded as falling under the OMA. In 40% of all cases, the summary report had been reviewed and classed. For 163 facilities, a risk assessment has been or will be performed (SAEFL, 1996a). The number of about 2 500 installations that fall under the OMA did not change since the first review.

The need for consistency in the application of the OMA throughout the different types of facilities and throughout the different regions of Switzerland was recognised at an early stage. Consequently, the SAEFL published a series of guidance documents for risk analysts and reviewers (i.e. enforcement authorities):

- *Handbooks* with the status of guidelines, explaining the technical hazard and risk assessment process to meet the OMA. In addition, separate guidelines have been published covering the evaluation of the extent of damage and the risk evaluation (SAEFL, 1996c).

- *Manuals*, which are specific to one type of installation (such as liquid gas storage tanks) and which contain detailed technical information on how to perform hazard and risk assessment for that particular installation. Manuals contain technical background information on the physical phenomena involved in the accidents to be analysed as well as a prototype event-tree/fault-tree risk model for a fictitious facility. So far, manuals have been published for LPG storage (Basler & Hofmann, 1992), high-pressure natural gas pipelines (SNCG, 1997) and large oil storage facilities (Carbura, 1999).
- *Case studies* for fictitious facilities. These are reference studies containing models and data meant to be transferred and/or adapted to a similar case involving the same type of facility. Some case studies contain reference computer codes for solving the event-tree/fault-tree models. So far, a case study for liquid petroleum storage facilities has been published (SAEFL, 1996b) and a case study for ammonia cooling units has been drafted (SAEFL, 1999).

The *manuals* and *case studies* of the guidance documentation accompanying the OMA define the state-of-the-art for hazard and risk assessment for a particular type of facility or installation. The fact that the guidance documents are developed in a joint effort by industry and enforcement authorities guarantees a consensus over what should be considered state of the art. If the state of the art changes because technology evolves, the guidance documents have to be revised. The initiative for such revisions can come from industry or from the enforcement authorities.

The risk assessment is used to (i) control the risk level in facilities where major accidents with severe consequences for the population and/or the environment could occur and to (ii) inform the public about existing risks. It is but one element in a strategy aimed at protecting the population and the environment from the consequences of major accidents.

The hazard and risk assessment studies are reported to the enforcement authorities. A digest of each risk assessment study is available publicly on request. The digest contains the main results and findings of the study. The OMA requires an update of the summary report when significant changes occur at the facility. Examples of significant changes are when the production or storage capacity is raised, new equipment is installed or backfitted or when safety-relevant modifications are made to the production and/or storage processes. Based on the updated summary report, the authority decides whether the risk assessment needs to be updated, following to the two-step process described above.

Considerable effort has been put into making the hazard and risk assessment simple and accessible to the facility owners. Still, it is expected that both risk analysts and reviewers (enforcement authorities) be knowledgeable in the principles of quantitative risk assessment. Usually, the owners of facilities contract a specialised engineering firm to perform the risk assessment. There are no requirements for the risk analyst to formally document his or her competence.

Legal/Policy issues

OMA requires the owner of a facility to take all appropriate measures to reduce risk consonant with the state of the art of safety technology and personal experience. Owners must also take all economically viable measures to reduce hazards, to prevent accidents and limit the consequences of possible accidents should they occur. In addition, OMA defines a risk control process described before. The nature of the risk reduction measures (if such measures are necessary) is not prescribed. This is perceived as an advantage, because it allows the owners of facilities to choose between a range of alternative solutions to reduce risk.

Description of summary reports and risk studies

Hazard identification

The *summary report* with the hazard assessment must contain the following main items:

- A list with the maximum amount of any potentially hazardous substance kept at the facility at any given time *and* for which the threshold value given in the OMA is exceeded [note: the thresholds defined are the same as or lower than those of the Seveso-Directive (EC Directive 96/82 and EC Directive 90/219)].
- A description of *safety* measures in place at the facility or installation.
- An estimation of *the* extent of possible damage to the public or the environment resulting from major accidents, regardless of the (un-)likelihood of the accident(s) (maximum probable loss).

Appendix I of the OMA (1991) contains a list of potentially hazardous substances and products. Above all, it contains criteria for the identification of potentially hazardous substances. These include toxicity, ecotoxicity, flammability, explosion hazard as well as criteria for dangerous micro-organisms. If the quantities of substances stored at a stationary facility exceed the substance-specific thresholds of OMA (appendix I), they must be included in the summary report discussed above.

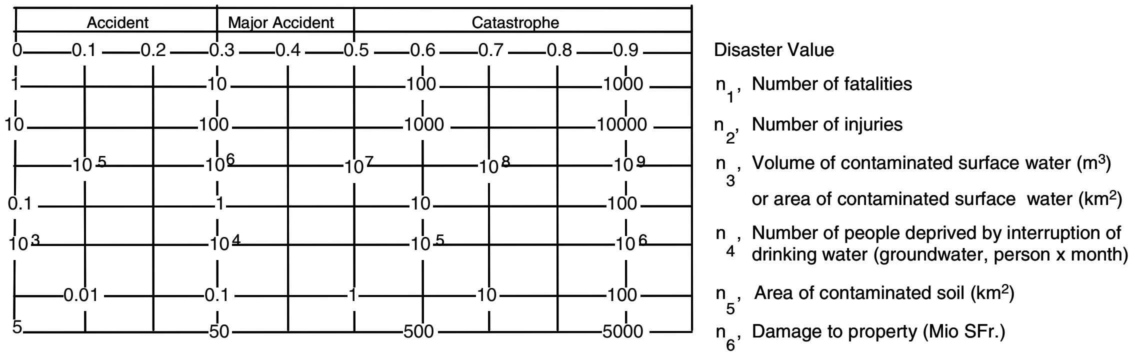
Only those damage indicators relevant to the case at hand need to be assessed (Table 1). For instance, for the three examples appearing in this paper (LPG, chlorine and ammonia), the number of fatalities (indicator n_1) proved to be the only relevant damage indicator.

Table 1. **OMA damage indicators as given in SAEFL (1996c)**

Man	
n_1	Number of fatalities [people]
n_2	Number injured [people]
Natural resources	
n_3	Polluted surface water [m^3 or km^2]
n_4	Polluted ground water [person x months]
n_5	Polluted soil [km^2]
Property	
n_6	Damage to property [SFr]

Figure 2 shows the mapping of damage indicators into the three categories “Accident”, “Major Accident” and “Catastrophe”. If a disaster value of 0.3 is reached or exceeded for any one of the relevant damage indicators, the authority orders the owner to perform and submit a risk study.

Figure 2. **Scale of extent of damage indicators (assignment of disaster values) (SAEFL, 1996c)**



Event scenario assessment

Event scenario assessment generally consists of the following steps:

- Identification of the *main accident scenarios* to be considered for the type of facility. The main accident scenarios are described at the phenomenological level and represent the link to consequence assessment (example: the occurrence of a BLEVE is a main accident scenario considered for LPG storage).
- Description of the *event sequences* associated with the main accident scenarios. These refer to facility-specific events (starting with the causes or initiating events) which must occur for the main accident scenarios to take place (example: a fire under the tank leads to a catastrophic tank rupture, which leads to a large and rapid release of liquefied gas which can trigger a BLEVE). The event sequences are the basis for the fault-tree/event-tree models.
- Modelling of the event sequences with of fault-trees and event-trees. To reduce the complexity of the event tree model (number of event trees, number of event sequences), *functional events* are sometimes defined (in the LPG example below, they correspond to the release categories; in the chlorine and ammonia examples, the functional events coincide with the main scenarios). The frequency of each functional event is calculated with a fault tree.

Event sequences can be identified in a top-down approach by searching for all possible ways to trigger one of the main accident scenarios. Alternatively, a bottom-up approach can be used in which malfunctions are systematically identified and analysed for their potential to trigger a scenario leading to unwanted consequences (FMEA, HAZOP and similar approaches). In practice, the top-down and bottom-up approaches are often used in combination.

As an example, Table 2 lists the main accident scenarios and the corresponding event sequences for the LPG, ammonia and chlorine examples (SAEFL, 1996b & 1999, Basler & Hofmann, 1999).

Human factors are considered to some extent through the modelling of human actions. Human actions are identified in the accident sequences and the corresponding failure events are quantified using Human Error Probabilities (HEP) found in the literature for similar actions. The risk models included in the *manuals* and *case studies* contain example human actions as well as reference HEPs. Safety culture and organisational factors are among the human factors not explicitly addressed in the risk assessment process.

Table 2. **Main accident scenarios and functional events for LPG. For ammonia and chlorine, functional events coincide with main scenarios (SAEFL, 1996b & 1999, Basler & Hofmann, 1999)**

LPG		**Ammonia and Chlorine**
Main scenarios	Release categories (functional events)	Main scenarios
BLEVE	Large (catastrophic) leakage	Large (catastrophic) release
Flash fire	Large (catastrophic) leakage; continuous leakage	Large continuous release
		Small continuous release
Vapor cloud explosion	(none identified)	
Fire torch	continuous leakage	
Flying debris	(consequence of BLEVE scenario)	

Consequence assessment

The methods and models used for consequence assessment depend on the physical processes involved and on the event sequence scenarios considered. However in general, the following items are assessed for each scenario:

1. Quantity of hazardous substance(s) involved.
2. (Time dependent) intensity or concentration over the area exposed, taking into account the effect of terrain features and structures.
3. Exposure (i.e. number of people exposed, exposure time).
4. Possible consequence mitigation measures.

Below, the approach to consequence assessment in each of the three examples (LPG, chlorine and ammonia) is briefly outlined for one representative scenario:

LPG, BLEVE scenario: In a first step, the amount of LPG participating in the BLEVE is determined. From this, the fireball radius (R) can be calculated. Next, mortality rates are derived for people within the fireball radius R and within a three-fold fireball radius (3R). Different mortality rates are applied for people outside (directly exposed to the fireball) and for people inside buildings. Evacuation is usually not considered feasible in the scenario due to the absence of a useful warning time.

Chlorine, large catastrophic release (tank rupture): The propagation of the chlorine gas from the ruptured tank is calculated with the help of a computer model. The time-dependent distribution of the chlorine concentration (Figures 3a and 3b) is obtained including such factors as the surface roughness of the ground and the speed and direction of the prevailing wind at the time of the accident.

Figure 3a. **Chlorine distribution for a 60 kg leakage from a storage tank. Lines of equal concentration (1 000 ppm) for different values of surface roughness**

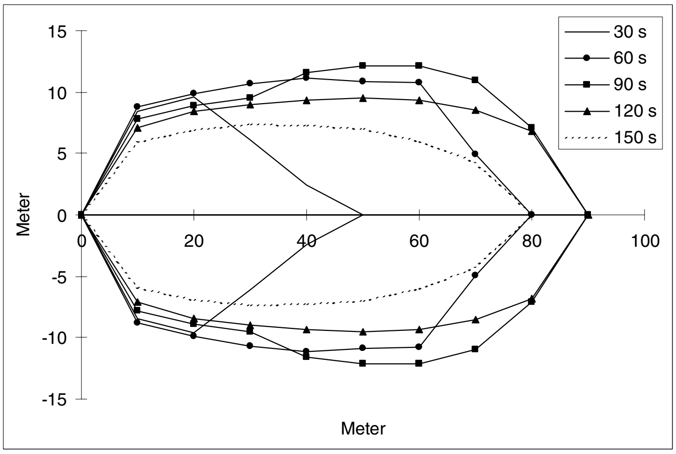
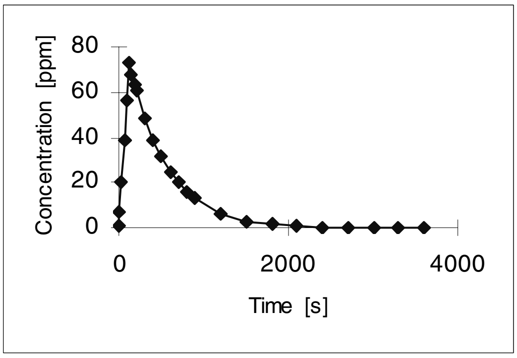


Figure 3b. **Time-dependent chlorine concentration in a building as the cloud passes by**



A dose-consequence relationship (probit function) is used to determine mortality as a function of the chlorine concentration and exposure time. For nearby buildings, separate chlorine concentrations are calculated assuming a constant air substitution rate. Evacuation is credited in the assessment of exposure times in scenarios where the warning time is sufficient to allow people to react and escape from the dangerous zone.

Ammonia, large (catastrophic) release: Similarly to the chlorine scenario described above, the time-dependent concentration of ammonia is calculated using a propagation program. A minimum required concentration for lethal exposure is used to delimit the perimeter within which exposure must be considered. Due to the speed with which the scenario develops, no credit is taken for evacuation.

Consequence mitigation measures can be (and should be, if adequate) included. They include the intervention of the fire brigade and evacuation of the population at risk. Credit can be taken for the fire brigade if it can be shown that there is a sufficient warning time for it to deploy. The success of evacuation generally depends on the warning time and on the population density in the exposed area as well as in the emergency evacuation routes (see also the examples of consequence assessment in section 5.1).

Risk estimation and risk comparison

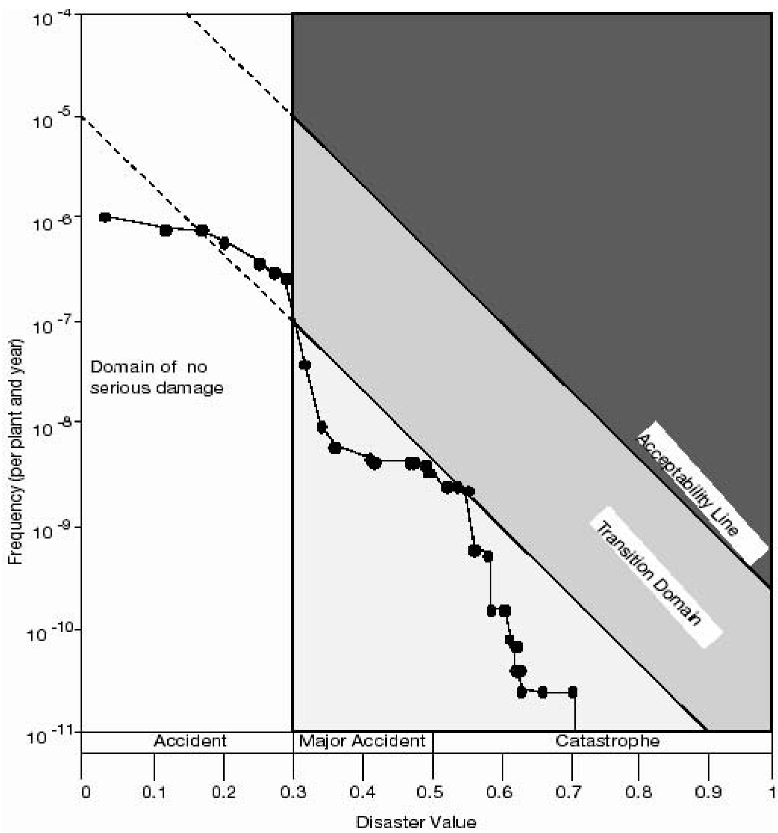
The likelihood of effects is expressed quantitatively in terms of the frequencies of the accident scenarios.

The diagram in Figure 4 is divided into four domains:

- no serious damage;
- acceptable;
- transition;
- unacceptable.

The slope of the boundary lines separating the three domains "acceptable", "transition" and "unacceptable" is quadratic. This is to account for the risk aversion commonly associated to accidents with large consequences. In risk estimation and risk comparison, the yearly frequencies of the relevant scenarios are plotted against the disaster values in a cumulative frequency distribution (Figure 4). From the cumulative frequency distribution, the acceptability or non-acceptability of the risk can be readily determined. Note that the slope of the boundary lines separating the three domains "acceptable", "transition" and "unacceptable" is quadratic. This is to account for the risk aversion commonly associated to accidents with large consequences.

Figure 4. **Societal risk criteria for major accidents (SAEFL, 1996c). Cumulative frequency diagram showing the number of fatalities (n_1) for the LPG storage example. The dots represent individual accident sequences.**



The enforcement authority evaluates the risk as follows (Figure 4):

1. If the cumulative frequency curve enters the unacceptable domain the owner of the facility is asked to reduce the risk, else the authority is empowered to take actions including operational restrictions or shutdown.
2. If the cumulative risk curve enters the transition domain, the enforcement authority will measure the interests of the facility owner against the needs of the public and the environment for protection from accidents. Depending on the outcome of these considerations, the risk has to be reduced to a level defined by the authority.
3. If the cumulative risk curve lies in the acceptable domain all through, the risk assessment procedure is complete. However, the owner must still take all appropriate measures to reduce risk (see below).

To obtain more insights on dominant risk contributors, separate curves can be plotted in the cumulative frequency diagrams grouping scenarios, which take their origin in the same initiator (Figure 5). A risk outlier can be defined as representing a substantial fraction of the total risk, where "substantial" is not further defined. A vulnerability is a risk outlier whose cause can be attributed to a system, type of component or operational practice of the installation under scrutiny. A vulnerability would further exist if a significant amount of risk were due to one particular type of accident (Figure 6).

Figure 5. **Cumulative frequency distribution showing the contribution of the different scenarios to the number of fatalities (n1) for the LPG storage example**

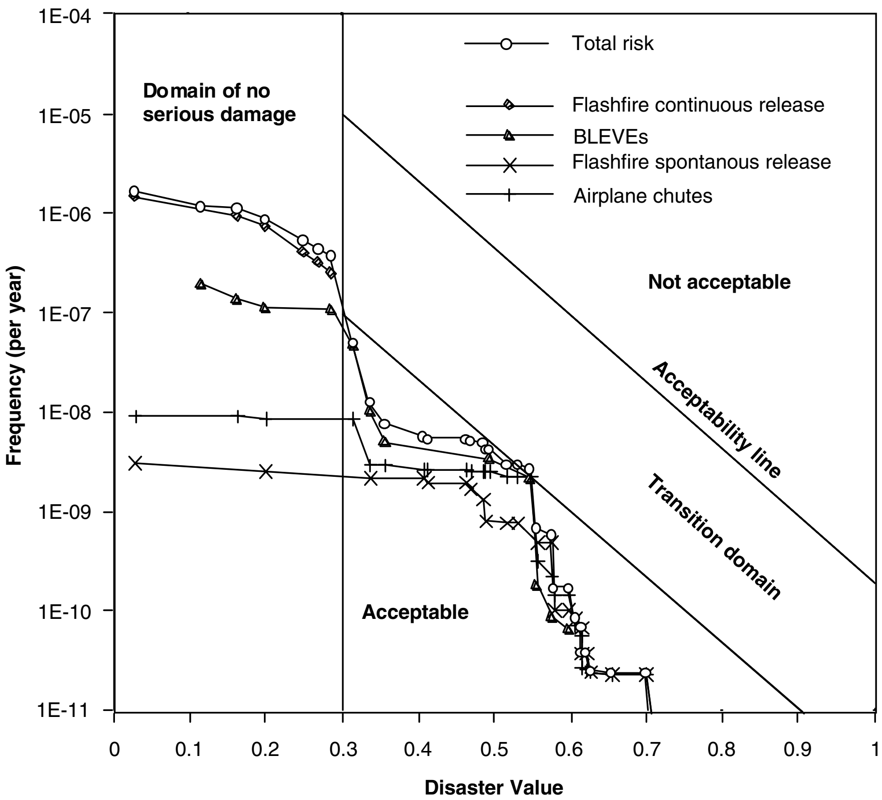
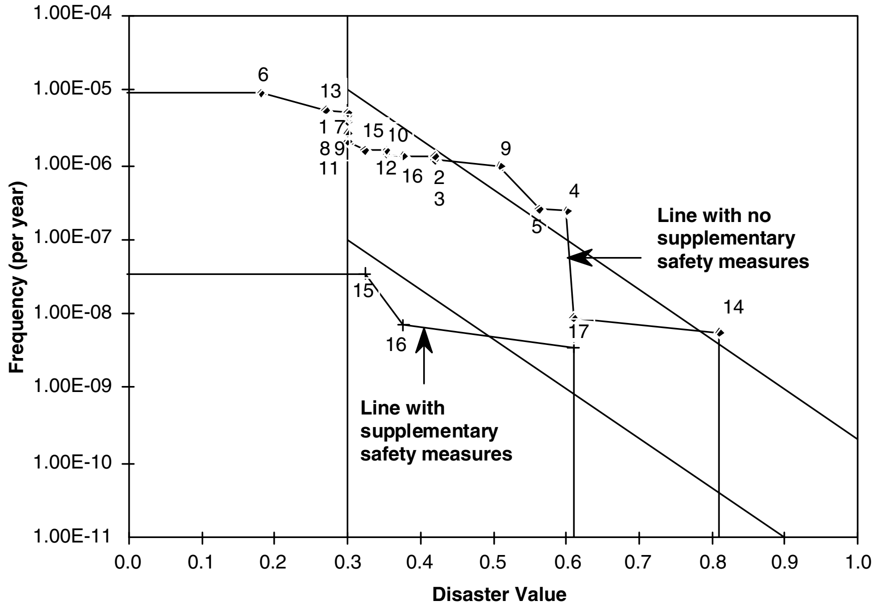


Figure 6. **Cumulative frequency distribution showing the number of fatalities (n1) for the example of the ammonia refrigeration plant in a public ice skating rink. The upper curve shows the risk before, the lower curve the risk after implementation of supplementary safety measures. The numbers correspond to individual accident scenarios**



Risk control in licensing and supervision of nuclear installations

Since the mid-eighties and the requirement for full-scope probabilistic risk studies (PSA) for nuclear power plant, control of risk from nuclear installations has played an increasingly important role in regulation in Switzerland. In 2005, a new legal framework will be introduced with the coming into force of the Nuclear Energy Act and its implementation rules, the Nuclear Energy Ordinance. The Energy Ordinance contains quantitative targets for the risk from nuclear installations. Furthermore, the Safety Guides issued by the Swiss Nuclear Safety Inspectorate HSK, currently under revision, will include guidelines for regulatory decision making which address both the risk and the uncertainties contained in the quantitative estimation of risk.

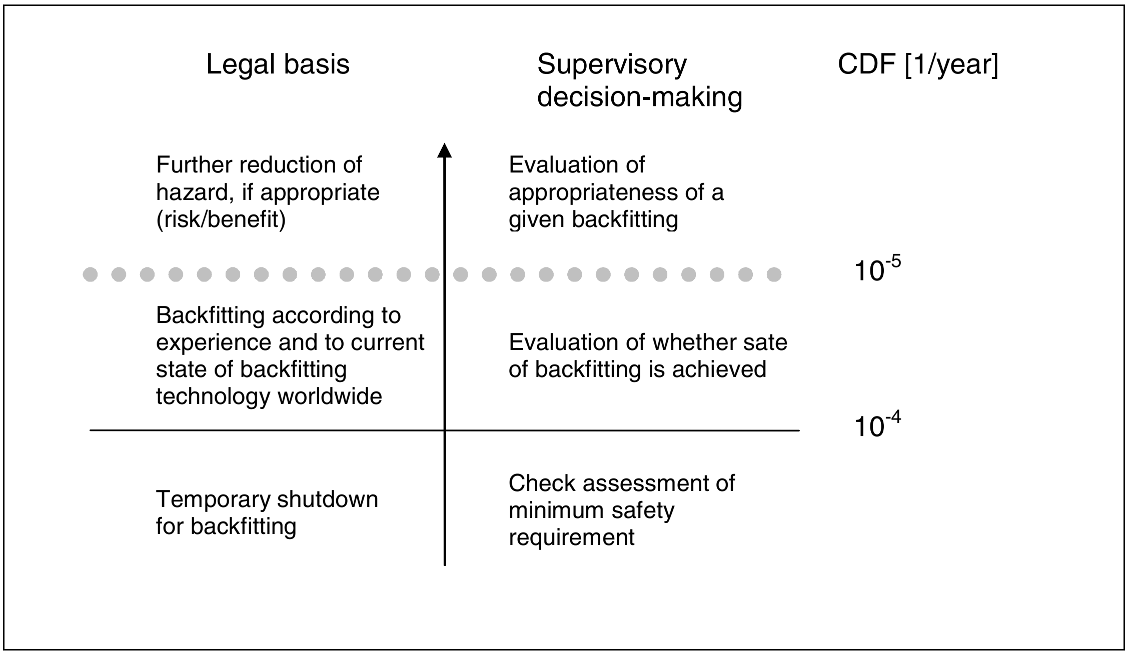
Legal basis

The Nuclear Energy Act requires the license holder to take the nuclear installation temporarily out of service and backfit it when certain criteria are met (article 22/3 of the Nuclear Energy Act). In response to this general rule, the Nuclear Energy Ordinance limits the total core damage frequency (CDF) for nuclear power plants. For new nuclear power plants commissioned after the coming into force of the Nuclear Energy Act, the CDF must be smaller than 10^{-5} per year and plant. For operating nuclear power plants, the CDF must be smaller than 10^{-4} per year and plant or else the plant must be temporarily shut down and backfitted. In fact, the target values recommended by the International Atomic Energy Agency (IAEA, 1992) are turned into firm shutdown rules by the Swiss regulations. Independently from probabilistic requirements, the Nuclear Safety Act also requires that operating nuclear power plants be "…backfitted to the extent necessary according to experience and the current state of retrofitting technology (worldwide), and beyond, provided this contributes to a further reduction of hazard and is appropriate" (article 22/2/g of the Nuclear Energy Act).

Supervisory decision making for the backfitting of nuclear power plants

Figure 7 depicts the proposed probabilistic basis for the future supervisory decision making process concerned with backfitting existing nuclear power plants (i.e. commissioned before the Nuclear Energy Act comes into force)[1]. Starting from the bottom of the picture, the lower safety limit for operating plants required by article 22/3 was set at a CDF of 10^{-4} per year. This corresponds to the value recommended by IAEA for operating nuclear power plants. Figure 7 also sets a target value at a CDF of 10^{-5} per year to discriminate between those backfits necessary to maintain safety with experience and the current state of retrofitting technology and those which further reduce hazard, if appropriate (article 22/2/g of the Nuclear Energy Act). For a well-balanced supervisory decision basis, these probabilistic criteria will have to be supplemented by criteria from design-basis and from operational experience.

Figure 7. **Core damage frequency (CDF) per year and legal basis and supervisory decision making**



The somewhat fuzzier delimiter used for the “state of the art” line means that the value is a target (recommended) value whereas the “minimum safe operations” line is considered a “hard” threshold. Note also that neither delimiter is frozen for all times: expected progress in safety technology is likely to move both delimiters towards lower values of CDF representing higher safety levels.

1. Although legally possible, the commissioning of new nuclear units in Switzerland within the next decade is not believed to be politically feasible. Consequently, as far as nuclear power plants are concerned, the Nuclear Energy Act and its ordinances will apply to existing units only.

Supervisory decision making for additional measures against severe accidents

Note that the decision-making framework proposed in Figure 7 is based on point-estimate (mean) values for the CDF. Figures 8a and 8b depict a somewhat more elaborate decision-making process where the uncertainty on the estimates is explicitly taken into account (Schmocker, 1997). The decision diagram in Figure 8b illustrates the steps of the decision-making procedure: if the 95%-fractile curve for the candidate nuclear power plant is smaller than the limiting curve for the mean ("limit mean"), then no further measures against severe accidents need to be considered. This would be the situation where the likelihood of core damage being lower than 10^{-5} per year could be demonstrated with 95% confidence (or conversely, that there is only a 5% chance that core damage is greater or equal to 10^{-5} per year). Next, the mean and 95%-fractile curves of the candidate nuclear power plant are checked against their respective limiting curves ("limit 95%" and "limit mean" respectively). If either of these criteria is violated, potential backfits against severe accidents need to be implemented regardless of costs involved ("Yes" path). If both criteria are met, potential improvements or backfits need to be implemented only if they are cost-effective ("No" path).

Figure 8a

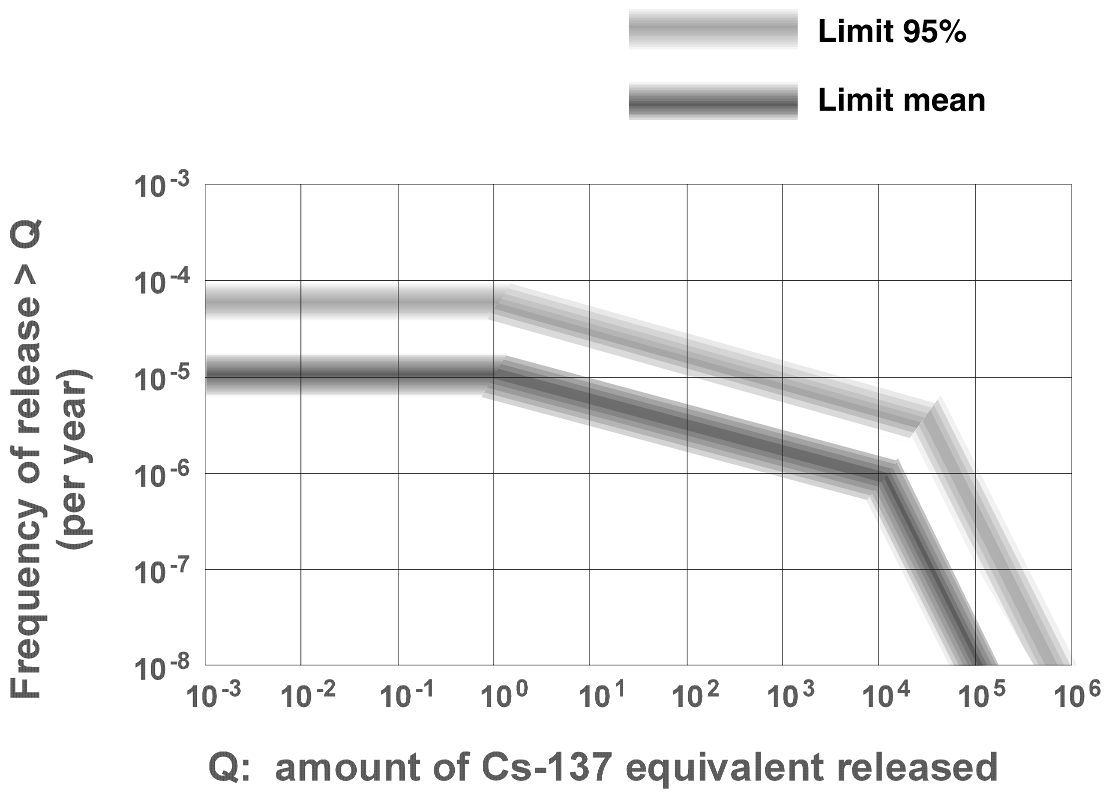
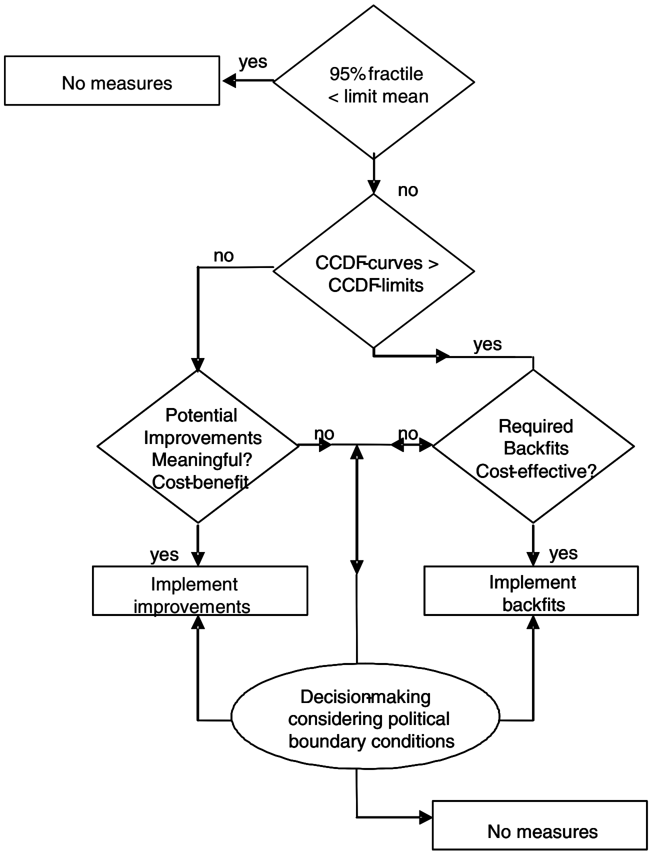


Figure 8b



This framework has been used by HSK to evaluate the appropriateness of additional measures to mitigate consequences of severe accidents in Swiss nuclear power plants. The frequency of release of radioactive aerosols (measured in terms of the amount of Caesium equivalent released) was chosen to evaluate the impact of severe accident measures. In contrast to the decision diagram depicted in Figure 7, which relies on a single point-estimate value, two percentiles (the mean value and the 95-percentile) from the release frequency distribution are independently controlled, effectively and explicitly involving the uncertainty of the estimate in the decision-making process. Note that uncertainty represented here as the difference between the mean and the 95-percentile of the distribution represents the sum total of epistemic and aleatory uncertainties which are quantified in the probabilistic model used to estimate release frequencies.

Decision making in the protection against major accidents vs. decision making in the control of nuclear risk

It is interesting to point out the differences in the two decision-making approaches described above. Although both of them are risk based, significant differences exist in system characteristics, in the approach and in the underlying methodology to quantify risk and uncertainty (Table 3).

Table 3. **Differences between two approaches**

	Chemical hazards (OMA)	NPP risk (Nuclear Safety Act)
System characteristics	Low to medium hazard potential. Hazard potential can be reduced.	Large hazard potential. Hazard potential difficult to reduce.
Decision-making approach	Hazard control through risk reduction.	Risk control through safety improvements.
Risk analysis methodology	Probabilistic, point estimate estimation.	Probabilistic, distributed input- and output parameters.
Treatment of uncertainty	Implicit, through reduction of risk.	Explicit. Risk criteria take into account uncertainty.
Backfitting rule	State of the art technology determines appropriate measures to reduce risk. Probabilistic target to determine supplementary safety measures to be implemented.	Probabilistic target for minimum safe operations. State of the art of backfitting technology must be implemented regardless of probabilistic target.

System characteristics

The OMA applies to installations with small to medium hazard potentials. Often, technological alternatives exist that allow more hazardous installations to be replaced by less hazardous ones (reduction in the amount of hazardous substances involved; changeover to a less risky technology altogether). The same is difficult to achieve for today's nuclear power plants: their radioactive inventory (hazard potential) is intimately linked to the power they produce. A reduction in hazard potential by a nuclear alternative would require a substantial technological step.

Decision-making approach

The decision-making approaches chosen are commensurate to system characteristics. Where risk reduction can be achieved by hazard control, the uncertainties on the remaining risks are minimised too. Where hazard control is not feasible, risk control is the (necessary) alternative.

Risk analysis methodology and treatment of uncertainties

There are only minor differences in the analysis and quantification of risks between the two approaches. Working with distributed parameters is a prerequisite to the explicit use of uncertainty in the decision-making process. One could argue that the treatment of uncertainties is implicit in the case of the OMA decision-making scheme: reducing risk to a residual level also reduces the uncertainties associated with those risks. In fact, this is the approach chosen by deterministic safety assessment, where safety substantial safety margins are used in design to rule out certain undesirable outcomes.

Backfitting rule

Backfitting is usually what drives the regulatory costs for existing installations. Consequently, backfitting rules are often important elements of regulation that reveal the true face of a decision-making approach. The most striking feature of both approaches is that they do not solely rely on risk criteria. Regardless of whether the risk criteria are met, the state of the art in safety technology must be implemented by the owner/the license holder.

Conclusions

- In Switzerland the Ordinance on Protection against Major Accidents (OMA, 1991) has been in force since 1 April 1991.

- Accompanying handbooks and guidelines published by the Swiss Agency for the Environment, Forests, and Landscape (SAEFL) which include an example of a summary report and a risk study as well as risk evaluation criteria have enhanced substantially the enforcement delegated to the Cantons.

- Hazard potentials have been reduced by many establishments with dangerous substances, products or special wastes below the quantity thresholds to avoid falling under the OMA.

- Safety measures in the great majority of establishments are now more thoroughly checked and updated if necessary.

- The OMA has initiated education and development of knowledge with regard to risk and safety. In particular, the Federal Institute of Technology at Lausanne and Zurich and at the University of St. Gall started postgraduate education in 1994 and many companies are keen to improve expertise.

- Information of the public is one of the main goals. However, the intention of the OMA is to disclose just the summary of the risk study on request. This rather restrictive information policy results from public indifference on the one hand and new regulations on privacy on the other.

- For many years, risk criteria have been a valuable tool for the targeted continuous improvement of the safety of nuclear power plants. In the future, risk-based decision making will receive a legal basis when the Nuclear Energy Act and the Nuclear Energy Ordinance become effective in the year 2005.

- In risk-control for nuclear power plants, decision making is moving from the use of point-estimate values towards the explicit consideration of epistemic and aleatory uncertainties.

Some thoughts from the perspective of safety assessment for nuclear waste repositories

The assessment of the hazards of nuclear waste repositories is specified in the Swiss regulatory guide HSK-R-21. The more likely scenarios for the release of radioactive substances are assessed deterministically using conservative assumptions to control uncertainties. The less likely scenarios have to meet a risk target, where the risk measure is the product of probability and consequences. A safety report is required that contains elements in analogy to the summary report for installations that fall under the OMA. But unlike in the case of the OMA, the elements are evaluated quantitatively. An important difference to both OMA and NPP safety is that nuclear waste repositories cannot rely on mitigation to prevent inadmissible releases, since such releases would take place in the far future. The repository has to be designed based on passive safety. While dose or dose risk is the primary measure, additional indicators such as the release of radionuclides across defined system boundaries or concentrations of radionuclides in defined system parts are used to characterise the safety of nuclear waste repositories. This could be compared to the choice of damage indicators of the OMA. As for scenario analysis, the main observation is that in the repository safety analyses, the description of the baseline case itself (the reference or "null" scenario) is very labour-intensive, since this first step is by no means trivial and requires challenging predictions into the future. In safety analyses performed so far, the possible risk target has not been used, but probabilistic calculations have been used to assess the effects of multiple uncertain parameters in particular scenarios. The results of these calculations were shown as cumulative damage frequency curves similar to the one in Figure 8a.

References

Basler & Hofmann (1992), *Manual for LPG Storage Vessels regarding the Summary Report and the Risk Study in Relation to Protection Against Major Accidents* (in French and German). Basler & Hofmann Consulting Engineers, Forchstrasse 395, CH-8029 Zürich, Switzerland.

Basler & Hofmann (1999), *Case Study of a Risk Study for a Chlorine-Based Cleansing Plant in a Public Swimming Pool* (in German). Basler & Hofmann Consulting Engineers, Forchstrasse 395, CH-8029 Zürich, Switzerland.

Carbura (1999), *Manual for the Safety of Large Mineral Oil Storage Facilities.* CARBURA and Swiss Agency for the Environment, Forests and Landscape (SAEFL), (revision 11), Zurich, Switzerland.

EC Directive 90/219 (1990), on the Contained Use of Genetically Modified Micro-organisms.

EC Directive 96/82 (1996), Seveso II Directive on the Control of Major Accidents Hazards Involving Dangerous Substances.

IAEA (1992), IAEA Safety Series No. 106, "The Role of Probabilistic Safety Assessment and Probabilistic Safety Criteria in Nuclear Power Plant Safety", 1998.

LPE (1983), Law Relating to the Protection of the Environment. Bundesgesetz vom 7. Oktober 1983 über den Umweltschutz (USG), SR 814.01, Berne, Switzerland.

OMA (1991), *Swiss Ordinance on Protection Against Major Accidents* (Ordinance on Major Accidents, OMA), SR 814.012, (in English, French or German) February 27, 1991 (Updated July 1994), Berne, Switzerland.

SAEFL (1991), Handbook I for the Ordinance on Major Accidents, OMA, Guidelines for Establishments with Substances, Products or Special Wastes (in French or German), Swiss Agency for the Environment, Forests and Landscape, SAEFL, Berne, Switzerland.

SAEFL (1996a), *Umweltschutz*, monthly publication of the Swiss Agency for the Environment, Landscape and Forests, SAEFL, Nr. 3/96, March 1996 (in German), Berne, Switzerland.

SAEFL (1996b), *Case Study of a Risk Study for a LPG Storage Vessel, Ordinance on Major Accidents* (in French or German), Swiss Agency for the Environment, Forests and Landscape (SAEFL), Berne, Switzerland.

SAEFL (1996c), Evaluation Criteria for the Ordinance on Major Accidents, OMA, Evaluation of the Extent of Damage, Evaluation of the Acceptability of Risk, Guidelines for Establishments with Substances, Products or Special Wastes (in French or German), Swiss Agency for the Environment, Forests and Landscape (SAEFL), Berne, Switzerland.

SAEFL (1999), *Case Study of a Risk Study for an Ammonia-Based Cooling Process in a Public Ice Rink* (in French or German, draft edition). Basler & Hofmann Consulting Engineers, Forchstrasse 395, CH-8029 Zürich, Switzerland.

Schmocker, U. (1997), *Technische Massnahmen zur Begrenzung der Folgen schwerer Unfälle*. SVA-Vertiefungskurs "Notfallmanagement innerhalb und ausserhalb des KKW", Winterthur, 15.-17. Oktober, 1997.SNGC (1997), *Manual for the Safety of High Pressure Natural Gas Installations.* Swiss Natural Gas Company (revised edition), Zürich, Switzerland.

DEVELOPMENT OF SAFETY CRITERIA IN GERMANY: AIM, PROCESS AND EXPERIENCES

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Introduction

Presently, a new plan for the management of radioactive waste in Germany is under development. Amongst the important cornerstones of this plan are the development and implementation of a new siting procedure, known under the acronym AkEnd ("Arbeitskreis Auswahlverfahren Endlagerstandorte" = Committee on a Selection Procedure for Repository Sites, AKEnd 2002a, b) and a revision of the Safety Criteria for the disposal of radioactive waste in a mine which were issued in 1983 (BMI, 1983). The revision is being carried out in order to account for the important developments in Germany and abroad in the fields of final radioactive waste disposal and repository performance assessment which have taken place over the last decades, to comply with the international state of the art in science and technology and to be consistent with the international development.

On behalf of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), GRS Köln drafted a proposal for the revision. The drafting process was supported by a body composed of experts from several German organisations and from abroad. The proposal was reviewed by the BMU's advisory committees RSK (Reactor Safety Commission) and SSK (Commission on Radiological Protection). An updated draft which takes into account the committees' comments was submitted to the BMU and is currently considered in order to establish and issue updated Safety Criteria. In parallel, a supporting guideline with requirements and recommendations for the post-closure Safety Case is being developed by GRS Köln, again with the support of experts from several German organisations and from abroad. This development has had and will have further implications for the revision of the Safety Criteria.

The proposals for revised criteria and for the guideline are based on national laws and regulations, especially the Atomic Energy Act (ATG, 2002) and the Radiation Protection Ordinance (StrlSchV 2001) as well as on recent international regulations and recommendations such as:

- IAEA Regulations e.g. the Fundamental principles for the safe handling of radioactive wastes (IAEA, 1995).
- The act on the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (BGB, 1998).
- Norms of the European Communities (e.g. EURATOM, 1996).
- ICRP regulations (e.g. ICRP, 1998).
- OECD recommendations.

Amongst the latter, the most recent NEA developments within the Integration Group for the Safety Case (IGSC) concerning the post-closure Safety Case for radioactive waste repositories, namely the drafting of the "Safety Case Brochure", were of utmost importance.

The criteria are exclusively related to radiation protection objectives and requirements specifying the damage precaution required by the Atomic Energy Act (ATG, 2002). The draft criteria require a multi-barrier system but place, in accordance with the AkEnd requirements, emphasis on the geologic barrier. They contain:

- Safety principles.
- Radiation protection objectives for the operational and the post-operational phases.
- Site requirements.
- Planning principles for the safety concept.
- Design and erection requirements.
- Criteria for the operational phase.
- Criteria for the post-operational phase (Long-term safety demonstration).

The elements required for the long-term safety demonstration are:

- Site characterisation.
- Geological and geotechnical long-term prognosis.
- Realisation of the safety concept.
- Fulfilment of the planning principles.
- Proof of criticality safety.
- Integrated safety assessment based on multiple lines of arguments using various performance and safety indicators.
- Demonstration of compliance with the safety goals.

This paper focuses on the choice of calculation end points for the required safety assessment and on how the uncertainties inevitably linked to such assessments have to be addressed.

Choice of calculation endpoints

The central radiological protection objective for the post-operational phase is to limit the risk of an individual sustaining serious health damage from exposure to radiation. The validity of this objective is unlimited in time. The applicability of the demonstration methods and the reliability of their results are, however, temporally limited since the time frames for safety assessments rely on the ability of geological and geotechnical prognosis concerning the future evolution of the repository system. It is stated in the draft criteria that beyond the time span of reasonable geological prognosis (ca.10^6 years) no credibility can be attached to integrated safety assessments and that, therefore, no assessments exceeding this timeframe should be undertaken.

The question of which calculation endpoint(s) for safety assessments would serve best the radiological protection objective "to limit the risk of an individual sustaining serious health damage from exposure to radiation" was exhaustively discussed by the experts involved in the criteria and guidelines developments. The most general interpretation of the word "risk" given by the IAEA Safety Glossary (IAEA, 2000) is:

"1. A multiattribute quantity expressing hazard, danger or chance of harmful or injurious consequences associated with actual or potential exposures. It relates to quantities such as the probability that specific deleterious consequences may arise and the magnitude and character of such consequences."

This definition is accompanied by the explanation

"In mathematical terms, this can be expressed generally as a set of triplets, R = $\{<S_i|p_i|X_i>\}$, where S_i is an identification or description of a scenario i, p_i is the probability of that scenario and X_i is a measure of the consequence of the scenario. The concept of risk is sometimes also considered to include uncertainty in the probabilities p_i of the scenarios."

The glossary also offers a definition which is in accordance with the widely used notion of "risk":

"2. The mathematical mean (expectation value) of an appropriate measure of a specified (usually unwelcome) consequence:

$$R = \sum_i p_i \cdot c_i$$

where p_i is the probability of occurrence of scenario or event sequence i and C_i is a measure of the consequence of that scenario or event sequence."

Amongst the explanations supplementing this definition are:

"The summing of risks associated with scenarios or event sequences with widely differing values of C_i is controversial. In such cases the use of the term "expectation value", although mathematically correct, is misleading and should be avoided if possible.

Methods for treating uncertainty in the values of p_i and C_i and particularly whether such uncertainty is represented as an element of risk itself or as uncertainty in estimates of risk, vary."

In addition, the glossary gives a third notion by saying:

"3. The probability of a specified health effect occurring in a person or group as a result of exposure to radiation."

This is accompanied by the explanations:

"The health effect(s) in question must be stated – e.g. risk of fatal cancer, risk of serious hereditary effects, or overall radiation detriment – as there is no generally accepted "default".

Commonly expressed as the product of the probability that exposure will occur and the probability that the exposure, assuming that it occurs, will cause the specified health effect. The latter probability is sometimes termed the conditional risk."

Assuming that the annual "risk of an individual sustaining serious health damage from exposure to radiation" is proportional to the dose rate of this exposure, the question remained, to what extent

- this dose rate and the likelihood to receive it; and
- the dose rates caused by different scenarios.

should be either presented separately or aggregated in calculation endpoints. The determination of a "total risk" like the expectation value given in the second IAEA definition can be seen as the highest degree of aggregation of these entities into one single number. However, the choice of the degree of aggregation should be determined by:

- the underlying philosophy;
- the practicalities concerning the assessment calculations to be carried out; and
- the practicalities of presenting results and communicating them.

Within the criteria development, it was seen as desirable to prescribe a dose constraint for likely scenarios (including the so-called expected evolution). However, for other (residual) scenarios the possibility of weighing low likelihoods against potentially high consequences was seen as sensible.

There were diverging views about how the weights (likelihoods) have to be determined for such scenarios which are governed by a (short-term) event (e.g. an earthquake). If one takes the perspective of a potentially exposed person and assumes that the annual risk that this person will sustain serious health damage is proportional to the annual dose this person is exposed to, this annual dose would have to be weighed against the likelihood that exactly this person will receive this dose. Such an approach would lead to risk as given in the second and third notions of the IAEA glossary as calculation endpoint for such a scenario.

However, given the extremely long timeframes of concern in long-term safety assessments, one could also (taking the position that an implementer wants to avoid any harm no matter when it might occur) arrive at the conclusion that the **total probability** that a scenario (i.e. its initiating event) occurs **at an arbitrary time** in the assessment timeframe should be the appropriate weight. Provided that the timeframe in which a scenario causes a significant dose rate is orders of magnitude lower than the assessment timeframe, this would, for short-term initiating events, lead to weights orders of magnitude higher than in the first approach. In the jargon of the experts involved in the criteria development, the approaches were called the "culprit's perspective" and the "victim's perspective", respectively.

Several proposals were discussed for the assessment endpoints. Amongst them were constraints for the residual risk for less likely scenarios in the form of a weighted sum of consequences, the weights being likelihoods of occurrence derived either from the "victim's" or the "culprit's perspectives". Finally, the following approach was agreed on:

- It shall be distinguished between "likely scenarios", "less likely scenarios" and "scenarios not to be considered in assessment calculations". In addition, "scenarios assuming direct human intrusion into the repository" shall form a separate group.

- For the likely scenarios, a dose constraint of 0.1 mSv/a was defined, while a constraint of 1 mSv/a shall apply to the less likely scenarios. A stylised biosphere model to determine individual doses from radionuclide concentrations/fluxes will be specified in a guideline based on present-day habits.

- Parameter uncertainties and uncertainties amenable to parametrisation shall be accounted for within probabilistic calculations. A dose constraint is regarded to be met if the uncertainty analysis gives 90% statistical confidence that the 90^{th} percentile of the underlying "true" distribution lies below the constraint.

- A limited number of scenarios assuming direct human intrusion to be studied will be defined in a guideline based on present-day practises in Germany. The objective of studying these scenarios is rather to justify siting and design decisions than to demonstrate compliance with a numerical criterion.

- The guideline which is presently being developed will provide guidance on how to classify scenarios based on their likelihood of occurrence. This guidance will be orientated on total likelihoods (that is, likelihoods that a scenario will occur at an arbitrary point of the assessment timeframe). The guidance will distinguish between scenarios caused by (unknown) features and by (natural or anthropogenic) processes and events. A "virtual threshold" of 10% likelihood of occurrence will be used as a background for distinguishing between likely and less likely scenarios, but no request to calculate such likelihoods will be formulated. For naturally caused processes and events, the guidance will be based on an extrapolation of the geological past of the site and comparable sites.

This approach and especially the decision to go without a risk calculation endpoint were based on a number of considerations, the most important ones being the following:

- Serious doubts were expressed concerning the possibility to quantify likelihoods of occurrence for the majority of the scenarios possibly to be considered.
- Even if it were possible to quantify (e.g. annual) likelihoods of occurrence for short term initiating events, it would be complicated to account for these likelihoods appropriately in a weighing scheme for potential consequences from different scenarios and it would be hard to communicate results of such assessments, especially since there would also be other uncertainties (e.g. concerning duration of exposure) to be considered in the calculation and presentation. The only reasonable way to do this would be a fully probabilistic assessment and it was not seen as desirable to prescribe such an assessment approach. However, the implementer would in the chosen approach still have the freedom to regard the time of occurrence of a scenario as an uncertain parameter to be addressed within a probabilistic assessment, provided he were able to choose the corresponding probability density function in a convincing way.
- A weighing using total probabilities ("culprit's perspective") would, although in principle desirable, produce a calculation endpoint which would not be comparable with the usual notion of "risk".
- Even though dose rates calculated in assessments are seen as indicators rather than as predictions, the BMU's advisory committees in their recommendations expressed, from a radiation protection point of view, serious concerns with regard to approaches which would allow "compensating" severe consequences by weighing them with low likelihoods of occurrence. Potential exposures of more than 1 mSv/a were seen as problematic regardless of the likelihood of occurrence.

Treatment of uncertainties

It will be distinguished between scenario, model and parameter uncertainties, being aware that such a categorisation is always somewhat arbitrary, subjective and dependent on the chosen modelling and assessment approaches. The possibility to parametrise times of occurrence for scenario initiating events (cf. above) might serve as only one amongst numerous examples for this. No distinction will be made between so-called subjective and so-called stochastic uncertainties.

According to recent developments, assessment calculations are seen as one of multiple lines of evidence to be provided in a Safety Case. The bulleted list at the end of the introduction of this paper gives other areas which are addressed in the Safety Criteria.

Scenario uncertainties

Uncertainties concerning potential future evolutions of the repository system are addressed by requiring a well-structured procedure for the development of scenarios in order to ensure that a comprehensive set of reasonable scenarios will be considered. The procedure should make use of national and international FEP databases and ensure the traceability of every decision made during the development process. The extent to which the character of such a procedure will be prescribed still needs to be decided.

The scenarios will be classified and assessed as described above. Whether or not a scenario is described "correctly" is seen as being subject to model uncertainty (cf. below).

The choice of scenarios with highly speculative character, namely of those assuming direct human intrusion, is guided as described above. Whether or not other rather speculative scenarios are considered (e.g. so-called "what if"-scenarios which might allow demonstrating robustness of certain repository components), depends on choices and decisions to be made by the implementer (possibly in dialogue with the regulator).

Model uncertainties

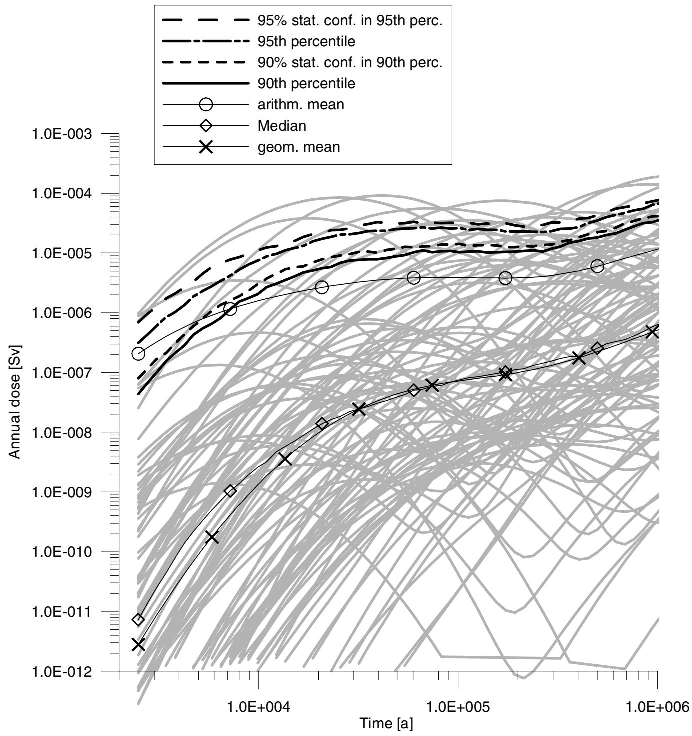
The conceptual, mathematical and numerical models (including codes) to be used in the assessments shall be developed according to established quality assurance procedures. Verification, validation and confidence building shall be carried out according to the state of the art in science and technology. If there are doubts concerning modelling assumptions or with regard to the presence and/or nature of processes, alternative assumptions shall be explored. If possible, conservative assumptions should be used and/or the robustness of the system against such uncertainties should be demonstrated.

Where, as in the case of biosphere modelling, there is room for highly speculative assumptions, the choice of such assumptions will be guided by regulations.

Parameter uncertainties

For uncertain parameters or assumptions amenable to quantification, either conservative choices are to be made or reasonable probability density distributions are to be derived. In either case, decisions have to be justified and to be documented in a traceable manner. For each likely or less likely scenario to be considered in assessment calculations, a probabilistic uncertainty analysis has to be carried out. As said above, a dose target for a scenario is considered to be met if, with 90% statistical confidence, the 90th percentile of the "true" distribution underlying the uncertainty analyses lies below the constraint. This fulfilment of this requirement can be demonstrated independent of the shape of the underlying probability distribution (Guttman 1970). The requirement is, e.g., fulfilled if 913 out of 1 000 realisations lie below the constraint. The choice of the 90th percentile and the 90% statistical confidence limit is still seen as preliminary. In contrast, a requirement that, e.g., the 95th percentile lies with 95% statistical confidence below the constraint would be fulfilled if 962 realisations out of 1 000 would be below the constraint, while 90% confidence with regard to the 95th percentile would require 960 out of 1 000 realisations lying below the constraint. The figure below gives an impression of how to compare these so-called "distribution-independent tolerance limits" with other well-known statistics.

Figure 1. **Dose rate results and statistics for a trial probabilistic assessment run (earthquake scenario). The statistics were calculated for 1 000 realisations; however, only the first 100 runs are displayed (grey lines).**



Concluding remarks

As stated in the introduction, the revision of Safety Criteria is not yet complete. Thus, the paper represents a preliminary status. This applies especially to the content of the supporting regulatory guidelines.

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References

Arbeitskreis Auswahlverfahren Endlagerstandorte – AkEnd (2002a) Site Selection Procedure for Repository Sites. Recommendations of the AkEnd – Committee on a Site Selection Procedure for Repository Sites. Final report, December 2002, http://www.akend.de/englisch/pdf/finalreport.pdf.

Arbeitskreis Auswahlverfahren Endlagerstandorte – AkEnd (2002b) Site Selection Procedure for Repository Sites. Recommendations of the AkEnd – Committee on a Site Selection Procedure for Repository Sites. AkEnd-brochure, December 2002, http://www.akend.de/englisch/pdf/broschuere_endg_eng.pdf.

ATG (2002), Act on the Peaceful Utilization of Atomic Energy and the Protection against its Hazards (Atomic Energy Act) of December 23, 1959 (Federal Law Gazette <BGBl.> I 1959, page 814), as Amended and Promulgated on July 15, 1985 (Federal Law Gazette <BGBl.> I 1985, page 1565), Last Amendment by the Act of April 22, 2002 (Federal Law Gazette, <BGBl.> I 2002, page 1351).

BGB (1998), Gesetz zu dem Gemeinsamen Übereinkommen vom 5. September 1997 über die Sicherheit der Behandlung abgebrannter Brennelemente und über die Sicherheit der Behandlung radioaktiver Abfälle (Act on the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management) BGBl Teil II, Nr. 31,S. 1752, 1998.

Bundesministerium des Innern (BMI 1983), Sicherheitskriterien für die Endlagerung radioaktiver Abfälle in einem Bergwerk (Safety Criteria for the Final Disposal of Radioactive Wastes in a Mine). GMBI. 1983, S. 220.

EURATOM (1996), Council Directive 96/29/EURATOM laying down Basic Safety Standards for the Protection of the Health of Workers and the General Public against the Dangers arising from Ionising radiation, Official Journal of the European Communities, L159, 29 June, 1996.

Guttman, I. (1970), Statistical Tolerance Regions: Classical and Bayesian. Griffin, London.

IAEA (1995), IAEA Safety Fundamentals: The Principles of Radioactive Waste Management. Safety Series No. 111-F, IAEA, Vienna.

IAEA (2000), IAEA Safety Glossary. Terminology Used in Nuclear, Radiation, Radioactive Waste and Transport Safety. Version 1.0.

International Commission of Radiological Protection (ICRP 1998) Radiation Protection Recommendations as Applied to the Disposal of Longlived Solid Radioactive Waste. Publication 81. Annals of the ICRP, Vol. 28, No 4.

StrlSchV (2001), Verordnung über den Schutz vor Schäden durch ionisierenden Strahlen – Strahlenschutzverordnung StrlSchV (Radiation Protection Ordinance) (Federal Law Gazette <BGBl.> I 2001, page 1713).

CONSIDERATION OF UNLIKELY EVENTS AND UNCERTAINTIES IN THE FINNISH SAFETY REGULATIONS FOR SPENT FUEL DISPOSAL

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Introduction

Spent fuel disposal programme in Finland passed in 2001 the decision-in-principle process that is crucial to the selection of the disposal site and to obtaining the political acceptance for the disposal plan. The regulator (STUK) participated in the process by reviewing implementer's (Posiva) safety case. The review was based on the general safety regulation[1] issued by the Government in 1999 and STUK's guide[2] of 2001 for the long-term safety specifying the general safety regulation. These regulations address also unlikely natural and human scenarios and related uncertainties. The criteria adopted for the judgment of the radiological impact from such scenarios depend on the type of scenario and the time period of concern.

General safety regulations

The general safety regulations give a dose based radiation protection criteria for normal evolution scenarios, which take place during the so called environmentally predictable future. For normal evolution scenarios occurring beyond that time period, the radiation protection criteria are based on the release rates of disposed radionuclides into the biosphere. The regulations include also specific criteria for dealing with unlikely disruptive events affecting long-term safety and for dealing with uncertainties involved with the assessments. The radiation protection criteria included in the general safety regulations are given below (in italics) and discussed in the subsequent chapters.

"In an assessment period that is adequately predictable with respect to assessments of human exposure but that shall be extended to at least several thousands of years:

- *the annual effective dose to the most exposed members of the public shall remain below 0.1 mSv and*
- *the average annual effective doses to other members of the public shall remain insignificantly low.*

Beyond the assessment period referred to above, the average quantities of radioactive substances over long time periods, released from the disposed waste and migrated to the environment,

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1. General regulations for the safety of spent fuel disposal (1999), Government Decision 478/1999 (1999).
2. Long-term safety of disposal of spent nuclear fuel, STUK Guide YVL 8.4 (2001).

shall remain below the nuclide specific constraints defined by the Radiation and Nuclear Safety Authority. These constraints shall be defined so that:

- *at their maximum, the radiation impacts arising from disposal can be comparable to those arising from natural radioactive substances; and*
- *on a large scale, the radiation impacts remain insignificantly low.*

The importance to long-term safety of unlikely disruptive events impairing long-term safety shall be assessed and, whenever practicable, the acceptability of the consequences and expectancies of radiation impacts caused by such events shall be evaluated in relation to the respective dose and release rate constraints.

Compliance with long-term radiation protection objectives as well as the suitability of the disposal concept and site shall be justified by means of a safety analysis that addresses both the expected evolutions and unlikely disruptive events impairing long-term safety. The safety analysis shall consist of a numerical analysis based on experimental studies and be complemented by qualitative expert judgement whenever quantitative analyses are not feasible or are too uncertain.

The data and models introduced in the safety analysis shall be based on the best available experimental data and expert judgement. The data and models shall be selected on the basis of conditions that may exist at the disposal site during the assessment period and, taking account of the available investigation methods, they shall be site-specific and mutually consistent. The computational methods shall be selected on the basis that the results of safety analysis, with high degree of certainty, overestimate the radiation exposure or radioactive release likely to occur. The uncertainties involved with safety analysis and their importance to safety shall be assessed separately."

Environmentally predictable future

The regulations define the so-called environmentally predictable future which is assumed to extend up to several thousands of years. During this period, the climate type is expected to remain similar to that nowadays in Northern Europe. However, considerable but predictable environmental changes will occur at the disposal site due to the ongoing land uplift: a sea bay will turn into a lake, then into wetland and the sediment might later on be used as farmland. The geosphere is expected to remain quite stable though slight, predictable changes will occur due to the land uplift and the heat generating waste.

In this timeframe, the engineered barriers are required to provide almost complete containment of the disposed waste in order to minimise the impacts from waste induced disturbances and to facilitate retrievability of waste. Consequently, people might be exposed to the disposed radioactive substances only as a result of early failures of engineered barriers, due to e.g. fabrication defects or rock movements.

Despite the environmental changes, conservative estimates of human exposure can be done for this time period and accordingly the safety criteria are based on dose constraints. In the STUK guide,[2] the radiation protection criteria are clarified as follows:

"The dose constraints apply to radiation exposure of members of the public as a consequence of expected evolution scenarios and which are reasonably predictable with regard to the changes in the environment. Humans are assumed to be exposed to radioactive substances released from the repository, transported to near-surface groundwater bodies and further to watercourses above ground. At least the following potential exposure pathways shall be considered:

- *use of contaminated water as household water;*
- *use contaminated water for irrigation of plants and for watering animals;*
- *use of contaminated watercourses and relictions.*

Changes in the environment to be considered in applying the dose constraints include at least those arising from land uplift. The climate type as well as the human habits, nutritional needs and metabolism can be assumed to be similar to the current ones.

The constraint for the most exposed individuals, effective dose of 0,1 mSv per year, applies to a self-sustaining family or small village community living in the vicinity of the disposal site, where the highest radiation exposure arises through the pathways discussed above. In the environs of the community, a small lake and shallow water well is assumed to exist.

In addition, assessment of safety shall address the average effective annual doses to larger groups of people, who are living at a regional lake or at a coastal site and are exposed to the radioactive substances transported into these watercourses. The acceptability of these doses depend on the number of exposed people, but they shall not be more than one hundredth – one tenth of the constraint for the most exposed individuals.

The unlikely disruptive events impairing long-term safety shall include at least:

- *boring a deep water well at the disposal site;*
- *core-drilling hitting a waste canister;*
- *a substantial rock movement occurring in the environs of the repository.*

The importance to safety of any such incidental event shall be assessed and whenever practicable, the resulting annual radiation dose or activity release shall be calculated and multiplied by the estimated probability of its occurrence. The expectation value shall be below the radiation dose or activity release constraints given above. If, however, the resulting individual dose might imply deterministic radiation impacts (dose above 0,5 Sv), the order of magnitude estimate for its annual probability of occurrence shall be 10^{-6} at the most."

The radiation protection criteria involve flexibility for the assessment of unlikely disruptive events. Whenever practicable, the assessment should be done in an aggregated way by calculating a radiation dose and the probability of its occurrence and by comparing the resulting expectation values with the respective dose constraints. But the regulations recognise that, due to inherent uncertainties, this is not always feasible and consequently allow also a more disaggregated and less quantitative assessment of consequences and probabilities of unlikely disruptive events.

The regulations specify three unlikely disruptive events that should at least be included in the list of scenarios to be analysed: a deep water well, core drilling and rock movement.

The water well scenario is quite natural because in Finland, tens of thousands of water wells bored at the depth of a couple of tens to hundreds of meters exist. Thus it is quite likely that such a well will exist at the disposal site at some time. The well might short-circuit the transport pathways of contaminated groundwaters and enhance radiation exposure of the critical group.

Considerable uncertainties relate to the analysis of the water well scenario. In order to calculate the arising radiation dose, the dilution factor should be known. Though illustrative analyses give a quite wide range for the dilution factor in case of crystalline rock, a reasonably conservative value can be adopted. The probability of the existence of a water well at the disposal site at a certain time, so that the people using the water are unaware of its radioactive contamination, is more speculative. Nevertheless, the deep water well scenario should be analysed quantitatively, taking into account the involved uncertainties, and the results should be discussed in relation to the radiation dose constraint.

Core drilling, hitting a waste canister, is a very speculative scenario. A reference scenario, preferably internationally adopted one, should be developed for the analysis of the radiological consequences of such events. Some estimates for probabilities, based on current frequencies of deep drilling, can be obtained, but their projection into far future is questionable. Because the probabilities are very low and the consequences can be even serious, the core drilling scenario should be assessed in a disaggregated manner.

The rock movement scenario involves an event where a seismic or aseismic phenomenon in the vicinity of the repository causes secondary rock displacements, one of which might intersect waste canisters. In Finland, such events are most likely in postglacial conditions, when the rock stresses induced during ice age are relieved and consequently, the intensities and frequencies of rock movements are by far higher than today. During the past few years, significant progress in the quantitative analysis of probabilities of such events has been achieved. Anyway, large uncertainties are involved with both consequences and probabilities of such scenarios and in the safety assessment, they should be dealt with in a disaggregated manner.

Era of extreme climate changes

Beyond about 10 000 years, great climatic changes, such as permafrost and glaciation, will emerge. The range of potential environmental conditions will be very wide and assessments of potential human exposures arising during this time period would involve huge uncertainties. A conservative safety case should be based on extreme bioscenarios and overly pessimistic assumptions.

The climatic changes affect significantly also the conditions in the geosphere, but their ranges are estimable. In this time period, substantial degradation of the engineered barriers cannot be ruled out, though they were planned to withstand the stresses due to the climate-induced disturbances in bedrock. As radionuclide release and transport in the repository and geosphere can be assessed with reasonable assurance and consequently, it is prudent to base the radiation protection criteria on constraints for release rates of long-lived radionuclides from geosphere to biosphere (so called geo-bio flux constraints).

In STUK's guide,[2] the general safety criteria addressing the era of extreme climate changes (see chapter 2) are specified as follows:

"The nuclide specific constraints for the activity releases to the environment are as follows:

- *0,03 GBq/a for the long-lived, alpha emitting radium, thorium, protactinium, plutonium, americium and curium isotopes;*
- *0,1 GBq/a for the nuclides Se-79, I-129 and Np-237;*
- *0,3 GBq/a for the nuclides C-14, Cl-36 and Cs-135 and for the long-lived uranium isotopes;*
- *1 GBq/a for Nb-94 and Sn-126;*
- *3 GBq/a for the nuclide Tc-99;*
- *10 GBq/a for the nuclide Zr-93;*
- *30 GBq/a for the nuclide Ni-59;*
- *100 GBq/a for the nuclides Pd-107 and Sm-151.*

These constraints apply to activity releases which arise from the expected evolution scenarios and which may enter the environment not until after several thousands of years. These activity releases can be averaged over 1 000 years at the most. The sum of the ratios between the nuclide specific activity releases and the respective constraints shall be less than one."

The release rate constraints have been derived so that they are in general compliance with the dose constraint of 0,1 mSv/a (considering also daughter nuclides), if typical boreal biosphere scenarios are assumed. The rules of application of different kind of scenarios for the release rate criteria are generally the same as those for the dose criteria (as discussed in chapter 3). However, it should be noted that the criteria allow the averaging of the releases over 1 000 years at the maximum. This provides a reasonable time dilution of peak releases, similarly as the risk or expectation value concepts do in case of probabilistic events. It also implies that in the very long term, the most important protection goal is not to try to limit incidental peak releases, albeit they might theoretically imply exposures well above the dose constraint, but to provide an effective overall containment of waste.

Treatment of uncertainties

According to our regulations, the backbone for the demonstration of the compliance with the long-term safety criteria is a scientifically sound, quantitative safety assessment which should be based on a deterministic, conservative approach, whenever practicable. It is, however, recognised that such rigorous quantitative analyses are not always feasible, and therefore the regulations allow some relaxations. The general regulations for safety assessment, quoted in chapter 2, are specified in STUK's guide[2] as follows.

"In order to assess the release and transport of disposed radioactive substances, conceptual models shall first be drawn up to describe the physical phenomena and processes affecting the performance of each barrier. Besides the modelling of release and transports processes, models are needed to describe the circumstances affecting the performance of barriers. From the conceptual models, the respective calculational models are derived, normally with simplifications. Simplification of the models as well as the determination of input data for them shall be based on the principle that the performance of any barrier will not be overestimated but neither overly underestimated.

The modelling and determination of input data shall be based on the best available experimental knowledge and expert judgement obtained through laboratory experiments, geological investigations and evidence from natural analogues. The models and input data shall be appropriate to the scenario, assessment period and disposal system of interest. The various models and input data shall be mutually consistent, apart from cases where just the simplifications in modelling or the aim of avoiding the overestimation of the performance of barriers implies apparent inconsistency.

The importance to safety of such scenarios that cannot reasonably be assessed by means of quantitative analyses, shall be examined by means of complementary considerations. They may include e.g. bounding analyses by simplified methods, comparisons with natural analogues or observations of the geological history of the disposal site. The significance of such considerations grows as the assessment period of interest increases, and the judgement of safety beyond one million years can mainly be based on the complementary considerations. Complementary considerations shall also be applied parallel to the actual safety analysis in order to enhance the confidence in results of the whole analysis or a part of it."

Obviously conservatism in absolute sense is unattainable, given the inherent uncertainties related to the long-term performance of the disposal system. The criteria imply that the result of the analysis (endpoint indicator) with reasonable assurance overestimate really occurring dose or release rate. Our regulations do not explicitly require rigorous quantification of the uncertainties e.g. in form of confidence levels; rather the implications of uncertainties should be illustrated by means of variant and sensitivity analyses and the confidence in the assessments should be enhanced by complementary considerations referred to above. Thus, though the safety criteria are quite unambiguous, compliance with them cannot be deemed in a straightforward way but will involve abundantly expert judgement.

RISCOM II – ENHANCING TRANSPARENCY AND PUBLIC PARTICIPATION IN NUCLEAR WASTE MANAGEMENT

M. Westerlind[1] **and K. Andersson**[2]
[1]Swedish Nuclear Power Inspectorate and [2]Karinta-Konsult, Sweden

Project partners: Swedish Nuclear Power Inspectorate, SKI, Sweden; Swedish Radiation Protection Authority, SSI, Sweden; Swedish Nuclear Fuel and Waste Management Co., SKB, Sweden; Karinta-Konsult, Sweden; UK Nirex Ltd, UK; Environment Agency, UK; Galson Sciences, UK; Lancaster University, UK; Électricité de France, EDF, France; *Institut de Radioprotection et de Sûreté Nucléaire*, IRSN, France; Posiva Oy, Finland; Nuclear Research Institute, Czech Republic; Diskurssi Oy, Finland (sub-contractor) and Syncho Ltd, UK (sub-contractor)

Background and objectives

RISCOM II is a project (FIKW-CT-2000-00045) within EC's 5th framework programme, and it was completed in October 2003. The RISCOM Model for transparency was created earlier in the context of a Pilot Project funded by SKI and SSI and has been further developed within RISCOM II. The overall objective was to support transparency of decision-making processes in the radioactive waste programmes of the participating organisations, and also of the European Union, by means of a greater degree of public participation. Although the focus has been on radioactive waste, findings are expected to be relevant for decision making in complex policy issues in a much wider context.

Experiences from the various national radioactive waste management programmes vary and countries are at different stages of developing long-term solutions to their waste problems. There are several examples of significant progress all the way to the siting of a final repository. The siting of radioactive waste installations has, however, also met substantial public opposition in several countries, and it is with this background that the RISCOM II project was initiated.

According to the RISCOM Model, to achieve transparency there must be appropriate procedures in place in which decision makers and the public can validate claims of truth, legitimacy and authenticity. The procedures should allow ***stretching***, which means that the environment of e.g. the implementer (of a proposed project), the authorities and key stakeholders is sufficiently demanding and that critical questions are raised from different perspectives. Accordingly, in RISCOM II the issues are analysed especially with respect to their value-laden aspects and procedures for citizen participation are tested. Furthermore, the impact of the overall organisational structure of radioactive waste management in a country on how transparency can be achieved is investigated.

There are several novel features of the project. First the focus on values in the otherwise very technically dominated area of radioactive waste management, and a multi-disciplinary approach opens new perspectives. Performance assessment (PA) is an important area where this is needed. PA has usually been an expert dominated activity where experts communicate with other experts. The users of PA results were mostly experts or decision makers with expert knowledge. Now, however, the group of users of PA has widened to include members of the public, concerned groups and communities involved in site selection processes. The PA experts thus have to communicate facts and values with stakeholders and decision makers. This project has analysed values in PA and explored statements and arguments from stakeholders, which should influence how future PAs are conducted and communicated with the public. Furthermore, as regulatory standards and criteria set the framework for PA, it is important to open them up for public input.

Summary of conclusions

The project has clarified how the RISCOM Model can best be used in radioactive waste management programmes:

- In parallel with possible further development and refinement of the RISCOM Model, its theoretical grounds in combination with its demonstrated applicability makes it ready for further use directly in radioactive waste management programmes for the design of decisions processes and means for citizen participation.
- In particular, it was shown by hearings organised by SKI and SSI, that the RISCOM Model can be used to support the design of public events and decision processes for the sake of transparency. The hearing format developed using the model was successful in many aspects such as a high level of involvement, the mental separation of structurally different issues and stretching without a too adversarial set-up.

One of the cores issues addressed in the study has been how PA can be made more transparent and accessible to the general public:

- To incorporate the value judgements of stakeholders into PA would include conducting PA by starting from the issues of concern among stakeholders and communicating with them during the PA work.
- PA should not be communicated by information departments – the real experts need to engage themselves so that people can see that they are honest, open about uncertainties and address the concerns of ordinary people.
- Regulatory standards and criteria is one important area where the principles of transparent decision making should be applied. If the authorities involve the citizens at the stage of developing the regulations, this would be a way to include their values into the framework of PA.
- PA must keep its identity as a scientific and engineering enterprise. Engaging in public dialogue must not dilute the science and steer experts away too much from their core activity.

Sometimes there may be unrealistic expectations that public participation should lead to consensus. This project has addressed how transparency relates to consensus building:

- A transparent and democratic decision-making process must not necessarily lead to consensus about a proposed project. Transparency, however, leads to a higher level of awareness of all aspects of the issue, which should be to the benefit of high quality decisions.

There is close relationship between transparency and public participation. The RISCOM Model can help in public participation and what that requires:

- The UK group has developed one set of criteria in the context of testing several dialogue processes.
- Evidence from the UK dialogue processes suggests that the actual use made of information is minimal. This suggests that great care should be taken in targeting information resources where they will be most useful.
- A nuclear waste management programme must have resources to allow for citizen participation. Proper resources will encourage positive engagement, improve decision making and increase public confidence.

SESSION 2

STAKEHOLDER INVOLVEMENT – PART I

Chair: José Ignacio Villadoniga, CSN, Spain
Vice-chair: Arnold Bonne, IAEA

1. Objectives

There is a world-wide recognition that the implementation of programmes for the long-term management of nuclear waste and spent nuclear fuel requires careful consideration of not only scientific/technical issues but also of e.g., social concerns, public participation and decision-making processes. An important purpose for the Conference on Geological Repositories is to explore actions taken to finding ways forward for the long-term management of nuclear waste and spent nuclear fuel.

The actors concerned with and engaged in the implementation of such programmes typically include:

- implementing organisation (R&D, facility design, siting etc.);
- regulators;
- political decision makers at different levels;
- NGOs at different levels, and
- the public (in particular those that are directly affected by a facility).

Stakeholder Involvement I will primarily give the implementing organisations' perspective on stakeholder issues. To complement this, an international, and thus more general perspective is included in the session.

2. Issues

This session will address how implementing organisations are developing their views on stakeholder involvement. Attention will thus be paid to these organisations' practical interaction with e.g., local/regional stakeholders since these are those directly affected by the siting of a repository.

The international perspective is largely based on work carried out by NEA's Forum of Stakeholder Confidence. This work has explored lessons learned by implementers, regulators, local/regional stakeholders, NGOs, social scientists and others. The lessons are systematically summarised, and constitute one starting point for sharing experience and for discussing good practice in stakeholder involvement.

Programme

Chair: **José Ignacio Villadoniga**, CSN, Spain

Vice-chair: **Arnold Bonne,** IAEA

Sumio Masuda (on behalf of Kazunao Tomon), NUMO, Japan

Valentine Vanhove, ONDRAF, Belgium

Chris Murray, NIREX, U.K.

Yves Le Bars, Chairman of the Board, Andra, France

Discussion based on papers 1-4.

The presenters of the first four papers form a small panel to address questions and comments from session participants.

Claudio Pescatore, OECD/NEA

STATUS OF HLW GENERATION AND STORAGE IN JAPAN

Kazunao Tomon (Speaker: Sumio Masuda)
Nuclear Waste Management Organization of Japan (NUMO)

Since the first operation of commercial nuclear power plant was started in 1966, the use of nuclear energy in Japan has expanded steadily. At present, 52 nuclear power plants are in operation, and nuclear power generation represented about 35% of total electricity generated.

In addition, several plants are now under construction and further more plants are planned at this stage. Japan is pursuing the reprocessing policy of spent nuclear fuel. Current inventory of vitrified HLW is 880 canisters which are in storage at JNFL Rokkasho storage facility and JNC Tokai reprocessing plant.

According to the current programme, the total amount of spent fuel is estimated to correspond to 40 000 canisters of vitrified waste by the year 2020.

1. Development of Japanese HLW disposal programme

The year 2000 was a turning point for Japanese programme, as it moved from the generic R&D phase since 1976 into the initial part of implementation phase. Following technical achievements of the H12 Second Progress Report, the "Specified Radioactive Waste Final Disposal Act" was promulgated in June 2000, and thereby the framework for implementation was established. According to the current national programme, operation of the repository is planned to start by the 2030s.

2. Legal background and regulatory aspects

Major points stated in the Final Disposal Act are as follows.

The first one is the "establishment of implementing organisation". Based on this, the Nuclear Waste Management Organization of Japan (NUMO) was organised in October 2000.

The other is that a "stepwise approach" should be taken for site selection of the repository site.

From this point of view, the Act specifies the following three stages:

- in the first stage, Preliminary Investigation Areas for potential candidate sites are nominated based on area-specific literature surveys;
- detailed Investigation Areas are then selected from Preliminary Investigation Areas by surface-based investigations, including boreholes; and

- in the final stage, detailed site characterisation including underground experimental facilities at Detailed Investigation Areas will lead to selection of the Final Disposal Site.

On the other hand, the Nuclear Safety Commission published a report entitled "Requirements of Geological Environment to Select PIAs of HLW Disposal" in September 2002. In the report, inappropriate conditions for PIAs to be confirmed by the literature survey are identified as requirements on geological characteristics for "active faults", "Quaternary volcanoes", "uplifts/ erosion" and so on, and when information on geological characteristics is lacking, specific conditions to be confirmed by further investigation after selection of PIAs are pointed out.

3. NUMO siting activities

Based on the legal requirements, and taking account of lessons learnt from Japanese experiences of nuclear waste management in the past a quarter century, we recognise that the following three aspects are of prime importance as we move forward with ensuring the public safety and building public trust. Those are:

- stepwise project development;
- engaging communities; and
- focusing on transparency.

To accomplish these, NUMO is now taking an approach consisting in:

- open solicitation of volunteer municipalities for selection of Preliminary Investigation Areas;
- building a long-term working relationship with local communities; and
- public involvement in decision making in the process of selecting sites.

4. Start of open solicitation

On 19 December 2002, NUMO officially launched the Open Solicitation programme by sending an "Information Package" to all of municipalities in Japan.

The "Information Package" consists of four documents, namely, "Instructions for Application", "Repository Concepts", "Siting Factors for the Selection of PIAs", and "Outreach Scheme".

All municipalities in Japan have a right to apply for the Open Solicitation programme, and the deadline for application is not set at present stage.

5. Repository concepts

The "Repository Concepts" document includes a set of repository concepts developed for the siting environments expected in a potential candidate site. This document is aimed to provide information on what the planned repository is and how it will be developed for siting environments at candidate sites.

6. Siting factors for the selection of PIAs

For selection of Preliminary Investigation Areas, "Siting Factors" must be taken into account for evaluation based on Literature Survey. These "Siting Factors" are developed and documented in two categories, namely "Evaluation Factors for Qualification" and "Favourable Factors". In developing the Siting Factors, the requirements specified in the Final Disposal Act and the Nuclear Safety Commission's "Environmental Requirements" were considered.

7. Site investigation community outreach scheme

The "Site Investigation Community Outreach Scheme" document includes plans for consultations with local residents of volunteer municipalities regarding measures that will contribute to industrial development and improvement of lifestyles in the area. This document is aimed at outlining the benefits to the municipalities, not only in financial terms but also from other positive social aspects. In order to build a long-term relationship with the host communities, we estimated economic benefits on local community arising from the repository as follows.

First, local order placements are estimated at 12 billion yens/year. Production inducement effect is estimated at totally 1.65 trillion yens, and employment creation effect is estimated as 2 200 people per year.

In addition to these, the Japanese Government will provide the "Incentive for Regional Acceptance" to volunteer municipalities, which are 210 million yens/year for a period of PIA selection stage, and 2 billion yens/year for a period of DIA selection stage.

8. Stakeholder involvement in siting process

At the time when a volunteer comes forward, NUMO will start an area-specific literature survey including past records for areas of the volunteer municipalities in collaboration with local experts.

After the survey, the area will be evaluated in terms of compliance with the Siting Factors and publicise results of investigation as a report.

The evaluation report will be opened to solicit written comments on the report from the public in relevant communities.

Then we will compile their comments through the public meetings at the concerned municipalities with responses to them as a document and publicise it.

Taking account of the evaluation results and all comments on them, PIAs will be selected.

And then an application for approval of the selection of the PIAs will be submitted to METI.

Following NUMO's selection, METI has to solicit opinions from the concerned Governors and Mayors and respect them in approving the NUMO's selections of PIAs.

After these activities, the programme will step into the next stage, namely start of selection of DIAs.

9. Publicity activities (1)

For the purpose of promoting public understanding of geologic disposal, NUMO has been conducting information campaign on the major leading newspapers, magazines, TV and so forth.

The core messages are:

- HLW existence awaits urgent solution, and
- intergenerational equity.

And the promotion words for the campaign have been developed as follows.

- we will not simply pass on the waste arising from our electricity production to the future generations;
- we will carry out our responsibility to ensure the safety of future generations, and
- homework for an electricity country.

Former two messages were used since October 2002, and currently the last message was used.

10. Publicity activities (2)

We also have been holding a series of NUMO Forum as one of our Public Relations activities.

The forum is co-hosted by leading local mass media, and is aiming to provide basic information to the public in order to obtain their opinions or concerns, and to contribute to their arguments on the voluntary host community for the repository site.

Before announcement of the open solicitation programme, we held such public meeting in 31 cities. So far, 16 panel discussions in different prefectures and their discussion turned into article of the local newspapers.

At the beginning part of the meeting, the moderator always asked the same question to the audience, “Do you know HLW?” The answers from most of the audience were “No” He asked a similar question at the end of the meeting. In contrast, most of the audience could recognise that disposal of HLW was their own issue.

Through such experiences, we have some sort of conviction as how to communicate with the general public. This indicates the importance of face-to-face approach.

11. Response to the open solicitation

There were remarkable increases of access to the NUMO’s website at the time when the “Site Recommendation of Yucca Mountain” was announced widely on TV and newspapers, and “official announcement of start of the NUMO’s Open Solicitation Programme” were released.

We found/news on TV/and newspapers in addition to effect of advertisement attracted much attention of the public to the issue of HLW disposal.

As of today, no municipality has made an official application. There are, however, some municipalities which might be now under consideration.

As a matter of fact, we have been receiving many inquiries from municipalities since the announcement in December of last year.

Conclusion

To summarise, the specific feature of NUMO's siting process is "open solicitation of volunteer municipalities".

We believe that most Japanese must have a social spirit, and some volunteer municipalities would someday in the near future come forward.

In the stepwise siting approach, it is particularly important to ensure that the decision-making process is transparent and traceable, as well as to ensure flexibility in programme.

For flexibility, there are "repository design options", "retrievability", "post-closure monitoring" and so on.

It is also crucial to obtain stakeholders' confidence. It is therefore essential to ensure scientific soundness and technical reliability for making safety case, Demonstration of technologies for site characterisation and repository engineering and organisational trust.

Last but not least, an independent competent regulator, working as a bridge between stakeholders and implementer, would help obtaining an increased public trust in a fair and equitable manner.

LOCAL PARTNERSHIPS:
STAKEHOLDER INVOLVEMENT IN LOW-LEVEL WASTE DISPOSAL

Valentine Vanhove, Evelyn Hooft
ONDRAF/NIRAS, Belgium

Anne Bergmans
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Until the international moratorium of 1983, Belgium relied on sea disposal for its low-level waste. Since then, ONDRAF/NIRAS, the Belgian radioactive waste management agency, has launched studies to look for land-based solutions. These studies, which are still going on, have gone through various phases. The sometimes harsh reactions in public opinion and the recommendations of independent experts, however, progressively led ONDRAF/NIRAS to question its work methodology.

The date of 16 January 1998 was a milestone in Belgian's nuclear waste management. On that day, the Belgian federal government opted for a final, or potentially final, solution for the long-term management of short-lived, low-level radioactive waste, a solution that also had to be progressive, flexible, and reversible. At the same time, the government entrusted new missions to ONDRAF/NIRAS – in particular that of developing methods to enable the integration of final repository project proposals at a local level – and restricted the number of potential sites for final disposal to the four existing nuclear sites in Belgium and to possibly interested local districts.

The government's decision made on 16 January 1998 forced ONDRAF/NIRAS to change its strategy. The agency set up a new work programme and worked out an innovative methodology. This new methodology aims to generate, at the level of the interested towns and villages, draft projects for a final repository supported by a wide public consensus.

1. Belgium in short

Belgium is a small country with a surface area of 32 545 km² and 10 372 469 inhabitants; it has a population density of 319 inhabitants per square kilometre, which makes her a very densely populated country. Belgium has evolved over the last decades from a unitarian State towards a federal State. As laid down in the constitution, Belgium is today a federal State composed of communities and regions. The power of decision no longer lies solely with the federal government and the federal parliament. Governance of the country is now in the hands of various partners, who exercise their powers autonomously in their fields.

The redistribution of powers and responsibilities revolved around two main axes. The first axis concerns language and, in a broader scope, everything relating to culture. That is how the communities came into existence. The concept of "Community" refers to the people who make up such a Community and to the bond that unites these people, namely their language and culture.

Belgium has three national languages: Dutch, French and German, and hence three communities: the Flemish Community, the French Community and the German-speaking Community. These Communities therefore correspond to the population groups.

The second axis of the State reform was historically inspired by economic interests. The Regions, which strove for more economic autonomy, reflect these interests. The latter resulted in the establishment of three Regions: the Flemish Region, the Brussels Capital Region and the Walloon Region. The Belgian regions are to a certain extent comparable to the American States and the German Länder.

The country is also divided into 10 provinces and 589 communes, each with its own powers.

The federal State, however, retains major powers, including foreign affairs, national defence, justice, finance, social security, parts of public health and home affairs etc. In addition, everything connected with nuclear energy, including the management of radioactive waste, falls within the competence of the federal State.

2. Nuclear Belgium in a nutshell

Belgium has a long nuclear history, starting with the creation of the Belgian nuclear research centre (SCK•CEN) in 1952 in Mol. Between 1956 and 1964, five research reactors were put into operation. At that moment, SCK•CEN was the largest producer of radioactive waste, together with the Union minière refinery in Olen, the world's largest producer of radium for years, created in 1922. To be able to take care of the waste produced, several facilities were built by SCK•CEN for processing and conditioning, the so-called Waste Department. In the early 1960s, Eurochemic, an experimental spent nuclear fuel reprocessing plant, was put into operation. In 1972 the radioisotope department of SCK•CEN became the Institute of Radioelements (IRE). This Institute, which supplies radioactive sources to industry and the medical world, is still located in Fleurus. Also in the seventies, the first commercial nuclear power plants were commissioned. At present, seven PWR units are being operated, grouped in two NPP located in Doel and Tihange. Together they have a capacity of approximately 5.7 GWe, covering around 55% of Belgium's electricity production. On 16 January 2003 the Belgian federal parliament voted in favour of a bill that aims at gradually phasing out the use of nuclear energy in the country from 2015 onwards, when the first of the four existing nuclear units of the Doel nuclear power plant commissioned in 1974 (the first ever in Belgium) will be closed down after its 40 years' lifetime.

Besides the power plants, Belgium has two fuel manufacturing plants: FBFC International, a uranium fuel manufacturing plant created in 1960 and Belgonucléaire, a MOX-fuel fabrication plant created in 1957. Both plants are located in Dessel. In 1974, Belgium decided to close down the Eurochemic pilot reprocessing plant. Since then, some of the spent fuel from the Belgian nuclear power plants is reprocessed in France by COGEMA under a contract concluded by Synatom. New reprocessing contracts have, however, been suspended by the government and the final destination of spent fuel still has to be decided upon. In the meantime, spent fuel is being stored at the nuclear power plants.

3. Radioactive waste in Belgium

Since 1980, the radioactive waste is managed by ONDRAF/NIRAS, the Belgian Agency for radioactive waste and enriched fissile materials. By creating ONDRAF/NIRAS, the Belgian authorities wanted to entrust the management of radioactive waste to a "single body under public control to ensure that the public interest prevails in all the decisions taken in this field". The missions and functioning of ONDRAF/NIRAS are laid down in laws and royal decrees. Practically, ONDRAF/NIRAS is entrusted with developing a coherent and safe management policy for all radioactive waste that exists on Belgian territory. This management includes the quantitative and qualitative inventory of radioactive waste, its removal and transport, its processing and conditioning, and its interim storage and long-term management. In addition to this main mission, ONDRAF/NIRAS is also responsible for the decommissioning of closed down nuclear facilities, the management of historical waste, and the management of enriched fissile materials. ONDRAF/NIRAS is also legally required to ensure the long-term financing of its activities. The costs of all of its services, including the costs of short-term and long-term management, are paid for at cost price by the waste producers.

Most of the radioactive waste comes from routine industrial, scientific or medical activities. An increasing share, however, will be generated by the decommissioning of closed down nuclear facilities. Routine radioactive waste comes for about 80% from the electronuclear sector, primarily from the operation of the seven nuclear reactors of Doel and Tihange. Radioactive waste is also produced by fuel manufacturing (by Belgonucléaire and FBFC International), Belgian spent fuel reprocessing (by the French company COGEMA, on behalf of Synatom) and nuclear research (by SCK•CEN, the universities and the Institute for Reference Materials and Measurements). The remainder arises from the production of radioisotopes by the National Institute for Radioisotopes (IRE), and from the use of such isotopes in the health sector, industry and private laboratories. At the end of 2002, Belgium's stock of conditioned waste was as follows: 12 439 m^3 of category A waste (low- and intermediate-level short-lived waste), 3 908 m^3 of category B waste (low- and intermediate-level long-lived waste), 236 m^3 of category C waste (high-level long-lived waste). All this waste is safely stored at Belgoprocess, the industrial subsidiary of ONDRAF/NIRAS, located in Mol-Dessel. ONDRAF/NIRAS estimates the total volume of waste that will be produced until 2060, i.e. the end of the dismantling activities, at 72 000 m^3 of category A waste, 8 900 m^3 of category B waste and between 2 100 m^3 (if all current and future spent fuel is reprocessed) and 5 000 m^3 (should the option of reprocessing be completely abandoned) of category C waste. This estimate is based on the complete dismantling of each of the seven Belgian nuclear reactors after their operating period of 40 years. It also implies that the non-nuclear industry and the medical world will continue to use radioelements at the present rate.

Day-to-day management of radioactive waste is now fully under control, while its long-term management is still in the research and development stage. The solution currently under examination by ONDRAF/NIRAS for the long-term management of category B and C waste is its disposal in a suitable geological formation. This is the subject of a separate research and development programme. In this paper we will focus on the long-term management of category A waste, in which the choice of the type of repository – on the surface or in the underground – remains open.

4. Twenty years of low-level waste management

ONDRAF/NIRAS started working on the long-term management of short-lived low-level waste shortly after its creation. Practised on a regular basis in Belgium until the early eighties, sea disposal of conditioned low-level waste had indeed become very uncertain in 1984, when Belgium decided to adhere to the international moratorium of 1983 between the signatory countries of the *London Convention on Sea Pollution*.

This decision prompted ONDRAF/NIRAS to launch studies to look for another solution, which would be safe and technically acceptable, for the final disposal of this type of waste on Belgian territory. These studies, which are still going on, have gone through various phases. The sometimes harsh reactions in public opinion and the recommendations of independent experts, however, progressively led ONDRAF/NIRAS to question its work methodology.

One of the agency's first actions after sea disposal had been suspended, was the development and implementation of a methodology for waste processing and conditioning, to ensure the stabilisation of short-lived low-level waste. At the same time, the agency began with the construction of interim storage buildings. All these activities are concentrated on the site of Belgoprocess, the industrial subsidiary of ONDRAF/NIRAS, located in Mol-Dessel. Once the short-term management of the waste had been ensured, ONDRAF/NIRAS was able to concentrate on the development of solutions for the long-term management of this waste.

ONDRAF/NIRAS' first study on the final disposal of short-lived low-level waste considered three options: disposal in old charcoal mines or quarries, shallow-land burial, and deep geologic disposal. The corresponding final report, the NIROND 90-01 report, published in 1990, concluded that shallow-land burial was the most promising of the three proposed options in terms of technical feasibility, safety and cost. It rejected the mines or quarries option, which was in fact no more than a type of deep disposal, because of a risk of aquifer contamination. It furthermore mentioned that the studies on Boom Clay carried out in Mol, had demonstrated the need for additional research on the chemical compatibility of the waste with the deep underground. ONDRAF/NIRAS therefore decided, after approval by its regulatory authority, to focus its efforts on surface disposal.

The studies carried out between 1990 and 1993 aimed to assess the technical feasibility of building a surface repository on various types of geological formations. The results were recorded in the NIROND 94-04 report, published in 1994. This report concluded the feasibility of disposing of at least 60% of the short-lived low-level waste produced in Belgium at surface level, while strictly following the recommendations of the various relevant international organisations. It also identified 98 zones on Belgian territory as potentially suitable, according to the bibliographical survey carried out, for hosting a surface repository for short-lived low-level waste. The multidisciplinary scientific advisory committee set up by ONDRAF/NIRAS' Board of Directors to examine the report issued a globally positive evaluation, but recommended extending the research to fields related to economics and human sciences.

Far from going unnoticed, the 1994 report was rejected unanimously by all the local councils on the list. To its surprise, ONDRAF/NIRAS had caused a general outcry. And yet, had it not been given the responsibility to develop and propose, through an objective and rational approach, a safe solution to the radioactive waste problem? Neither the political authorities nor ONDRAF/NIRAS had realised in due time what the implications were in the field of public consensus when it turned out to be necessary to look for a favourable geology outside the existing nuclear sites. As a result, the publication of the NIROND 94-04 report in April 1994 lead to a public deadlock.

5. When technique is confronted with local sensitivities

The working method applied in the past by ONDRAF/NIRAS aimed to select the future disposal site for short-lived low-level waste on the basis of a scientific approach that had been carefully worked out by its experts. At that time, ONDRAF/NIRAS thought – maybe rather naively – that the actual setting up of a repository would cause no problems once it had been proven that the chosen site was one of the best possible choices from a technical point of view. ONDRAF/NIRAS looked for a solution for the radioactive waste problem in an objective and rational manner. Gradually, the agency realised that important parameters were missing in its mathematical model. Setting up a disposal infrastructure would inevitably have economic, social and ecological consequences. Also, the public's reactions confirmed the validity of the committee's recommendations regarding the necessity to take into account the socio-economic aspects of setting up a final repository on the national territory. ONDRAF/NIRAS therefore progressively started to develop an adequate methodology to select, according to objective criteria, the best surface disposal sites among the 98 formerly identified zones. In addition to the expected geological, hydrogeological and radiological aspects, this methodology included environmental and socio-economic factors. Unfortunately, these last parameters were impossible to model satisfactorily.

In 1995, in an attempt to break the stalemate, the government commissioned a study by ONDRAF/NIRAS on the possible alternatives to surface disposal. The final report, the NIROND 97-04 report, published in 1997, compared surface disposal with deep disposal and prolonged interim storage. It recommended that the government should base its decision on ethical considerations. Indeed, ONDRAF/NIRAS supports the view that the current generations are responsible for ensuring that future generations will not have to actively take care of the management of the radioactive waste they will have inherited.

On the basis of this report the Belgian federal government opted, on 16 January 1998 for a final or potentially final solution for the long-term management of short-lived low-level waste. The government also wanted this solution to be implemented in a progressive, flexible and reversible manner. With this decision, the prolonged interim storage option was abandoned in favour of either surface disposal or deep geologic disposal.

At the same time, the government entrusted new missions to ONDRAF/NIRAS, to allow the government to make the necessary technical and economic choice between surface disposal and deep geologic disposal. ONDRAF/NIRAS was assigned to develop methods, including management and dialogue structures, necessary to integrate a repository project at local level. Furthermore, ONDRAF/NIRAS had to limit its investigations to the four existing nuclear zones in Belgium, namely Doel, Fleurus, Mol-Dessel, and Tihange, and to the local towns or villages interested in preliminary field studies.

6. The local partnership concept

The idea behind the partnership concept stems from the presumption that collective decision making in a democratic environment is always a process of negotiation. Different interests, opinions and values are thereby weighted one against the other. This weighting of interests is something that should be done by the stakeholders and not for them. The mere technical aspects of building and safeguarding a low-level waste repository, are but one element in the negotiations that inevitably precede decision making. Other elements such as the socio-economic context of the community concerned, the values, interests and, why not, emotions of different stakeholders, all play a part in the decision-making process.

Thus, early 1998, forced by both experience and a governmental decision, ONDRAF/NIRAS changed its strategy and opted for a voluntary siting process. Social acceptance became a prerequisite for technical feasibility. One was no longer looking for the optimal site, but instead, ONDRAF/NIRAS started looking for a suitable site; for a community willing, as well as able, to host a repository for low-level and short-lived radioactive waste. But how do you find such a willing community?

Simply asking a municipality if it would be so kind to host a low-level waste repository did not seem to be the most effective approach.

As it was understood that the best way to take the interests of all parties into account is to involve them in the decision-making process of the project, the idea of local partnerships has been developed.

Therefore, researchers from the Department of Social and Political Sciences (PSW) of the university of Antwerp (UIA) and the research group SEED (Socio-Economic Environment Development) of the university of Luxemburg (FUL), developed a methodology that would allow a potential host community to engage in negotiations with ONDRAF/NIRAS and to investigate thoroughly all aspects of hosting a repository, without committing itself to more than considering the possibility. In this way, a municipal right to veto was introduced into the process, in spite of the fact that such a right does not formally exist in Belgian legislation.

The local partnership project is an attempt to address the low-level waste disposal siting problem through both technical research and concept development, and interaction with the (local) stakeholders.

The mere technical aspects of building and safeguarding a low-level waste repository, are but one element in the negotiations that inevitably precede decision making. Other elements such as the socio-economic context of the community concerned, the values, interests and, why not, emotions of different stakeholders, all play a part in the decision-making process.

This means also that the concept of the repository project needs to be kept open for negotiation with the potential host community and that it should consist of more than just a repository project. It should strive for a win-win situation where the local community does not simply receive a "nuclear dumpster", but a broader project that is designed to fit its environment and brings added value to the community.

Once the basic concept of the local partnerships had been developed by the researchers, it was thoroughly discussed with different local stakeholders, and, on their recommendation, adapted to meet local needs. The way the local partnership should look like, how the local community would have to be represented in the partnership, what the agenda of the negotiations should be, etc. is itself the result of discussions with the affected community.

In this way the affected public were given a voice in an early stage, already during the planning and set up phase of the partnership.

7. Involvement of stakeholders at an early stage in decision making

The partnerships were and are intended to bring the decision-making process closer to the public, and to lower the threshold for active participation. As many stakeholders, with as many different backgrounds and opinions as possible, should therefore be invited to actively participate in the partnership.

Local partners should represent different political, economic, social, cultural and environmental movements or organisations within the community.

The idea was to create a representative body of the different stakes involved in this decision-making process. On the one hand this is necessary to obtain a complete picture of the viewpoints, interests, needs and values that are at stake in this particular community, regarding this particular issue. The general interest of the community will be the outcome of a process of dialogue and discussion among these different stakes.

On the other hand, this setup should provide the key to creating an inclusive, transparent, flexible and stepwise decision-making process that may be considered to be sustainable and fair by all parties. Even if, in the end, not everybody is completely happy with the outcome of the process, the fact that is was seen as fair, representative and transparent, may still make the outcome an acceptable one for the entire community.

Discussing in depth the pros and cons of a low-level nuclear waste repository in the surroundings, however, is not something that may practically be done through public hearings with several hundred people attending. Therefore, it was decided to work out an adapted, clear organisational structure that fits the goal.

8. A local partnership: A non profit organisation with a clear mission

So, a local partnership became a non profit organisation of volunteers; local engaged citizens, representatives of political, economic, social, cultural, environmental movements and organisations or groupings in the local community life, willing to discuss whether and under which circumstances they may possibly accept a repository; working out an integrated pre-proposal of a repository, integrated in an broader added value project designed to fit the specific environment supported by the local population.

9. Local partners run the business

It was considered important that the partnership should have its seat at the heart of the community concerned. A partnership is not a field office from ONDRAF/NIRAS, but an independent local organisation in which ONDRAF/NIRAS participates as the only non-local partner amongst a multitude of local stakeholders. This location "on site" gives the partnership a "face". A clearly visible presence in the community creates awareness amongst the not participating citizens and the premises of the partnership may serve as an open platform where citizens may come with their questions, remarks or concerns. On a practical level, it also facilitates the meeting of local participants in the discussions, for the simple reason that they do not have to travel too far.

10. Arena and facilitator for open dialogue

A local partnership is both the arena and the facilitator for an open dialogue between all stakeholders on the possible siting of a low-level radioactive waste repository in a community. This implies that the partnership is an active organisation, imbedded and clearly visible in the local community, properly equipped to serve as a platform for the interaction between ONDRAF/NIRAS and the local stakeholders. The necessary infrastructure for the project co-ordinators and the working groups and other bodies to assemble, should be available at the seat of the organisation.

Through dialogue, all interested parties are invited to express their interests, concerns, fears and values, to listen to the views of other parties and to come to terms on what this particular group of citizens, in this particular community, at this particular point in time defines as a common goal. In this way, ONDRAF/NIRAS, in its role of project developer, enters into direct dialogue with the local community, interested in hosting the project. Experts from ONDRAF/NIRAS are given a forum to explain what, in their view, a low-level radioactive-waste repository should look like and why they consider that to be a safe solution given the characteristics of the site in question. The members of the working groups may then question the ONDRAF/NIRAS experts directly and/or invite other experts, whose opinion they consider relevant. By entering into dialogue with the local community, the concept-designers have an opportunity to better explain their project to the local stakeholders. Questions and reactions from the public, however, may require them to be more creative and to rethink certain aspects of their initial concept or project.

11. A representative democracy at micro-level

A local partnership should in fact be considered as a representative democracy on a micro level.

Overseeing the whole "operation", a *general assembly*, uniting representatives of all participating organisations, decides on the main course and sets out the beacons for the actual discussions. The general assembly appoints an *executive committee*, in charge of the day to day management of the organisation.

The committee is, amongst many other things, responsible for the co-ordination of working group activities, decision making on budget spending and the supervision of the project co-ordinators.

In several *working groups* all different aspects of the implantation of a low level waste repository in the community are being discussed. Here all relevant existing research is taken into consideration, the need for additional studies is evaluated and independent experts are invited to participate in the debate. The working groups report regularly to the executive committee. The working groups are composed of both representatives of the organisations that founded the partnership, as well as individual citizens who expressed an interest to participate actively in this discussion forum. Since all these people participate on a voluntary basis, at least two full-time *project co-ordinators* need to be employed by the partnership. These project coordinators take care of administrative and communication tasks and support the working groups both logistically and scientifically.

The real work of the local partnerships is concentrated in four working groups. Three of them concentrate on the technical aspects, such as: siting and design, environment and health, safety assessment. One working group concentrates on social aspects: local development. The working group Local Development analyses socio-economic issues and projects, formulates prioritisation criteria and founding modalities. The more technical working groups evolve from general information through specific information on siting and the disposal concept towards a final disposal concept.

12. The core business of a local partnership

Interaction between all the partners in the local partnership is its "core business".

Together, these parties decide what the actual problem or issue is, and how they want to deal with it. Together they try to develop a repository project that could be acceptable for all parties involved, and that is imbedded in a broader added value project. Together they finally decide on the desirability and acceptability of the whole integrated project, before casting the formal decision making back to the political arena (firstly the municipal government, that decides whether to actually put forward the municipality as a potential host community and secondly the federal government that politically has the final say on where the repository will be located).

13. Importance of internal and external communication

By opening the process to selected stakeholders with whom the community may identify itself, public participation may be enhanced without making the process either too superficial or too complex. The participants in the partnership should therefore be recognised as representatives of their community by their neighbours, voters, co-members of their local organisation, relatives, friends and acquaintances. Since the participants only represent a fraction of the total number of stakeholders, openness to the community at large is crucial. In order to make sure that the requirements for openness and transparency are met, the partnership has to exercise an active and open, preferably highly interactive, communication policy. Throughout the process, the members of the community that are not directly involved in the partnership, have to be kept informed. Consequently, it is the task of all participants to "spread the word", to communicate what the partnership is all about, what items are being discussed and by whom. This is best realised through both formal (communication of the partnership as an organisation, directed at certain target groups or at the community as a whole) and informal (direct communication from the participants to their peers) communication channels.

14. Independence in decision making

Until the partnership has made its final proposal to the municipal council on whether, and under which conditions, a repository facility in the community would be acceptable, the partnership is the only body where decisions with regard to the potential repository are taken. There will thus be no question of parallel negations on other (for instance purely political, or more regional) levels. Since ONDRAF/NIRAS has only one member in both the general assembly and the executive committee (albeit with a veto on technical feasibility), it is the local community itself that decides on both technical and social feasibility.

The final outcome of the discussions in the partnership should therefore be either a "thanks, but no thanks" (i.e., based on all the information gathered, the community decides against the repository project for technical, safety or other reasons) or an integrated project, carried by both local stakeholders and ONDRAF/NIRAS.

In the end, it is the council which decide yes or no to support the proposal. They have a municipal veto right to reject or accept the proposal. They may also add some specific conditions. And they will decide whether or not to put the municipality forward as a potential host for a low-level nuclear waste repository facility.

Since the final word in this matter lays with the municipal council, it is also essential that council members are fully aware of the implications of their decision. To avoid the risk of conflicting interests between local politicians and the other members of the community, an active involvement of the representatives of the political arena is hence encouraged.

The federal government at last has to make a choice between surface disposal or deep disposal, and has to decide where the repository should be implemented.

15. Independence in budget spending

In order to allow the partnership to work independently, each partnership receives an annual budget from ONDRAF/NIRAS. This budget is managed by the executive committee. It serves to cover general expenses such as the salaries of the project co-ordinators and all "operational costs" (stationary, telephone bills, mailing, electricity, …), as well as logistical support for the working groups. This "logistic support" should be interpreted in the broadest possible way. Apart from serving the volunteers coffee and biscuits during their working group meetings, it also allows them to invite the experts of their choice, to order the studies they think necessary and to pay for site visits or other relevant trips or conferences.

The fact that the partnership budget may be used to order research or studies does not mean that all research activity is paid for by the partnership. ONDRAF/NIRAS pays for all necessary research with regard to the technical and safety aspects of the repository facility. The partnership, however, may decide that they are in need of some additional research in certain areas or that they do not entirely trust the ONDRAF/NIRAS results and want a second opinion. All non-repository related research is paid for by the partnership.

16. Mutual project development

Maybe the most important and probably the most innovative aspect of the partnership approach, is that the partnership does not only decide (or at least advises to the community council) on the repository concept and where it should (or should not) be implanted. Through the partnership, the local community may decide on what they consider to be the necessary conditions (technically, environmentally, aesthetically, etc.) for such a repository.

Furthermore, within the partnership, an accompanying local project that seeks to bring added value to the community will be developed.

Both the repository project and the accompanying local project are developed and discussed in depth within the partnership. All pieces of the puzzle (individual remarks, concerns and ideas from brilliantly innovative to absurd and not to the point; expert reports and interventions; interests of stakeholders; etc.) are brought together. When finally, all, or at least a majority of the parties involved come to an agreement on what their puzzle, their integrated project, should look like, this is presented to the municipal council.

17. Current situation and developments

We are engaged for four years now in the partnership methodology. At present, three local partnerships have been formed; the first with the municipality of Dessel (creation of STOLA in 1999), the next with the municipality of Mol (creation of MONA in 2000) and the third with the municipalities of Farciennes and Fleurus (creation of PaLoFF in 2003).

It is expected that STOLA-Dessel will finalise its report by March 2004. For MONA, this will be by June 2004. PaLoFF is expected to finalise its work in 2005.

Once they have finished their mission, the non profit organisation that the local partnerships are, will come to the end of their existence.

For ONDRAF/NIRAS it is clear that the partnerships, as the owners of their work, should be actively involved in the follow-up of the files introduced by them. The municipalities and the partnerships are invited to make a proposal on how they would like to see this follow-up organised.

It is clear that the knowledge, built up by all the involved stakeholders, should be preserved.

Now the focus should move to the federal level. The federal government is aware of this item. First contacts are made with the federal minister of energy to discuss the way to make a decision, taking fully into account the results of the work that has been produced locally.

The regulator is involved at a rather low level in the current discussions within the partnerships. At the technical level, regularly contacts exist between ONDRAF/NIRAS and the regulators at federal and at regional level. The contacts with the regulator should be managed in such a way that they keep their full independence in view of the legal licensing process. We consider that it is first of all the responsibility both of the partnerships and ONDRAF/NIRAS to make a proposal that fully respects the basic safety principles related to disposal projects.

Interaction is not only required for the follow-up of the file of the partnerships, but also on other subjects like the other categories of radwaste and the ongoing research and development. It is in dialogue and close consultation with the stakeholders that we should engage in a structure that provides answers to their needs and demands, and at the same time fulfil our expectations. A continued dialogue creates the possibility to understand what the local needs are, and how to respond to them.

18. Some lessons drawn so far

The following lessons have been drawn so far:

- close interaction with local stakeholders is a absolute necessity;
- the continuity of the approach is vital;
- a local partnership is about mutual learning, mutual understanding;
- respect, transparency, openness, ability to listen are key elements;
- it is a demanding and time consuming process;
- volunteers must feel that they can make a difference;
- both internal and external communication are vital;
- ordinary people capable of consuming technical knowledge;
- experts need to be responsive to local knowledge;
- the role of the implementer as initiator/facilitator. He is but one partner in the process;
- trust and confidence building are an essential part of the process;
- ongoing experience; not there yet;
- overall impression so far is positive; very few people opted out, all interested parties are taken on board, effective work programme, highly motivated group members, and

- open issues remaining are: next steps of decision-making process, future role during the follow-up of the files of the partnerships.

Conclusion

One of the major lesson we learned so far is that only through close interaction we may fully understand what the local stakeholder needs are. And inversely, in this way they may understand our needs.

Mutual learning, mutual understanding; that is what it is all about.

Respect, transparency, openness, ability to listen to each other, are key elements.

The partnership approach is an iterative process, but it was also a huge investment for all parties involved. For the local stakeholders, but also for our own organisation.

So, the continuity of what was started, is vital. ONDRAF/NIRAS is committed to continue this approach.

To be able to take into account new visions, new stakeholders and new approaches, the need for an open and flexible participative process cannot be highlighted enough.

Participative and co-decision making means a permanent dialogue on how to realise a project; not only today or tomorrow, but equally over a period of decades. Because it is a necessity to integrate a repository project in the every day life and the development over a very long time period. Indeed, the real question is not one of acceptance but of integrating a repository project in the social and cultural context of a specific place.

We are in the middle of a dynamic process. The Belgian approach is certainly not the way to do it, but it is a tailor-made concept, which responds to the needs of the Belgian programme, and as we see it, it is a good ground for legitimacy.

Acknowledgements

ONDRAF/NIRAS is aware of the fact that if we arrived at this point today, we have to thank and give the credit for it to the researchers of the Department of Social and Political Sciences (PSW) of the University of Antwerp and the research group SEED (Socio-economic Environment Development) of the university of Luxemburg, and to the municipalities of Dessel, Mol, Fleurus and Farciennes and all the local volunteers engaged in STOLA, MONA and PaLoFF, who accepted to commit themselves in this process.

STAKEHOLDER INVOLVEMENT IN THE UNITED KINGDOM

Chris Murray
NIREX, United Kingdom

Over the last three decades in the U.K. there have been repeated failures to implement a long-term solution for the disposal of very-long-lived radioactive waste. The most recent attempt ended with the refusal in 1997 by the then Secretary of State for the Environment, John Gummer, to grant permission for NIREX to construct a rock laboratory at a site near Sellafield in Cumbria.

Given this history, the question we are faced with is: is it possible to put in place a long-term solution in the U.K.? We at NIREX believe that it is – as long as the key lessons from previous failures are learned and then applied. The key lesson is the need to develop legitimacy: legitimacy in the way a solution is decided upon and legitimacy in the way it is implemented.

The first step in achieving this legitimacy must be to state the problem in the correct terms. For us this means the basic proposition that: *"The waste exists – it is an ethical problem"*.

Such an approach recognises the substantial legacy of U.K. radioactive waste that has built up since the 1940s and the inescapable fact that this waste would need to be dealt with even if all current nuclear activity were to cease overnight. We believe tackling the legacy, and tackling it now, is an ethical imperative, and that an ethical approach entails bringing to the forefront of the discussion the values that should underpin any decision taken.

These values include our attitude to future generations, our attitude to what we might owe a community that takes the waste, the price we put on our environment (both present and future) and how we regard safety and risk.

NIREX has developed these views following extensive dialogue with a wide range of stakeholders, particularly with the local communities and local government officials and elected representatives around the Sellafield site and in Scotland. Discussions with our own staff, Friends of the Earth, Greenpeace and other organisations specifically concerned with the environment have also helped develop our approach and, for example, we think that our work with Rachel Western from Friends of the Earth is indicative of a new positive way forward. Rachel played a key role in defeating our proposals for the rock laboratory in the lead up to the 1997 decision but now works alongside us three days a week, where she and colleagues in NIREX explore our relative positions and try to work out ways to resolve our very real differences.

Such a concentrated effort is required in the U.K. as there are very significant historical obstacles to achieving this requisite legitimacy. These barriers are embedded in our culture. For example, there is a history of strong opposition to all things nuclear, stemming from the genesis of nuclear power being the atom bomb and all the connotations that implies. This factor is compounded by the consequences of disasters such as at Chernobyl, where the radioactivity released spread over international borders in Europe in a matter of hours. At another level there is the issue of endemic secrecy in U.K. culture, particularly within the nuclear industry, and social aspects such as the changing attitude we all have towards "experts". This follows on from issues such as Thalidomide, BSE and many other situations where experts' self belief has been shown to be unfounded.

However, even given this backdrop, we believe that circumstances and some major developments are beginning to create a climate where progress may be made. Post Stakeholder Involvement in the United Kingdom December 2003 (Ref. 440156) Page 2 of 3 September 11, the option of extended surface storage is being queried – not least by those communities currently living with the radioactive waste. Changing our preferred disposal option (the NIREX Phased Disposal Concept) to incorporate an extended period during which the waste may be retrieved has shown local communities that their concerns will be addressed. In addition, NIREX believes that it may now model a geological site successfully and accurately and that the Sellafield site could satisfactorily host a repository. But more work would have to be done on the site to prove the case.

As stated though we believe that progress may only be made through adopting an ethical approach and through achieving legitimacy. To do this, it is vital to understand exactly what we mean by legitimacy. We believe that legitimacy does not call for consensus or even trust but instead requires transparency and accountability. One way of looking at legitimacy is to subdivide it into the following distinct but interlocking attributes:

- *Equity:* the decision must be viewed as "fair" to all involved, that is to the community or communities affected, the U.K. as a whole, to future generations etc.
- *Competence:* the underlying science and technology must be see as correct, robust and safe.
- *Efficiency:* there must be a proper balance in the use of resources, i.e., safety as paramount but no "gold-plating".

Of those three it is obviously equity that has been lacking in the U.K.'s previous attempts to implement a long-term solution. In this context equity may be addressed by tackling the following factors:

- *Structure:* we believe that in the U.K. the organisation dealing with the long-term radioactive waste issue must be independent of the nuclear industry, and the U.K. organisation dealing with short term (up to 150 years) decommissioning.
- *Process:* all decisions regarding radioactive waste must be dealt with in an open, transparent and accountable way. This will need to include a review of waste management options and an open site selection process, including consideration of what, if anything "U.K. plc" may owe to a host community. Work commissioned from an ethicist, Dr. Kate Rawles, suggests that given a number of pre-conditions, such as no trading of safety against benefit and complete openness, such an approach may be ethically sound.
- *Behaviour:* NIREX, and other organisations need to become open and willing to listen so that stakeholders and the public may influence our work and research programmes. In our case this led to our 1998 Transparency Policy, which committed NIREX to being transparent and accountable, and an Independent Panel that polices complaints and monitors progress.

At the end of 2003 we believe that some progress towards achieving legitimacy in the U.K. has been made but certain barriers still remain with regard to behaviour, structure and process, as described below.

1. Behaviour

Listening to the public has led us to change the NIREX geologic disposal concept to allow waste to be retrieved, if so desired, for several hundred years. The repository need not be backfilled immediately. It may be kept open, at a price that would include regular preventative maintenance and ongoing operating costs. The need for human intervention Stakeholder Involvement in the United Kingdom December 2003 (Ref. 440156) Page 3 of 3 over extended periods would have to be recognised. Nevertheless, we believe that such a change to the concept responds to legitimate concerns by the public over the prospect of immediate closure.

Contacts nationally and internationally make it clear that the idea of international repositories is strongly opposed at a local level in any country where it is raised. For example, the Finnish community that voted to accept the development of a national repository in their community made it a condition of acceptance that no international waste would be accepted into the repository. A similar fear of "international dumping" has been expressed in Canada, Sweden, France and the U.K.

Proposals for international repositories cause major difficulties for national programmes and recent interest expressed by Mr. ElBaradei, the Director-General of the IAEA, for such proposals causes particular concern. We believe that a country should deal with its own waste. This position is supported by the research and communications work carried out with local communities and other stakeholders in several countries. Our analysis of the views of local communities on this issue is that the siting of an international repository will be politically unacceptable (as well as near-impossible to implement) in a democratic State and unethical if an international repository were sited in an undemocratic State. There is also the basic point that a State which has the benefit of nuclear technology must face up to the social and political issues as well as the purely technical ones.

2. Structure

Creation of the U.K. Nuclear Decommissioning Authority (NDA) from April 2005, whereby the British Government will take over the great bulk of the nuclear liabilities of BNFL/Magnox and UKAEA, and will co-ordinate efforts on cleanup and decommissioning.

Announcement in July 2003 that NIREX is to be made independent of the nuclear industry. A further announcement on the way forward on this is expected imminently.

3. Process

Legal framework in the U.K. will be greatly strengthened by the EU Strategic Environmental Assessment (SEA) directive due to be implemented by July 2004. This is somewhat offset by concerns about aspects of the EU "Nuclear Package" directives regarding the timing and automatic assumption that geologic repositories are the way ahead.

The U.K. is continuing with consultations about which concept or concepts to take forward for the long-term management of radioactive waste. The Committee on Radioactive Waste

Management (CoRWM) began work in November 2003 and is aiming to make recommendations to Government by the end of 2005.

In summary, we believe that concrete progress is being made in the U.K. towards putting in place a long-term solution for the management of radioactive waste. The challenge now though will be to sustain the momentum and to continue to work to establish and maintain the requisite legitimacy across the board. We believe that this may only be done by going beyond the traditional technical and scientific considerations and specifically addressing the ethical and social dimensions of the problem.

THE NEA FORUM ON STAKEHOLDER CONFIDENCE: ITS ACTIVITIES AND MAIN LESSONS

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1. Creation and purpose

The Forum on Stakeholder Confidence (FSC) was created under a mandate from the NEA Radioactive Waste Management Committee (RWMC) to facilitate the sharing of international experience in addressing the societal dimension of radioactive waste management. It explores means of ensuring an effective dialogue with the public, and considers ways to strengthen confidence in decision-making processes.

2. First Paris International Workshop, August 2000

The Forum was launched in August 2000, in Paris, with an international workshop. This addressed a variety of topics ranging from evolving participatory democracy, stakeholder identity, and trust in the institutional framework, to the role of open dialogue in all aspects of radioactive waste management.

Here are some of the lessons learnt from the Paris workshop:

- Our environment is changing, technology is no longer perceived as a bright future, projects are no more trusted, and possibly rejected when stakeholders have not been actively involved.
- Their is a new dynamics of dialogue: no more decide, announce defend, but engage, interact and co-operate; and the technical side is no longer of unique importance: ability to communicate, to negotiate and to adapt is necessary.
- Institutions must adapt. Their must show clarity of role and position, a learning capacity, dedicated sufficient funding, and adopt behaviour of openness, willingness to be stretched, freedom from arrogance, recognition of limits, proactive practices, etc.
- The stakeholder is anybody with an interest or role to play. But stakeholders change with time, and their are interaction amongst groups and their respective role. Trust implies that an individual is willing to give up a certain measure of control to another person. Trust must be given in order to make it possible to receive it. Waste retrievability and

programme reversibility alleviate mistrust of technology, and help in decision making. Oversight contributes to keep trust.

3. Other international workshops

Since then, each year the FSC has held a highly interactive workshop in a national context. FSC delegates and a broad range of stakeholders from the host country come together to review cases illustrating societal involvement in decision making about RWM.

3.1 Finnish Workshop, November 2001

The Finnish Workshop, held in November 2001, reviewed the sequence of decisions that ultimately led to the Parliament's approval, in May 2001, of siting a geologic repository in the municipality of Eurajoki. The workshop was preceded by an encounter with the municipality representatives; community values, policies and economic standing were discussed. Feedback was provided to the workshop by experts in public management, strategic decision, community development and social psychology.

Workshop participants found that two structural aspects of the Finnish process were key factors of success. These were:

- the parliamentary Decision-in-Principle as part of a transparent, stepwise procedure, and
- the Environmental Impact Assessment as a framework and guide for public involvement and participation.

The role of the regulatory body STUK in building confidence by responding to stakeholder health concerns was also noticed. For the local municipality, the right of veto was a significant confidence factor. The proceedings are available from the OECD Bookshop, and an executive summary is posted on the NEA website.

3.2 Canadian Workshop, October 2002

The Canadian Workshop, held in October 2002, reviewed two dimensions of the national RWM programme. In March 2001, an agreement was reached between the Government and three communities in southern Ontario (visited by the FSC) to clean up and locally manage radioactive waste from past uranium processing. In June 2002 the *Nuclear Fuel Waste Act* became law, enabling Canada to move effectively towards a solution for the long-term management of "spent fuel waste". At the workshop, three key areas of inquiry were examined: what are the social concerns at play in radioactive waste management; how may these concerns be addressed; and development opportunities for local communities. Experts in radiation protection, community governance, ethics, and environmental deliberation participated.

The workshop enabled an analysis and appraisal of the Port Hope solution and the longer range spent fuel disposal programme and allowed a wide range of Canadian stakeholders to meet and exchange, in some cases for the first time. Experts in radiation protection, community governance, ethics, and environmental deliberation provided feedback. The discussions brought insight into Canada's situation and should assist Canada in undertaking the next steps. The proceedings were recently published; an executive summary is posted on the NEA website.

3.3 Belgian Workshop, November 2003

The Belgian Workshop was held in November 2003. It centred on the innovative "local partnerships" established between national RWM agency ONDRAF/NIRAS and four local communities who are developing integrated concepts for safe long-term management of LLW. FSC delegates visited each partnership. The workshop examined how to deal with different interests, values and knowledge in managing risk. Experts in regional development and in analytic-deliberative processes gave feedback. An artist took part in the final session;

Among the outstanding observations at the workshop were:

- The local partnership model was seen to bring many positive benefits: output of a repository concept that integrates both technical and societal needs; competence building in the community, and reinforcement of organisational adaptability for the national agency.
- The fact that as community members work through designing a management concept for LLW, they come to regard it as posing no significant risk if properly handled (this was seen at the Canadian workshop as well).
- The partnerships are mandated only to produce a concept, which is decided upon at the municipal and then federal level. At issue is how continuity will be achieved over the life of a repository project, to involve new decision phases and new sets of actors (from neighbouring communities, or in future generations). There is indeed a strong interest by the local partners not to lose the competence built so far and to be part of the future developments, if siting is made in their community.
- The need for regulators to step forward and become visible in the process (as they have in e.g., the Scandinavian countries).

4. Main lessons learnt so far

The work of the FSC provides useful lessons on the involvement of stakeholders in decision making on radioactive waste management.

The FSC has identified factors that contribute greatly to stakeholders' confidence in the waste management process. Needed are:

- *An open, transparent, fair and participatory decision-making process*. This should be decided on a national level, and national actors must demonstrate commitment to the process.
- *Clear roles and responsibilities* for different actors including local authorities.
- *Main actors' behaviour reflecting values* like openness, consistency, desire for dialogue, as well as demonstrating technical competence.

These needed factors form the framework for stakeholder dialogue and discussion: the three key words are; "process", "structure", "behaviour", which we learned from NIREX, U.K.

While identification of *stakeholder involvement* methods and practices is ongoing in the FSC, some major other requirements are seen today:

- sufficient time and resources must be devoted to outreach, consultation, and deliberation;
- a range of tools is needed for involving different publics – not all points of view will be expressed in written format;
- stakeholders should participate from the very early stages of a siting process – this may take place, for instance, in a multi-stakeholder group (societal and technical) mandated to produce a safe, integrated concept (see Port Hope and Belgian Partnerships);
- public interest in participation may be maintained only if stakeholders believe that they may have an influence on key decisions; and
- information on management options and alternatives is needed to create a balanced deliberation.

These factors and requirements have been explored in the FSC topical sessions, case studies and workshops. We have mentioned only bold headlines; the findings are extensively documented in the publications-in-progress.

As in any international endeavour, the question has been posed in the FSC of *how universal are the lessons learnt?* To what extent is experience tightly bound to national culture? To what extent may experience be transferred to other contexts? These questions were particularly felt and explored in the Finnish workshop. Several stakeholders emphasised that support found for the decisions and their perceived legitimacy may to a large extent be attributed to some unique features of Finnish political culture. Other participants, however, primarily the four thematic rapporteurs, expressed the view that although the Finnish decision-making culture may have played an important role, a number of siting elements of broader cross-cultural significance emerged from the discussions. This discussion is documented in the workshop proceedings and executive summary, both available for consultation. Subsequent workshops have revealed both commonality (see e.g., comments on the Belgian workshop above) and cultural specificity.

5. Conclusions and perspectives

Exchanges between institutions involved with nuclear energy and civil society are no longer confined to rigid mechanisms provided by the law. A more complex interaction is now taking place amongst players at national, regional and especially at local levels, and a broader, more realistic view of decision making, encompassing a range of actors in civil society, is emerging.

In its 36th meeting, the NEA Radioactive Waste Management Committee acknowledged the positive outputs of the Forum on Stakeholder Confidence and renewed its mandate. Alongside the goal of distilling in concise, published form the lessons learnt about stakeholder involvement, the expectation had been to provide a forum for direct exchange in an atmosphere of mutual respect and learning. These expectations are being met. The FSC is one of the rare fora where technicians, civil servants and social scientists may interact; it provides unmatched opportunities to analyse field experience in close co-operation with the local and national stakeholders. The FSC is proving to be an effective tool to stimulate a new approach to RW management and decision making. It is helping promote a cultural change in the participating organisations, through the active involvement of their members.

5.1 Prospects

Future FSC work will continue to go deeply into the relations of mutual influence among stakeholders in the RWM process. For example, three upcoming topical sessions are planned for the fifth FSC meeting of June 2004:

- HLW decision-making processes at the strategic choice stage: How are different stakeholders involved, and which values are taken into account? (comparison from Canada, Great Britain, France, three countries with the same deadline, 2005, for strategic choices);
- Media relations: How may FSC constituencies build fruitful relationships with media? and
- How to manage organisational and cultural changes in the organisations to face interactive processes? What is the impact within institutions of addressing issues raised by stakeholders? We have seen since the Denver conference some cultural changes in implementing organisations (cf. ONDRAF and NIREX presentations), and in regulators. Are these changes enough in depth, and how to help industry, government agencies, international agencies to go in the same direction?

And we hope to introduce in our discussion topics as:

- How to increase the credibility of the experts? The science side, the behaviour side…
- Could opinion on RW management evolve? Which "image" opinion have of radioactive waste?
- And… study similar topic regarding risk management; RW repository as cultural landmark: from function to cultural dimension.

"The real question is not one of acceptance, but of integrating a repository project in the social and cultural context of a specific place", said Valentine Vanhove (ONDRAF).

STEPWISE DECISION MAKING FOR THE LONG-TERM MANAGEMENT OF RADIOACTIVE WASTE

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The context of long-term radioactive waste management is being shaped by changes in modern society. Values such as health, environmental protection and safety are increasingly important, as are trends towards improved forms of participatory democracy that demand new forms of risk governance in dealing with hazardous activities. These changes in turn necessitate new forms of dialogue and decision-making processes that include a large number of stakeholders. The new dynamic of dialogue and decision-making process has been characterised as a shift from a more traditional "decide, announce and defend" model, focused on technical assurance, to one of "engage, interact and co-operate", for which both technical assurance and quality of the process are of comparable importance to a constructive outcome. Consequently, the scientific and engineering aspects of waste management safety are no longer of exclusive importance. Organisational ability to communicate and to adapt to the new context has emerged as a critical contributor to public confidence.

In the new decision-making context it is clear that (a) any significant decisions regarding the long-term management of radioactive waste will be accompanied by a comprehensive public review with involvement of a diverse range of stakeholders; (b) the public, and especially the local public, are not willing to commit irreversibly to technical choices on which they have insufficient familiarity and understanding; and (c) any management options will take decades to be developed and implemented, which will involve stakeholders who have not yet been born. Thus, a "decision" no longer means opting for, in one go and for all time, a complete package solution. Instead, a decision is one step in an overall, cautious process of examining and making choices that preserve the safety and well-being of the present generation and the coming ones while not needlessly depriving the latter of their right of choice. Consideration is thus increasingly being given to the better understanding of concepts such as "stepwise decision making" and "adaptive staging" in which the public, and especially the most affected local public, are meaningfully involved in the planning process.

Features of a stepwise decision-making approach

The key feature of a stepwise decision-making concept is a plan in which development is by steps or stages that are reversible, within the limits of practicability. In addition to the institutional actors, the public is involved at each step and also in reviewing the consequences of previous decisions. This is designed to provide reassurance that decisions may be reversed if experience shows them to have adverse or unwanted effects. Discrete, easily overviewed steps facilitate the traceability of waste management decisions, allow feedback from regulators and the public, and promote the strengthening of public and political confidence. They also allow time to build trust in the competence of the regulators as well as the implementers of a waste management project. A stepwise approach to decision making has long been implemented in national waste management programmes, e.g., since the early 1980s in the U.S.A. and in the Scandinavian countries. However, despite the early implementation of the stepwise approach to decision making, the subject has not been widely developed and debated. In particular, accepted guiding principles have not yet been formulated, the roots of any such process in empirical social science research have not been fully reviewed, nor the difficulties of its implementation analysed. A satisfactory analysis might not have been possible until recently, however, before more experience was accumulated. The NEA Forum on Stakeholder Confidence has examined the above points in a report[1] soon to be released, whose key messages are summarised hereafter.

1. Decisions are already being made in a stepwise and participatory fashion and there is thrust to increase public participation in decision making

Decisions are already being taken – and progress towards radioactive waste management solutions is already being made – in a stepwise fashion. Governments and the relevant institutions are incorporating provisions that favour flexibility in decision making, such as reversibility of decisions and retrievability of waste. In addition, governments and the relevant institutions are increasingly implementing instruments of participatory democracy that will require new or enhanced forms of dialogue amongst all concerned parties. For example, partnerships are created with local communities or communities are given means to interact significantly with the decision-making process. These arrangements promote the building of trust in decision makers and implementers.

2. Stepwise decision making requires the reversibility of decisions

Reversibility denotes the possibility of reversing one or a series of steps at any stage of a programme. Such a reversal, of course, must be the result of careful evaluation with the appropriate stakeholders. This implies a need for review of earlier decisions, as well as for the necessary means (technical, financial, etc.) to reverse a step. Reversibility also denotes the fact that fallback positions are incorporated both in the long-term waste management policy and in the actual technical programme. In the early stages of a programme for waste disposal, for instance, reversal of a decision regarding site selection or the adoption of a particular design option may be considered. At later stages during construction and operation, or following emplacement of the waste, reversal may involve the modification of one or more components of the facility or even the retrieval of waste packages from parts of the facility. Thus, reversibility in the implementation phase requires the application of a retrievable waste management technology.

Not all steps or decisions may be fully reversible, e.g., once implemented, the decision to excavate a shaft cannot be reversed and the shaft "un-dug". On the other hand, these decisions may be identified in the process and used as a natural hold point for programme review and confirmation. Reversibility is thus also a way to close down options in a considered manner. If, for instance, in repository development the need to reverse course is carefully evaluated with appropriate stakeholders at each stage of development, a high level of confidence should be achieved, by the time a closure decision is to be taken, that there are no technical or social reasons for waste retrieval.

3. Competing requirements of technical safety and societal control are to be reconciled in long-term waste management

Due to the extremely long-lasting potential danger of radioactive waste, the primary feature that waste management facilities should demonstrate is long-term safety. At the same time, several stakeholders demand future controllability and retrievability of waste when these are placed in underground repositories. Only a step-by-step approach to technical implementation may assure that the competing requirements of safety and controllability may be met simultaneously, and that robust systems for waste management may be established. Such robust systems include monitoring during characterisation, operation and, in the case of final disposal, the post-operational phase. In response to the competing requirements of technical safety and societal control, many implementing organisations are focusing their efforts on developing a final repository from which the waste is retrievable. In some cases retrievability is also a legal requirement.

4. Public involvement and social learning processes are facilitated by a stepwise approach

There is significant convergence between the approach that is being taken by the practitioners of radioactive waste management and the indications received from field studies in social research. Empirical research studies in social science identify confidence in the radioactive waste management methods and trust in the decision making and implementing institutions as key factors of public acceptance. These studies also indicate that gaining familiarity with, and control over, radioactive waste management technologies and institutions are crucial for building up trust and confidence. Familiarity and control are to be gained through public involvement and social learning processes. Therefore, bottom-up approaches are proposed, where decision makers and other stakeholders are advised by scientific experts, but at the same time, decision makers and experts consider the objectives, needs and concerns defined by stakeholders. Bottom-up approaches are largely facilitated by stepwise procedures that provide sufficient time for developing, through deliberation, discourses that are both competent and fair.

5. Competing social values exist and lend complexity to decision making

Research on organisational management suggests that competing values inevitably need to be embodied in societal decision processes for these to be successful, and that the dominant values may change over time. For example, in the past, decisions related to radioactive waste management were dominated by a technical command-and-control approach, focusing primarily on finding technically optimal solutions. Later, this approach has given way to an individual-rights orientation, with a focus on participation and on reaching decisions that have community support, even if they may not result in optimal solutions initially chosen by the experts. When participation and community support are accommodated, a further shift is then seen in seeking distributive equity. The tension that exists between competing values like technical efficiency, community support and distributive equity, lends complexity to decision-making processes. Research indicates that it is impossible to satisfy all the competing values by an idealised decision-making process. In a highly developed democratic society, however, all desired criteria should be accommodated at least to a degree.

6. Overarching principles of public involvement, social learning and adaptive decision making are emerging from practical experience and social research

A consensus appears to emerge from the experience in both social research and practical radioactive waste management. Three overarching principles are the essential elements of any decision making that seeks broad societal support, namely:

- public involvement in decision-making processes should be facilitated, e.g., by promoting interactions between various stakeholders and experts;

- social learning should be facilitated, for example by promoting constructive and high-quality communication between individuals with different knowledge, beliefs, interests, values and world views; and
- decision making should be iterative and provide for adaptation to contextual changes.

7. In the radioactive waste management context, a set of specific action goals should be targeted

A set of goals specific to the radioactive waste management context may be stated as a way of translating into action the principles outlined above. In particular, in order to identify and implement solutions that are widely regarded as legitimate, it will be important:

- to have an open debate and decisions on the national policy regarding energy production and the future of nuclear energy;
- to develop a broad understanding that the status quo is unacceptable and that an important problem needs to be solved;
- to define clearly the goals of the waste management programme, including the source, type and volume of waste to be handled;
- to define a technically and politically acceptable waste management approach;
- to identify one or more technically and politically acceptable site(s) for a waste management facility;
- to negotiate tailor-made compensation/incentive packages and community oversight schemes with host and neighbouring communities; and
- to implement decisions by fully respecting agreements.

8. Implementing a stepwise process raises a number of methodological issues to be resolved

Long-term solutions to manage radioactive waste will typically take decades to be implemented. Incorporating the views of national, regional and local stakeholders and allowing for the integration of their views will likely be difficult to implement in the decision-making process. In particular, progress may no longer be expected to be linear when an iterative approach is used.

The concrete arrangements for sketching out and agreeing on decision phases, for selecting and involving stakeholders in a participatory process, and for adapting institutions to meet long-term expectations, will require careful planning and tuning in each national context. Criteria will be needed for balancing the social sustainability and the efficiency of a process made more lengthy and uncertain by added decision checkpoints. It will be important that focus and attention are kept with time and that a guarantor of the process be properly chosen. Continued reflection and exchange on an international level may make a positive contribution to these efforts.

Reference

[1] NEA (forthcoming), Stepwise Decision-making in Radioactive Waste Management, OECD, Paris.

UNCERTAINTY GOVERNANCE: AN INTEGRATED FRAMEWORK FOR MANAGING AND COMMUNICATING UNCERTAINTIES

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Introduction

Treatment of uncertainty, or in other words, reasoning with imperfect information is widely recognised as being of great importance within performance assessment (PA) of the geological disposal mainly because of the time scale of interest and spatial heterogeneity that geological environment exhibits. A wide range of formal methods have been proposed for the optimal processing of incomplete information. Many of these methods rely on the use of numerical information, the frequency based concept of probability in particular, to handle the imperfections. However, taking quantitative information as a base for models that solve the problem of handling imperfect information merely creates another problem, i.e., how to provide the quantitative information.

In many situations this second problem proves more resistant to solution, and in recent years several authors have looked at a particularly ingenious way in accordance with the rules of well-founded methods such as Bayesian probability theory, possibility theory, and the Dempster-Shafer theory of evidence. Those methods, while drawing inspiration from quantitative methods, do not require the kind of complete numerical information required by quantitative methods. Instead they provide information that, though less precise than that provided by quantitative techniques, is often, if not sufficient, the best that could be achieved. Rather than searching for the best method for handling all imperfect information, our strategy for uncertainty management, that is recognition and evaluation of uncertainties associated with PA followed by planning and implementation of measures to reduce them, is to use whichever method best fits the problem at hand. Such an eclectic position leads naturally to integration of the different formalisms.

While uncertainty management based on the combination of semi-quantitative methods forms an important part of our framework for uncertainty governance, it only solves half of the problem. Communication of its results with a variety of stakeholders is essential. The concept of “network PA communities” has been developed for this purpose, where members, including ourselves, other stakeholders and interested individuals, are linked through the internet with resources for PA, e.g., PA codes and databases provided on line on demand.

In this paper the underlying concept and framework of our uncertainty management and communication approach is discussed together with example applications.

Uncertainty management – integration of different formalisms

Types of uncertainty

There are a number of studies that have attempted to classify uncertainties associated with PA [1][2]. In the current paper, following the recent work concerning an integrated approach to uncertainty analysis [3], the following classification is adopted;

- vagueness;
- ambiguity;
- chance (variability).

Vagueness can be used to describe certain kinds of uncertainty associated with linguistic or intuitive information. Examples of vague information are that the data quality is "good" or that a rock mass has "low permeability". From a set theoretic point of view, vagueness implies that the boundary of a set is not clearly defined and, thence, it can be treated by introducing membership functions as a means to represent an assessor's belief of containment in a fuzzy set [4]. Fuzzy logic is a many-valued extension of Boolean logic based on the fuzzy set theory in which truth values are continuous function between the endpoints of the interval [0, 1]. The logic operations and associated arithmetic operations are those of conjunction, disjunction, and negation. The min and max operators are used for conjunction and disjunction respectively in fuzzy logic. The law of "excluded middle" in probability theory, i.e. $p(x \vee x') = 1$, where p denotes probability and x' is negation of x, does not hold here.

Ambiguity, on the other hand, lies in the assignment of an element "x" from a universe of discourse X to one or more crisp subsets of X. The crisp subsets have no uncertainty about their boundaries as fuzzy sets do in the case of vagueness. For example, it is not possible to decide whether a missed measurement exceeds unity or not despite the fact that the subset is clearly defined, i.e., $\{x|x > 1\}$. The uncertainty arising from ambiguity is associated with lack of evidence to establish an assignment. Ambiguity can be measured by using a set function $v(A) \in [0,1]$ for $A \subseteq X$ satisfying the following [3];

(i) $A \subseteq B \rightarrow v(A) \leq v(B)$;

(ii) a conjunctive operator $v(A \cap B)$ is associative, commutative and monotonic with identity 1;

(iii) a disjunctive operator $v(A \cup B)$ with identity 0.

A probability measure P satisfies the conditions listed above with;

(1) $P(A \cap B) = P(A|B)P(B) = P(B|A)P(A)$;

(2) $P(A \cup B) = P(A) + P(B) - P(A \cap B)$.

Since ambiguity is not a random notion, the probability measure should be interpreted as the subjective probability rather than the relative frequency. For this reason P can be rewritten as P_s to denote that it is subjective (personal) probability. Hence P_s implies that the assessor is prepared to bet an amount P_s in exchange for 1.

The other candidate is possibility measures Π with;

(3) $\Pi(A \cap B) = \min[\Pi(A), \Pi(B)]$;

(4) $\Pi(A \cup B) = \max[\Pi(A), \Pi(B)]$.

Possibility can be thought of as being complementary to the degree of surprise that a person experiences if an event occurs, as opposed to whether it occurs as a matter of chance. Both probability and possibility measures are generally normal, with $P_s(X) = \Pi(X) = 1$, for a probability measure, this entails additivity $\int_{x \in X} p_s(x) = 1$, while for possibility measures this is $\max_{x \in X} \pi(x) = 1$. Many methods are available to convert a given probability distribution to a possibility distribution, and vice versa. One of the most prominent is the maximum normalisation or ratio scale method [5]. Given a probability distribution $p_s(x)$, then it can be converted to a corresponding possibility distribution

$$(5) \qquad \pi(x) = \frac{p_s(x)}{\underset{x \in X}{Max}\, p_s(x)} \; ;$$

so that $\max_{x \in X} \pi(x) = 1$ is asserted. On the other hand, a probability distribution

$$(6) \qquad p_s(x) = \frac{\pi(x)}{\int_{x \in X} \pi(x) dx} \; ;$$

may be defined based on a possibility distribution $\pi(x)$ to achieve $\int_{x \in X} p_s(x) = 1$. Possibility theory, with its maximal normalisation which is weaker than probability, is sometimes portrayed as equivalent to fuzzy set theory, and thus possibility measures are presumed to be determined by the same methods of expert elicitation. However possibility measures and fuzzy sets are representations with distinct formal and semantic domains, which should be reflected in the elicitation process. Possibility measures can have significant advantages over the strict use of probability measures in studies such as system reliability [3].

Chance describes the uncertainty in the occurrence of an event, i.e., it is not possible to decide whether the event will or will not occur due to its random nature. Probability based on the relative frequency theory, denoted as p_f, is best suited for measuring chance.

In case that the hydraulic conductivity of a rock mass at a location has a 95% chance of being less than 10^{-10} m/s, there is a 5% chance that it is over 10^{-10} m/s. However, in fact it could be extremely conductive. On the other hand saying that a rock mass at a certain location has a high membership in the set "impermeable" rock, could involve two different types of uncertainty, i.e., vagueness and ambiguity. If the uncertainty is mainly due to fuzziness in the definition of the set "impermeable" rock, then it arises from vagueness. In this case, there is a high likelihood that the rock could still have quite a low permeability even if its conductivity turns out to be more than 10^{-10} m/s. However, if the uncertainty originates from lack of evidence, e.g., no measurement has been made and it is only inferred from the fact that similar rock in an analogous setting has a conductivity less than 10^{-10} m/s, it is due to ambiguity. There is some non-zero membership of not being "low permeability" and, as in the case of uncertainty arising from chance, it could be very conductive. However, there is an important philosophical difference, in that it has already been decided, in this case, whether or not the rock conductivity is over 10^{-10} m/s: it is just unknown. Once the conductivity is measured, the uncertainty due to ambiguity or chance will disappear but vagueness will not.

In most of the situations envisaged in PA, uncertainties from different sources are mixed together. One particularly important example is the mixture of ambiguity and chance, i.e., lack of evidence about the occurrence of events that might occur randomly. In these situations, it is extremely difficult, if not impossible, to obtain evidence to show that the event in question is indeed of a random nature. In other words ambiguity "masks" the nature of the events and processes to be assessed.

Gaines and Kohout [6] distinguish between events E that are "traditionally possible" in that $P_f(A)=\varepsilon>0$ [10] and thus must occur in the limit of infinite time, and those that are not impossible but still need not ever occur. This latter case can be identified as "properly possible". Building from this, it is possible to draw on Zadeh's measure of compatibility between a probability distribution for chance and possibility distribution for ambiguity as

$$(7)\qquad g(p_f,\pi)=\sum_{x\in X} p_f(x)\pi(x).$$

Joslyn **[7]** identified the condition of strong compatibility when $g(p_f,\pi)=1$, which requires that the possibility is unity wherever the probability is positive. Thus, from this perspective, traditionally possible events, including all events that are actually observed, require total mathematical possibility $\Pi(E)=1$ and positive (frequency-based) probability. However, properly possible events are those such that $\Pi(E)>0$ yet such that $P_f(E)=0$. These are the rare events that are so important in reliability studies of high-consequence systems. As was shown by Joslyn, possibilities becomes probabilities as the information granularity, i.e., ambiguity of the information, becomes more specific if the event in question is indeed of a random nature. This is a very nice feature in modelling ambiguity and chance at the same time in the case where the quantity and quality of information available is improved as time proceeds. However it should be noticed that, in the case of PA, ambiguity seldom diminishes as the timescale of interest is beyond our experience and due to the limited number of measurements of spatial heterogeneity.

Bayesian framework for updating uncertain knowledge

Since there are different types of uncertainty and associated measures, integration of the different formalisms to treat uncertainties is required for the purpose of the uncertainty management. In addition, taking into account the scope of uncertainty management, i.e., recognition and evaluation of uncertainties associated with PA followed by planning and implementation of measures to reduce them, it is essential that a framework for such integration is able to take account of improvements in the available information in order to update the evaluation. As a candidate for such a framework, the Bayesian method as in [3] is employed.

Bayes' rule describes, in light of information *H*, the following relationship among probabilities of events (*X* and *Y*) in terms of conditional probability.

$$(8)\qquad P(X\cap Y;H)=P(Y|X;H)P(X;H)=P(X|Y;H)P(Y;H)$$

By equating the two expressions and rearranging the associated terms,

$$(9)\qquad P(X|Y;H)=\frac{P(Y|X;H)P(X;H)}{P(Y;H)},$$

or alternatively,

$$(9')\qquad P(X|Y;H)\propto P(Y|X;H)P(X;H)$$

10. For traditional probability measure based on the relative frequency, P is denoted as P_f in this paper.

is given. Now, suppose that $Y=y$ has been observed. Then what is the assessor's uncertainty about X; i.e., what is $P(X; y, H)$? Since the assessor has actually observed $Y=y$, the first factor in the right hand side cannot be interpreted as a probability any more. Hence it is called the likelihood function and denoted as $L(X; y, H)$. Using the likelihood function, (9') can be rewritten as

$$(10) \quad P(X; y, H) \propto L(X; y, H) P(X; H).$$

(10) serves as a systematic scheme to update probabilities in light of data. $P(X; H)$ is called the prior probability distribution of X, while $P(X; y, H)$ is called the posterior distribution.

Note that *the likelihood function is not a probability and therefore does not need to obey the law of probability.* It simply connects the two probabilities: the prior distribution and the posterior distribution. The likelihood function is a purely subjective function that enables the assessor to assign relative weights to different values of X. Because of this characteristics of the likelihood function, the Bayesian method can be used to link probability theory with fuzzy logic and possibility theory. Specifically, probability measures relate to fuzzy sets and possibility measures through the membership functions. The associated membership function can be interpreted as a likelihood function since the process of defining a membership function is subjective in nature and the membership functions are nonnegative. Then for a given probability-based prior distribution, the membership functions, as likelihoods, can be used to produce a probability-based posterior distribution. An example of application of this approach to average hydraulic conductivity of a rock mass is depicted in Figure 1.

Integration of uncertain information

Defining a likelihood function is a subjective exercise reflecting the assessor's opinion. For the problems with incomplete, imprecise and/or inconsistent information where conditional probabilities cannot be supplied or rationally formulated, a possibility-based approach offers a structured methodology to eliciting expert judgement and reflecting it into the likelihood function. In what follows two examples of such an approach are illustrated.

Derivation of a possibility distribution using evidence theory

The safety case relies partly on the stability of the geological environment and the long time scale associated with flow and transport through the geosphere. A conceptual site model integrates numerous types of information into an internally consistent understanding of these features. The model then rationalises quantitative safety analyses and develops complementary, often qualitative, arguments that support the safety case. A systematic treatment is required to integrate all the relevant geological information to form a representation of the geological environment and its evolution. The approach illustrated here is based on Evidential Support Logic (ESL) [8], which is a generic mathematical concept based on the evidence theory and consists of the following key components.

Suppose a proposition is formed by integrating and interpreting a number of information items from different sources. The first task of ESL is to unfold this proposition by constructing a process model. The "top" proposition is subdivided iteratively to form an inverted tree-like structure, with propositions at each lower level corresponding to intermediate interpretations. The subdivision is continued until the original information is reached.

After constructing the process model, confidence in the top proposition is evaluated. The degree of confidence in the support for each lowest-level proposition from corresponding information (i.e.

evidence) is estimated in terms of the interval probability and propagated through the process model using simple arithmetic (see Appendix). Interval probability, unlike the conventional "point" probability, defines an upper- and a lower-bound for the probability of a proposition A to be true, $\underline{P_s}(A) \le P_s(A) \le \overline{P_s}(A)$. Then $\underline{P_s}(A)$ and $\overline{P_s}(A)$ do not follow the theory of probability, i.e., $\overline{P_s}(A) + \overline{P_s}(A^c) > 1$, $\underline{P_s}(A) + \underline{P_s}(A^c) < 1$ where A^c denotes negation of A. In fact it has been shown that $\overline{P_s}(A)$ can be identified as the possibility of the proposition A being true while $\underline{P_s}(A)$ can be regarded as the necessity of the proposition A being true, i.e., complementary to possibility of A being false (Figure 2). Thus interval probability is an expression equivalent to possibility measures.

Figure 1. **Bayesian framework for updating uncertain knowledge using possibility-based likelihood function**

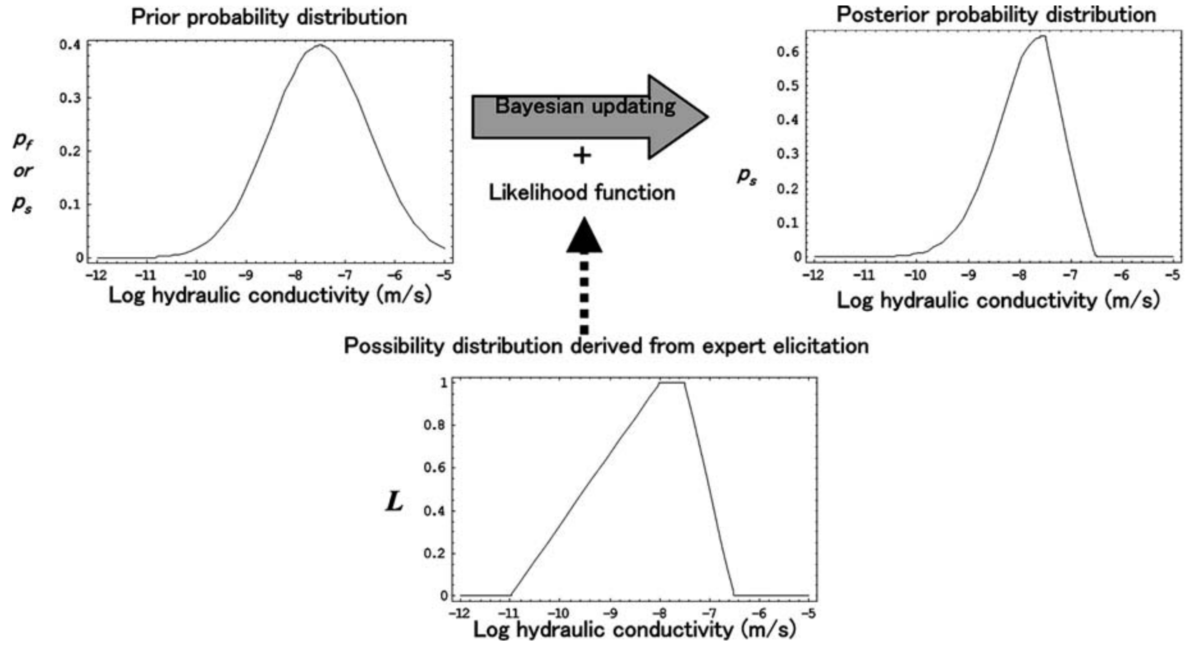


Figure 2. **Interval probability and possibility measures**

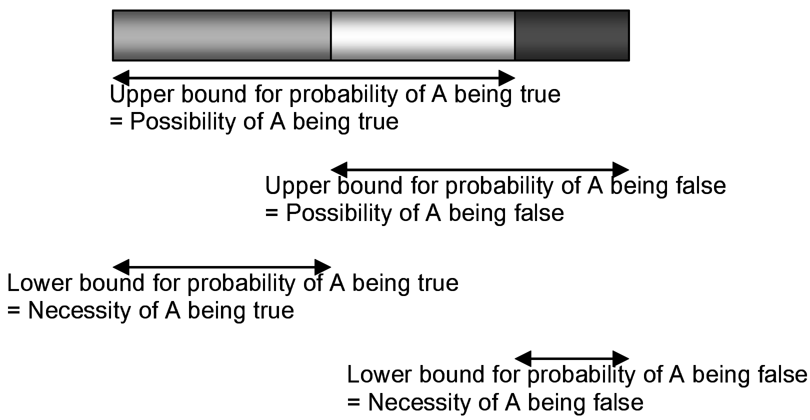


Figure 3. **Example of a process model constructed to evaluate degree of confidence in stability of the current saline-fresh water interface**

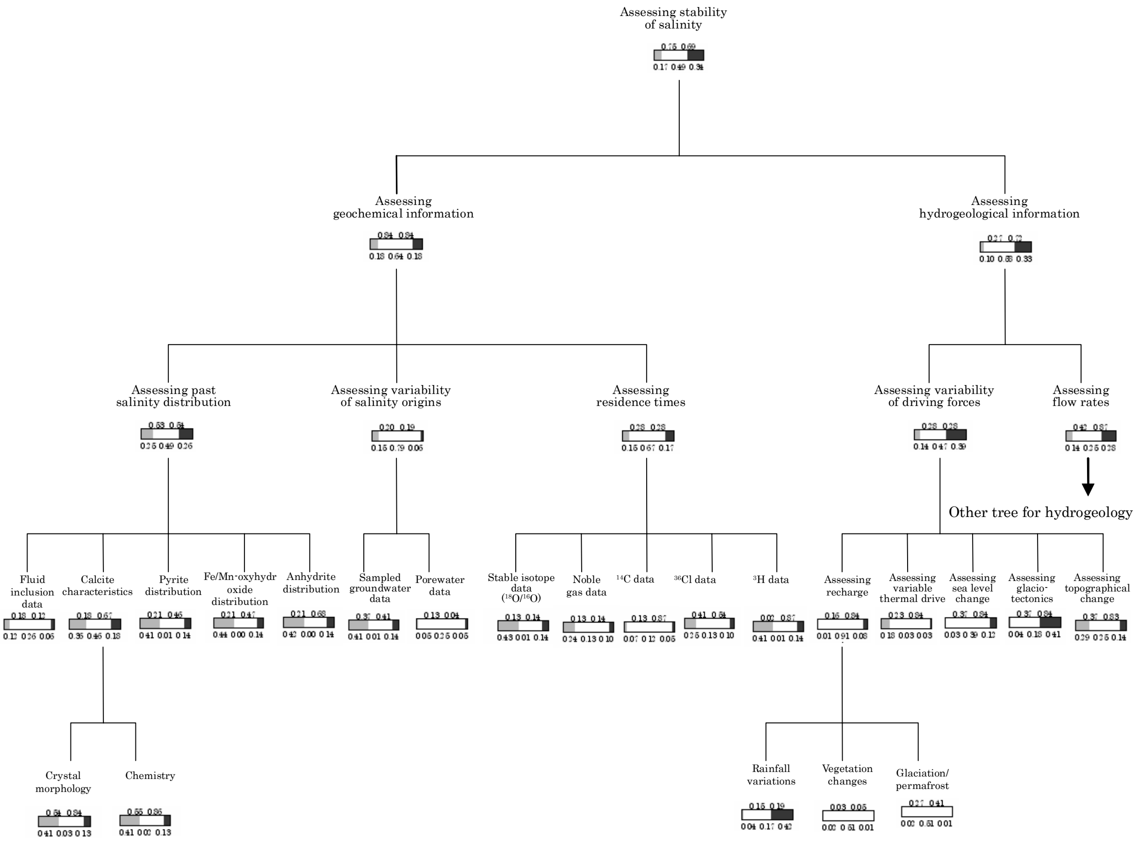


Figure 3 illustrates an example process model to evaluate the degree of confidence that a variety of evidence from a hypothetical site supports the stability of the current saline-fresh water interface.

The process model represents a logical structure that supports a conceptual site model, or its components, based upon available geological information. The degrees of confidence that the propositions at various levels are supported by evidence illustrates how uncertainties of various (multi-disciplinary) origins are propagated through the process model. Thus, use of ESL could increase the transparency and traceability of the underlying reasoning behind a conceptual site model. In turn this increase in clarity would expedite the communication of confidence and understanding of the geological environment and its evolution. In addition to this, a "ratio plot" (Figure 4) can be used to summarise and compare confidence in a number of competing conceptual model options. The *y*-axis of the ratio plot is $\log[p/q]$ and the *x*-axis is *u*, where *p* (*q*) is the minimum degree of confidence that the model option is supported (not supported) and *u* is the uncertainty associated with the evaluation. Hence a model option with stronger relative support ($\log[p/q]$) and one with greater uncertainty correspond to larger *y*- and *x*-coordinates respectively. By locating the competing model options in the ratio-plot, their characteristics can be summarised graphically and compared.

Construction of the process model and evaluation of confidence should be carried out iteratively as the siting process proceeds. To support planning of the next stage of site characterisation, it is useful to classify the importance of different types of evidence by sensitivity analyses. In the case of

ESL, this can be done by calculating the reduction in the uncertainty associated with the top proposition assuming that uncertainty in each piece of evidence vanishes in turn (Figure 5). The results of the analysis can then be used as an input to prioritise further data acquisition.

Figure 4. **Example of a "ratio plot"**

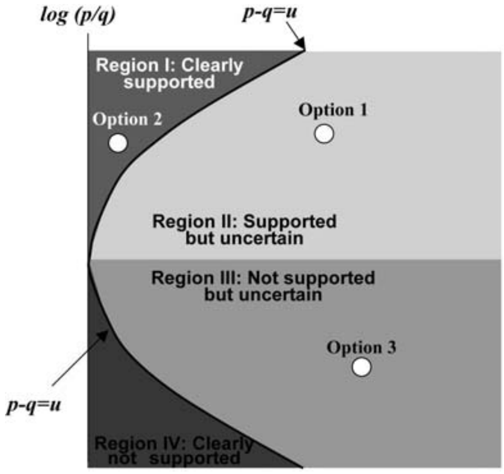
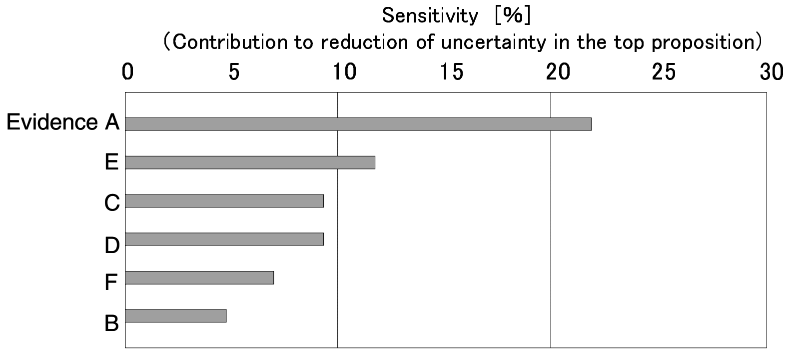


Figure 5 **Example of sensitivity analysis**



Aggregation of possibility distributions

Uncertainty involved in PA, i.e., non-unique choice of scenarios, models and parameter values, originates from a number of different sources and it is often necessary to decompose it into different factors. For example, *Kd* value for Cs to be used in PA could be associated with the following uncertain factors;

- uncertainty related to whether the current hydrogeological condition remains or change significantly;
- uncertainty related to the average salinity under present conditions;
- uncertainty related to the average salinity after the current hydrogeological conditions change;
- uncertainty related to *Kd* value at a given salinity level.

Let $\pi(H_0)$ be the possibility of current hydrogeological conditions remain unchanged, and $\pi(H_1)$ be the possibility that the saline front moves substantially [Figure 6 (a)]. These quantities could be estimated by using ESL analysis as illustrated in the previous section. Similarly we define $\pi(H_0, S_-), \pi(H_0, S_0)$ and $\pi(H_0, S_+)$ as the possibilities of salinity being "low", "intermediate" and "high" under current condition respectively, $\pi(H_1, S_-)$, $\pi(H_1, S_0)$ and $\pi(H_1, S_+)$; possibility of salinity being "low", "intermediate" and "high" provided the saline front moves substantially in future (Figure 6 (b)). Then the possibility of future salinity can be estimated by using the "Min-Max" rule as follows;

$$
\begin{aligned}
&\pi(S_-) = Max[Min(\pi(H_0, \pi(H_0, S_-))), Min(\pi(H_1, \pi(H_1, S_-)))],\\
(11)\quad &\pi(S_0) = Max[Min(\pi(H_0, \pi(H_0, S_0))), Min(\pi(H_1, \pi(H_1, S_0)))],\\
&\pi(S_+) = Max[Min(\pi(H_0, \pi(H_0, S_+))), Min(\pi(H_1, \pi(H_1, S_+)))],
\end{aligned}
$$

where $\pi(S_-), \pi(S_0)$ and $\pi(S_+)$ denote the possibilities of the salinity in the future being low, intermediate and high respectively.

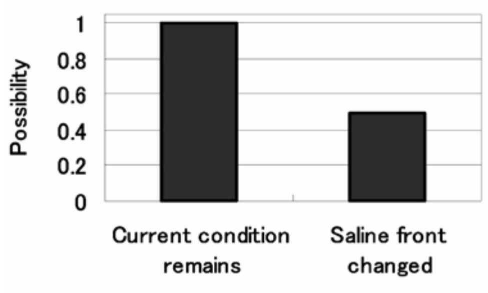
Suppose a possibility distribution of *Kd* values for Cs is estimated from the results of sorption experiments at low, intermediate and high salinity levels $\pi(S_-, Kd(x)), \pi(S_0, Kd(x))$ and $\pi(S_+, Kd(x))$, (Figure 6 (c)). Then the possibility distribution of the *Kd* being *x*, $\pi(Kd(x))$, can be estimated by the following equation;

$$(12)\quad \pi(Kd(x)) = Max[Min(\pi(S_-), \pi(S_-, Kd(x))), Min(\pi(S_0), \pi(S_0, Kd(x))), Min(\pi(S_+), \pi(S_+, Kd(x)))].$$

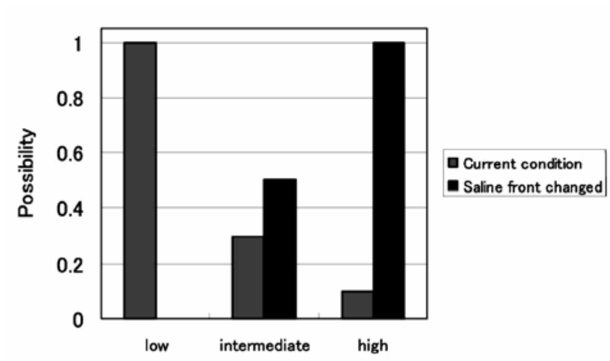
(11) and (12) can also be formulated in terms of fuzzy relations and their composition **[3]**.
Figure 6 (d) shows $\pi(Kd(x))$ calculated by applying (11) and (12).

Figure 6. **Aggregation of possibility distributions for Cs *Kd* value taking a number of uncertain factors into account**

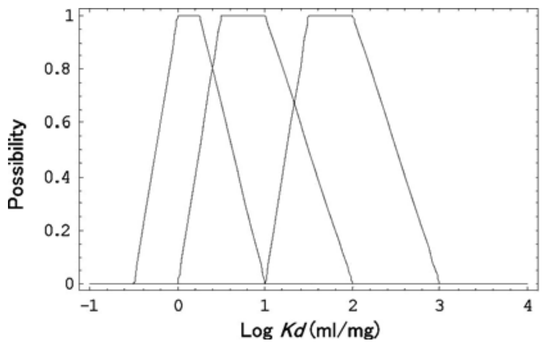
(a) Uncertainty related to stability of current conditions



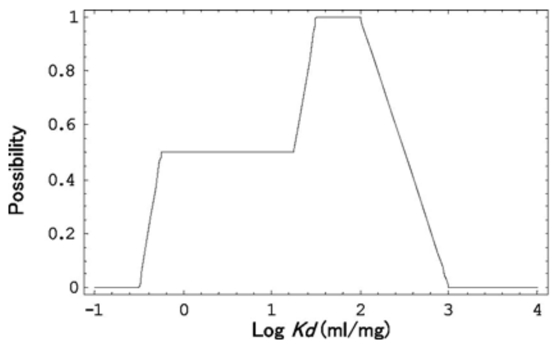
(b) Uncertainty of salinity under future given conditions



(c) Uncertainty of Cs *Kd* under given salinity levels



(d) Overall uncertainty of *Kd* to be used in PA



Uncertainty in system performance assessment

The compatibility between probabilistic and possibilistic approaches for treating uncertainty provides flexibility to system performance assessment. For example, the application of the probabilistic approach to handling conceptual uncertainties associated with selection of scenarios and model options, suffers from the philosophical difficulty of assigning probability to known options since there always remains the possibility that other unknown options exist. Thus it is not possible to define the cumulative probability of the known options, which might be significantly less than unity. In these circumstances, possibility theory can provide practical measures to treating uncertainties.

Another important aspect is related to interdependence between two or more uncertainties. There are a number of uncertain factors associated with PA for multi-barrier systems. If the correlation between these uncertain factors was known, then it could be incorporated in terms of conditional probabilities to formulate the problem in the probabilistic framework. In reality, however, sufficient information about the correlation between these factors does not typically exist. Let a and b be a measure for uncertainty due to ambiguity and/or chance. Then, by denoting the conjunction of a and b by $f(a,b)$, both $f(a,b)$ itself and $g(a,b) = a + b - f(a,b)$ have to be associative. The general formula satisfying this requirement is given by,

$$(13) \qquad f(a,b) = \log_s \left[1 + \frac{(s^a - 1)(s^b - 1)}{s - 1} \right],$$

where $s \in [0,1]$ is a constant and is called Frank's *t*-norm [9]. $f(a,b)$ in (13) approaches multiplication ab asymptotically as $s \to 1$ and $Min(a,b)$ as $s \to 0$. This implies that it is possible to bound the uncertainty originating from the lack of information on interdependence of uncertain factors by the estimates based on probabilistic and possibilistic approaches. To illustrate the above idea, an example is presented in what follows.

A multi-barrier system consisting of;

- glass waste form that dissolves congruently with a dissolution rate constant over time;
- canister that contains the waste form for approximately 1 000 years to avoid its contact with groundwater;
- bentonite buffer whose hydraulic conductivity is low enough to keep the groundwater flow rate through it negligible compared with transport by diffusion;

- host rock that can be regarded as a continuum and the nuclide transport through it takes place along a one dimensional uniform path;

is considered.

The corresponding nuclide transport model is shown schematically in Figure 7, where the diffusion equation in the one-dimensional cylindrical coordinate in the buffer is combined with the advection-dispersion equation in the Cartesian one-dimensional coordinate in the host rock via a mixing cell representing the excavation disturbed zone.

Furthermore it is assumed that the glass dissolution time has the uncertainty shown in Figure 8. The possibility distribution in Figure 8 is derived from expert elicitation and the corresponding probability distribution is obtained by the maximum normalisation (5). It is also assumed that the hydraulic conductivity of the host rock and the *Kd* of Cs exhibit the uncertainty depicted in Figures 1 and 6 respectively. Either the probability distribution or the equivalent possibility distribution, which are exchangeable via equations (5) and (6), is used depending on the type of analysis, i.e., probabilistic or possibilistic. For simplicity, input values for the other parameters are fixed as in Table 1.

Results obtained by probabilistic and possibilistic approaches for normalised release rate of Cs-135 from the geosphere are compared in Figure 9 together with the uncertainty bounds. Figure 10 summarises the complementary cumulative probability distribution, $P(x)$, and the complementary cumulative possibility distribution, $\Pi(x)$, defined by,

$$(14) \qquad P(x) = \int_x^\infty p(x)dx\,;$$

$$\Pi(x) = \underset{y \ge x}{Max}[\pi(y)].$$

The area bounded by $P(x)$ and $\Pi(x)$ illustrates the size of the uncertainty originating from lack of information on the interdependence of uncertain factors as a function of time. The results are presented in a disaggregated manner in Figure 10, i.e., calculated consequence and its plausibility in terms of probability or possibility are shown separately. In contrast to the case of the properly possible events (see the next section), this mode of presentation seems more adequate since difference in the implication of probabilistic and possibilistic approaches is more evident here.

Figure 7. **Nuclide transport model for system performance assessment**

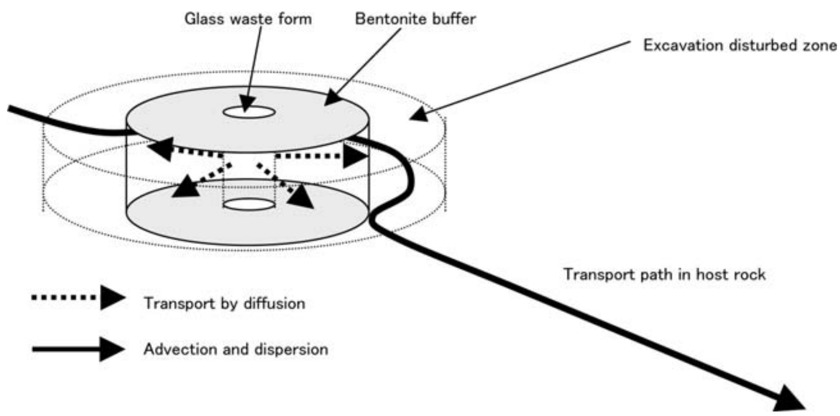


Table 1. **Input parameter values for the example calculations**

Buffer thickness (m)	1	Transport distance through host rock (m)	100
Effective diffusion coefficient in buffer (m^2/s)	0.01	Effective porosity of host rock (-)	0.2
Porosity of buffer (-)	0.4	Density of host rock (kg/m^3)	2700
Density of buffer (kg/m^3)	2700	Hydraulic gradient (-)	0.01

Figure 8. **Probability distribution and possibility distribution of glass dissolution time**

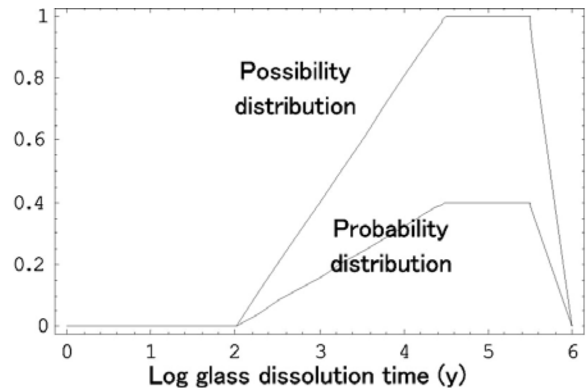
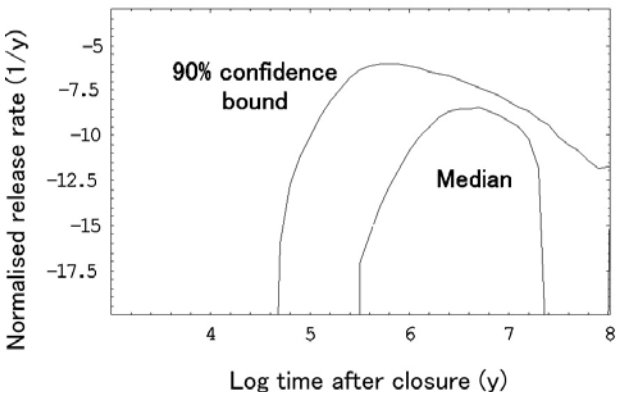


Figure 9. **Probabilistic and possibilistic uncertainty bound for normalised release rate of Cs-135 from geosphere**

(a) Probabilistic



(b) Possibilistic

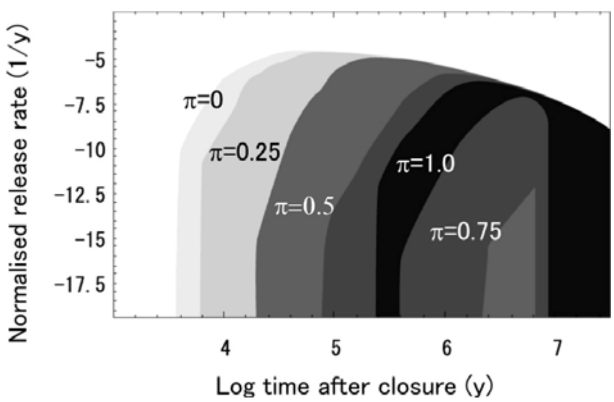
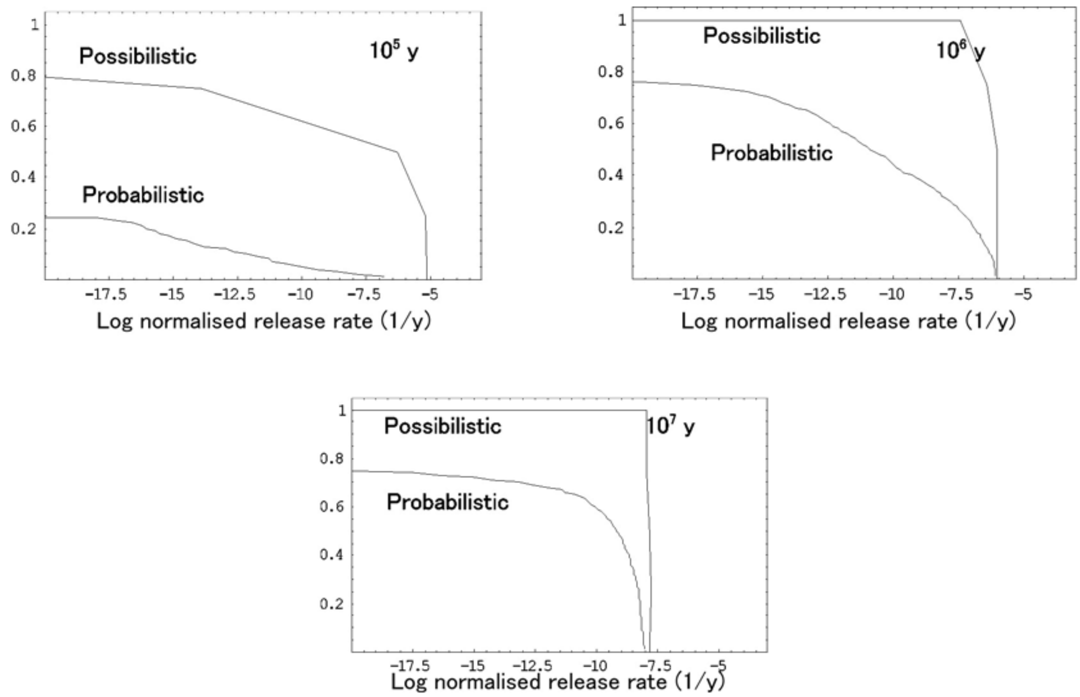


Figure 10. **Comparison of probabilistic and possibilistic complementary cumulative distributions**



Probability of occurrence of properly possible events

As was stated in section "*Types of uncertainty*", it is important to distinguish between events E that are "traditionally possible" in that $P_f(E)=\varepsilon>0$ and thus must occur in the limit of infinite time, and those that are "properly possible", i.e., they are not impossible but still need not ever occur. The properly possible events are those such that $\Pi(E)>0$ yet such that $P_f(E)=0$. These are the rare events that are so important in reliability studies of high-consequence systems.

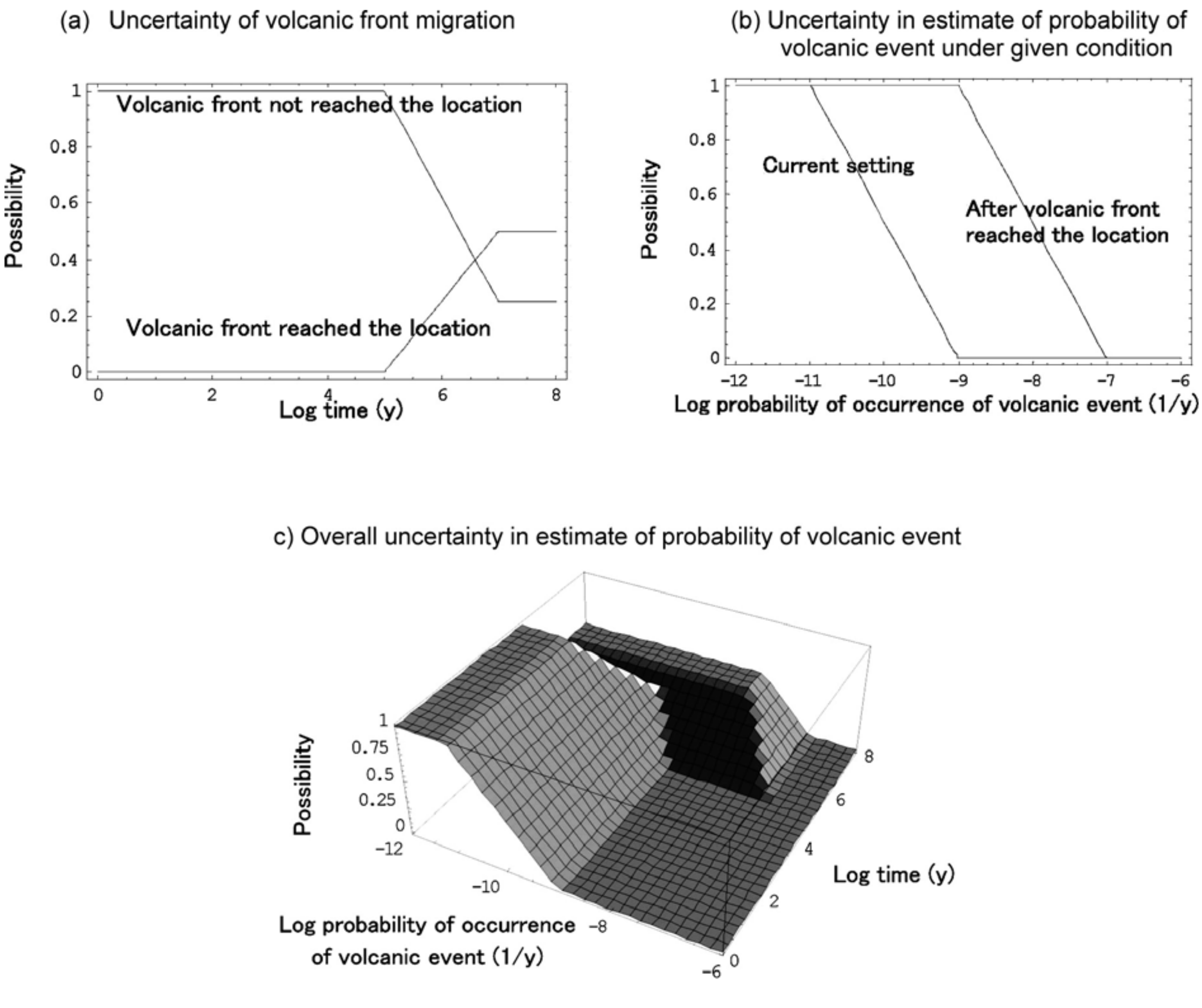
The key to the assessment of the properly possible events is in assigning some non-zero (subjective) probability of occurrence, $P_s(E)>0$. For this purpose, it is useful to express uncertainty in the estimate of $P_s(E)$ in terms of possibility distribution. This idea goes in parallel to "probability of fuzzy events" in [10].

By regarding the probability of occurrence as a fuzzy set described by a possibility distribution, the techniques described in section "*Integration of uncertain information*" can be applied. For example, probability of occurrence of a volcanic eruption at a location which is away from the current volcanic front can be estimated by aggregating the following uncertain factors;

- the possibility that the volcanic front will have migrated and reached the location by time *t*, $\pi(t)$;
- the "possibility of probability of occurrence" of a volcanic eruption at the location before and after the volcanic front reaches the location, $\pi_0(p_s)$ and $\pi_1(p_s)$.

The possibility $\pi(t)$ can be derived based on a knowledge of the range of the volcanic front migration rate, whereas $\pi_0(p_s)$ and $\pi_1(p_s)$ can be estimated through assessing the range of frequencies of volcanic events in areas where those events have actually occurred in the past. By applying the procedure as in section "*Aggregation of possibility distributions*" the overall uncertainty of $P_s(E)$ in terms of possibility distribution $\pi(t,\ p_s)$ (Figure 11) can be derived. Product of $\pi(t,\ p_s)$ and the potential consequence of an volcanic event can be regarded as the possibility distribution of risk concerning the volcanic eruption, which combines the uncertainties arising from ambiguity and chance.

Figure 11. **Aggregation of uncertain factors into the estimation of the probability of a volcanic event**



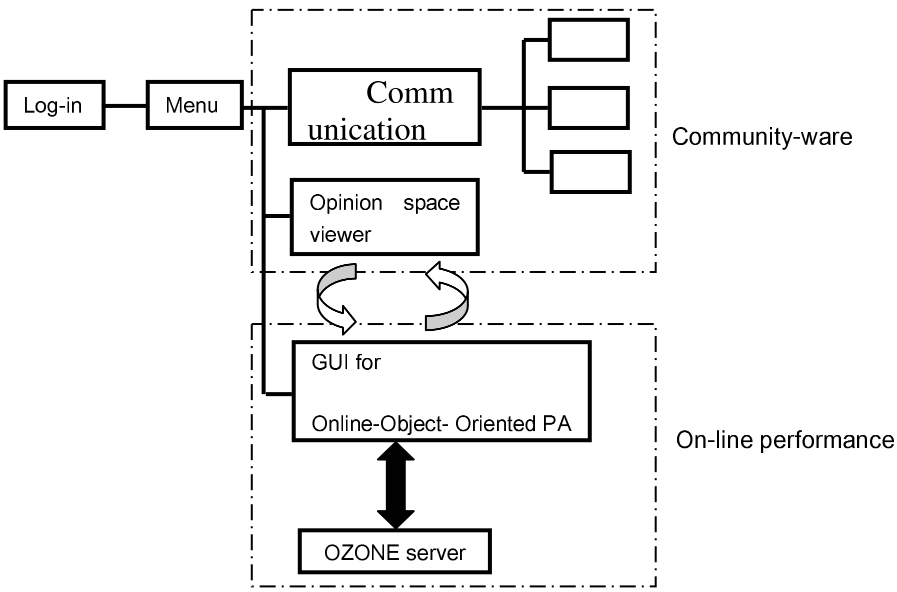
Uncertainty communication using internet communities

While uncertainty management based on the combination of the various formalisms forms an important part of our framework for uncertainty governance, it only solves a half of the problem. It is needed to communicate safety assessment results to a variety of stakeholders. Decisions concerning geological disposal necessitates an underlying knowledge concerning long-term safety. Unlike information, however, knowledge is strongly linked with beliefs and commitment which can only be obtained through experience of the individuals. Hence, in addition to transmitting the results of our uncertainty analysis to stakeholders, interested individuals are encouraged to create their knowledge based on the provided information but, at the same time, independent from implementors' beliefs and commitment. This can be achieved by members of voluntary communities exchanging information, finding partners to collaborate with, and conducting their own PA and uncertainty analysis. Key to this approach is the concept of "network PA communities" as shown in Figure 12, where members are linked through internet with resources for PA, e.g., PA codes and databases, are provided on line on demand [11].

A voluntary PA community to test validity of this approach has been initiated [12]. For this purpose, issues other than the quantitative PA calculations have to be addressed as well. To expedite such activities, a "community-ware" has been developed so that members of PA network communities can grasp their relative positions in an "opinion space" and find possible partners to collaborate with, and allow newcomers to recapture a summary of the previous discussions. In addition, the history of past discussions together with the results of iterative PA calculations will, from time to time, provide useful insight for understanding and modelling the process of consensus building.

From the point of view of uncertainty analysis, PA calculations carried out by numerous individuals through network communities provides a chance to explore "possible" evolutions of the system and the resulting radiological consequences in an exhaustive manner. Furthermore discussion on the individual results among the members of communities, via challenging and defending the assumptions in the PA calculations done by other members, will support the developing knowledge on the safety of the disposal system and the associated uncertainty.

Figure 12. **Structure of the on-line performance assessment community system**



Conclusion

To manage the uncertainties from various sources associated with PA for geological disposal, a number of mutually complementary methodologies have been applied. These are based on various formalisms such as probability theory, Bayesian theory, possibility theory, and evidence theory. In addition a framework has been developed so as to allow implementors to integrate a number of different formalisms to form an eclectic approach to the variety of uncertainties envisaged in PA. Application of this approach to a number of examples have also been illustrated.

To communicate the understanding of the types and sizes of the uncertainties in PA to a variety of stakeholders, an approach utilising PA network communities is proposed, where members exchange information, find collaboration partners, and conduct their own PA and uncertainty analyses. In this way, communities can create their own knowledge based on the provided information but which at the same time is independent from our beliefs and commitment. This approach may play a complementary role to the conventional presentation of PA results.

Reference

[1] NEA (1987), *Uncertainty Analysis for Performance Assessments of Radioactive Waste Disposal Systems*, Proceedings of an NEA Workshop, OECD, Paris.

[2] European Commision (1995), Review on development of methodologies for modelling with uncertainty and variability: Munvar project, EUR16174EN.

[3] Ross, T.J., J.M. Booker and W.J. Parkinson (2002), Fuzzy logic and probability applications; Bridging the gap, Society for industrial and applied mathematics, Philadelphia.

[4] Zadeh, L. (1976), The concept of a linguistic variable and its application to approximate reasoning: Part 3, Inform. Sci., 9, pp.43-80.

[5] Klir, G. (1990), Developments in Uncertainty Based Information, Advanced in Computors, Academic Press, pp.255 – 322.

[6] Gaines, B.R. and L.J. Kohout (1976), The logic of automata, Internat. J. Gen. Systems, 2, pp. 191-208.

[7] Joslyn, C. (1997), Distributional Representations of Random Interval Measurements, Uncertainty Analysis in Engineering and Sciences: Fuzzy Logic, Statistics, and Neural Network Approach, Kluwer Academic Publishers, pp. 37-52.

[8] Hall, J.W., D.I. Blockley, J.P. Davis (1998), Uncertain inference using interval probability theory, International Journal of Approximate Reasoning, 19, pp.247-264.

[9] Frank, M.J. (1979), On the simultaneous associativity of F(x,y) and x + y – F(x,y), Equations Math, 19, pp. 194-226.

[10] Zimmerman, H.-J. (2001), Fuzzy set theory and its applications, 4th edition, Kluwer Academic Publishers.

[11] Takase, H., M. Inagaki and T. Noguchi (2003), Development of an on-line performance assessment system, Proceedings of ICEM'03: The 9th International Conference on Radioactive Waste Management and Environmental Remediation.

[12] Tanaka, H., H. Yokoyama, H. Kimura and H. Takase (2004), Social Technology for Nuclear Safety (XIII): Development of Community-ware for Performance Assessment of HLW Disposal, Proceedings of the Atomic Energy Society of Japan, Spring Meeting, (in Japanese).

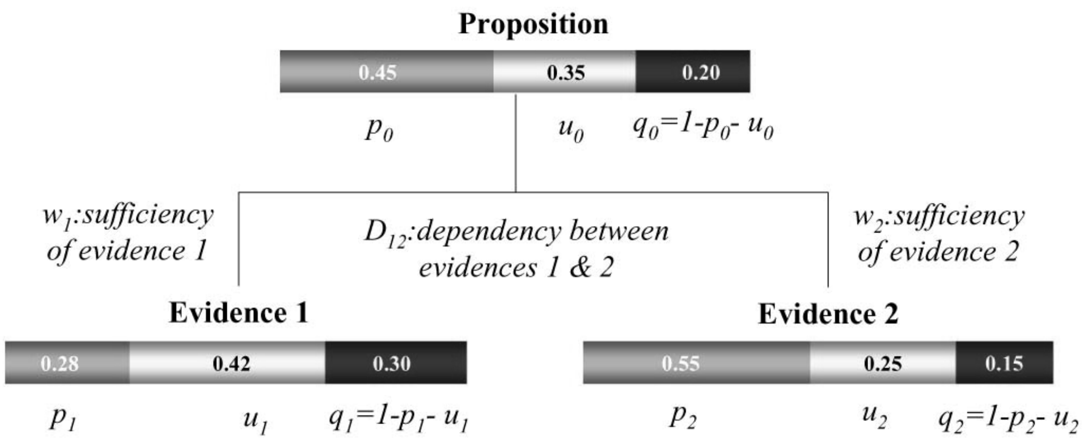
Appendix

The degree of confidence that some evidence supports a proposition can be expressed as a subjective probability. However, since evidence concerning a complex system is often incomplete and/or imprecise, it may be inappropriate to use the classical (point) probability theory. This theory cannot account for uncertainty in an actual evaluation of support, because if some evidence supports a proposition with probability p, the probability against the proposition is automatically $1\text{-}p$. For this reason ESL uses the interval probability theory, which allows us to say "the degree of confidence that evidence supports the proposition lies between p and $p+u$". In this case, the degree of confidence that evidence does not support the proposition is between $1\text{-}p\text{-}u$ and $1\text{-}p$. Hence the following items are derived (Figure A):

- the minimum degree of confidence that some evidence supports the proposition is p;
- the minimum degree of confidence that some evidence does not support the proposition is $1\text{-}p\text{-}u$;
- the uncertainty is u.

The arithmetic used to propagate degrees of confidence upward through the process model is depicted in Figure A, where "sufficiency" of an individual piece of evidence or lower level proposition can be regarded as the corresponding conditional probability. That is, "sufficiency" is the probability of the higher level proposition being true provided each piece of evidence or lower level proposition is true. A parameter called "dependency" is introduced to avoid double counting of support from any mutually dependent pieces of evidence.

Figure A. **Evaluation of confidence using interval probability theory**



$$p_0 = w_1\ p_1 + w_2\ p_2 - \rho_{12} Min(w_1\ p_1\ , w_2\ p_2\ )$$

$$q_0 = w_1\ q_1 + w_2\ q_2 - \rho_{12} Min(w_1\ q_1\ , w_2\ q_2\ )$$

where $$\rho_{12} = \frac{(1-D_{12})(w_1\ p_1\ \ w_2\ p_2\ )}{Min(w_1\ p_1\ , w_2\ p_2\ )} + D_{12}$$

WORKING GROUP 1

RISK MANAGEMENT AND DECISION MAKING

DISCUSSION OF RISKS IN THE CONTEXT OF THE ENVIRONMENTAL IMPACT ASSESSMENT OF THE SPENT FUEL REPOSITORY IN FINLAND

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Introduction and context

In May 1999 Posiva submitted an application for the so-called Decision-in-Principle (DiP) on the final disposal facility of spent fuel to the Finnish Government (Posiva, 1999a). In this application Posiva proposed that the spent fuel from the Loviisa and Olkiluoto nuclear power plants should be disposed of in a KBS-3 type final repository which would be built at Olkiluoto near the Olkiluoto power plant site. According to the Nuclear Energy Act the main purpose of the DiP is to judge whether the facility is in line "with the overall good of society". In doing the judgement the Government – and later the Parliament – should pay particular attention to the alternatives of the proposed project, including the "zero alternative", i.e. the alternative of not realising the project.

The Government approved Posiva's application in December 2000 and the decision was ratified by the Parliament in May 2001. The next major milestone will now be the construction licence, the application for which is planned to be submitted in the early 2010s.

The basis for the Decision-in-Principle application was laid in the report from the Environmental Impact Assessment (EIA) procedure that was started in 1997 and completed in May 1999 (Posiva, 1999b). It was decided that the EIA programme would focus on the issues and concerns that various stakeholder groups find of greatest importance. Consequently, while safety issues played a central role in the early phases of the EIA process, later the focus was more and more shifted to discussion of alternatives, and the comparison of alternatives was given a significant role in the EIA report and the application for DiP. In practice this meant that instead of discussion of the absolute risks of geologic disposal the focus was placed on the relative risk of the proposed project vs. the zero alternative.

Programme formulation

To identify the issues that the various stakeholder groups considered as most important for the EIA Posiva started a major campaign of public interaction, first in the candidate site municipalities, later also nation-wide. As expected, safety issues were usually raised as primary concerns at meetings with the public; it was probably also behind the concerns about *local image*: a central topic of discussion was whether the public image of the municipality would be spoilt if the municipality accepted the siting of the repository. However, as regards safety the concerns were slightly different depending if the question was about the long-term safety of disposal, the operational safety of the disposal facility or the safety of spent fuel transportation. As regards the operational safety and the safety of spent fuel transportation people were interested in the expected radiation levels and consequences of accidents, whereas concerning the long-term safety the main issues seemed to be whether anything at all can be said about that, whether the long-term safety assessments deserve any credibility.

The site selection process for the spent fuel repository was started already in the early 1980s. In parallel to site investigations a research programme into long-term safety was established. For the EIA process the research, development and site investigations activities were extended to address the questions the stakeholders held as important. This meant, in particular, new research into social, socio-economical and socio-psychological aspects of the project and also new studies on the operational and transportation safety.

Shifting emphases

As the EIA process progressed the discussion was more and more shifted from basic issues of safety to wider aspects of the disposal project and its alternatives. In their comments on the EIA programme The Ministry of Trade and Industry recommended that more attention should be given to the assessment of alternatives – even to those alternatives that were not legally available at present. Accordingly, Posiva prepared a structured assessment of the alternatives proposed for the high-level waste management. The assessment was made in three stages: first the broad alternatives including space disposal and other exotic proposals, secondly a comparison of the options that were considered realistic and finally a comparison of the reference alternative (the proposed project) and the zero alternative. At the final stages of the Parliament discussion of the DiP the alternatives came on top of the agenda: while the safety aspects were still questioned, the main comparison was between the risk of long-term interim storage (with wait-and-see attitude on permanent solutions) and the risk of geologic disposal. Two risk scenarios were contrasted: on the one hand, the scenario of an abandoned interim storage of spent fuel; on the other hand a leaking underground repository.

Similarly, at the local level of the candidate municipalities the main discussion moved to the question of what the local community would gain and what it would lose if it chose to accept the siting. Instead of risks it was more often than not the concern about *bad image* that was seen as the main negative impact. A clear distinction was also discernible between the candidate municipalities: the people of those candidate municipalities that had nuclear power plants in their area understood that the spent fuel already existed and was being stored, and the repository would mainly mean bringing the spent fuel from the surface storages to underground repositories; for the other municipalities the project would mean more essential changes. This distinction turned out to be important for the public opinion.

Scholarly critique

The Finnish EIA obtained a lot of interest from the social scientists and several studies have been made in which the process is critically reviewed. Several scientists noticed the shift of emphasis in the public discussion. Some of them described this as surprising and ungrounded and suggested that it was in fact Posiva who wanted to lead the discussion from thorny problems of safety to an area in which the arguments could be more in favour of the proposed project.

For Posiva the shift in emphasis was, indeed, welcome because it meant that the discussion was focused on the real decision-making situation: the DiP was not to judge if disposal would be safe or not, but it would answer the question whether Posiva should continue with preparing for the disposal and concentrate the site investigations on Olkiluoto. However, it was the public criticism and the official statements about the EIA programme that brought about the shift in emphasis, not Posiva's original proposal for the EIA programme that gave only a rather brief discussion of alternatives.

Lessons learned on risks

The experience obtained from the discussion around the EIA and DiP in Finland can be summarised in the following theses:

- Risk as a quantitative mathematical or engineering entity is not interesting to laymen. For laymen *risk* means primarily the possibility that a certain action may entail negative consequences.
- Outside the community of "risk professionals" the risks can mainly be discussed in terms of consequences and management of the scenarios that may lead to negative consequences; the modalities can only be discussed in qualitative terms, and even then the calibration of such qualitative descriptions may be difficult.

As a corollary to these theses it follows that for the stakeholder decisions on nuclear waste disposal quantitative risk estimates are of little value; more important is how much scope the decisions will leave for future action.

In what follows the theses are explained in more detail.

The problems of the mathematical risk concept come at two levels: First, the justification for the risk formula in which the probability and the consequence are in symmetric positions is questioned. For laymen, the quality of consequences is important and cannot be simplified to a number of deaths or other similar simple measures. Secondly, low or high probabilities can be distinguished by almost anyone, but when it comes to giving a numerical value to a "small" probability the answers may differ over an order of magnitude. So a small probability means completely different things for different persons. The same holds for other proposed measures of uncertainty and the problem is valid for laymen and professionals alike.

People are interested in risk scenarios. In discussing the risks of continued interim storage many people referred to news about collapsing societal systems in countries where such situation some years ago was still hardly imaginable. People also had an idea about the consequences of unguarded, uncontrolled storages of highly radioactive material. Against this was the scenario that with time the canisters buried in the bedrock would start leaking.

Still more important, however, was the sense of how these scenarios could be managed. Many Parliament members pointed out that the DiP would not mean that the project would be realised overnight. Instead, the project could still be improved, modified or even cancelled, if better solutions would become available (retrievability was generally considered as an essential requirement for disposal). On the other hand, at the moment there were no other realistic alternatives available for disposal and the rejection of the DiP would mean that no steps were taken at all to protect against the scenario of abandoned waste storage.

Such thinking is an example of the desire to manage the risks, instead of just choosing the risks. As explained by Strydom (2002) in his detailed account of risks in history, the introduction of new stakeholder groups into decision making on actions entailing risks will necessarily mean the end of the paradigm in which the experts assess the risks and the decision-makers then choose the lowest risk. The stakeholder participation means that the cognitive understanding of risks (constructivist risk) means more than the risk numbers. In addition, the experience shows that in such situation the focus is shifted from risk acceptance to risk management, to the question of how to act in a situation in which there are dangers of negative effects.

Strydom's description of changing risk paradigms is clearly visible in the present discussion of high-level nuclear waste disposal. Independent of the opinions of nuclear waste experts, retrievability and possibilities for long-term monitoring are highly valued in public discussion. Both ideas reflect the desire to incorporate some level of manageability in the waste disposal plans, how final they ever are supposed to be.

References

Posiva Oy (1999a), *Application for a decision in principle on the final disposal facility of spent fuel*. Posiva Oy, Helsinki (in Finnish).

Posiva Oy (1999b), *The final disposal facility for spent nuclear fuel – Environmental impact assessment report*. Posiva Oy, Helsinki.

Strydom, P. (2002), Risk, environment and society. Buckingham, Open University Press.

EXPERIENCE OF RISK PERCEPTION FROM OSKARSHAMN MUNICIPALITY

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General background

The Municipality of Oskarshamn is one of two Swedish municipalities currently subject to site investigations for a possible final repository for spent nuclear fuel. The site investigations follow feasibility studies in eight Swedish municipalities. The implementer Swedish Nuclear Fuel and Waste Management Company – SKB has plans to file a license application for a repository in 2008. The application must, among other documentation, include a comprehensive safety analysis report, a detailed site specific systems description and an Environmental Impact Assessment – EIA.

Licensing of a repository in Sweden is subject to three major acts – the Act on Nuclear Activities, the Radiation Protection Act and the Environmental Act. The Swedish Nuclear Inspectorate – SKI prepares the government decision according to the Act on Nuclear Activities. Radiation protection regulations that will have to be followed are set by the Radiation Protection Institute SSI. The Environmental Court prepares the government decision according to the Environmental Act. The municipality has the possibility to veto a repository according to the Environmental Act.

Introduction

Is a final repository safe? That is the key question for the public and the decision makers in Oskarshamn. Before other aspects of a possible final disposal can be discussed there must be a convincing answer to this question.

The main difference between a "conventional" project and a final repository is the comparatively extreme time span during which the spent fuel will have a high potential to threat human health and the environment, should the isolation of the spent fuel not work. The public is well aware and concerned by this fact.

The public is also well aware that the problem must be solved and that it should not be postponed posing a burden to future generations. From several polls there is a clear advice to the experts to continue to develop and test new technology in parallel to the continuous study of geological disposal. In summary the message from the public concerning our spent fuel is – OK go ahead and carry out site investigations for a geological repository but continue to invest in alternative technology where the time span can be shortened.

The consent of the public to a repository will require unbroken trust in the safety case. This does not necessary mean a detailed understanding of performance assessment and all the processes and events that are evaluated and calculated. In a complex safety case like this I would argue that there are probably not even experts that has a detailed and complete understanding of the entire safety case. In the scientific word various facts and quality assurance in a calculation is built up around publishing and peer review.

Where lack of knowledge exist and other uncertainties can not be removed the use of conservative assumptions and scenarios to test the robustness of the system must be used. One can say that if a conclusion is supported by a broad majority of experts it becomes a fact and remains a fact until replaced by another conclusion or theory. The public is well aware of this process and can give examples of the evolution of science in the past.

Siting of a repository is not a decision by experts. It is nor an issue of taking the risk-based decision making from the experts and give it to the public. It is rather the challenge to facilitate risk-based decisions by a sound and balanced participation by all stakeholders in their respective role. From many experts I hear this is not possible, participation requires a certain level of knowledge etc – maybe like a green card in order to play golf – I think such an expert position is a threat to progress in waste management.

In a democratic society final decisions are political and taken by laymen in government and in the case of Sweden also by the laymen in the municipality elected council. The other reality is that the elected decision makers can not take such a decision without public support and the public does not have resources or time to study the detailed safety case. To be provocative the final decision if a repository is safe or not is completely in the hands of laymen.

How then to establish that an acceptable safety case exist with the laymen decision makers?

This is a question that has concerned those of us working with the issue of siting a final repository for many years and I am quite optimistic that there are ways to reach rationale decisions also in a complicated safety case as a repository. There are many aspects of this work and it would take to long to cover them all. In order to trigger this working group discussions I have organised this talk around four key aspects:

- A clear description of what the project is all about and what the alternatives are.
- A well defined decision making process and clearly defined roles of the key actors.
- An open process allowing for participation and influence.
- Facts, values and stretching.

A clear description of what the project is all about and what the alternatives are

Spent nuclear fuel and high level waste is extremely hazardous for hundred thousand years or maybe more. If not handled correctly in the short term and effectively removed from the biosphere in the longer term it poses significant threat to many generations. Temporary solutions in the form a an interim storage may be OK for shorter time periods of say hundred years but for longer term a final solution must be found. The solution that most scientists and experts are suggesting is to finally solve the waste problem by disposing it in a geological formation. This is also what is reflected in the Swedish legislation. This is also what many national programmes initially has aimed for and it has been pointed out as the only solution but strong public opposition has brought especially the siting projects to a halt.

In response to public concerns the original goal – a final disposal – has been re-defined by adding features to comfort the public and decision makers. Phased decision making, long term monitoring, pilot plants, reversibility and retrievability are such additions. From a long term safety perspective none of these additions play any importance e.g. there are hardly points that stem from experts or performance assessment requirements. These are additions that have been introduced for management reasons because they are thought to ease public concern.

From the experience in Oskarshamn none of these additions are "required" by the public as often is referred to in waste management seminars and symposia. From our discussions in Oskarshamn we rather see the opposite required namely to bring a clear message about what waste management is al about, an open discussion about the general options – wait and see, long term monitored surface storage, transmutation, geological disposal etc with the public and the decision makers. These parties can among themselves with expert support work out the arguments and reach conclusions on the preferred option. One conclusion reached in Oskarshamn supported by 80% of the public and 49 out of 50 council members is that we shall continue to work on the geological disposal option by carrying out site investigations in preparation of a licence application. The public is here in pace with the experts – namely development of a geological disposal seems to be the preferred option as of now but the door should also be kept open for other alternatives. I do not think all programmes have this platform.

A well defined decision making process and clearly defined roles of the key actors

In complex decision making the format is as important as the content. Changing rules, parallel discussions about process and content, vague roles of the participants and a feeling of being excluded by the public are ingredients that will stop any nuclear waste project.

A system starting with a clear legislation, a stringent safety standard defined in advance, a clearly defined implementer with authority to propose solutions and sites, a strong regulator with a mandate to follow and review the implementer programme – and stop it if necessary, a local veto or at least a strong local role together with well defined decision making steps are what I would define as necessary ingredients of a sound national nuclear waste programme.

An open process allowing for participation and influence

Reality is that the public does not have much interest in a national R&D programme for how the nuclear waste is to be handled and disposed. The interest will arise when the finger is put on the map and potentially interesting sites are identified. From an expert point of view the programme has probably been running for decades and solutions are seen as mature. For the public a completely new issue is now on the agenda and they see this as the staring point and also see it as their right to question all and any aspect of the proposal. This is frustrating to the experts as they already see many questions as finally solved. Maybe this is the most critical point for any nuclear waste project and where probably the explanation is to be found why so many fail.

At this juncture the experts and laymen must meet, allow time for discussions and be prepared to give and take. If the experts takes on the role that they know all the answers and only takes it as an information problem there is again a large likelihood of failure.

The key is to take the time required for participation and influence. How can the project be set up to allow true participation by the local public and the local decision makers and how can the local expertise be utilised to form a better project? The answers to these questions are key to progress in any siting programme. For those experts and managers that do not think there is anything to learn from the public and local decision makers and that participation is only a burden I can foresee large problems and distrust.

Facts, values and stretching

With this fourth point I will try to address how to formulate the answer to the question from the public – is it safe?

As implied by the questions given to WG 1 in the invitation to this workshop answers are sought on questions on to what level should the safety case be presented to the public and decision makers. I am sorry to say that there are no answers to these questions. My answer is rather formulated as a recommendation on how to work – go out there and engage and you can be sure that the decision makers and the public will guide you to what level they are interested.

Important is to set up various forums where expert and laymen can meet. From our experience it is of crucial importance that the experts from the regulator participate in these forums.

Safety analysis does no only include facts but also contain value judgements on several levels.

My experience from Oskarshamn tells me that the answer to the question – is it safe? – contains two main components namely how the soundness of the system itself is perceived and secondly can the experts be trusted. The experts can roughly put in three groups – those who are developing the technical details (for the implementer) those who are critical and maybe also linked to the environmental groups and those working for the regulator who review and approve. The role of the regulator is often underestimated. A strong, competent regulator with the legal tools and resources to participate is based on our experience in Oskarshamn crucial if we are to reach solid and respected decisions.

For the critical experts from e.g. the environmental groups we must find forums where they can ask their questions and where these questions are addressed by experts from both the implementer and the regulator. The RISCOM project has developed a model how this can be handled. The concept of stretching is one important aspect of establishing authenticity by the experts and thus in the extension in their recommendations. To establish a demanding environment for the experts where the issues can be thoroughly stretched is one important ingredient if decision makers and the public will trust the safety case or not.

CONCEPTS OF UNCERTAINTY CLASSIFICATION AND NEW METHODS OF RISK ASSESSMENT FOR THE DISPOSAL OF RADIOACTIVE WASTE

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Introduction

Risk and uncertainty assessments are the topics of the Working Group discussions. "*How can tools and experiences from outside the nuclear waste field be used in the characterisation of uncertainties*" was one of the questions sent out to the participants. The authors of this paper are working for several years on the concepts of uncertainties and risks in geologic investigations. They came to the conclusion that the application of up-to-date mathematical methods is crucial for the handling of uncertainties and risk in geology in general, and particularly in the field of nuclear waste disposal (Bárdossy and Fodor, 2003). The results of their investigations and examples of their test calculations are reviewed in this paper, considered as an answer to the above question.

Definition of the uncertainties and their classification

Uncertainty is in our opinion a general term expressing a lack of certainty and precision in describing an object, a feature or a process. Of course, this is a first approximation. The term has been defined more precisely by mathematicians:

> *"Uncertainty implies that in a certain situation a person does not dispose about information which quantitatively is appropriate to describe, prescribe and predict deterministically and numerically a system"* (Zimmermann, 2000).

According to Dubois and Prade (2000) and Zimmermann (2000) the following types of uncertainties can be distinguished in mathematical respect:

1. *Imprecision or inaccuracy,* expressing the deviation of measurements from a true value. The term *error* represents the numerical difference of the measurement result from the true value. It is a well known axiom that all measurements inevitably result in some – even very small – error. The term *bias* is used in the case of consistent under- or over-estimation of the true value.
2. *Vagueness or ambiguity* expresses the uncertainty of non-statistical or non-measurable properties or objects. In these cases the measurements are replaced by observations or linguistic descriptions ("semantic ambiguity").
3. *Incompleteness* is a type of uncertainty when the amount of information or knowledge is insufficient to perform an adequate evaluation of the given problem.
4. *Conflicting evidence* when information is available pointing to a certain evidence, but there might be some further information, contradicting and pointing to another evidence.

5. *Belief* when all available information is subjective. In this context one must always distinguish *objective information* (measurements, descriptions, observations) from *subjective information.* The well known term *expert's opinion* belongs to latter group.

The above classification is valid for geological problems as well. However the complexity of most geological investigations require a more detailed classification. Recently such a classification has been elaborated by us, based on the *sources of uncertainty* (Bárdossy and Fodor, 2003, in press).

Only the main groups are listed here:

1) Uncertainties due to natural variability.

2) Uncertainties due to human imperfections and incomplete knowledge.
   2.1. In the phase of preparing the input data.
   2.2. In the phase of evaluation and modelling.

It is obvious that the different types of uncertainty need different methods of representation and mathematical evaluation. Natural variability is a property of Nature, existing independently of us. It can be studied, quantified and described, but it cannot be diminished. On the other hand, the uncertainties due to human shortcomings can be diminished to a certain extent. The fundamental difference of these two groups is often neglected even at recent geologic investigations. The above classification is of generic character. It must be completed by site specific and target specific types of uncertainties and this is the case of the disposal of the radioactive waste as well. The following types of uncertainties have been distinguished in the safety assessments performed by us, taking into account the internationally distinguished FEPs (features, events, processes):

1. *Uncertainties due to natural variability*. Structured and unstructured variability can be distinguished. Structured variability can be quantified and mathematically described by *trend analysis*. On the other hand, unstructured variability may occur unexpectedly, its spatial position and magnitude cannot be exactly predicted. The higher the proportion of the unstructured locations (spatial points), the higher is the uncertainty of the given site. Not only spatial, but also time dependent variables are among the FEPs, producing additional uncertainty.

2. *Uncertainties due to human shortcomings*.
   2.1. *In the phase of preparing the input data*
      2.1.1. Uncertainties of the concepts and requirements of the site selection
      2.1.2. Uncertain knowledge about the activity concentration of the waste to be stored in the given repository
      2.1.3. Uncertainties of the field observations at the future site
      2.1.4. Uncertainties due to incomplete sampling (outcrops, treches, boreholes, galleries)
      2.1.5. Uncertainties due to incomplete application of geophysical and geotechnical methods
      2.1.6. Incomplete selection of the types of laboratory measurements
      2.1.7. Analytical errors of the laboratory measurements

   2.2. *In the phase of evaluation and modeling*
      2.2.1. Conceptual and model uncertainties
      2.2.2. Uncertainties in the selection of possible future scenarios (base case, and additional cases)
      2.2.3. Uncertainties of mathematical modelling
      2.2.4. Uncertainties due to the incorrect application of mathematical methods

2.2.5. Uncertainties due to error propagation and the establishment of the final dose rates
2.2.6. Technical and other non-geological uncertainties

So far all safety assessments have been executed either by deterministic or by probabilistic methods. They are mathematically correct, but they have limitations, to be outlined in the next section.

Advantages and limitations of the deterministic and probabilistic methods

In the case of the *deterministic methods* the dependent variable is completely controlled by one or several independent variables. The input data have one (single) value, without any reference to their errors or uncertainties. Thus they are considered as true, crisp values. The final results are point-estimates, corresponding to the *best estimate concept.* This approach is straightforward, but do not take into account the inevitably existing errors and uncertainties. In our opinion, all input data of the safety assessments, seemingly precise (true), harbour some degree of uncertainty. Consequently, deterministic safety assessments can furnish unbiased results only if all FEPs are precisely known. To eliminate this shortcoming, single parameter *sensitivity analyses* are performed, one by one for the main FEPs. This procedure produces mathematically correct results, but again in the form of point estimates. For this reason the deterministic approaches are considered by us to be less suitable for the safety assessments.

The method called *worst case analysis* is an approach that acknowledges the presence of uncertainty in the system without modelling it explicitly. It takes into account the upper, or lower bounds of the distribution, attempting that no larger (or smaller) values will occur in the system. This approach has been applied in several safety assessments by designating “realistic”, “pessimistic” or “conservative” values. The realistic values correspond to the results of the “best estimate” and the latter expressions to the worst case. The method of their calculation is generally not presented in the safety assessment. The application of multiplication factors of 2, 5, 7, 10 and even of 100 to arrive to the “conservative” value lacks any geological justification and should be avoided. Experiences in other fields of research showed that many worst case analyses produced hyper-conservative results.

The well known *probabilistic methods* found broad application in safety assessments of several countries. These methods also operate with single (crisp) numbers as input data, but they express the uncertainty by probability distributions, and confidence intervals at chosen levels of confidence. In our opinion, the probabilistic methods have the following limitations for their application to safety assessments:

a) The uncertainties of several input data, listed in the foregoing section, cannot be taken into account

b) The basic axioms of the probability theory deal only with disjunct, mutually exclusive subsets. However in geology, including the sites of future repositories of radioactive waste, disjunct subsets are very rare. Transitions are much more frequent. At many sites there are more transitional zones than pure geological objects. In such cases artificial, sharp boundaries must be designated when applying stochastic methods. This is a gross distortion of the natural reality leading to biased final results.

c) Several statistical procedures require *repeated experiments (trials),* which implies that the variables must be random. Note that drilling and sampling of a borehole is in statistical sense also an experiment. Let us take a set of boreholes, drilled in a regular grid. The requirement of repeated experiments would mean repeated drilling of the grid after shifting and rotating the original grid locations. Obviously, such a procedure is unfeasible, even nonsensical. For this reason several statistics cannot be calculated in a mathematically correct way. Furthermore, uncertain propositions cannot be defined in terms of repeatable experiments.

d) Subjective probabilities, based on expert's knowledge cannot be correctly included into the classical statistical calculations.

e) The Monte Carlo simulation, one of the most frequently applied tool of numerical calculations of stochastic methods, generally works with the assumption of *independence* between the random parameters. However, this very rarely occurs in geological systems, particularly for the FEPs of the safety assessments. Interdependence of the variables may lead to significant errors in the final results. Finally, Monte Carlo analysis is inappropriate for semi-quantitative and qualitative input data and for non-statistical uncertainty.

For the above reasons probabilistic safety assessments might be more or less biased. As all the input data are crisp numbers, only the natural variability can be taken into account by the probabilistic methods. The errors due to human shortcoming, often of significant amount, cannot be correctly evaluated by the traditional methods. This is the reason for the application of the *uncertainty oriented* mathematical methods to be reviewed in the next section.

Review of the uncertainty oriented mathematical methods and their advantages

During the last decades new mathematical methods have been developed that are capable to handle the above listed limitations and shortcomings of the traditional methods. The first attempts were made with the aim to include subjective information and prior probabilities into the probability calculations. Note that probability is an abstract mathematical concept that may be defined in two different ways: *Frequents probability* is defined as a limiting frequency of a particular outcome in a large number of identical experiments. *Bayesian probability* can be defined as the degree of belief in a particular outcome of a single experiment. Thus it depends not only on the phenomenon itself, but also on the prior state of knowledge and the beliefs (experiences) of the observer. Bayesian probability changes with time, as our knowledge increases about the given phenomenon. This approach is called "Bayesian" because its proponents use the well known *Bayes theorem* of conditional probabilities for the calculation of subjective probabilities. In this context a *prior probability* is the probability of an event prior to updating, that is using new information. On the other hand, *posterior probability* is the updated probability of the event, based on all new information. According to our experiences the concept of Bayesian probability is suitable for the safety assessment of radioactive waste disposal, particularly to take into account valuable subjective information.

The *Dempster-Shafer theory of evidence* is another approach to use probabilities in subjective judgements. The theory is based on two ideas: obtaining degrees of belief for one question from subjective probabilities and the Dempster's combination rule for aggregating degrees of belief when they are based on multiple sources of evidence. The theory and its application are discussed in detail in the book of Bárdossy and Fodor (2003 in press).

One of the main tools of statistical calculations, including safety assessments is the *Monte Carlo simulation.* The method requires the knowledge of the probability distribution of each variable, their mean and variance. However this is in many cases not known. The bias due to the assumption of independence of the variables has been already mentioned in the foregoing section. Ferson (1994, 1996) pointed out that the results of Monte Carlo simulation often under-estimate the probability of high exposures and the high-consequence effects of such exposures. He suggested the application of "*dispersive Monte Carlo simulation*" under the assumption of linear correlation among the variables, and *„dependency bounds analysis"* when no assumptions are made about the type of correlation. Another solution is the application of the *Latin hypercube sampling*, assuring a more complete sampling of the sample space.

Let us stress that the frequently used term of "*uncertainty analysis"* was applied so far only to deterministic and probabilistic safety assessments, as the uncertainties and errors of crisp input data cannot be evaluated by these approaches. The main advantage of the uncertainty oriented methods is that they are able to describe the uncertainties by different *uncertain numbers.* The simplest of these methods is the *interval analysis.* It replaces the crisp input numbers by uncertainty intervals. It is assumed that the true value is somewhere within the interval. Interval analysis lacks gradations, but it guarantees that the true value will always remain within the uncertainty interval. During the calculations the intervals become wider and the final results are mostly hyper-conservative.

The *possibility theory,* a generalisation of the interval analysis, provides a suitable model for the quantification of uncertainty by means of the possibility of an event (Zadeh, 1978). The theory acknowledges that several types of data cannot be handled by probability distributions. Instead it uses *membership functions* to represent non-statistical uncertainty. The membership value of a number, varying between zero and one, expresses the plausibility of occurrence of that number. The related *fuzzy set theory* operates with fuzzy sets, that is, sets without clear boundaries and well defined characteristics. Fuzzy numbers represent estimates of uncertainty at different levels of possibility. Fuzzy numbers are by definition unimodal and they must reach at least in one point the possibility level one, that is the full possibility. The smallest and the largest possible values of the given variable represent the lower and the upper bounds of the fuzzy number. All arithmetic calculations can be carried out with fuzzy numbers. One of their great advantages is that they do not require the knowledge of correlations among the variables and the type of their probability distribution. They are not influenced by the limitations of the "closed systems". Fuzzy numbers can be reconverted into crisp numbers. This calculation is called *defuzzification.* But the main advantage is that prior geological experience can be incorporated into the construction of the fuzzy numbers. The frequent transitions of geological FEPs, mentioned in the foregoing sections can be also represented by fuzzy numbers.

The *probability bounds theory* is a combination of the probability theory with interval analysis. It expresses the uncertainty of the input data by two cumulative probability distributions. The area between the two curves represents the extent of uncertainty of the given variable. The advantage of this method is that it can apply different probability distributions, but the method works also without making any prior assumptions. The probability bounds get narrower with more empirical information about the given geological object (site). The calculations with this method are more complicated than with the foregoing methods. Nevertheless, it can be highly efficient for safety assessments, when prior information is abundant.

The method of *hybrid arithmetic* (Ferson and Ginzburg, 1996) combine probability distributions with uncertainty intervals, fuzzy numbers and probability bounds. Its greatest advantage is its ability to combine different uncertain input data. Guyonnet *et al.* (2003) suggested another hybrid method combining Monte Carlo simulation with fuzzy numbers.

In our opinion, no single uncertainty theory can be claimed to be the best for all types of uncertainty and all geological objects and situations. This is particularly valid for the case of safety assessments. According to our experiences the fuzzy set theory seems to fit well in most cases, because of its relative simplicity, transparency and its ability for the inclusion of prior geological information. But it can be completed, according to the site specific conditions, by the other methods outlined above.

Risk analysis and its application to radioactive waste disposal

Risk is a common term in science, economy and industry. The notion of risk has been defined in many different ways leading to much confusion. We apply therefore the definition of the Society of Risk Analysis: "Risk is the potential for the realisation of unwanted consequences of a decision or an action". Risk analysis is of particular importance for the safety assessment of radioactive waste disposal. To our knowledge, only deterministic and probabilistic risk analyses have been performed so far in this field. However, the evaluation of the related uncertainties is of crucial importance for the reliability of the risk assessments. This problem has been discussed recently in detail by Helton (2003) based on probabilistic methodologies. These methods are mathematically correct, but in our opinion not optimal. This is why we suggest the application of the above listed uncertainty oriented theories.

A common feature of the traditional methodologies is the assumption of linearity and independence between the input parameters. Unfortunately, this is almost never valid for the sites of radioactive waste disposal. As already mentioned above, the application of the traditional Monte Carlo simulation often leads to the under-estimation of the "tail-probabilities", that is of risks of low probability, but of severe consequences. The methods of fuzzy arithmetic and fuzzy logic have been applied to risk analysis first in the nineties, for industrial and ecologic problems. A joint stochastic and fuzzy approach for risk analysis has been published by Ru and Eloff (1996). A very attractive feature of this approach is that the output for each identified risk-factor is provided on the same scale, so that they can be directly compared. The hybrid approach of Guyonnet *et al*., (2003) mentioned above is able to take into account both crisp and uncertain data for the risk analysis. Thus it allows the quantitative assessment of the *reliability of the risk statements* of the given safety assessment.

It is of key importance that risk analyses should not be considered as a black-box system which magically provides answers that need to be fully trusted. The user should be able to follow each step of the risk analysis, checking and if necessary correcting it. This transparency is fully provided by the fuzzy methods, suggested by us. The application of this methodology is illustrated on two examples performed by us in Hungary.

Examples of safety assessments performed by the methodology of the fuzzy set theory

The first example is the acting repository of low and medium radioactive waste of **Püspökszilágy,** situated 32 km to the northeast of Budapest. Its construction has been finished in 1976. It is a surface repository located on the flat top of a low hill. The full capacity of the repository is 5 120 m^3. Two safety assessments have been performed in the year 2000, one by the AEA Technology (United Kingdom) and the other by ETV-ERŐTERV (Budapest), both applying deterministic methodology. The test calculations of the authors were carried out in 2002, based on the fuzzy set theory.

The hill is elongated in NW/SW direction and is flanked by two creeks, being the hydrogeological base of the groundwater system. The upper part of the hill consists of Quaternary loess of 5 to 30 m thickness. It is underlain by marine clay of upper Oligocene age, of 400 to 500 m thickness.

5 930 waste packages arrived to the repository until 31 December 2001. They have been disposed in four types of disposal units: most of the waste in large concrete vaults in plastic bags or in metallic drums. A smaller amount of waste was disposed in small concrete vaults in metallic drums. A further part in stainless steel wells of 40 to 100 and 200 mm diameter for sealed radiation sources. The repository is covered by a 60 cm thick concrete slab and a clay layer of 2 m thickness. The following

main components of the waste have been involved into the calculations: ^{3}H, ^{90}Sr, ^{137}Cs, ^{63}Ni ^{14}C and ^{239}Pu (the letter present in very small amount).

The following normal *evolution scenario* was established: The repository will be closed on 1 January 2006. It is estimated by the experts that the concrete slab cover will collapse gradually after 500 years. This allows the infiltration of meteoric water and the leaching of the radioisotopes will start. The solutions will migrate downward to reach the groundwater level, situated about 20 m below the bottom of the repository. Hydrogeologic boreholes established that the groundwater slowly migrates laterally, mainly in south-eastern direction, to reach the Szilágyi creek at a distance of 1 000 to 1 100 m. A smaller portion migrates south-westward to reach the Némedi creek at a distance of 400 to 500 m. The dissolved radionuclides will reach the biosphere along these two creeks.

First the activity of the six selected radioisotopes was established for the reference date of 1 January 2006, fuzzy numbers expressing their uncertainty. For the decay of the waste packages estimates were made by experts, based on their own experiments and on international experiences. Fuzzy numbers were constructed by us for all types of waste packages. Below the minimum value of the fuzzy number no escape of radioisotopes is estimated. On the other hand, when reaching the full membership, no more protection is estimated for the given type of package. Further fuzzy numbers were constructed for the decay of the of the disposal units.

In the next step activity concentrations were calculated by us for the leached radio-isotopes, just below the bottom of the repository. The results were listed in 58 time levels, ranging from the first to 100 000 years, separately for the six studied radioisotopes. The uncertainties are expressed again by fuzzy numbers. The estimation of the time interval of downward migration includes a large amount of uncertainty, that could be adequately expressed by a trapezoidal fuzzy number. According to the experts, no significant dilution of the solutions occurred during this downward migration. The activity concentrations (Bq/m^3) were calculated again for the 58 time levels at the groundwater level, below the repository.

For the time interval of the lateral groundwater migration further fuzzy numbers were constructed, the minimum time being 150 and the maximum 500 years for the Szilágyi creek. Hydrogeologic investigations demonstrated that the migration occurs almost parallel, no migration fans are formed. Laboratory measurements showed that 20 to 80 % of the dissolved radioisotopes are absorbed by the sediments during the lateral migration. The high uncertainty of these measurements can be taken into account by further fuzzy numbers. Finally the activity concentrations for the 58 time levels were calculated at the arrival of the solutions at the Szilágyi creek, that is the biosphere. The results were presented in tables and in time dependent diagrams. As a final step, the sum of the activity concentrations and dose rates were calculated, the uncertainty of the estimate expressed by fuzzy numbers. The results are in good agreement with a recently finished probabilistic safety assessment, the payoff being the sound and mathematically correct quantification of the estimation uncertainties.

A second safety assessment performed by fuzzy numbers has been finished recently for the underground repository to be constructed at **Bátaapáti,** in southern Hungary. The assessment is based on the recently finished geological and geophysical surface investigations. The repository will host waste of low and medium activity of the Paks nuclear power plant. The host rock is Carboniferous granite, fractured by Hercynian and Alpine tectonic movements. A special hydrogeologic model was constructed to take into account this particular feature. In 2000 a deterministic "preliminary" safety assessment was carried out by ETV-ERŐTERV (Budapest). For our safety assessment the construction of the fuzzy numbers occurred in the same way as in the foregoing case. Furthermore, a detailed mathematical model was applied, based on the model suggested by Hedin (2002). Instead of crisp numbers fuzzy numbers have been inserted into Hedin's equations. The results obtained are in good accordance with those of the deterministic calculations. The main advantage is the transparency of the calculation and the quantification of the uncertainties and of the overall reliability of the safety assessment.

Conclusions

Both theoretical evidences and the results of our test calculations demonstrate that the application of the uncertainty oriented mathematical methods for safety assessments is justified and useful. Their main benefit is the mathematically correct, sound quantification of the uncertainty of the given safety statement. The new methods are considered by us as complements to the existing deterministic and probabilistic methods.

The authors of the paper suggest to perform test calculations parallel with the traditional probabilistic safety assessments, based on the same set of input data. International cooperation would facilitate to start such calculations.

The mathematical correctness of the calculations is crucial for the success of the calculations. It is suggested therefore to involve skilled mathematicians into each test calculation.

Selected references

Bárdossy G., J. Fodor (2001), New possibilities for the evaluation of uncertainties in safety assessment of radioactive waste disposal – Acta Geologica Hungarica, 44, pp. 363-380.

Bárdossy G., J. Fodor (2003), Evaluation of Uncertainties and Risks in Geology – Springer Verlag. Heidelberg, New York, 230 p. (in press).

Dubois D., H. Prade (2000), Fundamentals of Fuzzy Sets – Kluver Academic Publishers, Boston, London, Dordrecht, 647 p.

Ferson, S. (1994), Naive Monte Carlo methods yield dangerous underestimates of tail probabilities. Proc. High Consequence Operations Safety Symposium, (SANDIA Report SAN94-2364, pp. 507-514.

Ferson, S. (1996), What Monte Carlo methods cannot do – Human and Ecological Risk Assessment, 2, pp. 990-1007.

Ferson, S., L.R. Ginzburg (1996), Different methods are needed to propagate ignorance and variability – Reliability Engineering and System Safety, 54, pp. 133-144.

Guyonnet, D., B. Bourgine, D. Dubois, H. Fargier, B. Come, J-P. Chiles (2003), Hybrid approach for addressing uncertainty in risk assessments – Journal Environ. Eng. Assos, 129, pp. 68-78.

Hedin, A. (2002), Integrated analytic radionuclide transport model for a spent nuclear fuel repository in saturated fractured rock – Nuclear Technology, 138, pp. 179-205.

Helton, J.C. (2003), Mathematical and numerical approaches in performance assessment for radioactive waste disposal: dealing with uncertainty – In: “Modelling Radioactivity in the Environment”, E.M. Scott (Ed.), Elsevier Science Ltd, Amsterdam, pp. 353-390.

Zadeh, L.A. (1978), Fuzzy sets as a basis for a theory of possibility – Fuzzy Sets and Systems, 1, pp. 3-28.

Zimmermann, H.-J. (2000), An application oriented view of modelling uncertainty – European Journal of Operational Research, 122, pp. 190-198.

WORKING GROUP 2

REGULATORY REQUIREMENTS AND REVIEW OF UNCERTAINTY AND RISK IN SAFETY CASES

SSI's REGULATIONS IN CONNECTION WITH POST-CLOSURE RADIOACTIVE WASTE DISPOSAL

M. Jensen
Swedish Radiation Protection Authority, Sweden

Background

In the Swedish Nuclear Activities Act and the Radiation Protection Act, the waste producer has the full responsibility for i) siting, construction and operation, ii) research and development and iii) financing in connection with disposal of all waste from the nuclear power programme. The Swedish Radiation Protection Authority, SSI, and the Swedish Nuclear Power Inspectorate, SKI, ensure compliance with safety requirements through their programme of regulations and license conditions, supervision, review activities directed towards the operator, the SKB's, programme and their independent research.

The authorities' role in the on-going siting process for a high-level waste disposal facility is to ensure that the siting process is consistent with the requirements in the Swedish Environmental Code regarding the environmental assessment process, and that SKB takes into account the authorities' view in the implementation of their programme for each step. In this process the authorities must strike a balance between their involvement and their independence, in order to be able to carry out a fully independent review of SKB's coming license application.

For the involved municipalities the Swedish Stepwise implementation of the siting process with regular review gives a possibility for the authorities to respond to views and questions from municipalities, organisations and the public.

SSI's regulatory activities

SSI's regulations SSI FS 98:1

The Swedish Radiation Protection Institute's Regulations concerning "the protection of human health and the environment in connection with the final management of spent nuclear fuel or nuclear waste" was promulgated September 28, 1998. The regulations are deliberately and carefully worded in a general style, to account for early steps of repository development. The Swedish Environmental Code requires alternatives solutions to be presented for the proposed way of reaching the goal, and the SSI's regulation cover all such solutions, including such alternatives as very deep boreholes and partitioning and transmutation. The regulations cover both high- and medium level repositories, and thus includes the repository SFR for Intermediate level waste from reactor operation, near Forsmark nuclear power plant. The regulations do not cover landfills.

In its general form, the regulation addresses a large number of issues, such as:

- consequences outside Sweden's borders relating to national equity;

- optimisation and best available technique;
- environmental protection, i.e. protection of non-human species;
- protection of human health, using ICRP's consequence estimates, and a yearly maximum risk level of 10^{-6};
- intrusion and access issues with emphasis put on the undisturbed repository's safety; and
- two time periods with separate requirements. The periods are i) the first thousand years, and ii) the period after the first thousand years following repository closure.

The regulations defines a standard, but its condensed structure does not give guidance as to how the different requirements are to be understood and met in detail, such as is needed in a compliance demonstration.

In connection with the promulgation, SSI published comments and background material to the regulations, published in English in SSI Report 2000:18. These were mainly written to assist SSI's board in their decision to promulgate the regulations, and to explain the regulations to a broader audience. They explain some of the concepts in more detail than the regulations, and they also give justification for some of the decisions behind the regulations.

Experiences accumulated in the time since the promulgation of the regulations, and the progress in SKB's programme implementation has prompted SSI to publicise its assistance and advice in the form of a formal guidance document related to the regulations. The experiences mainly come from a dialogue with both the public, especially from the involved municipalities, and from SKB. These, and other stakeholder groups, have formulated questions regarding the regulations in statements, in part solicited by SSI in a series of meetings directed towards the regulations, regarding all aspects of the regulations but particularly about the concept of health risk limitation.

The scope of the guidance is limited to geologic disposal, which allows for a much more focused treatment, relevant for the current radioactive waste programme.

SSI's work on the guidance document takes up a number of issues, such as:

- Optimisation and best available technique. Today, ICRP proposes a broader definition of optimisation than before and this need to be reflected in the guidance. Best available technique, BAT, can sometimes be used in parallel with optimisation, but in some cases, optimisation may not be possible even if all exposure patterns are known, i.e. for protection of the natural environment.
- to what extent can ICRP's interpretation from publication 81, that siting issues play a role in optimisation, be expressed in regulatory documents?
- Human intrusion. Human intrusion is an illusive concept in more ways than one. The probability of its occurrence and the form of the intrusion are examples that may lead to endless speculation, unless precautions are taken. This is already recognised in the regulations to some degree, but there are still a number of questions, which may need guidance. Some examples are:
  - Where should the dividing line between intrusion and the undisturbed case be drawn for shallow depth repositories (tens of meters)? Is it intrusion to drill a well near, but not through, the repository?

- What is a reasonable effort in proving the mitigating or self-healing properties of the chosen repository concept?
- Should the value of post-closure archives in promoting a passive institutional control be expressed in the guidance?

- Definition of end-points. Issues related to the person(s) receiving the highest dose. Both USEPA and USNRC use a hypothetical test person, but ICRP has two concepts, the test person which is mentioned in publication 43 and the critical group from publication 81.
- Dilution. Is it acceptable that the main contribution to compliance is dilution in the Baltic Sea (or other water bodies) for a repository that would otherwise not be accepted?
- Technical issues, such as treatment of geosphere-biosphere interface. In radionuclide transport from the rock to the biosphere there are a number of potential accumulation processes must be taken into account.

SSI's work with the guidance document is planned to be finalised in 2004, and it includes both national and international consultation.

THE MANAGEMENT OF UNCERTAINTIES IN THE FRENCH REGULATION ON DEEP DISPOSAL: THE DEVELOPMENT OF A NON-RISK BASED APPROACH

P. Raimbault
DGSNR, France

The development of a safety case for disposal of high level and medium level long-lived waste in a geological formation has to handle two main difficulties:

- uncertainties associated to natural systems;
- uncertainties associated to the consideration of long time scales.

Licensing of the different steps leading to geological disposal implies thus that a sufficient level of confidence in the safety case will be obtained, at each step, among the different stakeholders.

The confidence in the safety case relies on the whole set of arguments of different natures which complement each other and build up the file. This means that, to be defensible, the safety case should be organised in such a way that it can be reviewed and scrutinised in a structured manner. This also means that individual elements of the safety case will have to be considered separately even if all elements should fit well in the integrated safety case. This segregation implies some inherent decoupling of parts of the system, of its evolution over time and of the events that may impact on it. This decoupling will thus introduce inherent uncertainties that risk or non-risk based approaches have to deal with since both approaches have to introduce transparency in the analysis. In the non-risk based or deterministic approach this segregation is pushed further in order to put into perspective the different elements of appreciation that allow to judge the safety case as a whole.

The French regulation on deep disposal presented in the basic safety rule RFS III.3.f, issued in 1991, takes these points into consideration to set the basis for the safety case in the framework of a deterministic approach. This basic safety rule is currently being revised in order to clarify some concepts and to take account evolution of ideas at the national and international level. However the basic rationale behind the safety assessment methodology will remain the same.

The approach presented in RFS III.2.f implies that at different levels in the safety case the emphasis is given on the transparency and traceability of the assessment and the arguments being developed rather than on the performance value in terms of dose or risk which is only one element of judgement among the whole set of arguments that are being reviewed in order to assess a safety case.

The present document will thus stress the basic choices made in developing RFS III.2.f that allow to put forward the different arguments of safety in order to build up a defensible safety case which may be thoroughly reviewed.

These elements may be identified as follows:

- complementary lines of evidence;
- focus on limited number of representative situations;
- multi-attribute judgement of radiological impact;
- thorough management of uncertainties.

These different aspects will be developed and compared with the situation when a risk-based approach is used.

The different components of the safety assessment

The basic philosophy of RFS III.2.f is that compliance with radiation protection objectives is only one element of the safety case. As indicated in the safety rule, the safety assessment should address the following elements:

- assess the adequacy of the components of the repository justifying their suitability by qualitative and quantitative arguments including traceability, quality management and qualification procedures;
- check the robustness of the repository by considering the different kinds of events and processes that may affect it and prove that there are adequate lines of defence in front of these events (in a qualitative and quantitative way);
- assess the future evolution of the repository and verify that radiation protection objectives are met.

The safety assessment, as described in the basic safety rule RFS III.2.f, comprises thus a set of qualitative and quantitative arguments that build up confidence in the safety of the disposal system.

This approach, presented in the safety rule, shows an evolution from the original trend of restricting the judgement on the safety case on the assessment of a global risk. Emphasis is given on the development of multiple lines of evidence which complement each other. This approach has been adopted at the international level and constitutes now the basis for the safety case recommended by the OECD/NEA. Therefore the risk approach, when it is used, concerns now only one of the different components of the safety case, the quantitative analysis which should assess compliance with radiation protection objectives.

Scenario analysis

In order to assess the future evolution of the repository the basic safety rule RFS III.2.f recommends to use a transparent method by considering a limited number of situations representative of the different families of events or sequence of events that may affect the repository.

The situations are classified into likely situations which take into account highly probable events and processes and for which consequences are the most important bases of judgement, unlikely situations where consequences as well as frequencies are considered and very unlikely situations which may have high consequences and for which the judgement is based mainly on the justification of the low frequency of the situation. Other situations associated with future actions are treated separately with stylised assumptions.

The RFS III.2.f recommends to analyse each type of situation separately and to draw an overall judgement on individual compliance for each situation.

In the case of a global probabilistic risk approach each situation corresponds to an individual sampling of all possible events and values of parameters in the time period of interest. Hundreds of situations or realisations are thus derived each leading to a different impact from the repository. The complete distribution of possible impacts allows to calculate a risk.

This global probabilistic risk approach is now seldom used even in the framework of a risk based assessment and the consideration of a limited number of representative situations is often preferred each leading to the estimation of an individual dose or risk. Judgement should therefore be used to put the emphasis on consequences associated to certain types of situations rather than others.

The restriction of the analysis to a limited set of representative scenarios clearly improves the transparency of the assessment and helps structuring the review of the safety case. It introduces however some uncertainties by not taking into account the complete set of combined events which are considered when using the full probabilistic approach described above. This implies that both for the risk approach and the deterministic approach a trade-off should be made between transparency and completeness.

Compliance with radiation protection objectives

In the RFS III.2.f, the radiation protection objectives for assessing compliance depend on the types of situations:

- For very unlikely situations the emphasis is given to the probability of the corresponding events and illustrations of the consequences.
- For likely situations a dose or several dose calculations are performed. The objective is to judge what are the margins between the result and the objective but more importantly the sensitive elements that may affect these margins. The emphasis is given to these sensitive elements and the safety case indicates all the efforts that have been put forward by conceptual design, R&D and site investigation in order to reduce uncertainties associated with this sensitive elements.
- For unlikely situations all arguments are considered and weighted to judge the acceptability of consequences. The comparison of the product of the consequence by the probability to the risk constraint is just one line of argument.

These objectives show that, even for a non-risk approach, frequencies of occurrence and probabilities are considered for judging the case. However, in a deterministic approach, and in contrast with the risk approach, consequences, probabilities and other elements of judgement are considered individually in the framework of a structured and transparent process. This is an important feature because each of these elements is not obtained with the same level of confidence and it should be given the appropriate weight in the global judgement.

Management of uncertainties

Uncertainties are the main sources of lack of confidence in the development of the safety case. The RFS III.2.f stresses that these uncertainties should be adequately addressed in an open manner and that they should be the basis for going from one licensing step to the next by improving site characterisation, experiments and design studies.

The different sources of uncertainties should be assessed: parameter uncertainties, uncertainties associated with simplification of modelling, conceptual model uncertainties, uncertainties associated with poor understanding of physical processes, uncertainties associated with unpredicted events or human behaviour. It is clear that only part of these uncertainties will be addressed with a probabilistic approach. Therefore the derived risk may not take into account all sources of uncertainties. In any case uncertainties should be thoroughly discussed in the safety case stressing the means which have been used to identify and reduce them. Application of basic safety principles such as demonstrability and robustness of the repository system will increase confidence and reduce overall uncertainty in long term behaviour.

As for quantifiable uncertainties, their influence on the radiological impact should be addressed. In a probabilistic approach, with a dose or risk criterion, this may be done using probability distribution functions and statistical sampling techniques. In a deterministic approach this is usually done by choosing, for individual parameters, best estimate and bounding values. The difficult question is the choice of the range of values to be retained or the choice of the distribution function. Important aspects in the process are thus the elements of judgement that have been used to make the above choices and how they have been traced. In any case, using a performing method for sampling values of parameters on their probability distribution functions and calculating a confidence bound or a risk do not resolve all uncertainty issues for a specific safety case.

Conclusions

The safety case of a HLW repository in a geological formation should satisfy two requirements. It should take into account all the informations about the components of the repository system and their evolution over time in an adequate manner in the objective to manage uncertainties in a uniform, systematic and logical framework. It should as well be transparent for the different stakeholders meaning that they should be able to appreciate the weight given to the different assumptions which have been used. The French basic safety rule RFS III.2.f, now under revision, emphasises the importance of both objectives for the safety case. It stresses the importance of using multiple lines of evidence, complementary qualitative and quantitative arguments and more important to develop a transparent and structured safety case that can be easily reviewed. The approach described in the basic safety rule does not advice to use a risk criterion and is thus considered as a deterministic approach. Nevertheless it takes into account probabilities of situations as one element of judgement and is open to treatment of uncertainties with probabilistic techniques which may be compatible with compliance associated to a dose criteria.

SESSION 3

STAKEHOLDER INVOLVEMENT – PART II

Chair: Saida Laârouchi-Engström, SKB, Sweden
Vice-chair: Veijo Ryhänen, Posiva Oy, Finland

1. Objectives

Siting any nuclear facility today is not only a scientific or a technical challenge but also a social and a political one. It is a common understanding in our societies to involve all stakeholders to participate early in the process of decision making.

Attention should thus be paid to the implementing organisations' interaction with stakeholders and also to the views of the local/regional stakeholders since they are the ones directly concerned by the siting of e.g. a geologic repository.

The purpose of Session 3 is to highlight one specific stakeholder namely the representatives for decision makers at the municipality level. The challenge they often meet has to do with the complexity of the decisions to be taken. Political and social decisions will be taken on matters of high scientific and technical complexity. The session aims to give an overview of the experience of siting a final repository for nuclear waste seen from a community or municipality's point of view. Speakers will talk about lessons learnt, challenges met and also describe what should characterise a good decision-making process in view of siting a nuclear waste management facility.

2. Issues that will be examined

- What are the lessons learned by decision makers at the municipality level from siting of nuclear facilities?
- What are the main challenges met by local decision makers in this respect?
- What would characterise a good decision-making process all aspects taken into account?

Programme

Chair: **S. Laârouchi-Engström**, SKB, Sweden

Vice-chair: **V. Ryhänen,** Posiva, Finland

F. Dosé, Meuse MP and Mayor of Commercy, France

A. Lucander, Municipality of Eurajoki

M.J. Song, Nuclear Environmental Technology Institute, Korea Hydro and Nuclear Power Co., Korea

P. Wretlund, Mayor of Oskarshamn, Sweden

Discussion participated by the audience and panel.

C. Bataille, MP, France

A. Lucander, Municipality of Eurajoki, Finland

C. Thegerström, SKB, Sweden

M. Westerlind, SKI, Sweden

P. Wretlund, Municipality of Oskarshamn, Sweden

Moderator and Rapporteur: **S. Laârouchi-Engström**, SKB, Sweden

RADIOACTIVE WASTE MANAGEMENT: THE DECISION-MAKING PROCESS (BURE, MEUSE, FRANCE)

François Dosé
Meuse MP and Mayor of Commercy, France

In 1991, at the initiative of a left-wing government, the French Parliament as a whole and irrespective of the political parties involved, adopted an ***act on the management of high-level long-lived radioactive waste.*** The document prescribes three research areas:

- reversible or irreversible disposal in a deep geological formation;
- transmutation… partitioning; and
- improvement of waste packages.

In 1993, at the initiative of a right-wing government, after legislative elections, it was decided to implement the 1991 Law, also known as the "Bataille Law", from the name of its proponent (Socialist MP).

The new Prime Minister then entrusted Mr. Bataille, who had been re-elected MP – but in the opposition, this time – a specific mission: to convince a few territorial communities to submit their applications…

On the whole, the two research areas allotted to existing laboratories did not pose any acceptance issues with researchers, but the selection of a natural site was much more sensitive.

I must say that, by structuring the management of high-level long-lived waste on behalf of public authorities, the 1991 Law finally put an end to some pretty strange practices: upon several occasions during the 1980s, the Minister of Research and Industry had simply issued decrees ordering some geological studies to be conducted in preparation for a future underground repository, but with no intention of holding a parliamentary debate… The strong opposition of local populations disheartened the project owner and the operator, so much so that it led to a democratic achievement in the form of a legislative reference.

At that time, I was the mayor of a small French town in Lorraine; I was also elected to both our Regional Assembly and to the Council of our department, the Meuse. Since the geological features of our department are very stable thanks its clay formations. I was associated with the search of suitable sites for the implementation of an underground laboratory.

The decision-making process was based on the following principles:

- *if the Departmental Council refused* the implementation of the underground research laboratory on its territory… *all other investigations would stop*, and
- *if the Departmental Council agreed* – after a debate – to the implementation of an underground research laboratory… *a call for volunteer applications would be launched throughout the communes* of the department.

After listening to the issue at stake, as explained by Mr. Bataille himself, the Meuse Departmental Assembly accepted unanimously – and irrespective of the political affiliation of its members – the potential implementation of such a laboratory in our Department.

The discussions – at the department level – were sometimes tough, but *without consulting either the public or other representative institutions, we agreed on a unanimous decision:* I know, because I was there! That was ten years ago. Today, in an effort to understand better the current debate, perhaps it would be useful to highlight the *five most significant observations that were made back then:*

1. *"Our decision is not binding… but only permissive";* if no territorial application is submitted, the case would be closed, but it would open up the way… for others."

2. *"80% of all French electricity is generated by nuclear power…* We ALL benefit from it EVERYWHERE… Everyone should therefore contribute in his own way to the well-being of the public utility (Électricité de France): some have power stations, while others end up with an entanglement of poles and cables. Whether we are pro-nuclear or anti-nuclear, *a solution has to be found to manage the waste."*

3. "Since the *population rate is low in this department* (200 000 inhabitants for 500 communes), not to mention tax revenues, the proposed financial subsidies would have a considerable impact at all levels:

   - the Departmental Council approving the project;
   - the host communes where the worksite would be actually located; and
   - the adjacent communes to the host communes.

   (I must also add that three departmental councillors proposed an amendment to refuse subsidies in order not to alter the debate: a conservative, a liberal and I, a socialist). All in all, only four people voted in favour of the amendment!"

4. "The 1991 Law prescribes that *the implementation of underground laboratories (in the plural)* shall make it possible to validate the suitability of the rock shield by 2006, as scheduled. Obviously, the idea that the risk was shared geographically with others made acceptance easier."

5. "The Departmental Council agreed that:

   - if communes actually apply;
   - if one of them is selected for the implementation of an underground laboratory; and

- if the laboratory becomes later a disposal facility, the irreversibility of the waste repository would never be considered…”

Today, since I am here with you, in Stockholm, you may easily guess what happened in the meantime:

- *as early as 1994,* four communes… or more exactly *four groups of communes submitted their applications.* I must admit that the fact… the mere fact… for those volunteer communes to apply meant a non-negligible and almost miraculous financial input.

- public authorities designated Andra, the French Radioactive Waste Management Agency, as the operator of the new project. The Agency put its technical and scientific skills at work in order to validate the best application; other interveners, such as the Departmental Council and local personalities took over the responsibility to appease or discard any remaining apprehensions… sometimes through persuasion… sometimes through contempt… In the end, the ministry in charge finally gave the green light.

Hence, after a long period of political procrastination shaken by electoral deadlines and their trails of negotiations and compromises – all within an acceptable legal framework, mind you –, *the first worksite of its kind was launched in France at the dawn of the third millennium.*

Now, in December 2003, civil-engineering activities are definitely very advanced… but also definitely a very long way from the ultimate goal, while optimists and pessimists assess the same mathematical reality on the basis of their own opposite convictions.

At the end of this brief presentation, please allow me to present a few suggestions, without really concluding:

1. *The debate on the public utility and the social utility of that specific research area, on one hand, and the confrontation between territorial opportunity and national necessity,* on the other, certainly have the democratic legitimacy granted by legally and democratically elected decision-making authorities (Parliament, Departmental Council, Municipal Councils), but there were no exchanges with the other intermediate bodies, before and after political decisions were taken, or those exchanges were so clumsy that we are still experiencing in our close community life and on a daily basis, some signs of hatred, resentment, violence and disruption that are often excessive, but perfectly understandable.

   In order to reach a final decision, living in a participatory democracy may seem to be insufficient, but it is necessary, healthy and essential, and there is no reason why it should not be effective. That last point was unfortunately forgotten.

2. Financial incentives were not “diabolical” *per se*, and certainly did not bear with them all sorts of perversions, but the lack of precision – or even the opacity – of the terms and conditions of the attributions, the variable geometry of the subsidy amounts, the failure to understand the nature of the allocations due to an absence of priorities all resulted, notably during the first years, in undermining the moral and ethical credibility of those people – whether elected or not – who were supposed to defend the collective interest and the relevancy of the project.

3. The need to establish a sound debate – in words and attitudes – in a spirit of both confidence and respect, the legitimacy of feelings and of good old common sense, the terminology used by scientists, the management methods of the operators, the relevancy of the various authorities and counter-authorities were never a real concern and both sides preferred to remain barricaded into their own certainties.

4. *The ambiguity between words and reality*

   On one side, you have irreversibility, a disposal concept that has not been discarded completely as a working hypothesis… On the other side, you have a plan for several "laboratories" to be implemented, and yet, there is actually only one in France for the time being… Furthermore, you have deadlines, notably the 2006 one, that are already impossible to meet, and yet, are still being maintained… Finally, you have those Members of the National Assembly who vote in Paris for a scientific research area, but join anti-nuclear opponents who demonstrate in the streets not to have any nuclear facilities in their own constituencies.

   All those factors certainly do not promote the primacy of the general interest.

5. *The difficulty to submit ourselves to a scientific assessment is also linked to the nature of the product itself*. The combination of two words, "radioactive" and "waste", express the fear and mistrust haunting us: "Waste"… means death! "Radioactive"… reminds us of Hiroshima!

Is a disposal or burial facility not compared to a "trash can" or a "cemetery"? Any mention of radioactive waste obviously evokes the notion of nuclear energy. Malraux once wrote: "Even when life does not seem to be worth anything, nothing is more valuable than life." As we know, it is easier to accept to deal with the hazards of a nuclear power plant as a "vital source of energy" than with the lesser risk of a waste repository associated with the decay and the "death" of a substance.

Perhaps the solution lies in bringing both of those notions of radioactivity together and disposing of nuclear waste close to its production site… as it is the case in Finland?

If this contribution – however incomplete and prejudiced as it might be, but always respectful of the various opinions of all stakeholders – may help you in your discussions, then it will not have been made in vain.

EURAJOKI: THE MOST ELECTRIC MUNICIPALITY IN FINLAND

A. Lucander
Municipality of Eurajoki, Finland


5th nuclear power station to Olkiluoto
decision 15.10.2003
permanent jobs for 150-200 persons
direct effect at the construction site is, estimated to be from 11,000 to 13,000 man-years
during the 5 year construction time 1000-2000 persons will be placed in Olkiluoto


Eurajoki municipal council
parties:
center party 12
social democrats 9
coalition party (right) 4
– left union 2
TOTAL 27


The Process of Stepwise Decision Making in Finland
The role of municipality is important according to the Finnish law.
Discussions during the 70's concerning spent fuel


The Process of Stepwise Decision Making in Finland
1983 target schedule set forth by the government for final reposition of spent fuel from Olkiluoto into the Finnish bedrock.
Eurajoki's strict negative position against final disposition until December 1994.


The Process of Stepwise Decision Making in Finland
Negative clause removed from municipality's strategic plan after voting result 15 – 10.
Discussions started "from clear table"


Important milestones for the local decision makers:
1983 the Government's decision about time schedule for final disposal of spent fuel


Important milestones for the local decision makers:
1994 the Nuclear Act was amended by the Parliament so that since 1996 nuclear waste could not be exported from Finland. At the same time, importation of nuclear waste to Finland was prohibited.


Important milestones for the local decision makers:
Environment Impact Assessment (EIA) –legislation.
Founding of Posiva Oy.


Final local discussion period did take about 5 years
Working groups like:
- Liaison group Municipality/Posiva
- Liaison group Municipality/TVO
Municipality's strategy plan Eurajoki 2000 starting with 4-field SWOT analysis


Final local discussion period did take about 5 years
EIA process formed an excellent platform for public and open local discussions.
Results of research and investigations have been presented in open EIA-seminars.


Final local discussion period did take about 5 years
Final acceptance for Decision in Principal Application was given in municipal council meeting 24.1.2000. Result 20 – 7 in favour of the project.

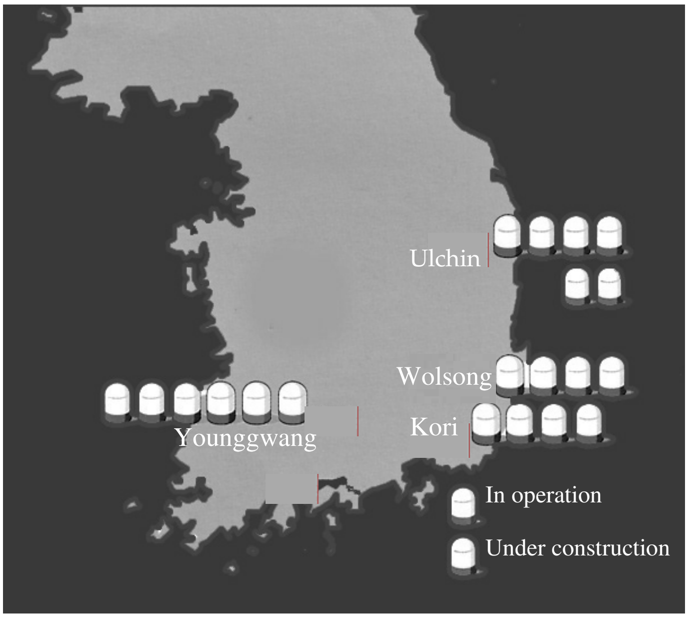

Final local discussion period did take about 5 years
Important for favourable decision was that only spent fuel produced in Finland may be reposited

SITING A FINAL REPOSITORY FOR LOW- AND INTERMERDIATE-LEVEL WASTE IN KOREA

M.J. Song
Nuclear Environmental Technology Institute
Korea Hydro and Nuclear Power Co., Korea

Introduction

- Nuclear Power Generation in KOREA
  - 18 NPPs in operation
  - 2 NPPs under construction
  - 6 NPPs are to be constructed from 2004
    - 15.7 GWe (total electricity power capacity in 2003)



- Radioactive Waste Generation in KOREA
  - Arising of LILW from:
    - Nuclear Power Plants (NPPs)
    - Application of Radioisotope (RI) Users
  - Amount of radioactive waste storage in drums (June 2003)

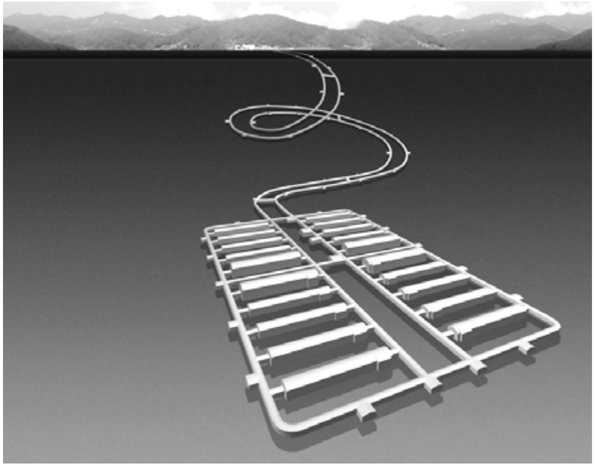
Location	Number of Reactors	Storage Capacity	Cumulative amount	Year of Saturation
Kori	4	50 200	31 724	2014
Yonggwang	6	23 300	11 372	2011
Ulchin	4	17 400	12 825	2008
Wolsong	4	9 000	4 354	2009
TOTAL		99 900	60 275	
RI Waste		9 277	4 743	2010

National Radioactive Waste Programme

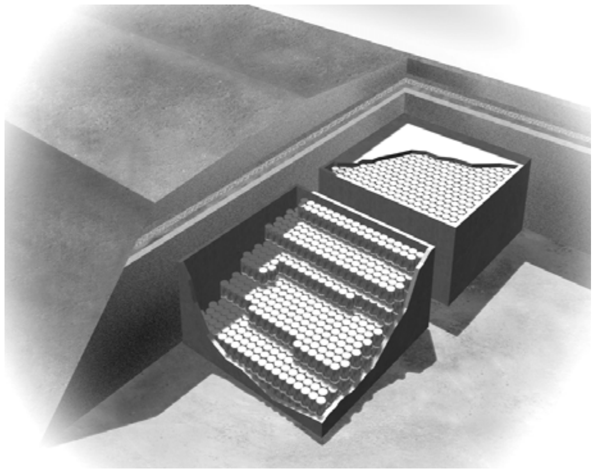
- Radioactive Waste Management Principles
  - Approved by Atomic Energy Commission:
    - 30 September 1998
  - Fundamental Principles:
    - Direct control by the government
    - Top priority on safety
    - Minimisation of waste generation
    - "Polluter pays" principle
    - Transparency of site selection process
- Implementation and Construction Plan for LILW
  - On-site management of LILW:
    - LILW should be minimized at its generation sites until the opening of a repository at 2008.
  - LILW repository will be opened from 2008:
    - 100 000 drum capacity (Phase I)/800 000 drum (Final)

On-site storage in concrete buildings (10 buildings) ← **2008** → **Final disposal at a repository**

Determination of disposal type



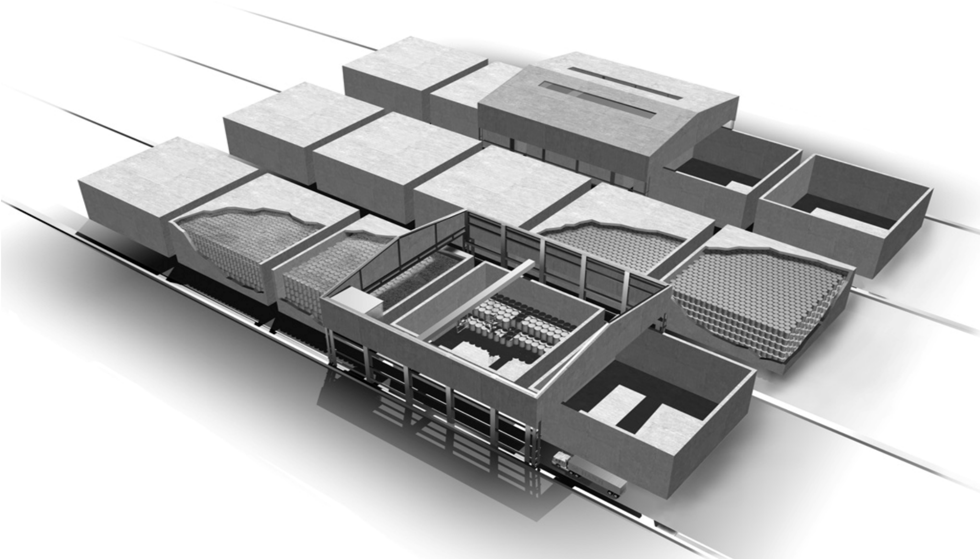
Rock cavern type



Vault type

Radwaste disposal facility

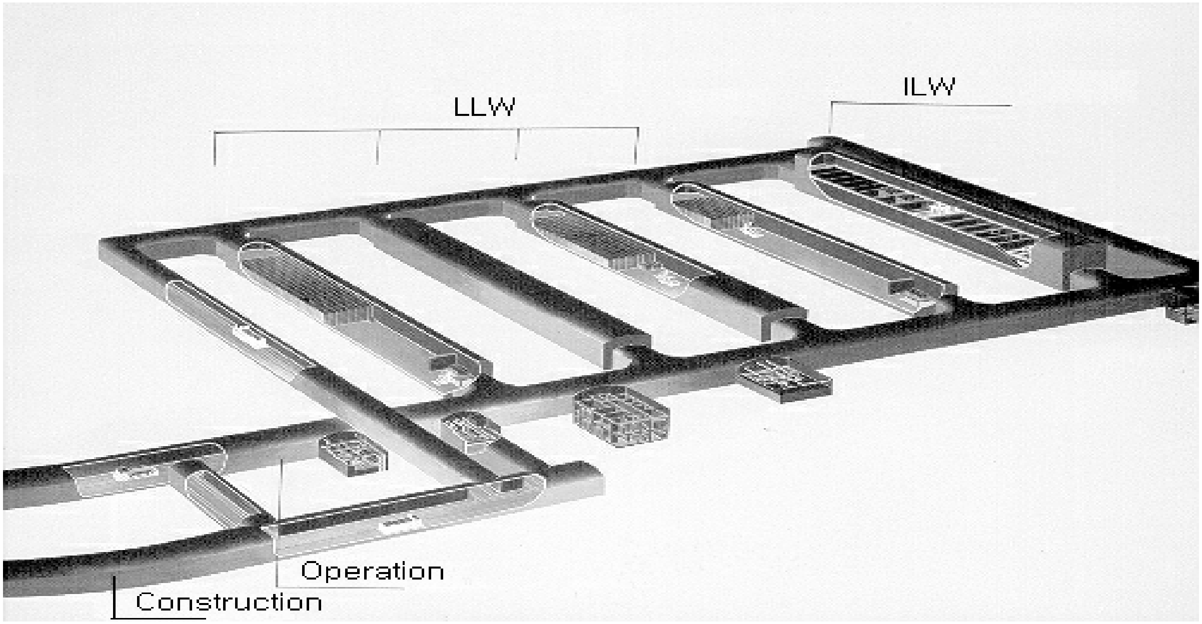
- Vault-type disposal facility
  - Dimension of a vault: 20 m x 20 m x 8.1 m
    - Disposal capacity: 5 000 drums/vault
  - Mobile roof during the waste package loading
  - Final cover: 6.4 m thick multi-layer system
    - Low percolation, water drain, intrusion resistance



- Rock Cavern-type disposal facility
  - Entrance tunnels
    - Operation tunnel
    - Construction tunnel
  - Disposal caverns
    - Remote handling caverns

      19 m (W) *x* 21 m (H) *x* 140 m
    - Contact handling caverns

      20 m (W) *x* 10 m (H) *x* 140 m



History of disposal site selection

- 1986 Commencement of radioactive waste disposal site selection
- 1988~'89 Attempts for siting in eastern seashore:
  Yongduk, Ulchin and Youngil
- 1990~'91 *Anmyondo* was selected (226th AEC) and cancelled
- 1995 *Gulupdo* was proposed and cancelled
- 1997 KHNP took over the responsibility for siting

Past site selection activities

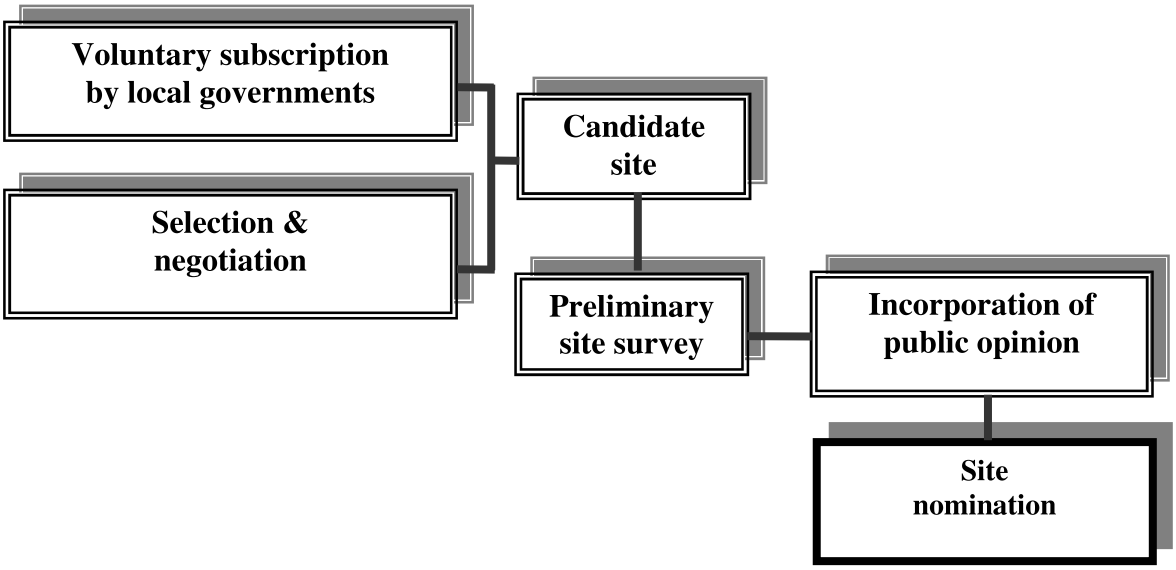
- Attempt for siting in eastern seashore (1988~'89)
  – Stopped due to opposition by local residents

- Anmyondo (1990 ~'91)
  – Cancelled due to strong opposition by local residents

- Gulupdo (1995)
  - Cancelled after discovery of active faults

KHNP's site selection strategy

- Voluntary application of local government
- Negociation with local government after the selection of the candidate site



First attempt for open solicitation

- Site subscription results (June 2000 ~ June 2001)
  - Nine (9) communities were organised in coastal areas for the voluntary site subscription
  - Seven (7) communities submitted petition to their local governments
  - All petitions were rejected by the local governments

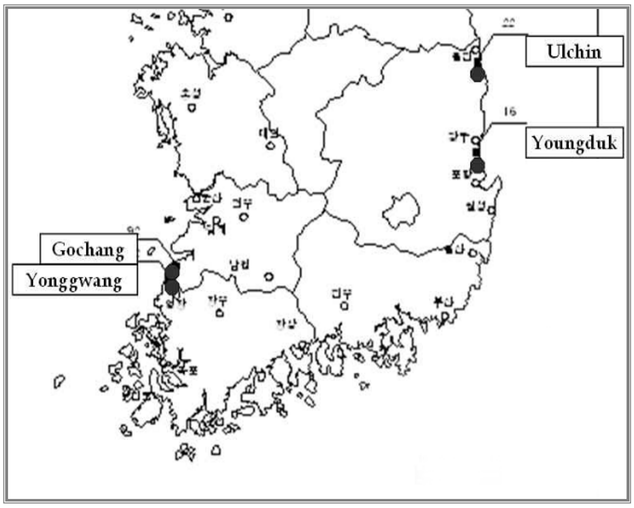
Community	Petition date	No. of petitioner/No. of voter	Ratio(%)
Yonggwang	21 July 2001	21 636/49 400	43.8
Gochang	29 July 2001	13 573/54 000	25.1
Kangjin	15 July 2001	16 387/37 000	44.3
Jindo	28 July 2001	6 150/32 000	19.2

Candidate site announcement

- Announcement of 4 candidate sites (4 February 2003)
  - MOCIE and KHNP
  - Two sites in eastern coastal area
    - Youngduk and Ulchin
  - Two sites in western coastal area
    - Younggwang and Gochang

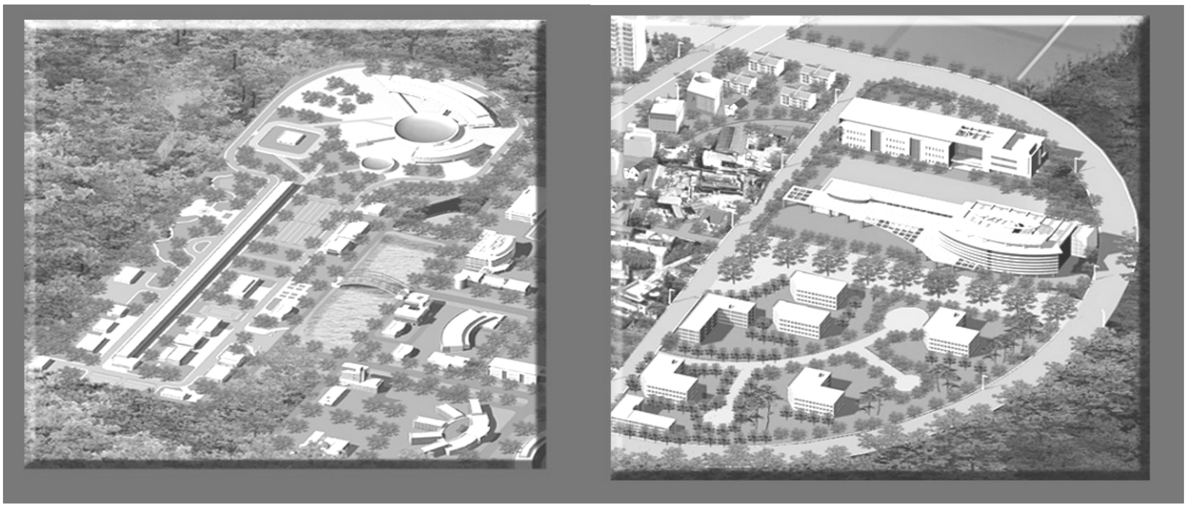
– Based on five steps of screening processes in consideration of:

  • Social and natural environment
  • Waste transportation, etc.

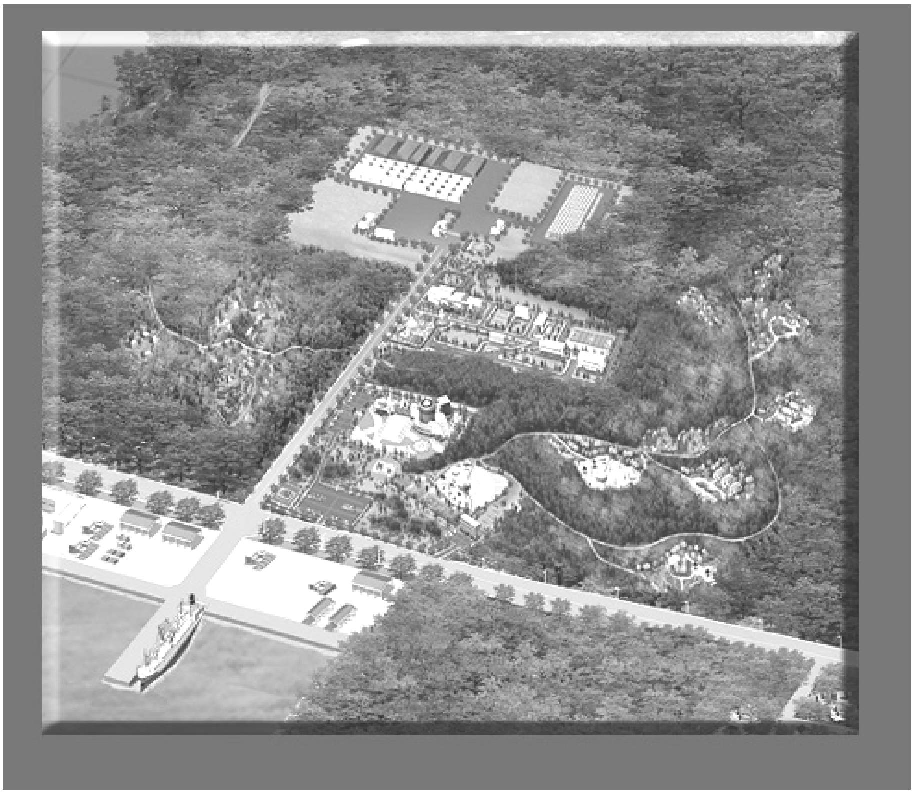


New announcement

- Announcement of new voluntary site subscription system (15 April 2003)
  – Enhanced local community development package
    • Proton Accelerator Project to be combined
    • KHNP Headquaters to be moved to the host county

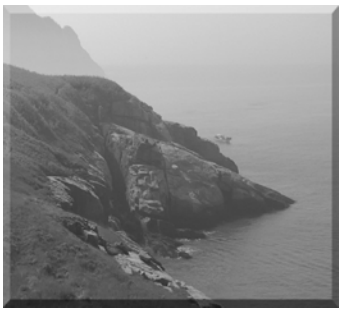


- Announcement of new voluntary site subscription system
  - Voluntary subscriptions open to other local governments in addition to the 4 candidate sites announced in February 2003



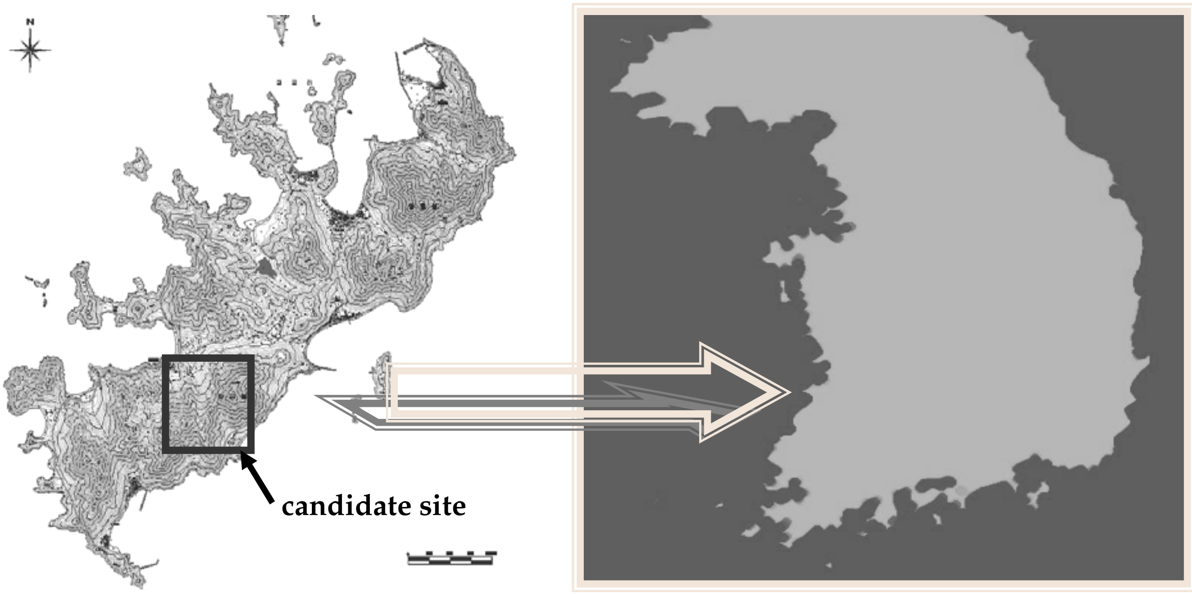
Wi-do Candidate site

- Voluntary application by Buan county – 14 July 2003



- Preliminary site evaluation committee
  - 14 members: government, universities, research organizations, journalist

– Preliminary site evaluation (17 categories)
  - Natural environment
    – Geology, seismisity, hydrology, etc.
  - Social environment
  - Project implementation related factors
– Announcement of the Wi-do candidate site (24 July 2003)



– Annual precipitation: average 1 167 mm (recent 10 yerars)

– Rock type: Tuff and Andesite

– No significant seismic activities

⟹ Acceptable in accordance with the siting criteria

Project milestone

• Detailed site survey	August 2003 – April 2004
• Site nomination	July 2004
• Site characterisation	July 2004 – July 2005
• Application for building permit	October 2005
• Start of construction	October 2006
• Completion of construction	December 2008

Lessons learnt

- Legitimate decision-making process
- Mutual understanding among stakeholders
- Trust and confidence in government and the project implementing organisation
- Participation of public in the site selection process
  - Significant preparatory efforts
  - Time delay
- Official channel for dialogue between the government and the opposition groups opened in 16 October 2003

ESTIMATES OF POST-CLOSURE RISK IN REGULATORY DECISION MAKING: ENVIRONMENT AGENCY ISSUES AND OPTIONS

S.L. Duerden, I.J. Streatfield, and R.A. Yearsley
Environment Agency, United Kingdom

Introduction

The Environment Agency of England and Wales (the Agency) is responsible for the authorisation of radioactive waste disposal under the Radioactive Substances Act 1993.

British Nuclear Fuels plc (BNFL) is currently authorised to dispose of solid low-level radioactive waste at a disposal facility near the village of Drigg on the Cumbrian coast, in north-west England. In accordance with Government Policy, the Agency periodically reviews authorisations for the disposal of radioactive waste.

The Agency intends to commence its next review of the Drigg authorisation in 2003/4. To inform its decision making, the Agency required BNFL to submit new safety cases for the Drigg disposal facility in September 2002. These have been received from BNFL and made publicly available (via national public registers):

- The Operational Environmental Safety Case [1] considers the impacts of the facility on the environment and the public in the period whilst the site remains operational and under institutional control, which BNFL estimates might be 2150.
- The Post-Closure Safety Case [2] considers the long-term environmental impacts of the facility after 2150 and includes a Post-Closure Radiological Safety Assessment, which is a risk assessment.

This paper deals with estimates of post-closure risk, it specifically excludes the operational phase and regulatory controls thereon. The paper summarises work undertaken by the Agency to consider potential regulatory actions against different levels of risk in relation to the risk target set out in the published regulatory guidance [3]. The work was undertaken principally in preparation for review of BNFL's Drigg post-closure safety case and authorisation.

Regulatory guidance

Disposal Facilities on Land for Low and Intermediate Level Radioactive Wastes: Guidance on Requirements for Authorisation" [the GRA]

The Agency is assessing BNFL's safety cases against the requirements set out in the UK Environment Agencies[1] publication "*Radioactive Substances Act 199 – Disposal Facilities on Land for Low and Intermediate Level Radioactive Wastes: Guidance on Requirements for Authorisation*" [the GRA][3] and more recently published UK Government guidelines on environmental risk assessment and management [4].

The GRA describes general principles for protection of the public, detailed radiological requirements, technical requirements for the safety case and guidance on the supply of supporting information. In particular, the GRA states:

- The best practicable means (BPM) shall be employed to ensure that any radioactivity coming from a facility will be such that doses to members of the public and risks to future populations are as low as reasonably achievable (ALARA).
- **After control is withdrawn**, the assessed radiological risk from the facility to a representative member of the potentially exposed group at greatest risk should be consistent with a risk target of 10^{-6} per year.
- If for the chosen design the risk to a representative member of the potentially exposed group at greatest risk is above the target of 10^{-6} per year, the developer should show that the design is optimised such that any additional measures which might reasonably be taken to enhance the performance of the chosen design would lead to increases in expenditure, whether in time, trouble or money, disproportionate to the reduction in risk. The demonstration of optimisation should also take into account any other relevant benefits and detriments.
- However, if the risk to potentially exposed groups is below the target, and the Agency is satisfied that the safety case has a sound scientific and technical basis, that good engineering principles and practice are being applied in facility design, construction, operation and closure, then no further reductions in risk need be sought.

Regulatory decisions will not be made exclusively on quantitative estimates of risk. The post-closure safety case will also be assessed against multiple and complementary lines of reasoning as set out in the principles and requirements in the GRA. The GRA requires, for example, demonstration of the use of good engineering practice in design construction and operation of a radioactive waste disposal facility. There is also a requirement for application of good science in investigating the suitability of the site; in supporting research and development work; interpreting the resulting data; and developing safety assessment methodologies. All the separate lines of reasoning contributing to an understanding of the performance characteristics of the disposal facility and an appreciation of the robustness of the safety case will inform regulatory decisions.

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1. Environment Agencies are the combined Agency's of the UK, namely the Environment Agency (of England and Wales), the Scottish Environmental Protection Agency (SEPA) and the Department of the Environment Northern Ireland – Environment & Heritage Service.

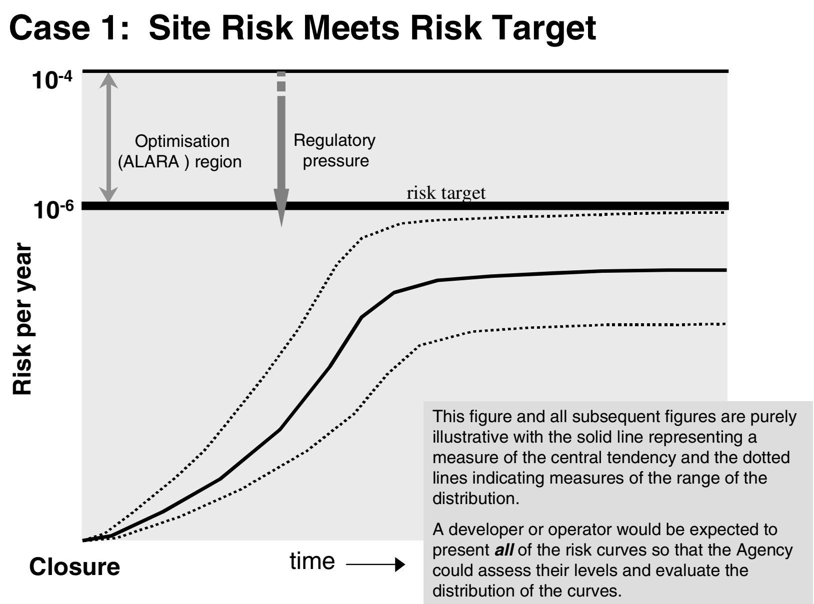
A review methodology developed and implemented by the Agency, which is firmly based on the principles and requirements set out in the GRA, is described in Duerden *et al*, 2003 [5].

In addition, the Agency has recently published results from an R&D project which investigated how post-closure safety case review outputs, and estimates of dose and risk, might be used to support regulatory decisions on the authorisation of facilities for the disposal of solid radioactive waste [6].

Guidelines for environmental risk assessment and management

The UK Government guidelines on environmental risk assessment and management [4] describe general principles that can be applied across a wide range of functions and are intended to be used in conjunction with other guidance (principally the GRA in the case of radioactive waste disposal). The guidance provides a framework for environmental risk assessment-risk management, to which specific risk guidance, such as that provided in the GRA, can refer, and allows for detailed quantitative risk assessments to be considered within a framework of other factors including social and economic costs and benefits. Decisions on risk management options or combination of options will involve a balance of risk reduction, costs, benefits and social considerations.

Illustrative Risk Results and Potential Agency Actions



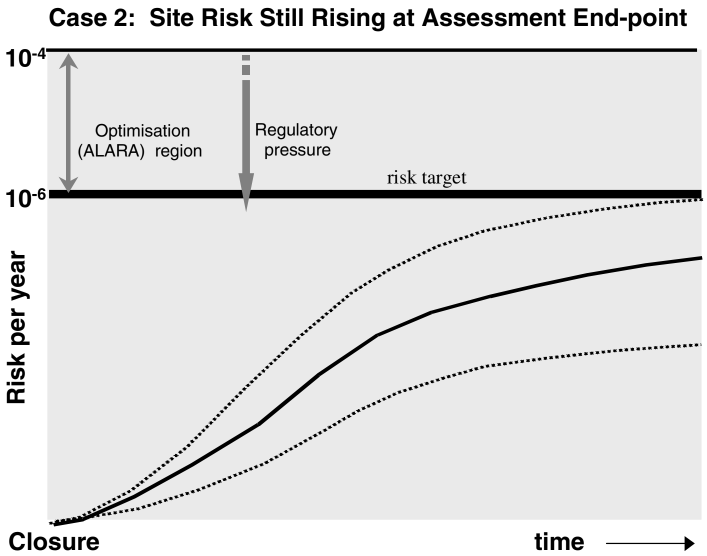
Case 1: Site risk meets risk target

The post-closure radiological safety assessment demonstrates that the site meets the risk target and the Agency has no, or only minor, concerns with respect to other aspects of the safety case. Some of the key questions that the Agency will consider here are listed in Appendix 1.

This would be a positive outcome, which nevertheless might result in a requirement for further work by the operator, for example, to:

- Ensure the safety case continues to demonstrate best practicable means (BPM) and that risks are as low as reasonably achievable (ALARA).

- Undertake further iterations of the safety case and risk assessment to incorporate scientific and technical developments:
  - To improve understanding of the risks, and of the relevant features, events and processes,
  - To reduce uncertainties.
  - To build confidence in models, calculations, assumptions and the overall risk assessment and safety case.



Case 2: Site risk meets the risk target but the risk is still rising at assessment end-point.

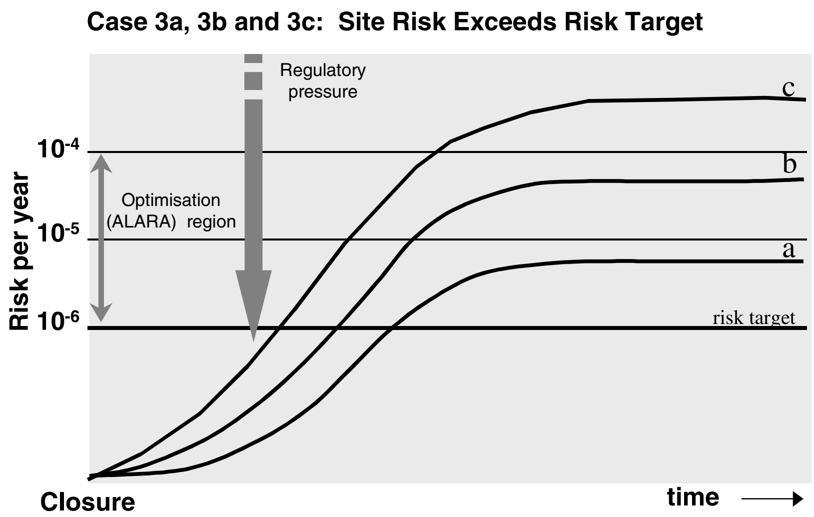
This raises a number of questions **in addition** to those in Appendix 1:

- Timescale – has the assessment been run long enough to go past any potential peak?
- What, and how plausible, is the terminating event and its timing?
- What happens if the terminating event is in the relatively near future, and what are the potential related releases? For a coastal, near surface facility, a near-future terminating event might be enhanced coastal erosion driven by climate change.
- What are the risks during and after the terminating event?

Actions that the Environment Agency might require of the operator

Same as in Case 1 but additionally, the Environment Agency might require the operator to:

- Provide the rationale underlying the selection of the terminating event.
- Undertake further iterations of the risk assessment to demonstrate that the selected timescale for the terminating event is justifiable.
- Investigate the consequences after the terminating event if this occurs in the relatively short term.



Case 3: Site risk exceeds risk target

Likely questions that the operator will need to address:

- What risk management measures can be applied to reduce overall risk and demonstrate optimisation?
- What costs are likely to be involved in reducing overall risk?
- When, and for how long, is the risk target likely to be exceeded?

Actions that the Environment Agency might require:

Same as in Case 1 but the Environment Agency might require the operator to undertake different, although not mutually exclusive, actions depending on where the assessed risks lie in relation to the regulatory risk target. Some examples of possible actions are:

Case 3a: If risk is in the range 10^{-6} to 10^{-5}/year

Demonstration of optimisation by identifying and implementing appropriate risk management measures, taking into account economic and social factors.

Case 3b: If risk is in the range 10^{-5} to 10^{-4}/year

Identification and assessment of an appropriate range of risk management options to reduce risk and associated uncertainties and to demonstrate optimisation.

Case 3c: If risk exceeds 10^{-4}/year

Identification and assessment of an appropriate range of risk management options that might be applied within a reasonable timescale and cost.

Analysis of alternative waste management options and their costs and benefits.

In this case the Agency would need to determine whether, or on what basis, development of a new facility, or disposals to an existing site, could continue, pending further investigations.

Concluding remarks

The Environment Agency seeks to ensure that radioactive waste disposal facilities provide an appropriate level of radiological protection to current and future generations. Risk provides an important indicator of post-closure performance of such a facility and risk can inform the decision-making process but on its own is insufficient. Decision making requires a safety case that provides multiple lines of reasoning based on sound science and engineering, which present clear arguments to support assessed post-closure performance.

References

[1] BNFL (2002), Drigg Operational Environmental Safety Case. Sept 2002.

[2] BNFL (2002), Drigg Post-Closure Safety Case. Sept 2002.

[3] Environment Agency, Scottish Environment Protection Agency, and Department of the Environment for Northern Ireland (1997), Radioactive Substances Act 1993 – Disposal Facilities on Land for Low and Intermediate Level Radioactive Wastes: Guidance on Requirements for Authorisation. Bristol: Environment Agency.

[4] Department of the Environment, Transport and the Regions, Environment Agency and Institute for Environmental Health (2000), Guidelines for Environmental Risk Assessment and Management. London: The Stationery Office. 88pp (ISBN 0-11-753551-6).

[5] Duerden S.L, R. Yearsley and D.G. Bennett Environment Agency, Environmental Policy – Risk and Forecasting, Guidance Note no 44. Feb 2003. Assessment of the Post-closure Safety Case for the Drigg Low-level Radioactive Waste Disposal Site. Drigg 2002 Post-closure Safety Case Review Plan.

[6] Bennett, D.G., R.V. Kemp and R.D. Wilmot, Linking Reviews of Post-closure Safety Cases for Radioactive Waste Disposal Facilities to the Process for Authorising Waste Disposal. Environment Agency R&D Technical report P3-090/TR. Dec 2003. ISBN 1-84432-242-4.

Appendix 1

Questions relating to assessed risk

Regulatory decisions will not be made exclusively on quantitative estimates of risk.

The Agency will need to determine the confidence that can be placed on quantitative estimates of risk and the contribution that the risk assessment makes to the overall understanding of the performance of the facility and the robustness of the safety case. The Agency has identified a number of questions that may help in this respect:

- Has risk been assessed using models and codes that have been adequately verified and validated (at least to present day conditions and accepted standards)?
- Do the conceptual models and parameter values underpinning the risk assessment represent acceptable descriptions of the site?
- Has an adequate range of alternative conceptual models been considered?
- Is there a clear and acceptable rationale for selection of the scenarios incorporated? What is the relative likelihood of each scenario?
- Have the scenarios giving the most likely or most representative assessments of risk been clearly identified and sufficiently well analysed?
- What are the terminating events for scenarios and associated risks (to people/environment)?
- What Features, events and processes (FEPs) are included/excluded and are these explicit in the conceptual models, codes and parameter values used to represent the site? What is the rationale behind any subsumed FEPs and is it appropriate?
- What are the uncertainties and assumptions associated with the assessed risks and are they explicit in the way the PCSC and PCRSA is presented. How robust are the underlying assumptions?
- How far has parameter uncertainty been explored and included in the risk assessment and is it adequate?
- Have parameter combinations leading to potential high estimated risks been adequately explored?
- What are the key factors contributing to risk and have these been adequately assessed?
- Have any low probability/high consequence scenarios been eliminated on the basis of their low probability and, if so, is there a sound justification for their elimination?
- Which parts of the assessment are robust? In which areas is there less confidence? In which areas is there greatest uncertainty? Where is there scope for continued improvement and confidence building?

PROPOSED REVIEW OF CURRENT REGULATORY SAFETY CRITERIA FOR THE HLW

C. Kirchsteiger and R. Bolado-Lavin
European Commission, DG JRC,
Institute for Energy, The Netherlands

Research question

In line with a general international trend to move for many high risk activities to a more risk-informed management of the underlying hazards involving all stakeholders, the issue of how to provide a high degree of transparency in order to ensure commensurability and consistency in the approaches is high on the research agenda.

This paper considers the case of assessing the risks[1] from a specific "risk activity", i.e. the long-term storage of high level radioactive waste (HLW) in a deep geological formation.

Further, in order to provide consistent and systematic insights in the similarities and main differences among the existing different technical approaches on how to assess HLW risks, this paper proposes to:

- develop a generic template that allows to capture, map and communicate in a consistent way the existing large variety of current approaches, and
- to perform on the basis of this template a systematic review of current HLW risk assessment approaches as recommended or prescribed in various countries.

If successful, the results of the proposed work would not say whether the risks originating from specific nuclear waste repositories are acceptable or not, but contribute:

- to better communication of these risks among all stakeholders; and
- to their more consistent mapping and cross comparison.

Relevance of the issue

The safety assessment of HLW repositories is quite peculiar within the risk assessment community. Firstly, it inherits the basic steps, methods and know-how of the classical safety/risk assessments for nuclear power plants. Secondly, the specific sources of hazard are well known and

1. Following ISO-IEC Guide 51, "safety" is understood here as "freedom from unacceptable risk", and risk as the combination of the probability of an event and its (undesired) consequence (see also footnote 2).

bounded, not as, for example, in the case of the chemical industry where the screening and identification of the potential hazard sources is often the main challenge for modelling. And, last but not least, the degree of international cooperation during the last, at least, fifteen years has been very intensive, and has achieved some background implicit harmonisation in the approaches.

During the last years there has been a large collaboration among different countries dealing with the HLW problem to get deeper insights about different ways to establish regulatory safety criteria, sharing knowledge and experience, usually under the umbrella of international organisations such as IAEA and OECD, in addition to the EC. In some cases risk-based criteria are proposed, in other cases non-risk based ones. Even among those proposing risk-based criteria there are significant differences, for example some of them are based on mean values (and their evolution versus time), others on the exceedance of probabilities. In some regulations, risk-based and non-risk based criteria are combined.

In spite of the harmonisation already achieved, some relevant differences among different national approaches remain, and this paper proposes that the study of these differences is a relevant issue at this stage.

Some potential sources of discrepancies shall be mentioned in the following, clearly non-exhaustive list:

- A potentially main difference between different regulations is the framework approach chosen. It could be a probabilistic or a more deterministic one. In a probabilistic approach, uncertainties are explicitly tackled, and extensive efforts are dedicated to their characterisation and propagation. In a deterministic approach, uncertainties are also considered, but in a different way: Usually, most of the effort is put either on the finding of a central case (best estimate output) or on the finding of a worst case (worst case analysis). In some cases, there is a combination of deterministic and probabilistic elements in the same overall approach.
- For these different approaches, different types of safety criteria could be considered. Some magnitudes used to set these criteria are purely probabilistic (e.g. a risk criterion in the sense of ICRP), while others could be used in different ways to set either probabilistic or deterministic criteria. For example, safety criteria could be set on individual doses, on collective doses or on risk. Additionally, ancillary performance indicators, such as the concentration of pollutants in water, integrated releases of pollutants in a given time frame, fluxes or flows could also be considered.
- In the case of a probabilistic approach, for some specific measures, the safety criteria could be based on different statistical measures, such as the mean, the median or some percentile (typically 95% or 99%).
- Different regulatory bodies consider different time scales during which safety should be demonstrated, usually periods of 10^4, 10^5 and 10^6 years are considered. Moreover, in some cases regulations also differentiate between different time scales in order to set safety criteria. Perhaps doses or risks could be used for the short term, while “softer” performance indicators like concentrations or flows could be used for long-term periods.
- The safety criteria considered so far in this paper are related to the performance of the entire system. Usually, however, the system is divided in three main parts: The near field, the far field and the biosphere. Some regulations could impose some additional criteria to the performance of some of these barriers (essentially the first two), or to some of its components, such as the canister or the clad as parts of the near field.

- Event scenarios play a fundamental role in HLW safety assessments ("performance assessments"). They are related to the "what can go wrong" component of risk.[2] In some approaches, the analysis of some specific scenarios could be prescribed, in other cases the screening criteria are also considered, either based on likelihood or on consequences or even on a combination of both. Further, human intrusion scenarios could play an important role in some approaches.
- Safety criteria and performance indicators can be, and in many cases are, aggregated measures, summing up the effect of many different radionuclides and different scenarios into single plots or numbers. Non-aggregated results could also be demanded to provide further insights into the model.

In different regulations, any of these elements (and presumably many more) could be considered in a different level of detail.

To further harmonise current approaches, it is proposed to study in depth their different underlying criteria and to benchmark the different approaches on this basis. That benchmarking could also take into account additional comparison criteria, such as the consideration of different types of uncertainty, different time scales, ability to uncover risk dilution, provision of relevant information to all stakeholders, etc.

JRC has performed in the past various benchmark exercises on risk assessment approaches for major hazardous activities, including the entire life-cycle of energy technologies,[3] and is currently organising together with several institutions from Europe, USA and Japan a network on reviewing risk regulations from different industry sectors for the purpose of providing support to policy DGs.[4] The proposal briefly summarised in this discussion paper could represent one of the contributions to this network.

3. Proposed benchmarking method

As mentioned, the main working method would be development of a generic template that allows capturing, mapping and communicating in a consistent way the existing variety of current approaches, and performance of a systematic review of current HLW risk assessment approaches on this basis.

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2. That corresponds to the well-known triplet definition of risk, saying that in order to answer the question "What is the risk?" it is necessary to answer three subsidiary questions: What can go wrong? How likely is it? What are the consequences? (S. Kaplan, B.J. Garrick, "On the Quantitative Definition of Risk", Risk Analysis, Vol. 1, No. 1, 1981).
3. Past JRC benchmark exercises include the ones on various PSA-related issues, such as common cause failures, human reliability analysis, expert judgement, etc.
4. RISKREG network; further informations can be obtained from the authors.

The main underlying assumptions of this approach are:[5]

1. Risk assessment is a process accomplished by carrying out a series of distinct steps.
2. These steps can be decomposed and hierarchically organised to as fine an operational level as is needed to collect and communicate information on the nature of a specific risk assessment with the desired level of understanding.
3. The elements of the hierarchy can be defined generically enough to be inclusive of most approaches to risk assessment.
4. Each operational step in the risk assessment process should be addressed in some fashion regardless of whether addressing it is either an explicit operation requiring great technical sophistication or an implicit assumption requiring virtually no affirmative action.

A way how to map out the process of risk assessment is by looking at a number of factors based on steps common to a range of risk assessment approaches. For example, four elements could describe the major elements of risk assessment:

- hazard identification;
- release/exposure scenario;
- hazard/subject interaction (i.e. dose/response);
- and likelihood.

Within each element, sub-elements, categories, and descriptors capture the details of the different approaches used to assess risk. All the ideas shown in Section 2 of this paper provide preliminary hints to design such a hierarchy. Authorised individuals from within a network of interested institutions enter data into the system, usually experts in a particular law, regulation, or case study.

Expected outputs

By assessing existing differences w.r.t. current practice in regulatory end points for nuclear waste repositories between European and other countries, the outcome of the proposed project would mainly be to draw lessons/recommendations for future development needs so that a holistic concept for EU policy support could be developed.

Summary

This paper presents the concept of a proposed project on reviewing current regulatory safety criteria for the HLW and shall be considered a discussion document to identify interested parties and to further develop possible project tasks.

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5. I. Rosenthal, A.J. Ignatowski, C. Kirchsteiger, "A Generic Standard For The Risk Assessment Process", in: Special Issue of the Safety Science magasine on International Workshop on Promotion of Technical Harmonisation on Risk-Based Decision-Making, Pergamon Press, Elsevier Science, Oxford, Vol. 40 (Nos.1-4), February 2002, pp. 75-103.

USE OF RISK INFORMATION IN REGULATORY REVIEWS

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Introduction

The regulatory framework for licensing any high-level waste repository at Yucca Mountain in the United States, calls for appropriate use of risk information to ensure operational safety during the pre-closure period and long-term safety during the post-closure period. This paper focuses on the post-closure period. Regulations in the Code of Federal Regulations (CFR), Title 10, Part 63, apply to any repository at Yucca Mountain and envision use of probabilistic methods to develop quantitative risk information. Accumulated engineering and scientific experience at Yucca Mountain and analog sites and quantitative risk information from studies conducted by the implementer, regulator, and others are combined to formulate "risk insights," which are then used to plan and execute regulatory reviews. The U.S. Nuclear Regulatory Commission (NRC) and the Center for Nuclear Waste Regulatory Analyses (CNWRA) recently consolidated the knowledge gained during several years and developed such risk insights for the potential repository at Yucca Mountain. This paper discusses the types of risk information used to generate risk insights and how the risk insights will be used in regulatory reviews. A companion paper presents more details on sensitivity analysis methods used to generate risk information.

Types of risk information

NRC and CNWRA developed a computer code, the TPA code [1], to estimate the long-term performance of a potential repository at Yucca Mountain for the nominal and disruptive scenarios. Three scenario classes are analysed with the TPA code: (i) nominal scenario, which includes seismicity; (ii) faulting; and (iii) volcanism. Eventual failure of the waste packages and transport of radioactive waste with the groundwater over time constitute the nominal scenario. Faulting and volcanic disruption of the repository are examples of disruptive scenarios. The consequences from each scenario are weighted by their probabilities of occurrence to yield a contribution to the total system risk. The faulting scenario was determined to not make significant contributions to the total system risk and is not discussed further. Total system performance analyses and system-level sensitivity analyses result in quantitative risk information. Different types of risk information and the resulting risk insights from that information are presented next.

Understanding is gained on the expected behaviour of the total system as a function of time and its sensitivity to parameters, assumptions, and model formulations.

- *Radionuclide contributions*. Total system performance analyses show most of the radiological dose to a receptor within 10 000 years after permanent closure of the repository can be attributed to the low-retarded, long-lived radionuclides Tc-99 and I-129

[1, Figure 3-35; 3, Figure 5(c)]. Within 100 000 years, a moderately retarded radionuclide, Np-237, dominates.

- *Pinch-point analyses*. For the nominal scenario, radionuclide releases from the engineered barrier subsystem within 10 000 years are attributed to the small fraction of waste packages assumed to have defects (i.e., juvenile failures). Evaluation of radionuclide releases from the unsaturated and saturated zones shows Np-237 and Pu-239 are delayed significantly in the saturated zone [2, Figures 3-27 and 3-31].
- *Parameter sensitivity analyses*. Parameter sensitivity analyses on the nominal scenario show the system performance is sensitive to the retardation coefficient for Np-237 in the alluvium unit of the saturated zone [2, Table 4-10]. Parameter sensitivity analyses on the volcanic disruption scenario show the greatest sensitivity to the airborne mass load parameter above a fresh ash deposit.
- *Alternative conceptual models*. Substantial effects are observed on the system performance for the nominal scenario when different transport assumptions from those used in the basecase are applied [2, Figure 3-38]. The largest increases in dose are associated when retardation is assumed not to occur for Pu, Am, and Th, which supports the high significance for retardation in the alluvium unit of the saturated zone. For the nominal case, a passive film exists on the waste packages. When passive conditions are assumed absent for a fraction of the waste packages, the radiological dose increases substantially. For the volcanic disruption scenario, the alternative conceptual model for magma flowing along drifts significantly increases the number of waste packages damaged and the related consequences compared with the nominal case model for a vertical conduit. Another study determines the number of waste packages damaged in a volcanic eruption is potentially significant to the estimated risk [3, Table 2].
- *Component sensitivity analyses*. Component sensitivity analyses show substantial individual contributions to waste isolation are provided by the waste package, unsaturated zone, and saturated zone [2, Figure 6-2]. Further investigation determines most unsaturated zone performance is attributed to the capability of the unsaturated zone above the repository for reducing the amount of water contacting the waste package [2, Section 6.4.1].

Example risk insights

Risk insights are conclusions drawn about the significance of a specific physical component to waste isolation. The rating (high, medium, low) of significance to waste isolation is based on three criteria: (i) potential to affect waste packages, (ii) potential to affect radionuclide release from the waste form, and (iii) potential to affect radionuclide transport through the geosphere and biosphere. The risk insights are derived from the results of quantitative risk information.

Based on the risk information presented previously, the following are presented as examples of risk insights with high significance to waste isolation:

- Persistence of a *passive* film on the waste package.
- Retardation in the saturated zone alluvium.
- Inhalation of resuspended contaminated volcanic ash.
- Number of waste packages damaged by volcanic disruption.

Conversely, closure welding defects on the waste package, such as flaws that could promote other degradation processes leading to early failure, are limited to a small fraction of the total waste packages and are assigned a low significance to waste isolation.

Application of risk insights in regulatory reviews

The guidance document for licensing reviewers is the Yucca Mountain Review Plan [4]. This plan instructs reviewers to base the depth of their review activities on the risk significance of the aspect (e.g., feature, event, or process) being reviewed. The overall risk-informed review philosophy is to audit every aspect of the license application and define the depth and scope of detailed reviews on individual aspects commensurate with their risk significance. The application of risk insights for a risk-informed review philosophy is discussed next using two examples.

One risk insight presented previously is that the estimated long life of the waste package is predicated on the persistence of a passive film on the metallic components and the absence of electrochemical conditions leading to accelerated corrosion rates of the waste package materials. Based on quantitative analyses and other evidence that indicate the overall repository performance is highly dependent on stability of the passive oxide, this aspect is rated as highly significant to waste isolation. In the risk-informed regulatory approach, a review of aspects related to the passivity of waste package materials will require greater scrutiny and resources. The extent of the technical basis required from the applicant on aspects with high significance to waste isolation would be much greater than for those aspects with low significance.

Another risk insight is that waste package defects are of low significance to waste isolation. Any license application for a high-level waste repository at Yucca Mountain must satisfy the requirements of the NRC regulation at 10 CFR Part 63. Adequate technical bases are required for all technical areas (even those areas with low significance to waste isolation). Therefore, if the U.S. Department of Energy shows that closure welding processes have a minor impact on waste isolation, then the staff may conduct a simplified review focusing on bounding assumptions [4, Section A1.3.3].

In closing, risk insights evolve as the design changes and as the system-level understanding matures. New analyses yielding additional or updated risk information may result in changes to the risk insights for a particular technical area. As part of a risk-informed program, new information must be gathered from recent analyses to periodically re-evaluate the risk insights and identify any changes.

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References

[1] Mohanty, S., T.J. McCartin, and D.W. Esh (coordinators) (2000), "Total-system Performance Assessment (TPA) Version 4.0 Code: Module Descriptions and Users Guide (Revised)." San Antonio, Texas: Center for Nuclear Waste Regulatory Analyses.

[2] Mohanty, S., *et al.* (2002), "System-Level Performance Assessment of the Proposed Repository at Yucca Mountain Using the TPA Version 4.1 Code." CNWRA 2002-05. San Antonio, Texas: Center for Nuclear Waste Regulatory Analyses.

[3] Bechtel SAIC Company (2002), LLC. "Risk Information to Support Prioritisation of Performance Assessment Models." TDR–WIS–PA–000009. Rev. 01 ICN 01. Las Vegas, Nevada: Bechtel SAIC Company, LLC.

[4] NRC. NUREG–1804 (2002),"Yucca Mountain Review Plan." Rev. 2. Washington, DC: NRC.

EXPERIENCE OF THE MUNICIPALITIES OF OSKARSHAMN AND ÖSTHAMMAR IN THE PROCESS OF SITING A FINAL REPOSITORY FOR SPENT FUEL IN SWEDEN

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Mayor of Östhammar, Sweden

Peter Wretlund
Mayor of Oskarshamn, Sweden

Background

It is with great pleasure that my colleague, Margareta Widén-Berggren, Chairman of the Municipal Executive Board in Östhammar, and myself, accepted the task of sharing with you our municipality experiences from participating in the Swedish final repository programme.

Together, we represent the two Swedish municipalities in which site inspections are now being carried out for possible final storage of highly radioactive spent nuclear fuel.

Content of the presentation

Our presentation is arranged as follows:

- as two Mayors, we would first of all like to introduce you to our two very pleasant municipalities, and at the same time give you background information about the position that our municipalities have in the Swedish system;
- a few general policy points on the municipal level in relation to nuclear waste;
- some words about where we are in the decision-making process;
- the basis of our decision to participate in site investigations;
- how we have organised ourselves and the work assignments of our local organisations;
- the challenges ahead, and
- finally, what we believe will be required if there is to be Swedish final repository for spent nuclear fuel.

1. Östhammar and Oskarshamn

Sweden is a long, narrow country, with a big land area but sparsely populated. Östhammar is located about one hour north of Stockholm by car, and Oskarshamn is located about three hours' travel southwards. Both municipalities face the Baltic, and the new dynamic Europe in the east.

Oskarshamn is surrounded by six neighbouring municipalities, which are also affected by the question of nuclear waste. The greatest disquiet is a possible negative effect on the very considerable tourist industry in the region. There is the island of Öland, the decorative glass making industry, and the world of children's book author, Astrid Lindgren, and they attract more than 200 000 visitor-nights during the summer months.

Östhammar also has close contact with its neighbouring municipalities, and this region also has a very large tourist industry, including visitors originating from Stockholm and Uppsala. There are, for example, over 7 000 resort cottages in the Östhammar municipality.

In relation to many central European countries, Swedish municipalities have very large areas. In our cases, they cover 1 000 km² and 1 500 km² respectively, the equivalent of roughly, 500 square miles.

Another notable difference between Swedish municipalities and municipalities in most other countries in Europe is a very large degree of independence as regards decision making. Swedish municipalities have a planning monopoly, and as regards the location of such facilities as a final repository, the local authority has the possibility of giving a veto. There is theoretically a so-called veto valve, but for both political and legal reasons, we do not really see any threat of the government using this method of opposing a municipality.

Swedish municipalities also have the right to impose taxes, and more than four-fifths of all direct taxes paid by wage earners in Sweden, go to municipalities.

We would therefore like you to understand that the municipalities have a very strong role in their participation in the nuclear waste programme.

Oskarshamn and Östhammar both have roughly the same number of inhabitants, and both have central towns with very good service and good schools. Every day in our municipalities, 13 000 and 10 000 people, respectively, go to their everyday work. Both municipalities have low unemployment. I mention this in order to show that terminal storage that offers 400 jobs is not a decisive labour-market question. It is mainly on the basis of other issues that our municipalities participate in the ongoing site inspections.

Our respective municipal budgets are about 100 million euros. The municipalities have extensive responsibility for health care, care of the elderly, education and technical service, and are substantial employers.

2. Existing nuclear installations

In both Oskarshamn and Östhammar there have been nuclear power stations for several decades. Both the Forsmark installation and the Simpevarp installation contain three blocks.

Oskarshamn 1 was the first commercial reactor commissioned in Sweden in 1972. All in all, 25% of the country's electricity is produced in our municipalities.

Apart from the nuclear power station, Östhammar hosts terminal storage for low and intermediate-level radioactive waste (SFR) and Oskarshamn for the central intermediate storage for spent nuclear fuel (CLAB).

3. Our relation to the nuclear issues

When we as municipalities look at the question of nuclear waste, there are several issues that come to the forefront, especially:

- we are two municipalities with extensive experience of working with the nuclear power industry;

- we do not accept that the intermediate storage which is now in operation should be converted to a permanent solution – we are obliged to work actively for a final solution to the question of radioactive waste;

- we have participated in feasibility studies for final disposal, we have conducted extensive local work on a democratic basis to engage our public, and we now have the full support of our inhabitants to participate in the site investigations which are ongoing, and

- through our strong position in the decision-making process, we have ensured that our questions are investigated, and that the decision-making basis elucidates the local perspective in detail, and we will continue to do so.

4. Joint municipality policy points

When we worked together with this assignment, we have agreed on six joint policy points that may form a platform for the work of the next few years:

- Safety is the question that overshadows everything – for us as decision makers, and for our general public.
- A requirement for that we should be able to find a solution for the question of nuclear waste is a transparent process – all information from all parties on the table during the entire process. It is only through such a way of working that we may build up trust in the actors and in the results that emerge.
- We as municipalities must actively participate and influence this work. Our contribution cannot be paid for by our taxpayers, but must be paid for, as it is at present, with funds from the Swedish Nuclear Waste Fund.
- Our inhabitants and environmental groups, who are engaged in the nuclear waste issues, are a resource in our work. The people who know best about our local situation are those of us who live in our municipality, and who know what we want to do with our future. Our environmental groups pose the difficult questions that must be answered.
- Our expert authorities, the Swedish Radiation Protection Authority and the Swedish Nuclear Power Inspectorate are our independent experts. It is the authorities who are to assess the proposals presented by industry, and give us their decision as to whether it is safe or not.
- Before we know whether the question of safety is satisfied, we cannot speculate about compensation or the maximisation of positive spin-off effects from establishment of final disposal in either of our municipalities. We do not allow this type of debate to interfere with our work of critically scrutinising and objectively investigating social effects, or ensuring that negative effects are limited. Discussion with industry must wait until we

know what the choice of industry is, and what the results of the regulatory review by the authorities are.

5. Programme and schedules

The Swedish siting programme is at the beginning of the site inspection phase. If industry's plans hold, we will need to take a position as to what method we are to use for solving the final disposal question in Sweden in about 5 years time, and we will have to decide where this is to be located.

6. Public participation and public opinion

Before decisions in our municipalities as to whether or not to participate in site investigations, it has been important to keep pace with our inhabitants. After several years of work with the issue in each respective municipality, it is clear that we have a great deal of support in continued work on the waste problem, and in our decision to accepting site investigations. In our two municipalities, support has been between 75 percent and 80 percent. In other municipalities with completed feasibility studies, in which experience of nuclear power has been lacking, support has been considerably lower.

7. Our decisions to participate

During the winter of 2001-2002, the respective municipal councils of Östhammar and Oskarhamn voted almost unanimously to say yes to site investigations. As an example the text of the decision that was made by the municipal council in Oskarshamn was "*Decision on March 11, 2002: The Oskarshamn municipality allows SKB to commence site investigations within the area designated by SKB, namely the Simpevarp peninsula and an area to the west thereof with the following conditions and clarifications*". As you can see, the decision was made with conditions attached.

The 13 conditions that the municipality of Oskarshamn made for agreeing to participate are that.

1. the participation shall be compensated financially;
2. any decision would only apply to Swedish waste;
3. the general public must not be kept out of discussions concerning safety;
4. authorities must keep us informed continually as to their assessments;
5. early shortcomings in connections between analysis of safety, criteria on deciding on a site, and the site inspection programme should be rectified;
6. in actual cases, complete system analyses would be carried out;
7. critical research results, which come to conclusions other than those of the Swedish Nuclear Fuel and Waste Management Company shall be scrutinised by the authorities;
8. capsules must not be made until it is known where they are going (the repository site should be selected);
9. voluntary agreements shall be made with land owners regarding access;
10. a complete site investigation programme shall be established and approved by the council;

11. those studies which are to be included in an environmental impact assessment shall be collected together in an EIA scoping report to be approved by the council;
12. after consultation, alternatives to the proposal from industry for geological final disposal in accordance with the KBS-3 method shall be investigated, and
13. the question of responsibility after the repository has been sealed shall be clarified in Swedish law.

Östhammar made a similar decision with similar conditions.

8. Local organisation

In both our municipalities we have formed organisations that have the task of following and influencing site investigations. The cores of these organisations are working groups, which broadly represent different interest groups in the municipalities. The task of these working groups may be summarised in the following six points:

- to follow up the site inspections and the safety issues;
- to follow up the conditions laid down by the municipalities;
- to initiate investigations which are required in the municipal decision-making bases;
- to increase the competence of the decisions makers and the inhabitants of the municipalities;
- to collect questions from the general public, and to make sure that these are investigated and answered, and
- to learn from local experience, from the nuclear waste programmes in other countries.

The ambition of the municipality to influence investigations and surveys which are carried out during the site inspection phase has different emphases in different areas. We agree that experts in geology and hydrology are mainly to be found in the Swedish Nuclear Fuel and Waste Management Company, and in the authorities.

Local expertise and local requirements for decision-making bases have their centres of gravity in social questions – socio-economic aspects and other environmental questions – it is therefore within these areas that we expect the greatest effect on the content of the studies to be carried out and on which surveys and investigations are to be completed.

9. Challenges ahead

What are the major challenges we see ahead?

As we have already touched on, it is totally decisive that industry has to show that safe final disposal may be scientifically demonstrated, and that the authorities will come to the same conclusion through competent scrutiny and independent analyses.

Other challenges are that:

- the efforts of industry to fulfil their time schedules should not lead to shortcuts, and thus to impaired quality of data and analyses;

- authorities should receive the resources required and may secure the competence required to scrutinise and assess applications by industry to the maximum – here we are very concerned that, in its general efforts to save money, the government may not give the Swedish Nuclear Power Inspectorate or the Swedish Radiation Protection Authority the resources that they require;
- we get the investigations and studies carried out that are required for our general public and for us decision makers to have a complete basis of information on which to make decisions, and
- we receive complete guarantees that we as municipalities will not be forced to receive nuclear waste from other countries against our will.

Conclusion

In conclusion, the following must happen before we municipalities may accept a final disposal:

- We must be convinced that the nuclear waste problem may be solved safely – here we are very dependent on our authorities.
- We must set a complete and exhaustive information basis for decision making, including a municipal perspective, in order to be able to say yes or no. This information basis must contain:
  - An environment impact assessment with all positive and negative effects presented in detail. This environmental impact assessment must also contain exhaustive socio-economic and social-scientific analysis.
  - Negative effects on environment and society must as far as possible be limited through measures put in place.
  - Finally, a municipal decision must have the support of the overwhelming majority of the inhabitants of our municipalities.

Lastly, as elected representatives, we are fully convinced that both the solution of the nuclear waste problem and our continued political duties must be based on solid support from our general public – or more concretely, for the sake of our parties and us personally, we must have the support of our electorate if we are to go forward.

If we work openly and with trust on this difficult question, we think we can get there.

SESSION 4

INTERNATIONAL INSTRUMENTS TO FACILITATE THE IMPLEMENTATION OF GEOLOGICAL REPOSITORIES

Chair: Kirsti-Liisa Sjöblom, STUK, Finland

1. Objectives

The objective of the session is to inform of the role of various international instruments in the context of geologic repositories and discuss their implications. In this area there have been important developments since the Denver Conference in 1999.

The *Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management* has entered into force and the first review meeting was held in November 2003. ICRP published the *Radiation Protection Recommendations as Applied to the Disposal of Long-lived Solid Radioactive Waste* (ICRP 81) in 2000. IAEA, in co-operation with OECD/NEA is working towards developing safety standards on geologic disposal of high-level and long-lived radioactive waste; the Safety Requirements on Geologic Disposal is expected to be approved for publication next year.

The safeguards system is a cooperative undertaking based on the Non-Proliferation Treaty and implemented by agreements between IAEA and member states to ensure that there are no undeclared nuclear material or activities and that the declared material is not diverted to nuclear explosive devices or unknown purposes.

According to the policy paper of the IAEA "Spent fuel disposed in geologic repositories is subject to safeguards in accordance with the applicable safeguards agreements. Safeguards for such material are maintained after the repository has been back-filled and sealed, and for as long as the safeguards agreement remains in force". The ongoing IAEA programme on evaluating safeguards for final disposal of spent fuel in geologic repositories has discussed on the interface and interaction between safeguards and radioactive waste management in this context.

The legal regime governing the civil liability and compensation for nuclear damage is established by two international conventions: the *1960 Paris Convention* and the *1963 Vienna Convention.* There is no doubt that the authors of both Conventions, at such an early stage in the development of the nuclear industry, did not take into consideration the special characteristics associated with activities relating to the back-end of the nuclear fuel cycle and, particularly, the liability which could arise from damage caused during very long-term storage or disposal of radioactive waste, for example, within geologic repositories. The revision of both the *Paris* and the *Vienna Conventions* (and the adoption of the *1997 Convention on Supplementary Compensation for Nuclear Damage*) provided for an opportunity to remedy this gap, although this raised complex legal issues in respect of the inclusion of such repositories in the scope of the Conventions, the determination of the date of the accident causing the damage, the assignment of liability, the nature and duration of the risk and the provision of financial security.

2. Issues

International and regional conventions and safety requirements are discussed in the Session.

Parallel with the development towards the realisation of geologic repositories progress is made in two somehow distinct areas:

- various international instruments that are related to the safety of the repositories have been or are being developed; and
- some long established international instruments have to be adapted to respond to new technical applications.

Programme

Chair: **Kirsti-Liisa Sjöblom**, STUK, Finland

Gordon Linsley, IAEA

Tim McCartin, NRC, USA

Bruce Moran, NRC, USA

Tapani Honkamaa, STUK, Finland

Patrick Reyners, OECD/NEA

Discussion participated by the audience and panel.

Moderator and Rapporteur: **Göran Dahlin**, SKI, Sweden

Panel participants: All speakers

Issues to be considered by panelists

- What is the role of regional instruments, such as Espoo and Aarhus Conventions in deep geologic disposal?
- Are there other international or regional instruments that have influence on development of geologic repositories?
- How could the international and regional co-operation in the framework of the Joint Convention be developed to support geologic disposal?
- Which kind of impacts the application of safeguards systems and the requirements of nuclear liability have to design, operation and closure of geologic repositories as well as to the post-closure control?

OUTCOME OF THE FIRST REVIEW MEETING OF THE JOINT CONVENTION ON THE SAFETY OF SPENT FUEL MANAGEMENT AND ON THE SAFETY OF RADIOACTIVE WASTE MANAGEMENT

Gordon Linsley
IAEA

1. Introduction

In November 2003 the first Review Meeting of the *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management* was held in Vienna. It signalled that the Joint Convention, the only internationally binding legislation in this field, is now fully operational.

The Joint Convention has, as its main objective, "to achieve and maintain a high level of safety worldwide in spent fuel and radioactive waste management".

The Joint Convention is a "sister" convention to the Nuclear Safety Convention, which has been operational for several years, and it shares the same basic mechanism for achieving its objectives. The mechanism consists of the preparation of national reports explaining how the country is complying with, or planning to comply with, the 25 technical articles of the Convention. This is, in itself, a form of self-assessment by the relevant organisations with responsibilities for radioactive waste management in the country concerned. The reports are then subjected to written questions by other Contracting Parties to which answers are provided in advance of the Review Meeting. At the Review Meeting the National Reports, the questions and answers are presented orally and form the basis of discussion between groups of Contracting Parties.

2. Role of the IAEA

A common misconception is that the Joint Convention "belongs" to the IAEA. In fact, the Convention is the property of the Contracting Parties; the IAEA has the roles of Depositary and Secretariat. This means that all important decisions regarding the Convention, its mode of operation, any initiatives or outcomes are those of the Contracting Parties. The IAEA's role is to serve the Convention to the extent possible and within its resources.

3. Effectiveness of the review process

It was concluded that the process had already contributed significantly to achieving the objectives of the Convention. Firstly, as a result of being prompted by the forthcoming Review Meeting, several Contracting Parties had made improvements to the management of spent fuel or radioactive waste in the period leading up to the Meeting, secondly, others acknowledged that the process of preparing the National Report had been beneficial since it had identified needs and deficiencies in the national arrangements for radioactive waste management and thirdly, still others had identified improvements for the future and volunteered to report on progress in their implementation at the next review meeting.

4. Relevance to disposal

The Review Meeting revealed a wide variety of long term spent fuel and radioactive waste management policies among the Contracting Parties. While it was clear that geologic disposal is the favoured option for the long-term management of spent fuel and high-level radioactive waste, some Contracting Parties are still viewing a number of different options and others are involved in national consultations involving all concerned parties and with all options "on the table". Some Contracting Parties have existing arrangements with other countries and others wish to examine possible regional solutions for disposal. In this context, one Contracting Party invited others from its region to attend a meeting on the subject in order to discuss the subject in some detail.

It was generally agreed that it is desirable for each Contracting Party to have a long term strategy in place for managing its spent fuel and radioactive waste.

A number of Convention articles address the safety obligations related to facilities, including disposal facilities; they include: Siting (Article 13), Design and construction (Article 14), Safety assessment (Article 15), Operation (Article 16) and Institutional measures after closure (Article 17).

Article 13, *inter alia,* requires information to be made available to the public concerning the safety of facilities and that Contracting Parties in the vicinity of the facility be consulted "insofar as they are likely to be affected by that facility and to provide them with general data to enable them to evaluate the likely safety impact…". These two obligations reflect, in part, the concerns of the regional Aarhus and Espoo Conventions. It is interesting to note that one Contracting Party drew attention to the second of these obligations during the Review Meeting in the context of requests made to another Contracting Party for information on a facility which it considered could affect its territory.

5. Other technical issues

There is a growing recognition of the need for countries to have in place integrated plans for decommissioning and waste management, containing schemes for managing all of the various different types of waste resulting from the decommissioning process. Of particular relevance in this context is the absence, at present, of agreed international criteria for the clearance of materials containing very low activity levels from regulatory control.

The emphasis in National Reports and in the discussions at the Review Meeting was on spent fuel and radioactive waste from the nuclear fuel cycle.

Comparatively little attention was given to the issue of managing disused sealed radioactive sources, an issue of principal interest for some of the smaller non-nuclear power countries and this together with the subject of effluent discharge control was identified as needing more consideration at the next meeting.

6. Public involvement

Public consultation is seen as being increasingly important in relation to long term radioactive waste management. The old policy of "decide, announce and defend" is no longer seen as being tenable and, in several countries, the public is being involved through consultation processes in decision making with regard to repository siting decisions, options for decommissioning and policies for effluent discharge.

7. International reference points

The IAEA safety standards were discussed in various parts of the meeting and topics on which international guidance is still needed were identified. However, there is no consensus on the relationship between the standards and the Joint Convention process. While most countries wish to use the standards as a reference point for interpreting the Convention articles, a few others see the Convention and its articles as being separate and self-standing.

8. Organisational aspects

This was the first review meeting of the Convention and already the need for improvements in its mechanisms have been identified. The main issue stemmed from the observation that the Country Group sessions were very variable in quality and activity – some resulted in a thorough examination of the programmes of the countries within the group while others produced a rather superficial review. Plans are in hand to revise the relevant mechanisms and guidance to the Contracting Parties.

9. Promotion of the Convention

At present, only 33 countries are Contracting Parties to the Convention and at the Review Meeting this was considered to be an issue of great concern. The Convention is relevant and potentially important to all countries in which there is radioactive waste, even to those where the only waste generated comes for the use of radioactive materials in medicine and research. Proposals were put forward on ways to increase the membership, for example, by holding regional meetings at which the benefits to countries in the region could be explained by representatives of existing Contracting Parties.

The Contracting Parties at the present time are: Argentina, Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Japan, Republic of Korea, Latvia, Luxembourg, Morocco, Netherlands, Norway, Poland, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, United Kingdom, United States.

10. Summary report

The outcome of the discussions at the Review Meeting was recorded in a publicly available summary report agreed upon by the Contracting Parties (available on the Joint Convention website). In addition, the national reports of 27 of the 33 Contracting Parties have been voluntarily placed on national and the Joint Convention websites.

See http://www-rasanet.iaea.org/conventions/waste-jointconvention.htm

THE DEVELOPMENT OF INTERNATIONAL SAFETY STANDARDS ON GEOLOGICAL DISPOSAL

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Introduction

Many governments are pursuing deep geologic repositories as a method for safe disposal of high-level radioactive waste. Geologic disposal is considered an appropriate method for ensuring protection of public health and safety because the potential hazard of high-level radioactive waste persists for thousands of years. Deep geologic disposal:

- greatly limits the potential for humans to come into direct contact with the waste;
- isolates the waste from a variety of natural processes and events occurring on the surface of the earth;
- reduces the impact of releases of radionuclides in ground water by the retardation processes of geological strata, which radionuclides must pass through prior to reaching portions of the biosphere where exposure of humans could potentially occur; and
- is expected to require no maintenance for future generations.

The IAEA Radioactive Waste Safety Standards (RADWASS) Programme is aimed at establishing a coherent and comprehensive set of principles and requirements for the safe management of radioactive waste and formulating the guidelines necessary for their application. This is accomplished within the IAEA Safety Standards Series in an internally consistent set of documents that reflect an international consensus. The RADWASS publications provide Member States with a comprehensive series of internationally agreed safety standards to assist in the derivation of, and to provide a point of reference for national criteria, standards and practices. The IAEA is in the process of completing efforts to develop a Safety Requirements publication that sets out the safety requirements related to the disposal of radioactive waste in geologic disposal facilities. The IAEA goal for Safety Requirements for geologic disposal is to set out:

- objectives and criteria for the protection of human health and the environment during the operation and after facilities are closed, and
- the requirements that must be met to ensure the operational and post closure (after the repository is sealed) safety.

The IAEA Safety Fundamentals document sets out the principles that apply to all radioactive waste management activities, including geologic disposal. As defined in the Safety Fundamentals:

> *The objective of radioactive waste management is to deal with radioactive waste in a manner that protects human health and the environment now and in the future without imposing undue burdens on future generations.*

IAEA Safety Requirements would meet this overall objective by specifying:

- objectives for the protection of human health and the environment in relation to geologic disposal, and quantitative criteria against which to judge the level of protection provided;
- the strategy for achieving safety in geologic disposal facilities; and
- requirements for the development, operation and closure of geologic disposal facilities to achieve a satisfactory level of safety and to build a sufficient level of confidence in their safety.

1. Objectives for the protection of human health and the environment

Geologic disposal facilities must be developed (i.e., sited, designed, constructed, operated and closed) such that human health and the environment are protected both now and in the future. In this regard, the prime concern is the radiological hazard that the radioactive waste presents. The protection objective during the operational period (beginning when waste is first received at the facility and ending with final closure and sealing of the facility) is:

The radiation doses to workers and members of the public exposed as a result of operations at the disposal facility shall be as low as reasonably achievable, social and economic factors being taken into account, and the exposures of individuals shall be kept within applicable dose limits and constraints.

Quantitative criteria are that:

- the occupational exposure of any worker shall not exceed an effective dose of 20 mSv (2 000 mrem) per year averaged over five consecutive years nor an effective dose of 50 mSv (5 000 mrem) in any single year; and
- the estimated average doses to the relevant critical groups of members of the public from all practices shall not exceed an effective dose of 1 mSv (100 mrem) in a year; and
- a geologic disposal facility (which constitutes a single source) shall be designed so that the estimated average dose to the relevant critical groups of members of the public who may be exposed as a result of the facility and its operation, satisfies a dose constraint of not more than 0.3 mSv (30 mrem) per year (corresponding to a risk of 10^{-5} per year).

The primary design goal of geologic disposal is the protection of human health and the environment after the disposal facility is closed. In this period, the release and migration of radionuclides to the biosphere and consequent exposure of humans may occur due to slow degradation of barriers and slow natural processes and, also, following discreet disruptive events that may alter the disposal system barriers or lead to the release of radionuclides in the short-term.

The protection objective for the post-closure period is:

Geologic disposal facilities shall be sited, designed, constructed, operated and closed so that protection in the post-closure period is optimised, social and economic factors being taken into account, and assurance is provided that doses or risks to members of the public in the long term will not exceed the applicable dose or risk that was used as a design constraint.

The quantitative criteria are:

- the dose limit for members of the public from all sources is an effective dose of 1 mSv (100 mrem) in a year, and this or its risk equivalent is not to be exceeded in the future; and
- a geologic disposal facility (which constitutes a single source) shall be designed so that the estimated average dose or risk to members of the public, who may be exposed as a result of the disposal facilities in the future, shall not exceed a dose constraint of 0.3 mSv (30 mrem) in a year or a risk constraint of the order of 10^{-5} per year.

It is recognised that radiation doses to individuals in the future may only be estimated and the uncertainty associated with these estimates will increase at longer times into the future. It is recommended that care be exercised not to apply the criteria beyond the time where uncertainties become so large that they may no longer serve as a reasonable basis for a decision maker.

2. Safety strategy

A *safety strategy*, as discussed here, would define the approach to developing a disposal facility focused on the aim of providing safety during the operational and post closure period. Post closure safety is achieved by designing and implementing a disposal system in which the components work together to provide and assure the required level of protection. This approach offers flexibility to the designer of a disposal system to adapt the disposal facility layout and engineered barriers to take advantage of the natural characteristics and barrier potential of the host rock. Operational safety will also need to be assured and this may require consideration of a number of complex issues, including the impact of operations on the potential post closure performance.

Besides the development of the necessary technical and operational capability, assuring the safe management of radioactive waste requires relevant laws and regulations, a regulatory body and a well defined regulatory process. First, the government needs to provide an appropriate national legal and organisational framework within which the geologic disposal facility may be sited, designed, constructed, operated and closed. This includes the clear allocation of responsibilities (regulator and operator), securing financial and other resources and provision for independent regulatory functions. Geologic disposal deserves special consideration for this framework because of the relatively long time needed for the development of such projects and, also, because of the need to consider institutional controls.

The fundamental aspect of geologic disposal is the requirement for multiple barriers (natural and engineered barriers) and the reliance on passive safety. Multiple barriers or safety functions means that safety is provided by multiple barriers whose performance is achieved by diverse physical and chemical processes. The presence of multiple barriers or safety functions enhances both safety and confidence in safety by ensuring that the overall performance of the disposal system is not unduly dependent on a single barrier or function. The requirement for passive safety means that safety of the facility does not depend on actions being taken after the closure of the disposal facility (after cessation of management of the facility). The cessation of management implies that the disposal facility as a source of radiation hazard is no longer under active control. Thus, the performance of the natural and engineered barriers must be sufficient to provide for long-term safety. In practice, institutional controls, including restrictions on land use, may be maintained even after the disposal facility is closed, e.g., to facilitate monitoring. Such controls and monitoring may be regarded as additional assurance measures, but should not be necessary to ensure safety of the disposal facility during the post-closure period.

3. Development of geologic disposal facilities

Geologic disposal facilities would be developed in a series of steps, each supported, as necessary, by iterative evaluations of the site, design and management options, and disposal system performance and safety. A step-by-step approach to disposal facility development is necessary to ensure the quality of the technical programme and associated decision making. A framework is thereby provided in which sufficient confidence in the technical feasibility and safety may be established at each step of the development. This confidence is to be developed and refined by iterative design and safety studies as the project progresses. The process should allow sufficient time and opportunities for the collection, analysis and interpretation of the relevant scientific and technical data, the development of designs and operational plans, and the development of the safety cases for operational and post closure safety.

The development of a safety case and supporting safety assessments are central to the development of a geologic disposal facility. The safety case is the collection of arguments and evidence that describe, quantify and substantiate the safety, and the level of confidence in the safety, of the radioactive waste disposal facility. The safety case is an essential input to all the important decisions about the facility. It will include the output of safety assessments and additional information, including supporting evidence and reasoning, on the robustness and reliability of the facility, its design, the design logic and the quality of safety assessments and its underlying assumptions. A safety case and supporting safety assessments need to be prepared and updated, 4 as necessary, at all steps during the development of the disposal facility. Supporting safety assessments need to be performed and updated throughout the development of the disposal facility.

Summary

The IAEA is developing a set of safety requirements for geologic disposal to be used by both developers and regulators for planning, designing, operating, and closing a geologic disposal facility. Safety requirements would include quantitative criteria for assessing safety of geologic disposal facilities as well as requirements for development of the facility and the safety strategy including the safety case. Geologic disposal facilities are anticipated to be developed over a period of at least a few decades. Key decisions, e.g., on the disposal concept, siting, design, operational management and closure, are expected to be made in a series of steps. Decisions will be made based on the information available at each step and the confidence that may be placed in that information. A safety strategy is important for ensuring that at each step during the development of the disposal facility, an adequate understanding of the safety implications of the available options is developed such that the ultimate goal of providing an acceptable level of operational and post closure safety will be met. A safety case for a geologic disposal facility would present all the safety relevant aspects of the site, the facility design and the managerial and regulatory controls. The safety case and its supporting assessments illustrates the level of protection provided and shall give reasonable assurance that safety standards will be met. Overall, the safety case provides confidence in the feasibility of implementing the disposal system as designed, convincing estimates of the performance of the disposal system and a reasonable assurance that safety standards will be met.

Acknowledgments

The development of the Safety Requirements publication made use of international experience through a series of consultants and Technical Committee meetings and reviewed by the Waste Safety Standards Advisory Committee (WASSC), the Advisory Commission for Safety Standards (CSS) and Member States. In addition, it is co-sponsored by the OECD Nuclear Energy Agency.

IAEA SAFEGUARDS FOR GEOLOGICAL REPOSITORIES

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In September 1988, the IAEA held its first formal meeting on the safeguards requirements for the final disposal of spent fuel and nuclear material-bearing waste. The consensus recommendation of the 43 participants from 18 countries at this Advisory Group Meeting was that safeguards should not terminate of spent fuel even after emplacement in, and closure of, a geologic repository.[1] As a result of this recommendation, the IAEA initiated a series of consultants' meetings and the SAGOR Programme (Programme for the Development of Safeguards for the Final Disposal of Spent Fuel in Geologic Repositories) to develop an approach that would permit IAEA safeguards to verify the non-diversion of spent fuel from a geologic repository. At the end of this process, in December 1997, a second Advisory Group Meeting, endorsed the generic safeguards approach developed by the SAGOR Programme.[2] Using the SAGOR Programme results and consultants' meeting recommendations, the IAEA Department of Safeguards issued a safeguards policy paper stating the requirements for IAEA safeguards at geologic repositories. Following approval of the safeguards policy and the generic safeguards approach, the Geologic Repository Safeguards Experts Group was established to make recommendations on implementing the safeguards approach. This experts' group is currently making recommendations to the IAEA regarding the safeguards activities to be conducted with respect to Finland's repository programme.

The objective of IAEA safeguards is to provide the Member States with credible assurance of the non-diversion of nuclear material from the declared activities in a state and of the absence of undeclared nuclear material and activities. IAEA safeguards verification activities are a requirement of the Non-Proliferation Treaty. Under the Non-Proliferation Treaty all signatory Non-Nuclear Weapon States are to conclude a comprehensive safeguards agreement with the IAEA. Following the discovery of an undeclared nuclear weapons programme in Iraq in 1991, the IAEA developed a supplemental agreement, the Additional Protocol, to be concluded with the Member States that would strengthen the IAEA's ability to detect undeclared nuclear materials and activities. For those States that have concluded both a Safeguards Agreement and an Additional Protocol and in which the IAEA has concluded the absence of nuclear material diversion and undeclared nuclear material and activities, the IAEA implements Integrated Safeguards. Integrated safeguards permits the reduction of some traditional safeguards requirements as it implements the optimum combination of safeguards measures under the comprehensive safeguards agreement and additional protocol.

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1. *Advisory Group Meeting on Safeguards Related to Final Disposal of Nuclear material in Waste and Spent Fuel (AGM-660)*, STR-243 (Revised), International Atomic Energy Agency, December 1988.
2. *Report of the Advisory Group Meeting on Safeguards for Final Disposal of Spent Fuel in Geological Repositories (AGM-995)*, STR-309, International Atomic Energy Agency, December 1997.

In comparison to the surface facilities, at which the IAEA has experience verifying design information and implementing safeguards monitoring and verification measures, geologic repository safeguards has unique challenges that make monitoring the construction and operation of the repository difficult:

- the space into which the repository will be constructed and the underground areas contiguous to the boundaries of the repository cannot be directly observed. In addition, the underground facility may extend beyond the security fence lines established for the surface facility;
- construction activities in the repository will continue through spent fuel emplacement operations and repository closure;
- the containers into which the spent fuel is loaded are not to be reopened and the continued presence of emplaced containers will be difficult to directly verify, and
- tunnelling into a geologic repository from outside the repository boundary is feasible and a closed repository may be re-excavated. The costs and time periods are probably less than those required for developing and building an enrichment facility.

In order to address the above issues, the IAEA issued the following, among others, safeguards policy statements:

- spent fuel disposed in a geologic repository remains subject to IAEA safeguards as long as the safeguards agreement with the state remains in force;
- IAEA safeguards should maintain unbroken continuity of knowledge of material content based on operator data that has been verified by the IAEA Inspectorate;
- design information verification is a key safeguards measure for detecting undeclared activities in the repository;
- if the IAEA safeguards system fails to maintain continuity of knowledge of the nuclear materials, reestablishment of knowledge of the repository inventory is practically impossible;
- safeguards measures should be redundant, integrated, and unattended; and
- interactions between the IAEA, State, and operator should begin at an early stage to establish a functional, non-intrusive, and cost-effective safeguards approach.

The objectives for monitoring a geologic repository for both safety and IAEA-safeguards purposes are not substantially different, that is, to ensure that the radionuclides emplaced in the geologic repository remain within the perimeter of the repository until they decay to safe levels. What is different are the forces against which the spent fuel must be protected. Repository safety must protect against natural forces; IAEA safeguards must detect undeclared activities by a state intent on recovering the nuclear materials for use in nuclear explosives.

The IAEA safeguards policy states that consultations between the State and IAEA should start at an early stage to agree on and incorporate safeguards measures for the repository. The safeguards experts meetings concluded that because of the differences in design and operation of the proposed geologic repositories, each repository should have a site-specific safeguards approach. Interactions between the IAEA, State, and repository operator need to start during the pre-operational period; that is, the time preceding receipt of nuclear materials. These interactions should, when possible, start before repository excavations begin. During these early interactions, the IAEA should obtain sufficient information through review of the operator's repository characterisation data and independent verification activities to establish assurance of the integrity of the geological boundaries of the repository. The early interactions should also establish and test practical monitoring measures that will permit the IAEA to maintain continuity of knowledge of the integrity of the boundary. The early interactions should also permit the IAEA to establish baseline values for the key parameters being monitored.

IAEA safeguards for a geologic repository begins at the surface facility. The objective of the surface facility safeguards approach is to provide a high level of assurance that the quantity of nuclear material in the spent fuel declared to be received at the spent fuel handling facility is received and leaves the facility in the declared disposal containers. The safeguards approach must verify the integrity of the received containers and the continued containment of the spent fuel in the containers while they are in storage. If the spent fuel is repackaged in the surface facility, the safeguards approach must also verify that the spent fuel removed from the transport casks is sealed into the disposal containers. These activities are accomplished through a combination of tamper-indicating seals, surveillance cameras, and radiation measurement equipment.

The IAEA safeguards objective for the underground facility is to provide a high level of assurance that the quantity of nuclear material in the spent fuel declared to be transferred into a repository is transferred into the repository and that the undeclared removal of the nuclear material would be detected.

The geologic repository safeguards approach is based on maintaining knowledge of the quantity of spent fuel placed into the container that is the geologic repository. Success of the safeguards approach is dependent on verifying the integrity of the geological containment, verifying that spent fuel containers are not removed undeclared through any pre-existing opening into the underground facility, verifying that spent fuel containers cannot be converted into smaller items that would be more difficult to detect, and verifying that the spent fuel is not processed to recover the nuclear material content.

The IAEA safeguards measures:

- verify the containment of the spent fuel in the disposal containers when they are transferred into the underground facility through the use of tamper-indicating seals or welds, camera surveillance, and radiation measurements;
- detect undeclared removal of nuclear material through repository openings through the use of radiation measurements, camera surveillance, and tamper-indicating seals, where practical;
- verify repository design and detect undeclared activities through human surveillance, environmental radiation measurements, and technical measures as may be appropriate (e.g., ground penetrating radar) to detect walled off tunnels and chambers; and
- detect undeclared tunnelling into the repository through the use of appropriate geophysical techniques (e.g., passive seismic monitoring).

After the geologic repository has been backfilled and closed, the safeguards approach will maintain knowledge of the spent fuel content of the repository through the use of satellite monitoring and unattended geophysical monitoring.

An IAEA Experts Meeting evaluated the monitoring needs of the IAEA, state regulatory authorities, and of the repository operator to determine where the IAEA safeguards monitoring needs overlapped those of the state and operator. Monitoring activities were identified in support of repository performance confirmation, quality assurance, operational safety, physical protection, material control and accounting, and IAEA safeguards. IAEAs needs overlapped with the states and operators monitoring needs in the areas of verifying the integrity of geological containment, assuring conformance with approved designs, verifying cask management and oversight, detecting movements of materials, verifying operational activities, and detecting radiological events. The Experts Group concluded that during:

- the pre-operational phase, the IAEA safeguards measures closely overlap with the state's and operators performance monitoring and quality assurance monitoring activities;
- the operational phase, the IAEA safeguards measures significantly overlap the state's and operators performance confirmation, quality assurance, operational safety, physical protection, and material control and accounting monitoring activities; and
- the post-closure phase, IAEA had the only monitoring requirement.

The IAEA's post-closure monitoring requirement was identified as a potential assist to states in addressing accidental intrusion scenarios.

An IAEA Waste Technology Consultants Meeting, that assessed the technological implications of IAEA safeguards on geologic repositories, concluded that the impact of IAEA safeguards on geologic repositories will not be significantly different from that at other nuclear facilities and that implementation of the safeguards measures would be consistent with envisioned operational controls and management practices. All IAEA safeguards impacts were expected to be resolvable through advance planning and co-operation.

The implementation of IAEA safeguards measures for the pre-operational phase of a geo logical repository will first be applied at Finland's Olkiluoto Geologic Repository, which is the subject of the next paper.

FINNISH APPROACH TO SAFEGUARD IN THE CONTEXT OF GEOLOGICAL DISPOSAL OF SPENT NUCLEAR FUEL

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Introduction

Olkiluoto, situated at the west coast of Finland, was approved as a site for final disposal of Finnish spent nuclear fuel. The decision-in-principle (DIP) was made by the government and ratified by Parliament in May 2001 by a clear majority of votes (159 votes were in favour, only three were against, and there were 37 abstentions). Hosting municipality, Eurajoki, had also supported the DIP application earlier with clear majority.

From now on Posiva, the company who is responsible for the final disposal of spent nuclear fuel, will perform detailed investigations in the Olkiluoto area. Above all, this includes construction of underground rock characterisation facility, ONKALO, which goes 400-600 m deep under the Earth's surface. Excavations of ONKALO will begin in 2004. It is expected, that the ONKALO will become a part of final underground repository. The construction licence for final disposal plant, comprising of an encapsulation facility and an underground repository, will be applied around 2012 and construction process of is planned to start 2013-2014. According to current plans operation of the plant will start 2020.

Safeguarding final disposal process is a challenge. Design information verification of underground facility is difficult after construction of the tunnels. Some geophysical methods exist to perform design information verification after construction, but they may create ambiguous results. Re-verification of nuclear fuel, which is a cornerstone of present safeguards approaches, will not be possible after disposal. The roles and responsibilities of the parties involved (operator, STUK, EURATOM, IAEA) must be determined with care.

1. Initial knowledge base

Since rock drilling and blasting of ONKALO ramp will start at the site next year, it is desirable to create common understanding about the baseline situation. This includes seismic monitoring and satellite imagery. These activities have been launched in this year. Passive seismic monitoring will continue at least until next autumn, and maybe also further. A few satellite images have also been taken.

In addition, relevant information has been collected in the environmental monitoring programme of operating Olkiluoto Power plant. This includes data from radiation monitoring network. Posiva has collected data from groundwater properties and seismicity.

The dataset available is rather comprehensive and it will be made available to the IAEA upon request. The IAEA should review and extract relevant knowledge out of this characterisation data and complement it with its own verification methods in order to conclude that there are no undeclared activities in the area. However, the initial data is not collected for safeguards purposes, therefore the review will not be an easy task.

2. Some specific challenges

The ONKALO will not be a nuclear facility under *Nuclear Energy Act*. However, it will, most likely to become a part of final of final underground repository. This creates a paradox: Authorities do not have legal mandate to regulate and verify the construction process of *de facto* nuclear facility during the years 2004-2012. Until now Posiva's plans have been reviewed by national nuclear safety authorities. This conduct where all parties accept their responsibilities may continue even without a clear legal framework. However, this "gentlemen's agreement" will be tested in the future, since both national and international authorities need to be assured, that design information provided by Posiva of the underground facility is correct and complete. This may require verification activities during the construction process and also access rights, which is clearly an expansion to current regulatory work done in Finland at the moment. Therefore, legal framework would clarify the situation.

Safeguards technology needs to be developed. Seals and surveillance to be applied should be fail-safe. Some advanced tracking methods may be applied. Verification technology prior encapsulation and final disposal needs development, since no current NDA verification method satisfies IAEA criteria.

Total amount of data created during the preoperational, operational and post-operational phases of the project is huge. The management and analysis of this data over long periods of time is organisational and technical challenge. The aim is that after the closure of the depository the documentation remains. From this documentation all future generations may draw their own conclusion about the situation and, hopefully, satisfy themselves that no nuclear material has been diverted to unannounced activities.

3. Finnish initiatives

Finnish support programme to the IAEA safeguards (FINSP) has been active in this area and clear steps forward have been achieved. FINSP has proposed a safeguards approach for encapsulation facility (2002). In autumn 2003 FINSP hosted an international expert meeting, where Olkiluoto specific safeguards issues were addressed. FINSP has not obtained any funding for future development of the final disposal concept, so other sources ("tits") of money should be searched for.

In November 2003 STUK's Director General Jukka Laaksonen sent a letter to IAEA DG, Mr. ElBaradei attached with some information in order to help the IAEA to begin to establish an initial knowledge-base on Olkiluoto. DG Laaksonen also expressed a hope that "the IAEA will be in position to determine the measures and practises that will satisfy the safeguards requirements, including that of the credible assurances of the absence of undeclared activities also during the construction of the ONKALO – and ultimately, during the construction and operation of the final geologic repository of spent nuclear fuel".

STUK as a Finnish national authority wants to have exact knowledge about nuclear activities in Finland also in the future. This requires development of technical capabilities, practises and experience. This also could make co-operation with international inspectorates fruitful. It is proposed, that EURATOM and IAEA could make better use of competences of Finnish state system of accounting and control (SSAC).

Conclusions

Final disposal concept of spent nuclear fuel has gained a wide acceptance within Finnish society. Political support is very strong both locally in Eurajoki municipality and also at state level.

However, this does not imply, that all issues are resolved. Safeguards implementation is a completely new challenge and need to be addressed appropriately. No undue burden is transferred to future generations. They should be pleased with the documentation left behind after all fuel is disposed and operation of the plant is concluded.

Further technical development is required. The necessary safeguards-related technology, which is not presently available, should be developed concurrently. All technological systems ant other sources of information create large amounts of data. Computerised systems to facilitate knowledge creation and sharing from this huge data source will also be essential.

The objective and responsibility of IAEA safeguards is "to provide the Member States with credible assurance of the non-diversion of nuclear material from the declared activities in a state and of the absence of undeclared nuclear material and activities". Geological Final disposal creates two challenges:

- design information verification is difficult for underground facilities. Therefore elaborate review of initial information may be required, and
- safeguards should not delay or hamper the final disposal process.

This creates extra time pressures to IAEA, since no unresolved issues should remain concerning any spent fuel batch at the time of its disposal. In other words, there will be a definite dead-line for IAEA conclusions for every spent fuel canister. Since disposal process is continuous, the IAEA should be capable of making and expressing out these conclusions continuously and in a timely manner for decades.

Reference

Rautjärvi J, Tiitta A, Saarinen J. *Preliminary concept for safeguarding spent fuel encapsulation plant in Olkiluoto, Finland.* Phase III report on Task FIN A 1184 of the Finnish support programme to IAEA Safeguards. STUK-YTO-TR 187, Radiation and Nuclear Safety Authority STUK, Helsinki, 2002.

THE NUCLEAR LIABILITY CONVENTIONS AS APPLIED TO RADIOACTIVE WASTE GEOLOGICAL REPOSITORIES: THE TEST OF TIME

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Introduction

While most of the radioactive waste resulting from the peaceful uses of nuclear energy is still stored on the site of the installations where it was generated, a growing number of countries are in the course of opening and operating dedicated facilities for their ultimate disposal. In respect of high-level or long-lived waste, emplacement in deep geologic repositories is generally regarded as the safest solution. This requires of course that a suitable legal framework be established beforehand and that, as is the case for all nuclear activities, the potential victims of an accident be protected.

When considering if and how the international system of liability and compensation for nuclear damage may apply to geologic repositories[2] used for the disposal of radioactive waste (including spent fuel if treated as waste), two different questions need to be addressed. The first is whether the existing rules are suitable in respect of the "active" operation of these repositories. The other is whether one may be confident that this system (in fact, any legal system) will continue to apply in the very long term after the closure of repositories. This paper will undertake to address both of these questions, while acknowledging that to answer the second is a somewhat speculative exercise.

Under international nuclear-liability conventions,[3] damage caused by radioactive waste is in principle subject to the same regime of liability and compensation as other types of nuclear materials. There is no indication that the authors of these Conventions, adopted in the early 1960s, intended to discriminate between them. As a matter of fact, the absence of specific provisions in relation to the risks created by the disposal of radioactive waste (RW) did not raise any particular difficulty for many

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1. The facts contained and ideas expressed in this paper are the responsibility of the author alone.
2. A wide range of factors are being used to assess the degree of risk presented by radioactive waste (one specially important being the period of radioactivity/half-life) and which serve therefore to decide the best management method for *its* disposal: *dispersion*; surface storage; shallow land burial; geological emplacement. This paper will concentrate on the latter, because the other options are comparatively less unique in terms of the liability questions they can raise.
3. Those conventions include:
   - the *1960 Paris Convention on Third Party Liability in the Field of Nuclear Energy,* as revised in 1964 and 1982 and as to be revised again in the beginning of the 2004 ("the Paris Convention");
   - the *1963 Vienna Convention on Civil Liability for Nuclear Damage,* as revised in 1997 ("the Vienna Convention"), and
   - the *1997 Convention on Supplementary Compensation for Nuclear Damage* ("the CSC"). Since the CSC is not yet in force, this paper will only address the application of the Paris and Vienna Conventions.

years. Indeed, it is only after several years of application that the question of whether these Conventions did cover facilities especially designed for the long-term storage or disposal of such waste was addressed by legal and technical experts, particularly within the OECD Nuclear Energy Agency. As a result of this study, the technical scope of the *Paris Convention*[4] was modified in a two-step approach. First, it was agreed that facilities for the disposal of RW during the period before their ultimate closure should be considered as "nuclear installations" in the meaning of the Convention. Second, on the occasion of the current revision of the Convention, the definition of "nuclear installations" has been amended so as to include, without the earlier qualification, those intended for the disposal of radioactive waste.[5]

This welcome clarification does not however answer some legal questions stemming from the fact that the disposal of RW implies the possibility that damage, if any, may not occur before several hundred or thousand years. In other words, one wonders whether a system of third-party liability designed to apply to today's risk of nuclear activities is adequate to cover extremely long-term hazards, for example those associated with RW repositories in deep geological formations. The time-scale involved here is in itself a challenge to the imagination. It also points to the central policy issue of the management of RW, that is the duty to safeguard the rights of future generations to a preserved environment, thereby ensuring the reliability of the liability and compensation schemes.[6]

1. Application of the special nuclear liability regime to RW geologic repositories[7]

In general terms, this special regime[8] applies to damage resulting from the management of RW provided that, like the other nuclear activities which are within the scope of the Conventions,[9] some conditions are met:

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4. No such action has been taken regarding the Vienna Convention.
5. For reasons of legal technique, the relevant provision of the Paris Convention [Article 1*(a)(ii)*] refers to "installations for the disposal of nuclear substances", it being understood that "radioactive waste" is a category of "nuclear substances" under the Convention.
6. The concept of responsibility towards future generations was embodied in the principle of "sustainable development", endorsed by the UN Rio de Janeiro Conference in 1992. Also relevant is the well-known "precautionary principle". In substance, according to these principles, one should not transfer to distant generations risks and charges which we would regard today as unacceptable and also avoid potentially hazardous actions where a scientific uncertainty exists as to their consequences. In our case, however, one is dealing with "acceptable risk", based on a very conservative scientific assessment, which, moreover, is meant to decrease over time due to radioactive decay. We should therefore resist the conclusion that the very act of passing on a potential exposure to damage caused by RW disposed in geologic repositories to generations to come is in itself ethically objectionable.
7. This paper makes extensive use of a report (unpublished) prepared in 1994 by Mr. Pierre Strohl for the NEA Group of Governmental Experts on Nuclear Third Party Liability, dealing with the liability regime applicable to the long-term storage and final disposal of radioactive waste. See also, P. Reyners, *Third Party Liability for Damage Caused by the Disposal of Radioactive Waste*, in *Tagungsbericht der INLA-Regionaltagung in Meissen*, *Nomos Verlagsgesellschaft,* Baden Baden, 1996.
8. Both the *Paris* and *Vienna Conventions* provide for a system of strict (no-fault) and exclusive liability of nuclear operators vis-à-vis third parties. Such operators must also provide a financial security (usually insurance) of a type and under conditions approved by the government concerned. In return, the Conventions allow for the possibility to cap the amount of such liability within specified limits. They also define the damage entitled to compensation, set specific time limitations in respect of claims and determine which Court will be competent for a particular accident ("nuclear incident").

   Bearing in mind the case of RW geologic repositories, this system is quite demanding. It is meant in practice to ensure that nuclear damage is compensated even in the absence of any fault on the part of the

- the damage suffered is a “nuclear damage” caused by a “nuclear incident” which occurred within the territorial scope of the Conventions;
- the incident occurred in a “nuclear installation” or during a transport to or from such an installation;
- there is a nuclear “operator” designated by the competent national authority in respect of the installation or transport concerned;
- the claims for compensation have been introduced within the prescribed time limits,[10] and
- an adequate causal link between the damage and the incident may be established.

Satisfying these conditions is not expected to raise particular difficulties during the “active” or “pre-closure” phase of the management of RW[11] inside “nuclear installations”, including during extended storage periods, as long as a nuclear operator is effectively in charge of the waste. On the other hand, as already indicated, the fact that the generic definition by the Conventions of nuclear installations made no mention of facilities used specifically for the disposal of RW left the status of such facilities unclear.

This situation could create a variety of problems. If RW repositories were not considered as a “nuclear installation” in the meaning of the Conventions, potential liability would remain indefinitely with the last operator in whose installation the radioactive waste had been held or processed prior to transfer to the disposal facility and the occurrence of the damage. In the case of a repository holding waste originating from various nuclear installations, which is a very likely situation, their operators could be held jointly and severally liable as it could be difficult or even impossible to determine with accuracy which particular waste had caused the damage. The obligation under the Conventions to maintain a financial security would also continue to apply indefinitely.

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operator. The fact that the technical conditions of the disposal entirely satisfied the prescription of the competent regulatory authority, that any emission of radioactivity was well under the limits set by applicable regulations, that the accident was entirely due to an unforeseeable act of another person (for example, an intrusion on the site), would not relieve the operator of its liability.

From the nuclear safety angle, the applicable international instrument is of course the *1997 Joint Convention on the Safety of Spent Fuel Management and on the safety of Radioactive Waste Management*. This Convention, which makes no reference to aspects of nuclear liability, defines several terms which are relevant to the disposal of RW in geologic repositories, such as “closure”, “disposal”, “operating lifetime”, “radioactive waste” (incl. management and facility), “spent fuel”, and “storage”. These terms do not appear in the nuclear liability Conventions, or are expressed in different ways and can therefore have a different meaning. As a consequence, such definitions belonging to the Joint Convention cannot validly be used when interpreting the latter Conventions, which may be a source of difficulty for the law-makers. In this paper, one will only use these definitions as provided in the *Paris* or *Vienna Convention*.

9. For example, uranium mining and milling tailings (because they are considered as a low-level risk) and disused radioactive sources intended for medical, industrial, agricultural, etc., purposes, are not covered by the Conventions.
10. It should be noted that the Paris and Vienna Conventions provided originally that actions for compensation in respect of damage caused by nuclear materials being lost, stolen, jettisoned or *abandoned* by the operator would be prescribed after twenty years. Such a provision which conceivably, though inappropriately, could have been applied to the disposal of radioactive waste, has now been eliminated in the Vienna Convention and will also be removed from the Paris Convention.
11. Contrary to “nuclear fuel”, spent fuel is not a defined expression under the Paris and Vienna Conventions and there is also no special definition of "waste" as opposed to “radioactive product”. However, there can be no doubt that if a spent nuclear fuel is treated as a radioactive waste it is then covered as such by the Conventions.

With respect of the *Paris Convention*, this undesirable uncertainty was removed by a decision, taken in 1984[12] by the Contracting Parties, to introduce RW disposal facilities into the scope of the Convention, but limited to their "pre-closure phase".[13] During that phase, indeed, it was considered that the activities involved were sufficiently similar to other nuclear operations covered by the Convention to warrant their inclusion in the same regime. This decision, on the other hand, deliberately left open the possibility of the future application of this regime to the post-closure phase, pending further consideration of the issue. In fact, that question was not to be settled before some twenty years and further studies within the NEA's competent body.[14]

Revision of the Paris Convention

As part of the revision exercise of the Paris Convention carried out recently, the Parties to that Convention reviewed its technical scope and decided to bring two modifications reflecting their intention to keep abreast with new developments and needs. First, they agreed that the Convention should continue to apply during the decommissioning phase of nuclear installations;[15] second, they introduced in the definition of "nuclear installations" those intended for the disposal of RW, without the restriction to the pre-closure phase decided in 1984. As a result, RW geologic repositories will now be covered by the regime without any limitation as to their operation or time.[16]

2. From "pre-" to "post-"closure – Some legal issues

In order to envisage that a nuclear operator of a radioactive waste repository may be held liable for nuclear damage occurring after that repository has been definitely closed,[17] leads to revisiting several key elements of the nuclear liability regime, such as:

- the nature of the "incident" and of the resulting "damage";
- the status of the "operator";

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12. Decision adopted by the NEA Steering Committee for Nuclear Energy, adopted on 11 April 1984, based on Article 1(a)(ii) of the Convention.
13. There has been no definition of what the notions of "pre-" and "post-"closure mean exactly but "closure" may be understood as the completion of emplacement operations on the site and the termination of engineering work intended to ensure the safe isolation of the waste, if one refers to the Joint Convention. From the more conservative angle of the liability regime, it might extend to the cessation of active monitoring of the disposed radioactive waste. Whether "closure" could be interpreted as the end of institutional control is debatable but, then, other difficulties could emerge as discussed later.
14. The Group of Governmental Experts on Third Party Liability in the Field of Nuclear Energy, now the NEA Nuclear Law Committee.
15. This amendment confirmed in fact an earlier decision of the NEA Steering Committee adopted in 1987, supplemented by another Decision adopted in 1990 which allows, subject to certain conditions, to relieve the operator of its liability under the Convention.
16. Revised Article 1(a)(ii) of the Paris Convention. It is again worth noting that the revised Vienna Convention makes neither reference to the decommissioning of nuclear installations (leaving therefore some uncertainty as to its application in this case), nor to disposal facilities (it only refers to installations for the (temporary) storage of nuclear material), which suggests that it does not apply to this category of nuclear installations. This means that there is now a significant difference between the two Conventions, as compared to their original texts.
17. The particular question of the retrievability of the waste during that period will not be addressed here because it would be tantamount to a resumption of active operations on the site and would logically require a reactivation of the application of the nuclear liability regime.

- the provision of the mandatory financial security, and
- the time-frame of the operator's liability.

In the case of a RW repository – particularly a deep geologic repository – which has definitely closed, a nuclear incident is not likely to manifest itself in the usual fortuitous, sudden way as it may be the case in a reactor or other nuclear installation. The release of radioactivity causing damage will probably be very gradual and continuous,[18] slowly migrating through the soil or groundwaters, and the resulting damage may not be noticed before a long period of time. This release, and the resulting contamination, is more likely to affect the environment[19] rather than cause direct damage to individuals. As to the possible magnitude of the damage (independently of the risk), this is obviously a matter for speculation and it will not be addressed in this legal analysis. One should simply recall that one justification of a special liability regime for nuclear incidents is the possibility of their far-reaching consequences.

Since the succession of events constituting the "incident" at the origin of the damage will probably extend over a long period, it may be difficult, perhaps impossible, to determine exactly when this form of continuous incident started and when it ended.[20]

This is important because the time limitations established by the Conventions[21] start from the date of the nuclear incident, while they make no reference to the time of occurrence of the damage itself which, in turn, may be difficult to identify in the case of low-level contamination. Furthermore, the crucial question of causality becomes increasingly complex as time goes on.

Considering the interest of potential victims, it has been suggested that the most favourable interpretation would be to define the time of the incident as that at which the final causal occurrence of the damage took place. If, as it is probable in the case of geologic repositories, the incident consists in a (successive) failure of the barriers intended to prevent the release of radioactivity contained in the RW, the date the person suffering the damage had knowledge – or should reasonably have known – both the damage and the liable operator, could in principle apply.[22]

2.1 Nuclear operator's liability: A perpetuity clause?

One of the original features of the nuclear liability regime is that no nuclear installation may be operated without an operator being designated as the person liable in the case of damage to third parties. Application of this feature to geologic repositories means that such an operator will remain potentially liable almost indefinitely for the reason that there is no legal device to put an end to this

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18. The definition of "nuclear incident" under the Conventions refers to any occurrence or series of occurrences having the same origin.
19. Impairment of the environment is now explicitly recognised as a category of nuclear damage, entitled to restoration.
20. This may have an impact in the determination of who is liable, in the event of a succession of operators for the same nuclear repository, which is not unlikely over time.
21. According to the Conventions, as revised, the right to compensation shall be subject to prescription or extinction after thirty years in respect of death or personal injuries, and after ten years for other nuclear damage [Paris Convention, Article 8; Vienna Convention, Article VI].
22. Paris Convention, Article 8(d); Vienna Convention, Article VII.3. This special time limitation is generally called the "discovery period".

obligation under the Conventions, other than to transfer it to another authorised operator.[23] The purpose of this rule is to avoid the possibility that a victim of a nuclear damage may find itself without a liable operator to which it may address its claim for compensation.

It should be noted in this respect that in the case of geologic repositories, contrary to other types of nuclear installations covered by the Conventions, there will be no phase of decommissioning after the termination of their active operation, and no physical dismantling, thus leaving no possibility to discontinue the statutory liability of the nuclear operator.[24]

Another type of question is related to the fact that the Conventions impose on the operator the obligation to cover his liability with a financial security, usually an insurance policy issued on a one year renewable basis. Also, for technical and actuarial reasons (the problem of "delayed" damage), the period covered by nuclear liability insurance cannot normally extend beyond ten years. Such a situation, obviously, questions the practical ability of any operator of a RW repository to guarantee that it will continue to exist over the quasi unlimited period of time. Apart from other technical or policy considerations, this strongly suggests that the management of RW repositories should not be considered as an activity suitable for private companies for which to continue to exist is not in itself a *raison d'être*. Rather, such responsibility should be entrusted, as it is already the case in many countries, to State institutions which offer a comparatively better assurance of durability. Another aspect is that the safe storage and disposal of RW over extended periods is more akin to a "public service" rather than to a commercial activity, as is the case for the nuclear industry in general. The ordinary rules of private law, to which the nuclear liability Conventions belong, may therefore not be best suited to govern the risks, if any, associated with RW repositories which are definitely closed.

2.2 Transfer of the liability to the State

Notwithstanding the previous remark, when a State acts as the operator of a RW repository, it is meant to assume in the same way as a private operator the potential liability for nuclear damage originating from the waste, with one significant difference in respect of the obligations which the Conventions assign to nuclear operators: it has no obligation to maintain a special financial security since it is a current practice that States can be their "own insurer" and because they are expected (at least in principle) to be solvent in all circumstances.[25] This solution would therefore have the advantage of removing the uncertainties as to the insurability of the risk created by the repository. Economically, it would also relieve the State of the burden of insurance costs to cover the very remote possibility of actual damage.

This is not to suggest that when RW are disposed of under the responsibility system will not be affected by time as well. It may prove therefore desirable to look for alternative arrangements when transferring the liability to the State.

One possibility which comes to mind is the establishment of a compensation fund. National policies often require money be put aside by operators to ensure that it will be available to cover, when the time comes, the cost of the decommissioning of nuclear installations or of the processing and

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23. Both Conventions allow however for the possibility to exclude from their scope a particular category of nuclear installation or materials if the small extent of the risk involved so warrants such exclusion but it is doubtful that such a provision could apply to RW geologic repositories.
24. See note 15 supra.
25. See Article VII.2 of the Vienna Convention. While there is no equivalent provision in the Paris Convention, a State remains of course free to offer a financial guarantee out of its budget.

disposal of radioactive waste. This is already the case for certain types of risks which, unfortunately, result regularly in actual damage, such as oil spills.[26] It appears doubtful, however, that such a solution would be adequate to cover such a highly hypothetical and distant risk as that related to RW geologic repositories, considering in particular the managerial complexity of such funds which would be exposed to the question of their perennity.

On the other hand, if it were considered inappropriate, from a political or ethical viewpoint, to exonerate the producers of radioactive waste of their obligation to maintain a financial security, because of the practical and legal difficulties just mentioned, then the solution of a one-off payment to the State, in the guise of an insurance premium (for example calculated on the basis of the amount and particular nature of the waste concerned), might be an acceptable compromise.

A choice of options

Keeping in mind the remarks above, various options are open to policymakers when considering the long-term liability associated with RW geologic repositories, once they have been definitely closed:

1. To terminate the application of the Paris and Vienna Conventions in respect of such repositories at a given time and under conditions to determine, for the reason that the risk is very low and that to guarantee their continued implementation over the periods of time involved appears impractical.[27] Such a solution, however, might not be very likely to win the confidence of the public which would probably be inclined to suspect the motives behind such a decision. It would also contradict the interest of protecting future generations, which is an important political factor.
2. To replace the Conventions by a different legal regime (at the international or domestic level) better suited to the specifics of RW repositories. Given the very low risk of an accident, the fact that such a regime would not necessarily offer much greater assurance of durability then the existing Conventions and the fact that very few repositories are planned to be built in the foreseeable future, this solution does not seem very likely to attract sufficient support.
3. Or to wait and see, considering in particular that the Paris and Vienna Conventions have no provision limiting their application over time and that in respect of RW repositories being currently covered by their provisions (at least as far as the Paris Convention is concerned), there is not really an urgent need to make special arrangements in this respect. In fact, the question of the durability of the liability and compensation regime is not essentially disconnected from that of the institutional arrangements intended to ensure the "memory" of the RW repositories over the passage of time.

To adopt this third option would not really be a case of "benign neglect", but rather that of pragmatism. It appears today increasingly likely, notwithstanding the confidence invested in technology to ensure the safety of exists, then it may be made liable as well under the Conventions.

26. For example, the International Oil Pollution Compensation Fund.
27. This would not in fact result in a legal vacuum, since the ordinary rules of civil law would then apply. Concerning the risk to safety, it is a prerequisite for authorising the disposal of RW (which legally can be compared to an act of abandonment) that the possibility of a total failure of the methods of waste isolation can be discarded with absolute confidence.

Subject, if necessary, to minor adjustments, the special nuclear liability regime may therefore continue to apply until the circumstances will require perhaps a new and better suited system.

3. Final remarks: From historical to geological time

The purpose of this short analysis was to discuss how the international instruments in the field of nuclear liability could apply to damage resulting from the disposal of RW in geologic repositories. As explained above, the regime of liability and compensation established by these instruments does apply and actually will continue to apply in the predictable future, i.e., during the pre-closure period of such repositories and also as long as effective mechanisms of surveillance and institutional "memory" will continue to be effective. Until then, this regime may be considered as "sustainable".

On the other hand, what is beyond our control in terms of duration of human institutions (is it a matter of centuries, millenniums), is by essence uncertain and becomes rather a philosophical issue, not very different from the more general socio-political debate about the disposal of waste and the legacy to future generations.

An inherent contradiction in the legal approach resides in the fact that it inevitably operates within a given time-frame while aspiring to be non-temporal, laying down principles independent from historical context. From this perspective, the time in which law operates stands in opposition to the time in which society exists. In extension of potential liabilities over time. The subject calls to mind what Spinoza said in his opus on ethics (1675), "the duration (of time) is the indefinite continuity of existence." This is, in substance, the challenge confronting governments when they establish the technical conditions and legal framework particular to geologic repositories of radioactive waste. Liability for possible damages constitutes only one of many aspects, and probably not the most critical, in a larger thorny issue.

WORKING GROUP 3

PRACTICAL APPROACHES AND TOOLS FOR THE MANAGEMENT OF UNCERTAINTY

THE ISSUE OF RISK DILUTION IN RISK ASSESSMENTS[1]

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Introduction

This paper explores an issue that was first highlighted more than 20 years ago during an inquiry concerning the Sizewell B nuclear power station in the UK. In the probabilistic safety assessment for this plant, the proponent had apparently reduced its estimates of risk by admitting to increased uncertainty about the timing of certain events. This situation is counter-intuitive, since an increase in uncertainty about the factors contributing to safety would be expected to lead to less confidence and hence to greater risk. This paradoxical situation was termed "risk dilution" and it has been a topic of interest to reviewers of safety cases since. The recent international peer review of the Yucca Mountain performance assessment[2] concluded that there was a potential for risk dilution in the assumptions and calculations presented.

The next section describes how assumptions about the timing of events and other aspects of an assessment may lead to risk dilution, and this is followed by two examples based on recent performance assessments. The final section discusses how potential problems can be identified in safety cases, and the types of response that a regulator might adopt as a result.

How can risk dilution occur?

A general definition of risk dilution is a situation in which an increase in the uncertainty in the values of input parameters to a model leads to a decrease in calculated risk.

The general cause of risk dilution is an overestimation of the spread of risk in space or time: risk dispersion might be a better name. Systems with a high degree of natural dispersion will be less susceptible to risk dilution than those giving rise to consequences that are localised in space and time.

There are several ways in which risk dilution can arise, each of which produces slightly different effects:

- Event timing.
- Spatial effects.
- Parameter Correlation.
- Parameter Distributions.

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2. IAEA and NEA, An International Peer Review of the Yucca Mountain Project TSPA-SR, 2002

The potential significance and regulatory responses to these different sources of risk dilution are also somewhat different, and so they are described separately below.

Event timing

The way in which the timing of events is treated in safety assessments is perhaps the most common reason that risk dilution is recognised as a potential issue of regulatory concern. The type of events that may require consideration in performance assessments include the onset of different climate conditions, the initiation of faulting in the geosphere, canister failure, and intrusion into the repository or a contaminant plume. All of these types of event have been considered in different probabilistic assessments using various methods.

For some types of event, such as changes in climate, there is extensive knowledge about past changes which allows for some assumptions to be made about extrapolating the occurrence of similar events into the future. For other types of event, particularly those relating to human activities, knowledge of the past does not provide a model for extrapolation into the future, and the most reasonable assumption that can be made is that future events will take place at random times.

In addition to imposed events, systems can exhibit "emergent" events, such as the arrival of a contaminated plume from a repository to the biosphere. There is no fundamental difference between an emergent or imposed event as far as the potential for risk dilution is concerned.

Simulating events at random in a probabilistic assessment means that each simulation will have a different history of events. If the event frequency is very low then the probability of an event occurring at a similar time in more than one simulation becomes very small. The overall significance of this in terms of the expectation value for dose or risk, and the potential for risk dilution, is dependent on how the consequences of the event affect the overall performance and, most importantly, the time over which these consequences persist.

If the event being simulated is one that initiates a new set of boundary conditions or has some other effect that persists for a long period, then the effect of different histories may be small. For example, the propagation of a new fault that provides an alternative pathway for radionuclides may be modelled as an event taking place at a random time. However, although the time at which the fault is formed is likely to be different in each simulation, there is a cumulative effect so that after some particular time faulting will have been simulated in the majority of the simulations. The expectation value of risk will change steadily over the period in which more and more simulations have the new conditions. This change may properly reflect the uncertainty in the time at which a fault might occur.

If the event initiates a change that is short-lived (compared to the frequency or range of possible initiation times), then the effect of different time histories may be much more significant. For these types of event, there is no cumulative effect in terms of consequences, and the effect of the event does not appear in a greater number of simulations at later times. Instead, the expectation value at any given time is derived from many simulations not affected by the event concerned and a few simulations with the effect. This is the situation that gives rise to risk dilution, because the peak value of mean consequence, which is the usual measure of risk, may be significantly lower than the mean value of the peak consequence from each simulation. We call the ratio between them the "Risk Dilution Ratio".

Spatial effects

When a potential exposure arises, for example, by accessing a contaminated plume through a well, there is a potential for risk dilution. Even if the plume location and concentration could be predicted precisely (of course, it cannot), the uncertainty in the location of wells needs to be treated with care. In a region where wells are common, it can be argued that the probability of a well being present is unity and so only the peak concentration is relevant. In a region where wells are rare, credit might be taken for the low likelihood of any well accessing the plume. In cases where wells will be present but not necessarily for the whole time, the "correct" approach is unclear – falsely taking credit for a probability of less than unity could be thought of as risk dilution. In general, any exposure that arises through human actions occurring at specific locations that are uncertain has the possibility of leading to this type of risk dilution issue.

There are other spatial effects that can lead to an undue reduction in risk but that are not risk dilution as such. In particular, the selection of inappropriate compartment sizes in models can lead to excess mixing and hence to an underestimation of concentrations. Thus, an inappropriate modelling assumption might lead to a reduction is risk. There would also be a reduction in the consequence of a deterministic case. Such problems should be avoided in the normal process of selecting and checking model assumptions.

Parameter correlation

If all of the parameters sampled in an assessment are independent, then consequences corresponding to the entire parameter space are possible. If, however, there are correlations between parameters, then some parts of parameter space will represent invalid combinations and the consequences of such combinations should not be used in calculating risk. The correlated parameters may, for example, determine the timing of an emergent event and the size of the consequence – ignoring the correlation might give impossible combinations of timing and consequence.

Ignoring known parameter correlations is equivalent to increasing the level of uncertainty, and so risk dilution can occur if the consequences from invalid parameter combinations are consistently low. However, as with the use of inappropriate pdfs (probability distribution functions) discussed below, it is also possible that invalid combinations will lead to high consequences and hence to an over-estimation of risk.

The best method for avoiding this cause of risk dilution is to account for parameter correlations within the parameter definitions and sampling methods used. Various approaches are available, depending on the parameters concerned, their distributions and the extent of the correlations, although care is required to avoid an undue reduction in the level of uncertainty when a correlation is imposed.

An alternative approach that has been used in some assessments is to apply only limited correlations at the sampling stage, but then to examine the output to determine whether the parameter combinations that have most effect on the expectation value are realistic. Although a close examination of the results should be a part of the analysis of all assessment calculations, determining whether sampled conditions are realistic or unrealistic is a subjective process. Eliminating high consequence cases on the basis of such judgements, and thereby reducing the overall expectation value of dose or risk, may not be transparent and could introduce an unintentional bias to the results. A further, serious, drawback of this approach is that the same level of scrutiny will probably not be applied to all sets of sampled conditions. This means that unrealistic conditions that result in low consequences are likely to be retained, possibly leading to risk dilution.

Parameter distributions

This type of risk dilution is perhaps the most readily avoided, because its cause is readily understood. It arises when the pdfs used to generate sets of parameter values are inappropriately biased towards the regions of the distribution leading to low consequences. Given a direct correlation between parameter value and the calculated consequence, this type of risk dilution arises if the sampled pdf is more negatively skewed than appropriate.[3]

There is no reason why pdfs should not be skewed. Indeed for parameters that cannot have negative values, a strongly skewed distribution is an accurate reflection of the uncertainty. When pdfs are supported by observations or experimental results, significant risk dilution from the use of inappropriate distributions is less likely to be an issue than when pdfs result from expert judgement or elicitation, although care is still required to avoid the inclusion of inappropriate observations.

A key concern when eliciting distributions is the phenomenon known as anchoring, whereby experts focus on a narrow range of values and underestimate uncertainty. Underestimating parameter uncertainty by defining pdfs that are too "narrow" will lead to an underestimate of uncertainty in the overall performance measure (dose or risk). Facilitators therefore encourage experts to think carefully about circumstances that may give rise to larger or smaller values than their initial estimates. The tendency toward anchoring and the consequent probing may lead analysts to extend the range of pdfs in order to compensate. It is this process of *ad hoc* increases in uncertainty that could lead to risk dilution. In practise, the converse effect of generating too high a consequence may also occur and lead to "risk amplification".

In summary, risk dilution through the inappropriate definition of parameter pdfs is only likely to be significant in a few circumstances. Undue pessimism arising from over-estimated levels of uncertainty is considered to be a more likely consequence of inappropriate parameter pdfs.

Is risk dilution a concern?

The preceding discussion has identified a number of ways in which risk dilution could occur in assessments of the long-term performance of facilities for radioactive waste. These are based on somewhat theoretical arguments which do not provide an indication of the potential significance of the effects in real assessments. Similarly, the recent international peer review of the Yucca Mountain performance assessment (NEA/IAEA, 2002) concluded that there was a potential for risk dilution, but neither the developer nor the reviewers established its possible significance. In this section, therefore, we provide two examples based on typical calculations for a repository for radioactive waste, with the aim of showing if there is indeed cause for regulatory concern if assessments are based on inappropriate assumptions or approaches.

An example based on SR97 involving event timing

One of the cases considered in SKB's SR 97 study was that of an initially failed canister, with a pin-hole that suddenly becomes much larger at some later time (this enlargement is the event of interest). This case was used by Hedin as the basis for the development of an analytic approximation[4] and was recently used as the basis for a code intercomparison exercise between AMBER and

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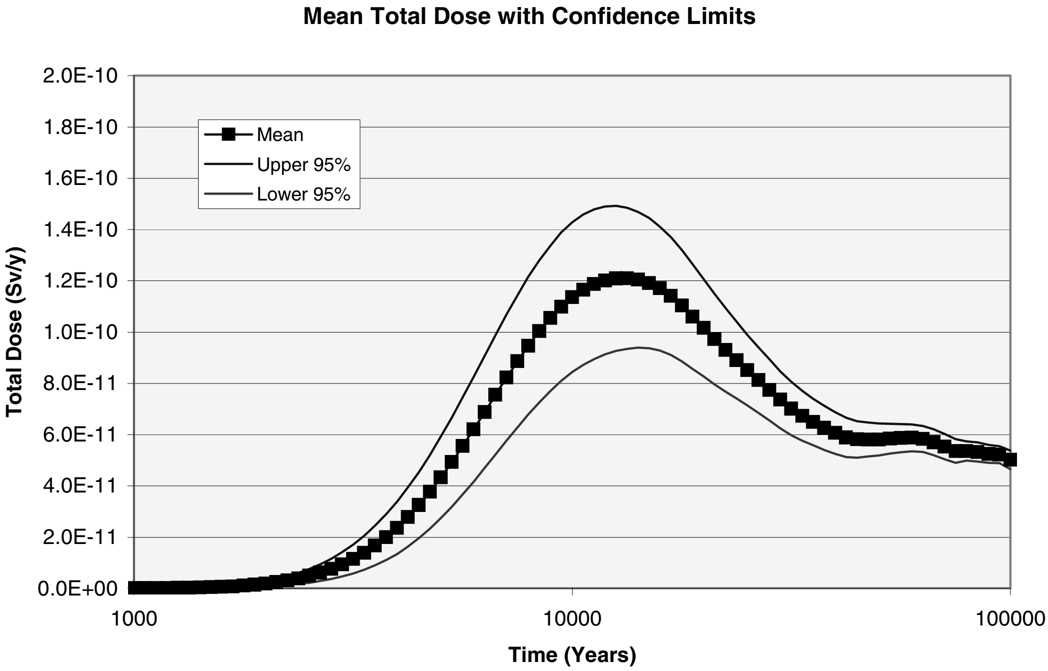
3. Similarly, inappropriate positive skewness will lead to risk dilution for parameters having an inverse correlation with calculated consequences.

4. A Hedin, Integrated analytic radionuclide transport model for a spent nuclear fuel repository in saturated fractured rock, Nucl Technol 2002; 138(2); 179-205.

Ecolego.[5] This is a full model, with release from spent fuel, release through the pinhole, diffusion in a bentonite buffer, release to a fracture, transport through the geosphere and migration in a biosphere.

Rather than attempt a full probabilistic analysis (the Hedin and intercomparison studies were deterministic), we focus on the timing of the enlargement event. In the original case this occurs after 20 000 years. In order to simplify the calculations, only four radionuclides were retained, those that give the highest consequences at early times: C-14, Ni-59, I-129 and Cs-135. The total biosphere dose was used as the measure of consequence. A probabilistic case was run with the time of enlargement sampled with a log-uniform distribution between 1 000 and 100 000 years (this distribution was invented for the purposes of the current illustration). A 100 sample run was made using AMBER. The mean consequence was plotted as a function of time and the peak consequence for each sample was stored.

Figure 1: **Mean total dose for the SR 97 example with enlargement time sampled**



5. P Maul, P Robinson, R Avila, R Broed, a Pereira and S Xu, AMBER and Ecolego Incomparisons using Calculations for SR 97, SKI Report 2003:28, SSI Report 2003:11.

Figure 2: **CDF of peak total dose for the SR 97 example with enlargement time sampled**

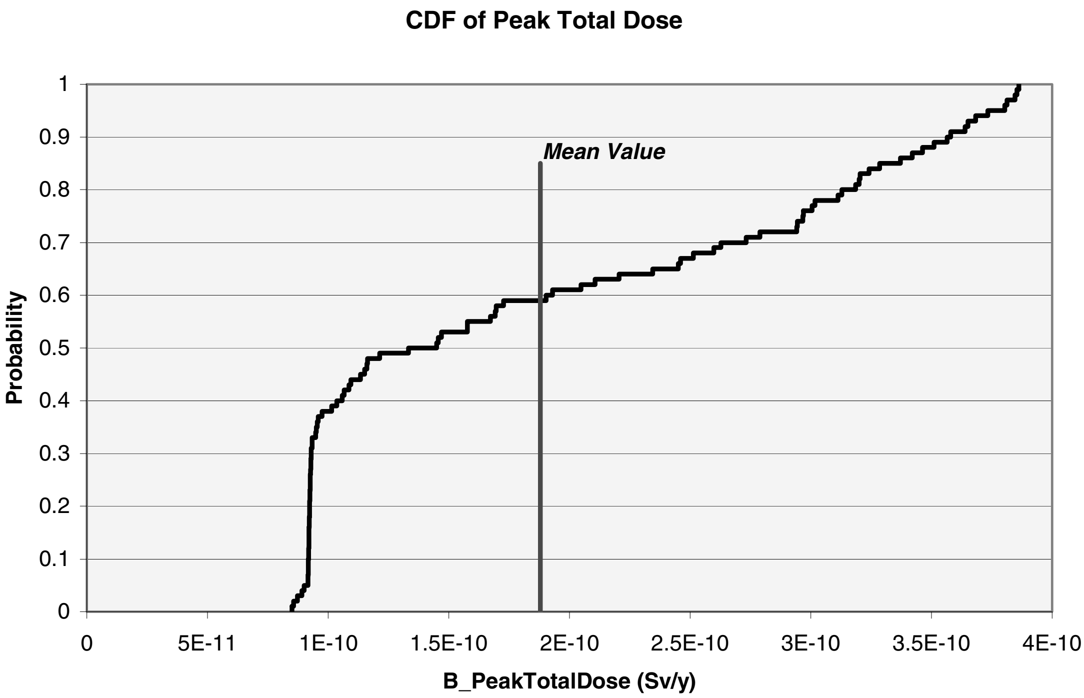


Figure 1 shows the mean consequence versus time, with a peak value of 1.21E-10 Sv/y. Figure 2 shows a CDF of the peak consequence, with a mean value of 1.88E-10 Sv/y. Thus, the risk dilution ratio here is 1.55.

This small ratio seems to be due to the highly dispersive nature of the SR 97 system. The pin-hole release model provides a lot of spreading, as does the release from the bentonite to the fracture. Finally, matrix diffusion spreads the consequences further. Thus, each individual sample gives a dispersed result leaving little scope for risk dilution.

To test that this was indeed the case, the model was altered to reduce the dispersion. Matrix diffusion was eliminated and the pin-hole release model was changed so that the radionuclides passed quickly into the buffer once the pin-hole had enlarged. With these two changes, the peak mean consequence becomes 2.62E-9 Sv/y and the mean peak consequence becomes 9.10E-9 Sv/y. Thus the risk dilution ratio becomes 3.47. This figure might be a cause of concern if risks were very close to a target value, but not otherwise.

Even with these two dispersive barriers disabled, the risk dilution ratio is less than an order of magnitude, suggesting that significant risk dilution in this type of system is unlikely.

An example arising in SFR assessments involving spatial effects

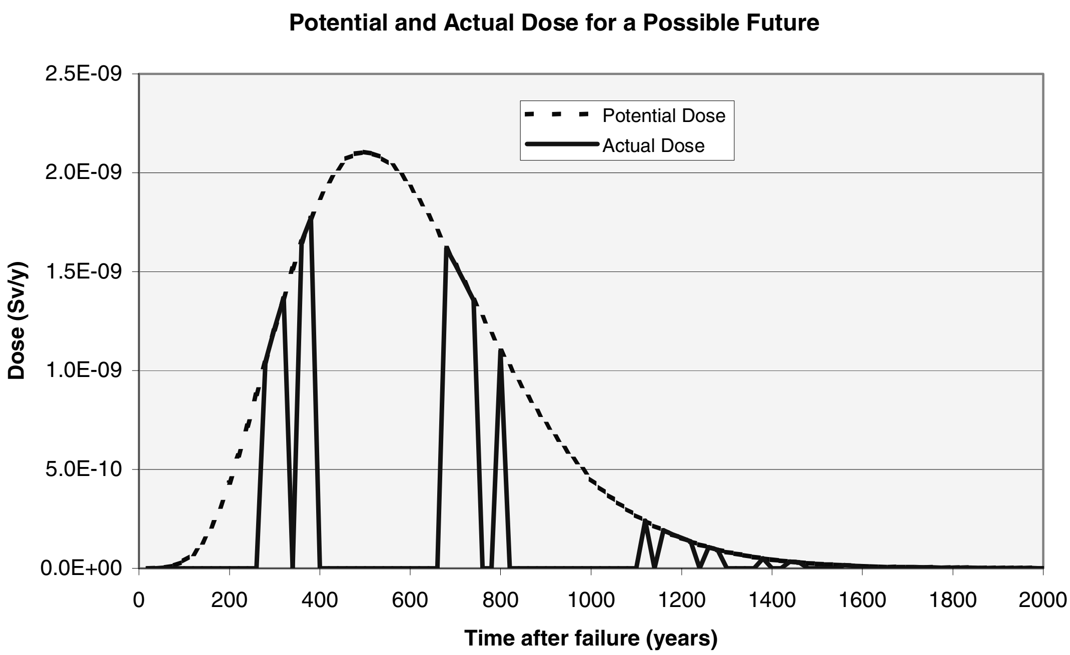
One possible pathway for doses to arise from SFR is for wells to access a plume of contamination downstream of the repository. Well drilling rates suggest that on average there will be 0.1 wells in the plume (the plume size is about 0.2 km^2 and the well density 0.5 wells/km^2).[6]

SKB calculate the risk from this pathway as the consequence when a well is present multiplied by 0.1.[7] Is this the correct approach?

Wells have a limited period of operation, so the average value of 0.1 effectively means that there is a well in the plume 10% of the time. Thus, a typical dose versus time curve might look like Figure 3.

Clearly, the average peak dose over such futures is close to the peak potential dose value, rather than a tenth of this. This appears to be a case of risk dilution.

Figure 3: **Potential dose and actual dose for a possible future in the well scenario**



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6. U. Kautsky (editor), The Biosphere today and tomorrow in the SFR area, SKB Report R-01-27.
7. SKB, Slutförvar för radioaktivt driftavfall, SFR 1, Slutlig säkerhetsrapport, Svensk Kärnbränslehantering AB, Stockholm, 2001.

Regulatory responses

The preceding discussion of the ways in which risk dilution could arise provides useful indicators of the ways in which it can be reduced or avoided. In this section, these indicators are brought together and are expressed in a form that could be useful in developing regulations or regulatory guidance.

In general terms, regulators can respond in three ways to the identification of a potential issue:

- Prescriptive regulations could be promulgated to ensure that the issue does not arise in a safety case or other documentation submitted to the regulator.
- Regulatory guidance could be issued to ensure that the developer is aware of the issue and therefore takes steps to avoid or minimise its effects.
- Review criteria could be used to ensure that the regulator considers the potential effects of the issue at the time of assessing or reviewing a safety case.
- There is overlap between these responses, especially with respect to review criteria which are likely to be necessary even if regulations or guidance are issued.

The choice between these various regulatory responses is related as much to the established style of regulation in a particular country as it is to the issue concerned. Because of the various ways in which risk dilution may arise in assessments of long-term performance, it may not be possible to establish prescriptive regulations or guidance on how it should be avoided. The following discussion therefore concentrates on more general guidance and review criteria. The examples discussed above provide some support for these discussions, but there is scope for additional calculations to provide further information and perhaps a quantitative basis for criteria.

In all cases, the presentation of distributions of consequences in addition to risk calculations is to be encouraged as an aid to general understanding.

Event timing

Regulators recognise that assessment calculations are a means of demonstrating system understanding and analysing uncertainties as well as showing numerical compliance with a risk or dose criterion. Furthermore, there are many other aspects of a safety case that play a part in demonstrating safety. The regulator would expect a safety case to include sufficient information for reviewers to be able to determine whether risk dilution was an issue. For example, the regulator would expect all assessment results to be available. These would show whether there were high consequence events in the majority of simulations. Without a corresponding increase in expectation value, such a pattern would indicate the potential for risk dilution.

A specific requirement would be a calculation of the risk dilution ratio, the ratio between the mean value of peak consequence and the peak value of mean consequence over a number of time-scales. Where results suggest that there is a potential for risk dilution, for example a ratio of more than 10, the onus must be on the proponent to explain and justify the approach adopted. It is likely that the conceptual models and assumptions responsible for such differences would be readily identifiable. Sensitivity studies would support this identification. A specific exploration of the causes of dispersion in the model could be a useful way of improving understanding and identifying possible sources of risk dilution.

Where a potential for risk dilution is identified because of uncertainties over the timing of events, the regulator could require calculations using a number of fixed times. These might not necessarily be used for comparison with a numerical criterion, but would help in understanding the importance of key uncertainties and consequently aid decision-making.

Spatial effects

The appropriate treatment of spatial effects is intimately entwined with the identification of potentially exposed groups (PEGs). Any guidance or review criteria from regulators concerning risk dilution must therefore be compatible with guidance and criteria concerning PEGs. This paper is not directly concerned with the definition of PEGs, but the potential for risk dilution does indicate that care is required in separating out the uncertainties concerning the location of a contaminant plume or release of radionuclides to the biosphere, the location of the PEGs (in both space and time), and the characteristics and behaviour of the PEGs.

The use of risk as an end-point for safety assessments can encourage the use of probabilities to characterise all sources of uncertainty and the presentation of a single value or distribution as a result. The many sources of uncertainty relating to the treatment of spatial effects and PEGs mean that such an approach may obscure assumptions that give rise to risk dilution. Where a potential for risk dilution is identified because of uncertainties over spatial effects, the regulator is likely to require calculations using a number of different assumptions. These might not necessarily be used for comparison with a numerical criterion, but would help in understanding the importance of key uncertainties and consequently aid decision-making.

Correlations

Assessment documentation must include an explicit consideration of parameter correlations. Form-based documentation provides a useful means for ensuring that the conclusions are available for review. The regulator would expect strong correlations to be taken into account through parameter definition or sampling methods. The exclusion of any identified correlations should be justified through sensitivity studies or similar reasoning. Any post-analysis assessment of the reasonableness of parameter combinations should consider all cases and not only those resulting in high consequences.

Distributions

Assessment documentation must include an explicit description of the basis for all parameter pdfs. Form-based documentation is a useful means of making relevant information available for review. The regulator would expect full documentation of any expert judgement and elicitation involved in establishing pdfs, including the identification of appropriate experts, the information and training provided to experts and the experts' justification for the pdfs.

Conclusions

This paper has described a number of ways in which risk dilution could occur in performance assessments of radioactive waste management facilities. The majority of these can be avoided through a systematic approach to developing a safety case and undertaking assessment calculations. Appropriate documentation is key in providing assurance to the regulator and other stakeholders that modelling assumptions have not led to significant under-estimation of risks.

The treatment of future events in probabilistic assessments remains an issue of regulatory concern. Where there is no information available, the assumption that such events might take place at random is unlikely to be a conservative assumption. A comparison between the peak value of mean risk and the mean value of peak risk over a number of timescales is the only prescriptive requirement that is likely to be generally applicable. It may be appropriate to develop additional criteria on a site-by-site basis. Where calculated risks are close to numerical criteria, for example, regulators are likely to require sensitivity studies regarding the timing of events, PEG characterisation, parameter correlations and pdfs, and other modelling assumptions

It seems from the example presented here that risk dilution is unlikely to be of concern in situations where only one barrier in a multiple barrier system is affected by an event – the other barriers will generally provide dispersive processes that will prevent highly localised consequences. Situations where consequences are more localised, are the most likely candidates for risk dilution.

RISK ASSESSMENT USING PROBABILISTIC STANDARDS

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Introduction

A core element of risk is uncertainty represented by plural outcomes and their likelihood. No risk exists if the future outcome is uniquely known and hence guaranteed. The probability that we will die some day is equal to 1, so there would be no fatal risk if sufficiently long time frame is assumed. Equally, rain risk does not exist if there was 100% assurance of rain tomorrow, although there would be other risks induced by the rain. In a formal sense, any risk exists if, and only if, more than one outcome is expected at a future time interval.

In any practical risk assessment we have to deal with uncertainties associated with the possible outcomes. One way of dealing with the uncertainties is to be conservative in the assessments. For example, we may compare the maximal exposure to a radionuclide with a conservatively chosen reference value. In this case, if the exposure is below the reference value then it is possible to assure that the risk is low. Since single values are usually compared; this approach is commonly called "deterministic". Its main advantage lies in the simplicity and in that it requires minimum information. However, problems arise when the reference values are actually exceeded or might be exceeded, as in the case of potential exposures, and when the costs for realising the reference values are high. In those cases, the lack of knowledge on the degree of conservatism involved impairs a rational weighing of the risks against other interests.

In this presentation we will outline an approach for dealing with uncertainties that in our opinion is more consistent. We will call it a "fully probabilistic risk assessment". The essence of this approach consists in measuring the risk in terms of probabilities, where the later are obtained from comparison of two probabilistic distributions, one reflecting the uncertainties in the outcomes and one reflecting the uncertainties in the reference value (standard) used for defining adverse outcomes. Our first aim is to delineate the approach, in comparison with the deterministic approach, to define the entities involved in the assessment and their relationship. The second aim is to identify possible strategies for deriving and combining the probability distributions. In the explanation we will use a terminology that is related to the exposure to radionuclides in the environment.

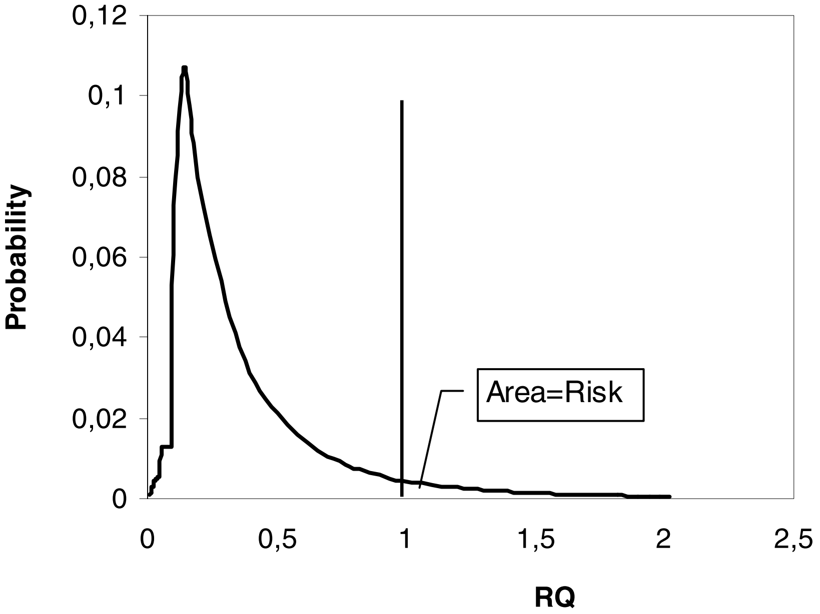
Probabilistic versus deterministic assessments

Lets consider the commonly applied risk quotient (RQ), which can be defined as the ratio between the exposure to a radionuclide in the environment and the reference value adopted for this radionuclide (equation 1). In a deterministic assessment, single estimates are used for the exposure and the reference value. If these were conservatively chosen and a value below 1 was obtained for the RQ, then it can be assured that the probability of the exposure exceeding the reference value is low, i.e. the risk is low. Obviously, the exposure and reference levels should be expressed in the same units, for example in units of dose, intake rates or environmental concentrations.

$$RQ = \frac{Exposure}{reference\ value} \qquad \text{(Equation 1)}$$

The essence of a "fully probabilistic approach" is to treat both the *Exposure* and the *reference value* (equation 1) as random variables. In this case, the RQ is also a random variable that can be described with a probability density function, commonly known as the "risk profile" (see Figure1). Hence, a deterministic RQ is just one value among the universe of all values than the RQ can possibly take. The probability that the RQ is above 1 (indicated area in Fig.1) is a quantitative measure of the risk. In contrast, the deterministic approach provides only a qualitative risk estimate.

Figure 1. **Example of probability density function corresponding to the Risk Quotient commonly known as the "risk profile". The area under the curve for RQ>1 is a quantitative measure of the risk**

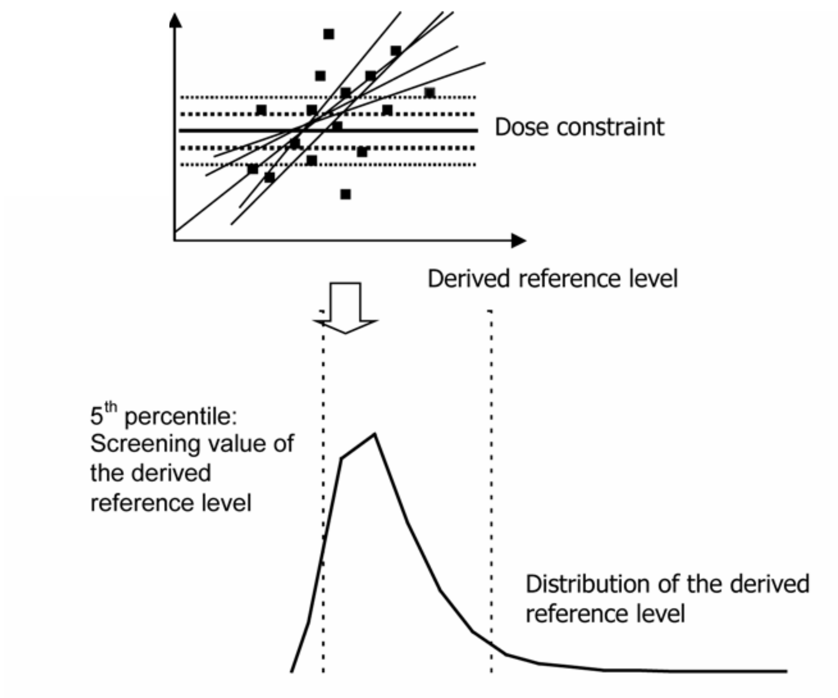


In the deterministic approach, normally, conservative values are used in equation 1. Given the multiplicative nature of the model, a substantial magnification (positive bias) of the conservatism may take place. For this reason, values of RQ close to or above 1 will carry very little information about the risks. A common way to deal with this problem is to carry out assessments in tiers. This means that more realistic quotients are estimated whenever a conservative assessment yielded RQ > 1. This approach could be seen as a simplified version of a probabilistic approach. In any case, the interpretation of the results would require knowledge about the distribution of the exposure and the reference value. For example, using mean values in equation 1 is meaningful only if the magnitudes follow a normal distribution, which is rarely the case.

Derivation of probability distributions for the standards

The derivation of probability distributions for the Exposure is rather straightforward, and we will not, therefore, address it in this presentation. The reference value (standard) should allow identifying adverse values of the exposure. The standard could, for example, be related to the effects of radiation and obtained from studies of dose-effects relationships and might be expressed in terms of a source related dose constrain that takes in to account possible exposure to regional and global sources. Derived reference levels, expressed for example as environmental concentrations or fluxes, could also be used. These could be obtained from existing quantitative relationships between the primary dose limits and the derived magnitudes. The quantitative relationships could be based on empirical data or could be derived with the help of mathematical models. A simple procedure for derivation of reference values, commonly known as the bootstrap method, is illustrated in Figure 2.

Figure 2. **Probability distribution for the reference value (standard) obtained from the quantitative relationship between the dose and a derived reference level using the bootstrap method**



Note that even if a single value is used for the primary reference level, a probability distribution is obtained for the reference value, reflecting uncertainties in the quantitative relationship between the primary and reference levels. Once the probability distribution of the derived reference level has been obtained, single values corresponding to different percentiles of the distribution could be used in deterministic assessments. For example the 5% of the distribution could be used in screening assessments.

The primary reference values, for example the dose constrains, can also be considered as random variables. If the method illustrated in Figure 2 is applied for obtaining derived reference values, then a probability distribution could be used for the dose constrain (represented by several levels of the dose constrain in Figure 2). This would reflect the variability among individuals in the sensibility to radiation, our imperfect knowledge of the dose-response relationships, the variability in the background radiation, etc.

Measuring the risk

To measure the risk the probabilistic distributions of the *Exposure* and the *Reference Value* has to be combined through equation 1. If simple analytical expressions for the probability distribution are available, then variance propagation can be applied for the deriving the risk profile. When analytical expressions are not available for the distributions, or when they cannot be combined analytically, these can be combined using Monte Carlo analysis.

The basis for a Monte Carlo analysis is straightforward: point estimates in a model equation are replaced with probability distributions, samples are randomly taken from each distribution, and the results tallied, usually in the form of a probability density function or cumulative distribution.

Advantages and disadvantages

A "fully probabilistic approach" provides a more complete quantitative characterisation of the uncertainties and is less likely to include a bias, than the more simple deterministic approach. Even with a tiered approach, each deterministic assessment provides single values for estimates of exposure from a given pathway. Such single-value risk estimates do not provide information on the variability and uncertainty that may be associated with an estimate.

When combined with sensitivity analyses, the probabilistic approach allows a more informative "what-if" assessment of the impact on the risk estimates of a change in a variable or a group of variables, thus providing a cost-effective tool for making risk management decisions.

This approach also permits more constructive comparisons of remedial alternatives when diverse attributes must be compared to systematically reduce the baseline risk. This includes comparing alternatives or intervening measures that could also cause other risks.

Finally, the use of probabilistic standards facilitates deriving standards. For example standards in terms of concentrations may be derived from standards in term of dose, even when there is variability and uncertainty in the relationship between the doses and the concentrations.

The main disadvantage of the probabilistic approach is that time and effort is required in order to set up the database and document the rationale for the probability density functions. The distribution patterns for some variables are often not definitively known, requiring the use of credible professional judgment or costly site-specific studies or data collection efforts. Also, the impact of inter-dependencies between or among variables may be difficult to quantify if their co-relations are not well known, as it is often the case.

In view of the above discussion, the probabilistic approach appears to be most appropriate when the risks are not trivial, for example in situation where the risk might be above or slightly below the acceptable level of risk or hazard, and where the costs for risk reduction are potentially high.

METHODOLOGY FOR RISK ASSESSMENT OF AN SNF REPOSITORY IN SWEDEN

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Introduction

The Swedish Nuclear Fuel and Waste Management Co., SKB, is currently pursuing investigations at two candidate sites for a spent nuclear fuel repository. An application to build a repository at one of the sites is planned for 2008, if the geologic conditions are found suitable. A methodology for the risk based assessment of post closure safety for the application is being developed [1]. This paper presents some aspects of the methodology related to the quantification of risk.

The repository will be of the KBS 3 type where copper canisters with a cast iron insert containing spent nuclear fuel are surrounded by bentonite clay and deposited at typically 500 m depth in saturated, granitic rock, Figure 1. The primary safety function of the concept is complete long-term isolation of the waste, achieved by the integrity of the copper canisters and supported by the strength of the cast iron insert. Should isolation for any reason be breached, the ceramic waste form, the damaged canister, the buffer and the host rock provide a considerable retarding capacity – the secondary safety function.

The principal compliance criterion states that the annual risk of harmful effects must not exceed 10^{-6} for a representative member of the most exposed group. The annual risk is to be obtained by multiplying the calculated **mean dose**, taken over all possible exposure situations, by the stipulated constant $\gamma = 0.073$ per Sievert so that the risk limit corresponds to a dose limit of approximately 14 μSv/yr.

The dual purposes of the assessment are to *i*) evaluate compliance and *ii*) provide feedback to design development, to SKB's R&D program, to further site investigations and to future safety assessment projects. While the first purpose could possibly be achieved by a pessimistic approach regarding uncertainties, the latter requires a more elaborate evaluation of the impact of various types of uncertainty on the assessment end-points, most notably the annual risk.

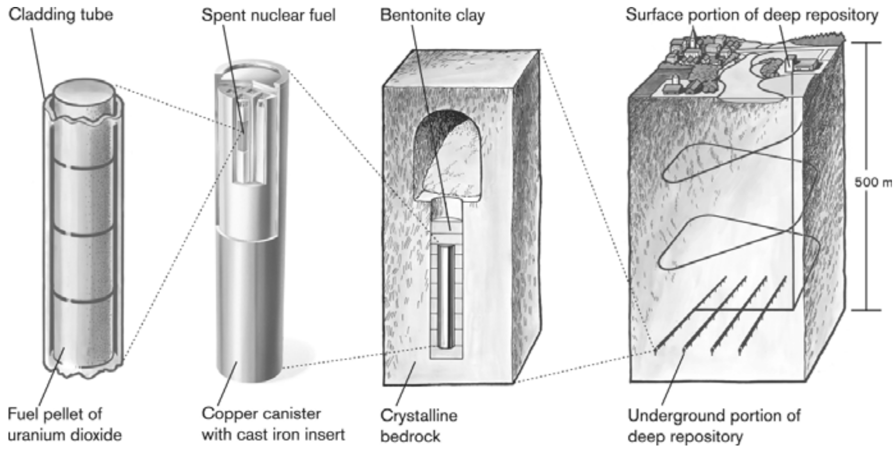
Approach to risk calculations

The approach to the numerical risk calculations is in short the following:

- Break down possible evolutions of the system into a number of representative scenarios and estimate scenario probabilities.
- Evaluate every scenario by studying the system evolution during the one million year assessment period.

- If evolution indicates breaching of isolation, calculate radionuclide transport and dose consequences probabilistically for barrier conditions derived from the system evolution.
- Add, using scenario probabilities as weighting factors, **the time dependent mean doses** from the different scenarios and convert to risk.

Figure 1. **The Swedish KBS 3 concept for geologic deposition of spent nuclear fuel**



The approach is thus **disaggregate** in the sense that, for each scenario, system evolution is studied and discussed and, if isolation is breached, a subsequent account is given of radionuclide transport and dose consequences. On the order of ten scenarios are envisaged, further sub-divided into variants.

The calculated result will to some extent be **a deliberate overestimate** of risk since many uncertainties will be treated pessimistically in the assessment. This will likely apply to several of the scenario probabilities and also to a number of processes which are favourable for safety but for which the understanding or modelling capability is insufficient for quantification. This is fully compatible with the purpose of assessing compliance, provided that there are sufficient safety margins to meet the compliance criterion also with the pessimistic assumptions. However, regarding the purpose of providing feedback, the omission or pessimistic treatment of some factors may yield a biased view of the importance of other factors treated more thoroughly. This needs to be acknowledged in any discussion of feedback in the safety report.

The possibilities of assigning realistic scenario probabilities are often limited. Regarding e.g. future climate, both repetitions of past 130 000 years glacial cycles and an alternative where this development is considerably perturbed by a greenhouse effect can be envisaged. While the two are mutually exclusive, both must be regarded as likely. In the risk summation, it will though be observed that the summed consequence of a set of mutually exclusive scenarios can, at any point in time, never exceed the maximum of the individual scenario consequences.

Scenarios involving **direct intrusion** into the repository will be assessed **separately** and excluded from the risk summation, according to Swedish regulations.

Quantification of input data uncertainty

While all the several hundred input data must be quality assured, only a limited sub-set are uncertain to an extent critical for the safety evaluation, thus requiring a detailed quantification of uncertainty. These data will be identified by sensitivity analyses of calculation results using input data ranges from earlier assessments. The results will be used to allocate resources to the determination of the final input data set. A common template for the discussion of input data is being developed. The nature of the uncertainty (epistemic/aleatoric) and correlations to other input data will be addressed. For critical parameters which are difficult to assess from experimental data, a formal elicitation procedure may be considered, involving experts in the relevant field as well as safety analysts. Input data will be expressed e.g. as an estimated range, possibly with a most likely value within it, based on which uniform, triangular or normal distributions (or the corresponding log distributions) could be selected. A number of different distributions will be tried to test sensitivity to these aspects. Other input data will be obtained as probability density functions from separate probabilistic analyses of e.g. the spatially varying transport properties of the host rock or the frequency of canister welding defects.

Sensitivity analyses

Sensitivity analyses will be applied to the calculated dose distribution at different points in time. The aim is to determine *i*) which uncertain input parameters give the most significant contribution to the width of the output distribution (the global uncertainty) and *ii*) the risk drivers, i.e. those uncertainties that have a significant impact on the mean value of the dose as a function of time. It has been demonstrated earlier that standardised rank regression is a suitable method for the former [2] and that conditional mean values are suitable for the latter [3].

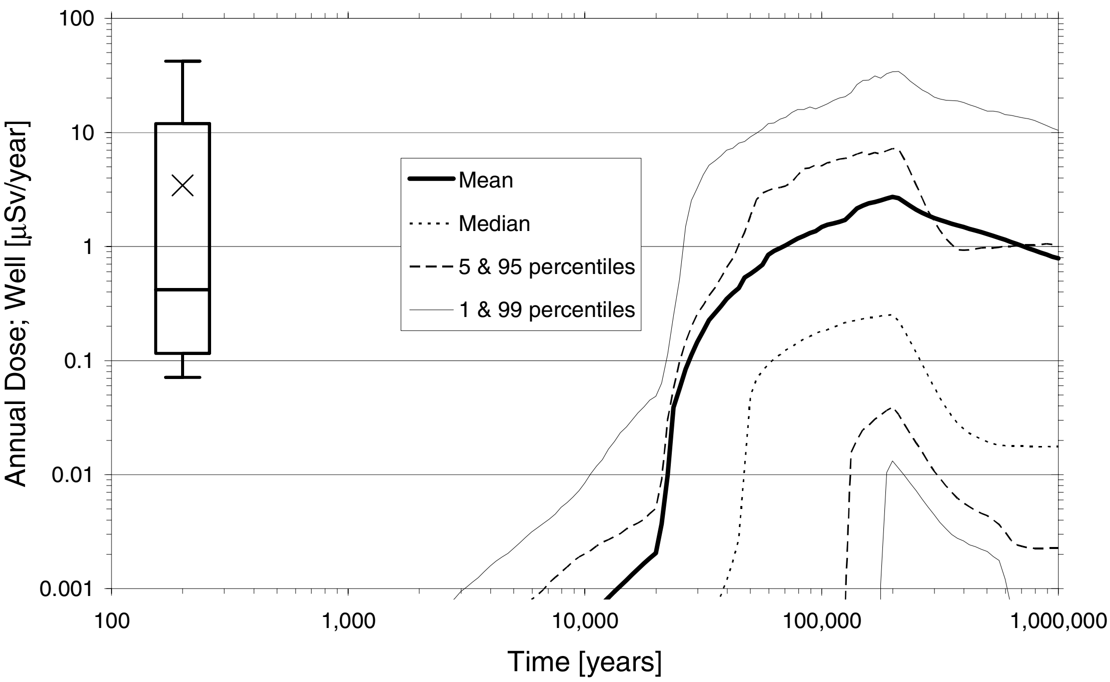
An important part of any sensitivity analysis exercise is to verify that all important sensitive parameters have been identified. This can be done *i*) by assigning constant central values to all identified sensitive input parameters keeping the full distributions for remaining input data which should yield a considerable reduction in output distribution width and *ii*) by using full distributions for only the sensitive parameters keeping others constant at central values which should yield an insignificant reduction in output distribution width.

As a complement to these more formal sensitivity analyses, it will also be discussed how the results and their sensitivities can be understood using simplified, analytical radionuclide and dose models.

Example calculation

Figure 2 shows the result of a radionuclide transport and dose example calculation developed to test quantitative aspects of the methodology. The example illustrates a scenario where all initially intact canisters maintain their integrity over the one million year assessment period despite the chemical and mechanical stresses they are subjected to. One per mille of the 4 500 canisters are assumed to have initial defects such that this leads to releases of radionuclides, starting however at a point in time which is highly uncertain. Based on extrapolation of experimental data, this onset time is in the present example assumed to be uniformly distributed between 300 and 200 000 years. Furthermore, it is pessimistically assumed that today's biosphere prevails and that all releases occur to the same well which is used at a self-sustaining farm for drinking water, irrigation etc. The input database was developed from an earlier assessment of the same system. The calculation scheme distinguishes between aleatoric and epistemic uncertainty in that canisters in the repository have position specific, correlated stochastic hydraulic variable distributions reflecting the variability of the host rock. Canister specific defect characteristics are obtained from a common distribution, reflecting the stochastic nature of failures in the canister sealing process. Epistemic uncertainty, affecting estimates of e.g. the fuel dissolution rate, is treated probabilistically where fuel in all defective canisters in a certain realisation is assigned the same value drawn from an input distribution obtained as discussed in section 2.1.

Figure 2. **Statistics of the dose distribution as a function of time, pessimistically assuming that all releases occur to the same well. The box-and-whisker to the left shows the same percentiles of the peak dose distribution and with the mean value represented by the cross.**



Treating instead all uncertainty as epistemic, i.e. assigning all defective canisters in a certain realisation the same properties, yields, as expected, the same mean dose, but also similar results for the other statistics shown in the figure, which is not necessarily expected. An alternative to be further explored would be to describe all epistemic uncertainty as intervals and to perform the risk calculation as a combination of Monte Carlo simulation and a bounding type of analysis, see e.g. [4].

The calculation was made for 17 radionuclides, however reducing this to only I-129 and Ra-226 yields an almost identical result. Furthermore, the top percentile of the distribution is almost entirely caused by Ra-226. The distribution is highly skewed since the mean is close to the 95th percentile. This is essentially a reflection of the skewness of a few important input distributions, rather than of the transformation properties of the model.

Sensitivity analyses as outlined above show that main contributors to global uncertainty are variables related to the number of initially defective canisters, the onset time of releases from these, the dissolution rate of the fuel, the transport resistance in the rock and the dose conversion factors in the biosphere for I-129 and Ra-226. The main risk drivers as identified by conditional mean analyses are the same as those contributing to global uncertainty except the dose conversion factor of I-129 and in addition a few variables related to the near field release of Ra-226.

Risk dilution

The term "risk dilution" is sometimes used to denote a situation where a higher degree of uncertainty in input parameters, i.e. a broader input distribution, leads to a lower mean value of an output entity e.g. mean dose or risk [5]. A seemingly paradoxical situation arises where less knowledge implies a more safe repository if the mean value to a highly exposed individual at a certain point in time is used as the safety indicator. Less knowledge will spread the dose over more individuals and over longer times. The total exposure to all individuals over all times could be the same or larger, whereas more distinct knowledge will "concentrate" the risk to fewer individuals and shorter periods of time. This can e.g. be the case when there is uncertainty concerning the point in time for the onset of releases from a damaged canister. The dose consequence at a certain time could then depend strongly on the assumed onset time. Averaging over alternative situations in which the onset and thus the peak dose occur at different times would reduce the resulting mean value at any point in time and more so the larger the span of possible onset times.

This effect is inherent in the concept of risk and is thus an inevitable consequence of a criterion based on risk as a function of time and where the entity to be determined is the time-dependent mean value considering all relevant uncertainties. The above effect should thus be tolerable given the Swedish regulations.

It is nevertheless interesting to elucidate and quantify risk dilution effects in the safety assessment. This can be done by comparing the peak of the mean dose curve in Figure 2 (2.7 μSv/yr occurring at approximately 200 000 years) to the mean value of the peak doses in all realisations irrespective of when they occur. This latter entity is 3.4 μSv/yr (the cross in the box-and-whisker to the left in Figure 2) which leads to the conclusion that risk dilution effects of this temporal type are not a concern in this system for these input data. This is largely due to the fact that once a canister is ruptured, releases will continue essentially undiminished for a long period of time, so that similar peak doses are obtained irrespective of the canister rupture time.

A related phenomenon concerns the biosphere development during the expected long periods of permafrost or glacial conditions. Assume that appreciable doses to man could occur only during temperate periods, and that these periods, as suggested by historical evidence relevant to Sweden, in the long run will prevail in total during about ten percent of the time but that the temporal location of these temperate intervals cannot be predicted beyond, say 10 000 years into the future. In principle this situation could be handled by simulating a number of future situations where the onsets of the temperate periods are allowed to vary randomly beyond 10 000 years. Averaging over all these results would, at each point in time beyond 10 000 years, yield a dose consequence a factor of ten smaller than that obtained during a temperate climate period. This simplistic example demonstrates another type of risk dilution, again caused by an uncertainty in the point in time of the occurrence of a phenomenon, which could in principle be compatible with the Swedish risk criterion. The effect can however be avoided in the safety assessment by assuming the same temporal sequence of climate types in each simulation or, as in the example given, a steady state biosphere.

It is also concluded that a broader input data distribution is not necessarily pessimistic, not even if it is broadened towards the high consequence end.

Conclusions

An approach to risk assessment for upcoming license applications for a spent nuclear fuel repository has been presented. The approach is adapted to the safety functions of the analysed system in that isolation potential is first analysed and then dose consequences in cases where isolation is breached. It is furthermore scenario based and disaggregate, it deliberately overestimates some aspects of risk and it handles direct intrusion scenarios separately. Input data uncertainties for probabilistic dose consequence calculations are quantified by following an established protocol, common to all input data types. In the consequence calculations, a distinction is made between aleatoric and epistemic uncertainty, global sensitivity to input data uncertainty is quantified and risk drivers are identified. Risk dilution effects are discussed and quantified. Apart for being useful for assessing compliance, the results are expected to provide useful feedback to the continued waste management program.

Finally, it is noted that risk is only one of several indicators of repository safety. Complementary indicators being considered include radionuclide concentrations in the groundwater and the flux of radionuclides to the biosphere.

References

[1] Planning Report for the Safety Assessment SR-Can. SKB Technical Report TR-03-08, Swedish Nuclear Fuel and Waste Management Co. (2003).

[2] Hedin, A. (2003), Probabilistic dose calculations and sensitivity analyses using analytic models. Reliability Engineering and System Safety 79: 195-204.

[3] Hedin, A. (2002), *Safety Assessment of a Spent Nuclear Fuel Repository: Sensitivity Analyses for Prioritisation of Research*. Proceedings of the 6th International Conference on Probabilistic Safety Assessment and Management, PSAM6. Elsevier Science Ltd.

[4] Ferson, S. and L.R. Ginzburg (1996), Different methods are needed to propagate ignorance and variability. Reliability Engineering and Systems Safety 54:133-144.

[5] NEA (1997), *The Probabilistic System Assessment Group: History and Achievements 1985-1994*. OECD, Paris.

SESSION 5

CONTRIBUTION OF RD&D

Chairs: Hans Forsström, European Commission
Sumio Masuda, NUMO, Japan

Objectives

The session will focus on the Research, Development and Demonstration (RD&D) Programmes being currently implemented in a number for countries worldwide in preparation of the construction of geologic repositories. During the 80s and 90s, the knowledge and understanding of processes and phenomena associated with the disposal of radioactive waste in deep geological phenomena have made significant progress thanks to in-situ observations and testing performed in Underground Research Laboratories.

However, some key scientific and technical issues remain to be addressed to assess the long-term safety and demonstrate the technical feasibility of geologic disposal concepts for high-level waste and spent nuclear fuel. The possible contribution of URLs to solving these issues will be examined.

International co-operation in RD&D contributes to developing and consolidating scientific and technical basis on geologic disposal complementing national efforts, through multi-national co-operation projects.

The co-operation through knowledge transfer should also benefit developing countries with lesser-advanced programmes in geologic disposal.

Issues

- Pending scientific and technical issues to the long-term safety and technical feasibility of geologic disposal concepts.
- Contribution and limitation (up scaling, uncertainties, etc.) of URLs to addressing scientific and technical issues.
- Role of international co-operation (developing expertise, building confidence, promoting knowledge transfer, etc.).

Programme

Chairs: **Hans Forsström,** European Commission

Sumio Masuda, NUMO, Japan

Piet Zuidema, Nagra, Switzerland

Hiroyuki Umeki, NUMO, Japan

Öivind Toverud, SKI, Sweden

Timo Äikäs, Posiva, Finland

Christer Svemar, SKB, Sweden

Panel discussion

Panellists: All speakers plus **Peter Ormai**, PURAM, Hungary.

Points for consideration by the panelists

- What part of the research is purely national, and what may be done on bilateral or international levels?
- What do you get out of the present international work?
- Is internationally agreed data useful?
- Ideas for future collaboration on research on an international level. Roles of IAEA, NEA and EC, etc.

OVERVIEW OF PROGRESS ACHIEVED ON SCIENTIFIC ISSUES SINCE THE 1999 DENVER CONFERENCE AND REVIEW OF PENDING KEY ISSUES

Piet Zuidema
Nagra, Switzerland

Research, development and demonstration (RD&D) are aimed at deriving the necessary understanding about key issues in waste management, in order to apply this understanding to individual projects and to show that the different issues at stake are under control. RD&D is thus used to derive adequate concepts (i.e., for geologic disposal: an adequate site and an adequate design), to achieve the necessary scientific and technological basis for implementing these concepts and to develop the information basis needed for the decision-making process leading to implementation. To evaluate the current status of RD&D, typical examples are reviewed with respect to:

- progress in waste management concepts and strategies;
- progress in specific programmes with respect to siting and repository design;
- the role of performance assessment studies in decision making;
- progress in optimisation of facility designs and of repository technologies;
- the status of testing of different repository concepts in URLs;
- progress in the use of URLs (both first-generation URLs aiming at basic RD&D as well as second-generation URLs used for site characterisation and site-specific RD&D), and
- progress in basic RD&D studies and experiments, many of which are performed in the framework of international co-operation.

In the area of waste management concepts and strategies, geologic disposal is the accepted end point in most countries. The concept of geologic disposal has now reached a stage of development where no fundamental questions remain open that would preclude implementation. However, in recent years, more emphasis has been placed upon monitoring and retrievability and corresponding RD&D has been initiated. In addition to geologic disposal, RD&D in complementary areas such as partitioning and transmutation and long-term interim storage has been pursued in several countries. For long-term interim storage, the recent start of operation of the HABOG facility in the Netherlands ("interim storage for 100 years or more") is a clear sign of the importance of this interim option for some countries.

For geologic disposal, progress in the U.S.A. (preparation of the licence application), Finland (Decision-in-principle for the Spent Fuel repository in Olkiluoto), Sweden (start of surface-based site investigations in Forsmark and Oskarshamn), France (start of construction of URL in Bure) and Japan (start of the implementation process based on a volunteering approach) are a clear indication of the significant maturity reached in the underlying RD&D. This is also documented in the Performance Assessment studies used as technical input for the decisions to take the above-mentioned and other programmes one step forward (TSPA-SR as input to the decision to move the Yucca Mountain Project towards licensing, TILA-99 as a technical basis for the Decision-in-principle in Finland, SR 97 as an important information basis for moving towards site investigations in Sweden, *Projekt Entsorgungsnachweis* in Switzerland as a means for Nagra to propose to focus future work in the HLW programme on the Opalinus clay of the Zürcher Weinland, etc.).

In parallel to these strategically important steps in individual programmes, large-scale testing in URLs (e.g., Prototype Repository in Äspö, FEBEX at the Grimsel Test Site) and optimisation of facility designs (e.g., KBS-3H as an alternative to KBS-3V) have been pursued. Much progress has also been made in the area of technology development; in particular, the welding and inspection techniques for canisters and the production of copper canisters in Sweden/Finland have made significant strides. Progress has also been made not only with first generation URLs (e.g., new facilities under construction in Japan (Horonobe, Mizunami), extension of existing facilities (new shaft and connecting gallery in Mol) and new experiments in existing URLs), but also with second generation URLs (continuing work at YMP, the start of construction of a URL at Bure). However, work has also continued in the area of "generic" RD&D, focused on such topics as geochemical immobilisation, waste form behaviour, canister performance and bentonite behaviour.

Based on this brief review, it may be concluded that progress in RD&D since 1999 has been evolutionary and that no "revolution" has taken place. Although no fundamental open questions remain for the concept of geologic disposal, RD&D continues to be important for optimising the specific repository designs under development when moving from demonstration of feasibility towards "industrial application". Site selection is also, from the scientific point of view, at an advanced stage (see progress in several countries), with progress being limited by societal rather than technical issues. However, site selection and characterisation may still require specific RD&D activities and in this case, URLs will continue to play an important role. Finally, it is important to mention that performance assessment methodology is sufficiently advanced to provide a platform for evaluating all the relevant information and integrating it into a sound technical basis for decision making (see examples mentioned above). An area that will continue to require attention is performance confirmation which includes in-situ monitoring but also monitoring of progress in science.

No general conclusions may be drawn about the future challenges on RD&D as these depend upon the specific system under investigation. However, it is expected that site characterisation (especially for sites with heterogeneous properties) and confirmation of the behaviour of engineered barriers under specific conditions (e.g., due to the use of concrete which is unavoidable in some cases) will remain important issues. Another major challenge is likely to be the development of technology towards industrial application, which requires optimisation with respect to reliability, throughput and costs. Thus, it is expected that RD&D will continue to play an important role:

- To justify that adequate systems have been selected and developed.
- To ensure that a sufficient level of understanding and an adequate level of industrial reliability have been achieved to implement the projects.
- To achieve and maintain scientific quality in our projects, which is also a means to ensure credibility. Some of these activities may be performed within the framework of international co-operation projects (some of them under the auspices of international organisations) whereas other issues will need to be addressed within individual programmes to take into account the specificities of both the site and the selected repository system.

THE NEEDS AND USES OF INTERNATIONAL DATABASES FOR MAKING A SAFETY CASE FOR DISPOSAL

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Nuclear Waste Management Organization (NUMO), Japan

Mikazu Yui
Japan Nuclear Cycle Development Institute, Japan

Introduction

Safe management of radioactive waste is a common concern in all countries which promote the development and utilisation of nuclear energy. All programmes, whether large or small, should be able to identify possible solutions of their radwaste management issues. From a technical point of view, this involves research and development (R&D) to support such solutions. It is widely recognised that building confidence in the long-term safety of geologic disposal is vital to the overall waste management strategy, even though specific concepts and programmes differ from country to country [e.g., Witherspoon and Bodvarsson, 2001].

Disposal of radioactive waste in a deep stable geological environment is intended to provide high isolation, both from human activity and from natural processes. Eventual releases of radionuclides will occur in the distant future and will be in such low concentrations that they do not pose a hazard to human health and the natural environment. To achieve this goal, careful siting/site characterisation and repository design, as demonstrated by safety assessment (SA), are required to provide a reliable basis for making a safety case.

Data provide the foundation for developing repository system concepts and assessing their safety. Data acquisition is generally one of the most extensive (and expensive) activities in repository development programmes. Appropriate and effective focusing of data acquisition activities may, however, be aided by recognising that:

- the type and source of data needed at various stages of the repository development differ, and

- the quality of data need not be the same for all parameters and may gradually improve as a project develops.

1. The role of international collaboration

International co-operation may play a substantial role in the development of disposal programmes by providing efficient access to state-of-the-art information and a broader basis for consensus. For smaller programmes, in particular, this may provide a better-founded scientific and technical basis for specific studies than would be possible due to inherently limited resources. For developing programmes, an important aspect is transfer of knowledge and technology from countries in more advanced stages.

In connection with individual national disposal programmes, international co-operation projects have been often conducted through formal bilateral and multilateral mechanisms. Both types of co-operation are extremely useful; in particular, bilateral co-operation has the merit of providing opportunities for focused in-depth discussions in mutual areas of interest. Multilateral co-operation may be more difficult to organise and coordinate, but provides a wider international arena for sharing experiences and may be the only way of mobilising sufficient resources to tackle large, multidisciplinary R&D projects.

In principle, two fundamental aspects of international databases may be distinguished – the production of databases as part of collaborative projects and the provision of resultant databases for use by the international community. Although these activities are often treated independently, it is often observed that only by participation on the production of databases may their limitations be completely understood (see next section).

The advantages of resulting international databases for geologic disposal may be summarised as follows.

- helping to convince the authorities and the general public of the safety and the acceptability of disposal concepts;
- sharing resources, which include:
  - facilities/infrastructures;
  - models and codes, databases for safety assessment, and
  - expertise, technologies and know-how in a number of areas;
- economical aspects;
- building confidence in each national programme;
- providing opportunity for researchers to learn from the international technical community, and
- building up a knowledge base that, in some cases, may be used also outside the nuclear waste field.

2. Examples of classical international databases and their application in national context

There are certain generic data which are required in any waste management programme and which, from the points of view of both resource utilisation and quality assurance, are better obtained from accredited international compilations rather than developed *ab initio*. Typical examples include radionuclide properties (half-lives, activation cross-sections, etc. as used for inventory development), physical properties of natural and engineering materials (mechanical, thermal, etc.) as used for facility design and EBS evolution studies and thermodynamic data (e.g., the OECD/NEA Thermochemical Data Base – TDB [e.g., Wanner, 1988; Grenthe *et al.,* 1992; Silva *et al.,* 1995; Rard *et al.,* 1999; Fuger *et al.,* 2001: Guillaumont *et al.,* 2003] as used for evaluation of radionuclides speciation and solubility under various geochemical conditions.

The utilisation of such data in a waste management context should, however, be treated with caution as the requirements of the original data-compiler might be different from the specific application considered. Thus data for power reactor applications may be poor or missing for some key safety relevant nuclides. Even more fundamentally, the assumption of thermodynamic equilibrium is rarely valid for repository conditions and thus an “in-house database” may need to be developed in each national programme based on a standard database, taking into account its own system conditions. An example of the latter may be seen in the JNC H12 project (JNC-TDB) for HLW disposal in Japan [e.g., Yui *et al.,* 2003].

A further type of database compiles more site- and/or concept-specific data from many sources – for example the NEA sorption database (SDB) [e.g., Ticknor, 1989]. Such data may be used to complement or check the consistency of more limited sets of data compiled in national programmes. Again such data must be used with caution but, especially at early stages of repository programme development, it is impractical to measure directly all desired data. JNC also developed an in-house database on sorption based on their own measurements and information from the NEA-SDB [Shibutani *et al.,* 1999] (both in-house databases have been opened through internet: http://migrationdb.jnc.go.jp/).

Scenario development is a particular area in which international audit against international databases of Features, Events and Processes (FEP) plays an important role for the evaluation of completeness of project-specific studies. The NEA has been promoting activities to develop both generic [OECD/NEA, 2000] and more specific FEP databases (e.g., FEPCAT for argillaceous media [Mazurek *et al.,* 2003]). The NEA databases have been used to encourage the comprehensiveness of the FEP database in the national projects, for example, the Opalinus Clay FEP Database developed by Nagra [Nagra, 2002].

Finally biosphere databases are worthy of mention. These range from compilations of specific parameters (e.g., uptake factors, K_d values [e.g., IAEA/IUR, 1994]) to entire reference biosphere specifications. Although the latter, in particular, must be regarded as rather unrealistic in many settings, they may be valuable to put SA data in context before site-specific biospheres may be defined.

It should be noted that these databases would need to be updated regularly in accordance with the evolution of knowledge in data and also to be modified at some stage by the feedback from users.

3. Databases for testing SA models and data

Some special challenges for safety assessment involve:

- timescales which extend to hundreds of thousands or even millions of years;
- spatial scales which include cubic kilometres of geosphere but which may involve processes (e.g., radionuclide migration) which require micro-scale (centimetric or less) characterisation;
- complex interfaces between various engineered and natural barriers, which generally evolve with time, and
- perturbation processes which are poorly understood at a mechanistic/theoretical level (e.g., colloids, microbes, organics, gas effects, etc.).

SA models and associated databases may be developed based on conventional laboratory or theoretical studies, but testing their applicability (“validation”) is particularly challenging. Possibilities are generally limited to long-term/large-scale studies in underground test sites or some kind of analogue system. Large efforts are often required to carry out such projects and the resultant databases are often used for international testing projects (e.g., GEOVAL [OECD/NEA and SKI, 1994], INTRAVAL [SKI, 1996], CHEMVAL [e.g., Read and Falck, 1996], DECOVALEX [Jing *et al.,* 1996]) or are made freely available to partners (e.g., the JNC/Nagra radionuclide migration database: www.grimsel.com).

Conclusion

Most participants acknowledge the output from the collaboration in developing and improving the applicability of common databases has been extremely valuable in improving their own repository programme. Apart from the database itself, spin-offs include identifying of areas of strength and weakness and either establishing complementary partnerships or identifying priorities for internal improvement. Additionally, active involvement contributes to confidence-building and establishing international credibility.

Even the process of making data available to others is not completely altruistic. It is increasingly recognised that success in one country's programme lends support to the programmes in all other countries. It is thus sensible to promote even more international collaboration to further our common final goal of developing safe and well-accepted repository projects.

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References

Fuger, J., Nitsche, H., Potter, P., Rand, M. H., Rydberg, J., Spahiu, K., Sullivan, J. C., Ullman, W. J., Vitorge, P. and Wanner, H. (2001): *Chemical Thermodynamics of Neptunium and Plutonium* (OECD/NEA Data Bank, eds.), *Chemical Thermodynamics,* Volume 4, ISBN 0-444-50379-X, Amsterdam, Elsevier Science Publishers B.V.

Grenthe, I., Fuger, J., Konings, R. J. M., Lemire, R. J., Muller, A. B., Nguyen-Trung, C. and Wanner, H. (1992): "Chemical Thermodynamics of Uranium" (Wanner, H. and Forest, I. eds.), *Chemical Thermodynamics,* Volume 1, ISBN 0-444-89381-4, Amsterdam, Elsevier Science Publishers B.V.

Guillaumont, R., Fanghänel, T., Fuger, J., Grenthe, I., Neck, V., Palmer, D. A. and Rand, M. H. (2003): "Update on the Chemical Thermodynamics of Uranium, Neptunium, Plutonium, Americium and Technetium" (Mompean, F. J., Illemassene, M., Domenech-Orti, C. and Ben-Said, K. eds.), *Chemical Thermodynamics,* Volume 5, ISBN 0-444-51401-5, Amsterdam, Elsevier Science Publishers B.V.

IAEA/IUR (1994) *Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments,* Technical Reports Series No. 364. IAEA, Vienna.

Jing, L., Stephansson, O., Tsang, C-F. and Kautsky, F. (1996): *DECOVALEX -Mathematical Models of Coupled T-H-M Processes for Nuclear Waste Repositories, Executive Summary for Phases I, II and III.*

Mazurek, M., Pearson, F.J., Volckaert, G. and Bock, H. (2003): *Features, Events and Processes Evaluation Catalogue for Argillaceous Media, Radioactive Waste Management,* OECD/NEA, ISBN 92-64-02148-5.

Nagra (2002): *FEP Management for the Opalinus Clay Safety Assessment,* Nagra Technical Report NTB 02-04, Nagra, Wettingen, Switzerland.

OECD/NEA and SKI (1994): *GEOVAL'94 Validation Through Model Testing,* Proceeding of an NEA/SKI Symposium Paris, France, 11-14 October 1994.

OECD/NEA (2000): *Features, Events and Processes (FEPs) for Geologic Disposal of Radioactive Waste: An International Database*, 2000 Edition (CD-rom), OECD, Paris.

Rard, J. A., Rand, M. H., Anderegg, G. and Wanner, H. (1999): "Chemical Thermodynamics of Technetium" (Sandino, M. C. A. and Östhol, E., eds.), *Chemical Thermodynamics,* Volume 3, ISBN 0-444-50378-1, Amsterdam, Elsevier Science Publishers B.V.

Read, D. and Falck, W. (1996): "CHEMVAL 2: A Coordinated Research Initiative for Evaluating and Enhancing Chemical Models in Radiological Risk Assessment", Vol. EUR 16648-EN of *Nuclear Science and Tech.* EC Series.

Shibutani, T., Shibata, M. and Suyama, T. (1999): "Sorption Database of Radionuclides on Bentonite and Rocks", Japan Nuclear Cycle Development Institute, JNC Technical Report, JNC TN 8410 99-050.

Silva, R. J., Bidoglio, G., Rand, M. H., Robouch, P. B., Wanner, H. and Puigdomenech, I. (1995): *Chemical Thermodynamics of Americium, Chemical Thermodynamics,* Volume 2, ISBN 0-444-82281-X, Amsterdam, Elsevier Science Publishers B.V.

Ticknor, K.V. and Rüegger, B. (1989): *A Guide to the NEA's Sorption Database*.

SKI (1996): *The International INTRAVAL Project, Final Results,* SKI and OECD/NEA.

Wanner, H. (1988): "The NEA Thermochemical Data Base Project", *Radiochimica Acta,* Vol. 44/45, pp. 325-329.

Witherspoon, P. A. and Bodvarsson, G. S. (ed.) (2001): "Geological Challenges in Radioactive Waste Isolation, Third Worldwide Review", Earth Science Division, Ernest Orlando Lawrence Berkeley National Laboratory, University of California, LBNL-49767, December 2001, Berkeley.

Yui, M., Rai, D., Ochs, M. and Shibata, M. (2003): "Applicability of Thermodynamic Database of Radioactive Elements Developed for the Japanese Performance Assessment of HLW Repository", *J. Nucl. Sci. and Tech.,* Vol. 40, No. 5, pp. 356-362, Atomic Energy Society of Japan.

THE ROLE AND LIMITATION OF UNDERGROUND RESEARCH LABORATORIES FOR GEOLOGICAL DISPOSAL OF NUCLEAR WASTE AND SPENT NUCLEAR FUEL

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The overall objective of Underground Research Laboratories (URLs) is to assess long-term safety and demonstrate technical feasibility of geologic disposal concepts for High Level Waste (HLW) and Spent Nuclear Fuel (SNF). In a URL it is possible to in-situ observe and confirm laboratory experiments and also develop methods for site investigations. The laboratory may also be used for testing of deposition technique and demonstrate repository operation for stakeholders.

The limitations of URLs are the short time frame for the possibility to study long-term safety. This is obvious for people working in Nuclear Waste Management but not for laymen. Periods for large scale testing are limited for those programmes that in the near future will apply for a license to construct a repository for HLW and SNF. Failures in some critical tests might cause a delay for advanced programmes where implementers have tight time schedules. Is shall also be noted that all tests and experiments are performed in a disturbed system where i.e., hydraulic boundary conditions are difficult to control. It is also obvious that all results are site specific (with some exceptions) why test confirmation also has to be done at the final site.

1. International underground research laboratories

Up to now many URLs have been constructed in several countries and in some countries URLs are under construction. Tests and experiments in the URLs have been performed in different geological media including crystalline rock, indurated clay (shale), plastic clay, salt and volcanic tuff.

2. Swedish underground research laboratories – SKB's proposals and SKI's comments

The Swedish regulator SKI early accepted and supported the initiative and decision of the nuclear industry (Swedish Nuclear Fuel and Waste Management Co, SKB earlier named SKBF), in co-operation with OECD/NEA, to construct a URL for in-situ testing and demonstration of functions related to safe handling of nuclear waste and spent nuclear fuel in a future repository.

The initiative from SKBF/SKB resulted in a decision to start planning of tests in the first Swedish URL Stripa in an abandoned iron ore mine 220 km west of Stockholm in an old mining district in southern central Sweden. The Stripa project running between 1980 to 1992 was divided into three phases where during the second phase between 1983 to 1988 the following nine countries participated: Finland, France, Japan, Spain, Sweden, Switzerland, United Kingdom and United States.

The Stripa International Project (NEA/SKB) addressed the following issues:

- understanding and modelling groundwater flows and solute migrations in fractured crystalline rock;
- developing instruments and procedures to characterise candidate repository sites, and
- designing engineered barriers capable of contributing to waste isolation by restricting groundwater flow near waste containers and the surrounding host rock.

SKI found that during the Stripa project important technical contributions were made in two main areas, namely:

- development and demonstrated application of new equipment and methodologies (geophysical, geochemical, hydraulic) for site characterisation, and
- development and in-situ evaluation of materials and construction methods for engineered barriers (buffer, backfill, seals), including an appreciation of their longevity.

However, the project also resulted in some shortcomings. One such shortcoming was that all tests could not be fully completed depending on strict deadlines (overlapping time phases). One example was the site characterisation and validation programme (SCV) experiments including totally eight experiments at 360 to 410-m level during five stages. Some of these tests could not be fully evaluated because difficulties with controlled hydraulic boundary conditions, i.e., ground water flow in the excavated disturbed zone (EDZ), the so called Macroflow test. It should be noted that many of the tests performed in the disturbed rock environment in Stripa URL continued in the undisturbed environment at Äspö HRL (see below).

Plans to construct a new URL in Sweden was presented by SKB in R&D Programme 1986 for the (at that time) responsible reviewing authority the National Board for Spent Nuclear Fuel (SKN). In its review of SKB's programme SKN was positive to the proposal but did not find any strong arguments for localising the repository to the Äspö island located 330 km south of Stockholm.

The pre-construction/excavation phase, named pre-investigation by SKB took place during 1986 to 1990, the construction phase lasted four years and the operation phase started in 1995 and is still going on. Seven organisations from six countries besides Sweden: Finland, France, Germany, Japan, Spain, Switzerland participate in activities at Äspö HRL in 2003. SKB's motivation for constructing Äspö HRL was to carry out RD&D activities in a realistic and undisturbed rock environment at future repository depth and provide the opportunity for a dress rehearsal before a repository is put into operation.

In the laboratory some planned and many ongoing tests take place between 220 to 460 m (bottom) level. Two tests, zone of excavation disturbance experiments (ZEDEX) and long term test of buffer material (LOT 1 Project) are completed. SKI noticed that some mishaps related to both tests occurred which influenced the interpretation and the outcome of the tests. In the ZEDEX experiment five of ten testing runs related to the drill and blast tunnel had to be re-blasted and in the LOT 1 Project some of the bentonite was lost when overcoring the package.

SKB presented in its RD&D Programme 1998 four stage goals for Äspö HRL which recently has been changed. The 1998 goals were:

- to verify pre-investigation methods;
- to develop finally methods for detailed characterisation;

- to test models for the description of the barrier function of the rock, and
- to demonstrate technology for and the function of important parts of the repository system SKI's opinion is that work undertaken in Äspö Task Force (modelling of ground water flow and transport of solutes), using different conceptual and numerical models for predicting the barrier function of the rock, is of high international standard with model teams from all participating organisations.

SKI also gives full support to the tracer retention experiments (TRUE) in detailed as well as block scale. The tests are performed to improve understanding of transport and retention in fractured rock using sorbing and non-sorbing tracers. SKI also supports the use of Äspö HRL in order to develop disposal technology and to demonstrate the performance of a final disposal system. However, also some criticism has been put forward by SKI i.e., initially the integration between the Äspö project activities and safety assessment needs was low – it is now improved. Experience of methods used for application in ongoing site investigations is not clearly presented by SKB – knowledge and experience exist within SKB but the coupling is not properly described for SKI. SKI has also found that it will be difficult for SKB (in its application plan) to use gained experience from buffer and canister experiments (Prototype Repository) depending on time frame – 20-year test period for the four inner canisters in the experiment.

3. International underground research laboratories – SKI comments

Related to international co-operation in URLs SKI may conclude that one positive outcome is that the exchange of experience between working specialists gives high quality performance for national as well as international programmes resulting in improved quality. A good example of this is that in most of the Äspö HRL experiments several countries participate, especially in the Äspö Task Force where all countries contribute with their knowledge. International co-operation creates confidence building especially within implementers but also for regulators. The outcome of international co-operation in URLs gives possibilities to transfer knowledge to countries with minor not fully developed disposal programmes.

The implementers (as well as regulators) must be aware of that it is difficult to compare and transform results between URLs constructed in different geological media. Implementers should also be aware of that experimental mishaps and deviations may entail the delay of expected results by several years resulting in a postponed application to regulators. Implementers should also consider the possibility to do cheaper large scale laboratory tests instead of underground tests.

4. Concluding remarks on Swedish underground research laboratory

SKI is of the opinion that the comprehensive ongoing and planned experiments and demonstration programme at Äspö HRL may be expected to provide a good opportunity for increasing understanding of important parameters and processes in crystalline rock, and for further developing methodology for site investigation and detailed characterisation.

SKI supports SKB's effort to include new large-scale experiments at Äspö HRL namely:

- The Äspö Pillar Stability Experiment (APSE), that is a complementary test of a Canadian URL study. The intention with the test at 450-m level in the laboratory is to demonstrate the capability to predict spalling in rock and to control predicted mechanical and thermal conditions in the rock.

- Testing of low-pH grout: high pH has a negative influence on the bentonite barrier.
- The KBS-3-H method (at 220 m level): horizontal emplacement of canister and bentonite.

It should be noted that SKI in the review of SKB's RD&D Programme 1995 gave the following recommendation to SKB: "The possibility of drilling a horizontal deposition hole at the end of the TBM tunnel (at 460-m depth) in Äspö HRL for testing a horizontal canister position in the tunnel should be considered by SKB".

5. Future RD&D

SKI foresee that tests could be carried out in any URL in virgin undisturbed rock under controlled boundary conditions to demonstrate the axial ground water flow (Macroflow experiment) in EDZ to apply the results in safety assessments. SKI is also looking forward to the outcome of the planned gas flow test LASGIT (Large Scale Gas Injection Test) at Äspö HRL. The test is related to passage of gas through the bentonite buffer surrounding canisters in a repository – it is also possible to perform this in a laboratory mock-up test.

PENDING TECHNICAL ISSUES

Timo Äikäs
Posiva Oy, Finland

Posiva has the task to safely dispose of the spent fuel from the Finnish nuclear reactors at Olkilluoto and Loviisa. An important step in the long-term programme was achieved in 2001 when the decision was made to select Olkiluoto site for deep geologic disposal. The proposed concept was based on KBS-3 disposal concept.

After site and concept selection Posiva's RD&D work aims at obtaining the construction license for the disposal facility. The facility planned for Olkiluoto consists of deep repository and above ground facilities, the most important of which is the encapsulation facility. The master plan of Posiva aims at to submittal of the application for construction license in 2012. According to the plan encapsulation and disposal of the spent fuel should commission in 2020. This in practice means that Posiva shall be able to construct the facility and apply for operation license well before the year 2020.

The RD&D work is divided into two main areas: to further development of the disposal concept and design the main facilities and to assessment of the properties of the site. The development of the concept and design of facilities comprises of work the purpose of which is to qualify the sub-systems and components of the engineered barriers of the disposal system. Very much emphasis is put on the manufacturing tests of the disposal canister, as well as on the sealing of the canister. The motivation for this is the safety concept in which the performance of the EBS plays an important role.

The challenges for future work are related to the following facts:

- The disposal system shall be as much as possible implemented as described in the safety assessment.
- The disposal facility shall be safe to operate and have adequate capacity to work efficiently.
- The overall cost of the disposal shall be acceptable to energy producers and finally to their customers.

In the development process for the geologic disposal three important aspect are important:

- *Technical feasibility*, can we really implement the system as planned?
- *Constraints*, in real site conditions what is allowed to do, what is not allowed as regards to long-term safety?
- *Optimisation*, is there only one way to do it or can we implement a safe system more cost effectively?

In Posiva's safety concept the bedrock shall provide favourable conditions for EBS to retain its good isolation properties. Safety assessment defines the scenarios to be considered in the design work and furthermore stands as a basis for developing functional requirements for the design of sub-systems and components. It is important to locate well-suited bedrock volumes at planned disposal depth for repository design and construction, which acts as cocoon for disposal system. To be able to do this Posiva has decided to go underground and construct an underground characterisation facility, which is called ONKALO. In addition to use ONKALO for acquisition of the information for detailed design of repository and safety assessment it plays a role in testing the feasibility of site-specific designs. The preliminary testing of the feasibility may be, of course, carried out elsewhere, for example at Äspö HRL.

The disposal system shall be designed for robustness, which means that the system shall not be vulnerable for imperfections. In addition of possible imperfections in implementing the system the robust system shall also be able to maintain the favourable properties of the site. In this sense the design work shall be able, in the interaction with safety assessment research, to recognise design issues, which may give limitation to construction methods, for example, or may require choices of particular design parameter to ensure conservativeness due to uncertainty. The disturbance caused by construction and operation of deep repository at Olkiluoto is a special issue, which has to be considered before any excavation will be commissioned. Disturbances may be hydrogeological or hydrogeochemical of their nature or caused by stray materials the impact of which has to be analysed.

Optimisation is basically a continuous activity for improving design solution and increasing cost efficiency. In practice this means that technical feasibility of methods for implementation will be improved to meet the desired efficiency. Desired efficiency, on the other hand, may change with time; the properties of the spent fuel will change (burn-up for example), amount of spent fuel will increase due to extended life time of reactors or new reactors. It is very different to design a system being capable disposing of 10 packages a day than 1 package a week. Design for concept variants may be useful in finding cost efficiency without jeopardising safety principles or robust design. SKB and Posiva are, for example, making efforts to develop KBS-3H, horizontal version of KBS-3. In trying to make the system simpler, the aim is also to decrease the impact of the repository to surrounding geological environment.

Although siting appears to be the most difficult issue in implementing geologic disposal and thus the social acceptance the key problem there are, however, plenty of technical and scientific issues left before we are able to implement a disposal system in accordance with requirements. The studies into technical feasibility bring forward open design issues (e.g., thermal dimensioning) which have to be solved in interaction with safety assessment. The design for excavation and construction needs understanding on site properties and predictions to future. The efforts to optimise cost shall be kept in mind in designing the numerous details of the disposal facility.

THE ROLE AND LIMITATION OF UNDERGROUND RESEARCH LABORATORIES TO FOSTER DEVELOPMENT OF EXPERTISE, INFORMATION EXCHANGE, TRANSFER OF KNOWLEDGE, AND CONFIDENCE BUILDING THROUGH INTERNATIONAL CO-OPERATION

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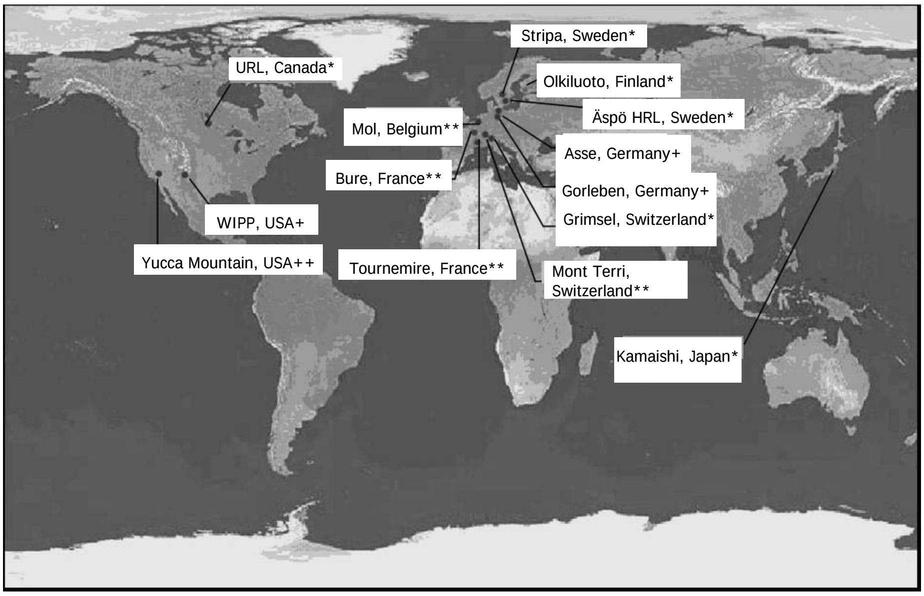
Introduction

The rationale for constructing and operating underground rock laboratories (URL) is basically the need for carrying out Research and Technical Development (RTD) work under realistic conditions in realistic environments. Full scale experiments and tests are possible. Because of the limited number of existing URLs in each type of considered repository host rock, see Figure 1, and the high costs for large scale experiments international co-operation and networking have become a fruitful as well as traditional way of conducting the work in the URLs.

Figure 1. Past, present and/or planned URLs: in crystalline rock (*), clay rock (**), in salt (+) and in tuff (++)



This co-operation and networking have progressively developed into other areas than pure RTD work, and show that added value may be achieved in URLs in also many other areas. The paper gives examples of good experience and points out future ways of enhancing this kind of added value within four areas:

- development of expertise;
- information exchange;
- transfer of knowledge, and
- confidence building.

1. Stripa Mine

The Swedish programme, like other programmes, came to the conclusion that rock characteristics are to complex to be studied in surface laboratory environment only, and that field experiments are needed in order to correctly determine its characteristics. In Sweden was this issue raised rather early, in the late 70s, and the exhausted iron mine Stripa was selected to be a representative crystalline rock site and suitable for arranging field tests. The plan attracted the US and the first international co-operation on nuclear waste management started. This co-operation was extended to other organisations and was developed into an OECD/NEA-supported co-operation. This start has been followed by a number of co-operate projects, and the URLs shown in Figure 1 represent each an example of such development.

From the beginning the co-operation was completely focused on technical issues but once networks were formed the area of co-operation expanded to many other fields in the national programmes, from the beginning just as information exchange and later as planned joint activities.

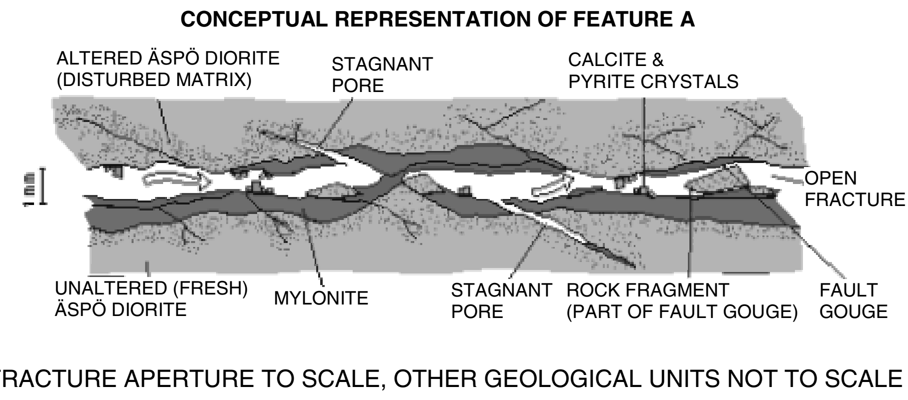
2. Expertise

Expertise is experienced to develop progressively by interactions in networks in many areas covering conceptual understanding of processes in rock and engineered barrier system (EBS) as well as in practical matters like excavation techniques and disposal methods. Frequent information exchange is a natural part of the interaction between the engaged scientists and engineers.

Even today are the "old" researcher and scientists, which took part of the Stripa Mine co-operation, talking about the successful networking and the fruitful climate that existed around the project work in the Stripa Mine.

A few examples of expertise developed in co-operation are presented below.

Figure 2. Developed common understanding of the water-carrying features in crystalline rock

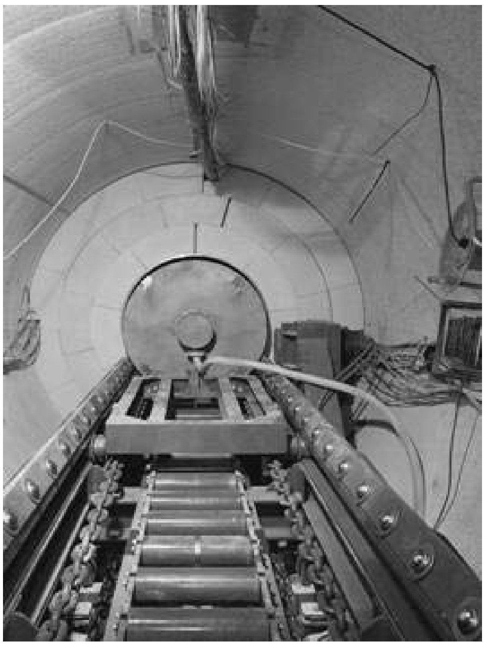


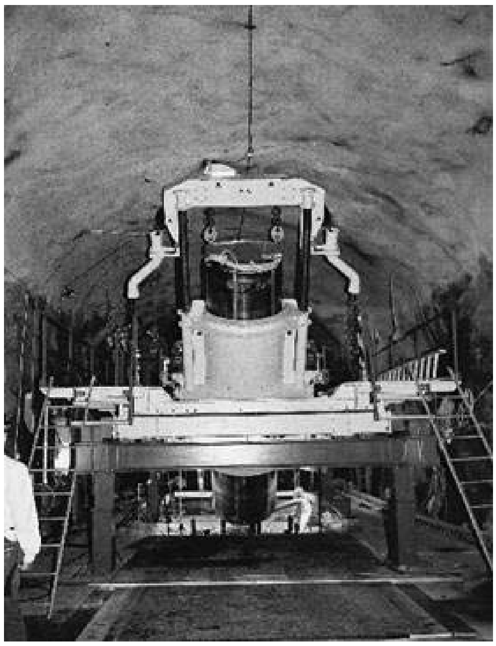
Properties and behaviour of bentonite buffer have been developed in common. A number of pilot to full-scale experiments have been carried through, and a common understanding of the key parameters as well as existing differences between different national deposits have been developed and made known to the participants.

Radionuclide migration in crystalline rock is determined by a complex set of interconnected factors. Sorption is one key process and consequently also the area available for sorption in the fracture and rock matrix on the side of the fracture. Laboratory and field experiments combined with conceptual and numerical model development in international joint work have resulted in the conceptual picture of a fracture as shown in Figure 2. Developed numerical codes have shown their capability to reproduce field experiments with sorbing tracers over transport distanced on 100-m scale.

Technology for handling and emplacing heavy canisters (weighing of up to 25 Mg) may look reasonable on drawings, but need to be tested in full scale in order to verify the generic assumptions made during the design work. Should the canisters be placed in a vertical or horizontal mode? Does it matter from the engineering point of view? Figure 3 shows the tests in the FEBEX and the Prototype Repository projects. The vertical mode was early selected and developed as the reference method for crystalline rock in Finland and Sweden. Many other programmes are based on a horizontal emplacement mode, especially when the canister is covered by a heavy overpack. By comparison of handling tests in the different URLs is it possible to define pros and cons for different packages and in different under ground environments. The facts have been shared and the engineers now have learned how to adapt to the most suitable mode from a safety and economical point of view.

Figure 3. Equipment for developing the emplacement techniques FEBEX (left) and Prototype Repository (right)





A last example taken here is the *CODE BRIGHT*, which is one of the most advanced numerical codes for predicting THMC (thermo-hydro-mechanical-chemical) processes taking place in the bentonite buffer during saturation as well as afterwards in the saturated state of condition. But, the code was originally developed for processes taking place in salt rock.

3. Information exchange

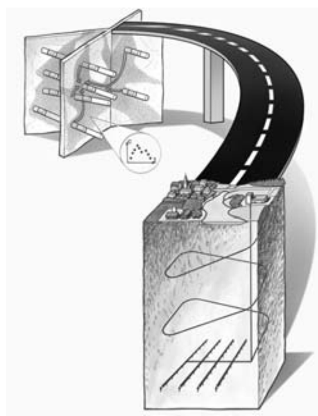
More pronounced *information exchange* is done in fora like workshops, visits, task forces on specific topics etc. Even if information is flowing freely, is a balanced exchange strived for and deemed needed in order to provide for a sustainable information exchange process. Agreements between parties tend to limit the free dissemination of general information, and all types of information exchange might in the future be more controlled than today. European Commission projects catalyse information exchange between URLs and one out of many examples is the CROP project (Cluster of Repository Projects). This project compiles, evaluates and discusses the results gain in different field tests in different URLs with focus on experiments that study the EBS. Organisations from nine countries with national responsibility for the high-level and long-lived nuclear waste participate. OPG of Canada and U.S. Department of Energy Carlsbad Field Office represent participants from non-EU member states. The group has during the course of the project developed a platform for exchange of technical experience and discovered that many topics are in common not only between URLs in the same host rock type but also between URLs in different host rock types represented in the work. Open and free information has frequently been exchanged also outside the scope of work of the project.

4. Transfer of knowledge

An important way of *transferring knowledge* is reporting of results in generally available report series. By tradition are all major results reported and the reports distributed to parties with the aim of having the results reviewed openly. But reporting has a limit in the fact that good results are over-represented and bad results tend to be poorly reported. These circumstances may be sorted out in a network or in workshops, but are then primarily only open to the participants having a close co-operation.

Another example is the IAEA initiative to organise a Network of Centres of Excellence covering the main URLs in operation today and open up these facilities to those countries not having such facilities. But the URLs have cost major sums for both construction and experimental work, and will have costs for every activity that will take place in the future. Consequently is participation a question of money for covering at least running costs. The transfer of knowledge is now, in the initial state of networking, focused on training and teaching, and exchange of researchers. No field experiments are included in the closest future plans of the organisations having no URL of their own.

Figure 4. Different experts learn to understand each other, and to together transfer data from e.g., URL tests to the full scale geologic repository environment



A similar but somewhat different approach has been taken by Nagra in the ITC School of Underground Waste Storage and Disposal, where specific nuclear waste management courses are given in different topics in co-ordination with the needs of the nuclear waste management community.

A special focus on the understanding as well as evaluation of the capability to numerically model different processes and different evolutions are set in groups addressing the same problem with the same set of parameters, which are taken from results of experiments conducted in above ground laboratories or in URLs. A number of examples exist on groups reaching the "critical mass", and providing excellent results together, which would not been possible if each and everyone would have worked on their own instead. The objectives of this work are illustrated in Figure 4.

5. Confidence building

Confidence building may also be expressed as the establishment of good credits by the general public, stakeholders and all others with a say in the process. Success in this work is very much dependent on the progress in the international community. The public seems to expect a wide consensus among the experts and is sensitive to technical developments in other countries than their own. But the possibility to get general information accepted on work done and how the future should be planned may be essential for success. Äspö, as one example, has annually more than 10,000 visitors underground, and polls made show both a positive experience of the visit and a more positive attitude to nuclear waste management afterwards. This positive response has also been conveyed from other countries were the reactions of URL visitors are evaluated. A drawback is that even the Äspö high number of visitors is small in relation to the need.

6. Concluding remarks

Two facts may favour the existing URLs in the future:

- an URL is costly not only to construct but also to operate, and
- the existing ones have succeeded in establishing a "critical mass" of scientists and engineers for RTD work on the issues the URLs were intended to address.

This may lead to specialisation, and consequently a need for increased interaction between URLs the objective being to more effectively than today avoid double work and to plan and carry through similar field experiments in different geological environments. The latter would aim at verification of the applicability of results from one URL to similar conditions in other URLs. One example is the co-ordination between the two projects FEBEX (Grimsel Test Site) and Prototype Repository (Äspö Hard Rock Laboratory) that was initiated by the European Commission.

But there are a number of topics of interaction between URLs that have not been explored yet, especially issues that are in common between different geological media (crystalline rock, clay, salt, and tuff). More intense co-operation is judged to be favourable for all parties. Also co-operation between countries having URLs and countries not having URLs, like the one initiated under the umbrella of the IAEA, has a potential for promoting substantial development. This interaction will most probably increase in the future.

The future co-operation in URLs may preferably focus on numerical tools, which require new but small scale field-tests. Later can the work address testing of construction methods and machines, especially those with specific design? Eventually may "dress rehearsals" be set up in order for crews and machines to become a team before disposal starts?

Such international co-operation would automatically open up for networking, fora for discussions and sources for planning joint developments. Experts would be engaged and experts would be trained. Information would be exchanged and vital knowledge would be transferred. The public acceptance would be enhanced just by the fact that a variety of technical alternatives are addressed, tested and evaluated in a uniform and comparable way.

Annex

PRESS RELEASE

Radioactive waste is associated with all phases of the nuclear fuel cycle and with the use of radioactive materials in industrial, medical, military and research applications. All such waste must be managed safely. The most hazardous and long-lived wastes must be contained and isolated for many thousands of years. There is international agreement that solutions are required that do not result in undue burden on future generations and impose reasonably predictable impacts that are not greater than those permitted for the current generation.[1] The international community is also adhering to the principle that those who generate the waste should provide for the appropriate management means.[2]

The participants in this conference have gathered to review the technical and political progress in radioactive waste disposal since the Denver Conference held in 1999. In undertaking this review they confirm their – and their organisations and countries – commitment to the safety and management principles agreed to in international documents, notably the IAEA's Safety Fundamentals[3] and the *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management*.[1]

Various long-term waste management options are being considered to protect humans and the environment both now and in the future. Disposal in engineered facilities, or repositories, located in suitable formations deep underground, is being widely investigated world wide as a suitable option. Engineered geologic disposal is thus seen as a radioactive waste management end-point providing security and safety in a sustainable manner that does not necessarily require monitoring, maintenance and institutional control.[4] Internationally, this option is regarded to be technically feasible;[5] acceptable from an ethical and environmental viewpoint;[6] and it is acceptable from an international legal perspective.[1]

Exchanging information and working cooperatively under the aegis of international organisations such as the International Atomic Energy Agency of the United Nations and the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development is key to develop a broad understanding of the issues at hand and to ensure that options are pursued that have international support.

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1. International Atomic Energy Agency, *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management,* INFCIRC/546, IAEA, Vienna, 1997.
2. In the spirit of "The Rio Declaration", A/CONF.151/26 (Vol. I), 12 August 1992, United Nations.
3. International Atomic Energy Agency, *The Principles of Radioactive Waste Management,* Safety Series No. 111-F, IAEA, Vienna, 1997.
4. Nuclear Energy Agency, *Geologic disposal of radioactive waste – Review of Developments in the Last Decade,* OECD, Paris, 1999.
5. Nuclear Energy Agency, *Progress towards geologic disposal of radioactive waste: where do we stand? An International Assessment,* OECD, Paris, 1999.
6. *The Environmental and Ethical Basis of Geologic Disposal – A Collective Opinion of the NEA Radioactive Waste Management Committee,* OECD, Paris, 1995.

GLOBAL SENSITIVITY ANALYSES METHODS FOR GENERATING RISK INFORMATION

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Introduction

The regulations for licensing a potential high-level waste repository at Yucca Mountain, Nevada, in the United States, call for use of risk information in demonstrating safety during the operational and post-closure periods. Regulations in the Code of Federal Regulations, Chapter 10, Part 63, for the Yucca Mountain repository [1] require application of probabilistic methods to develop quantitative risk information. Sensitivity analyses play a major role in developing quantitative risk information.

Several new sensitivity analyses methods have been developed at the Center for Nuclear Waste Regulatory Analyses (CNWRA), sponsored by the U.S. Nuclear Regulatory Commission (NRC). In this paper, three new methods applicable to Monte Carlo-based performance assessment models are described: (i) a parameter tree method, (ii) a partitioning method, and (iii) a mean-based method. The three CNWRA-developed methods belong to the class of Aglobal@ methods where sensitivity of the model outputs to changes in parameters is estimated for the entire range of values. In the discussion that follows, a *realisation* is defined as a set of input parameters, each parameter represented by a unique sampled value, and corresponding outputs predicted by the model. A convenient output typically used as a performance metric is the maximum dose for each realisation in a simulation period (the regulatory period specified in [1] is 10 000 years).

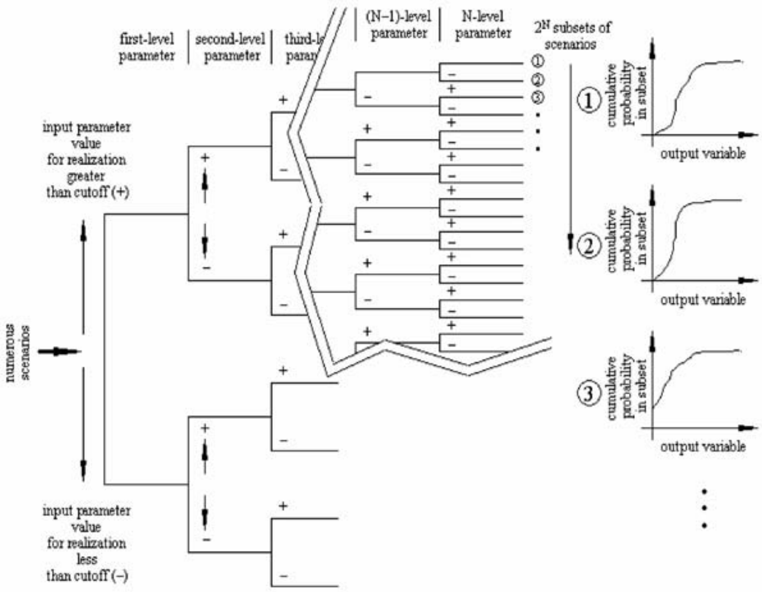
Parameter tree method

To construct a parameter tree, samples of input parameter values are treated as A+@ or Ạ@ based on the comparison of the parameter value to a branching criterion (such as the mean, median, or any percentile of the parameter distribution). The corresponding system outputs or performance metrics (e.g., maximum dose) are then aggregated into similar bins. The most important parameters are identified by applying the branching criterion, one parameter at a time, and defining a correlation between parameter branching and system output binning. A definition of such a correlation, selected as importance index I_i, is discussed in detail by Jarzemba and Sagar [2]:

$$I_i = \left| p_i^+ - p_i \right| \quad (1)$$

p_i^+ is the probability that a realisation in the A+@ parameter branch belongs to the A+@ system output bin, and p_i^- is the probability that a realisation in the Ạ@ parameter branch belongs to the A+@ system output bin. The probabilities are estimated by counting the number of realisations satisfying the conditions. If there is no relationship between the branching of the parameter and system output, the two probabilities, p_i^+ and p_i^-, are similar, and the value of I_i is close to zero. The most important parameters are identified by sorting the importance index. A multiple level branch tree can be constructed by combining various parameters, each tree level associated with a single parameter (see Figure 1). The probability that a realisation in a given branch also belongs to the A+@ system output bin is a measure of the importance of the parameter combination. If the median of the parameter is selected as the branching criterion, the number of realisations belonging to a given branch is approximately $r/2^N$, where r is the number of realisations, and N is the number of parameters considered (i.e., the number of branching levels). A detailed application of the parameter tree approach to analyse output data produced by the Total-system Performance Assessment code for the Yucca Mountain system is available elsewhere [2].

Figure 1. **Generalised parameter tree**



Partitioning method

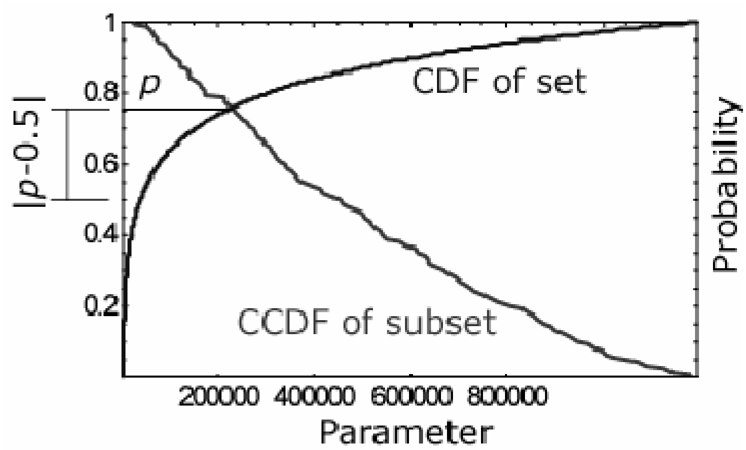
In the partitioning method, realisations also are divided into two sets depending on the comparison of a system output (e.g., maximum dose) to a threshold value (e.g., mean of the set of maximum doses for all realisations). For each parameter, the set with the fewest realisations (characteristic set) is selected, and the complementary cumulative distribution function (CCDF) of the parameter is computed. This CCDF of the subset of parameter values is compared with the cumulative distribution function (CDF) of the complete population of parameter values. The intersection in the probability axis, p, can be used to define an importance metric for the parameter (see Figure 2).

The distance away from 0.5, $|p0.5|$, is a measure of the parameter influence on the performance metric [3]. A positive value of the $p0.5$ statistic indicates a positive correlation between the parameter and the system output. A significance test for the $|p0.5|$ statistic has been derived recently [4]. The standard deviation of the p statistic, σ_n, in a random selection of n elements is:

$$\sigma_n = \frac{0.246}{\sqrt{n}} \tag{2}$$

The collection of parameters most important to the system output is identified by sorting the $|p0.5|$ statistic, selecting only those parameters that satisfy a criterion such as $|p0.5|>2\ \sigma_n$. The partitioning method can be combined with the parameter tree method to define a robust importance index of parameter combinations, considering the subsets of system outputs (e.g., maximum doses) belonging to a particular branch. The partitioning method has been combined with the principal component decomposition to analyse outputs that are functions of time [4].

Figure 2. **Graphic description of the determination of the *p* statistic in the partitioning method**



Mean-based sensitivity method

A cumulative distribution sensitivity analysis technique was developed by Mohanty and Wu to rank influential parameters [5]. The technique was intended to estimate the response in a particular percentile of system output to changes in the first and second moments of input parameters. The unique aspect of this technique is that a single multiple-realisation Monte Carlo run is sufficient to assess the change in a particular percentile of system output. Recently, the technique was extended to estimate responses in the mean of the system output to changes in the first and second moments of an input parameter distribution [6]. The mean-based sensitivity of the system output Y on the parameter X_i is defined as

$$S_{Y_\mu} = \frac{1}{r}\sum_{j=1}^{r}\left[u_i Y\right]_j \tag{3}$$

where r is the number of realisations, and u_i is the result of mapping parameter X_i onto a normal distribution with a zero mean and unit standard deviation. If Y is independent of changes in the mean of parameter X_i, then S_{Y_μ} is zero. A statistical significance test on the mean-based sensitivity, S_{Y_μ}, can be implemented by comparing P_i

$$P_i = \frac{S_{Y_\mu}}{\sqrt{E\left[u_i^2 Y^2\right]/r}} \tag{4}$$

to a confidence percentile of the standardised normal distribution. Those parameters for which $|P_i|$ is greater than the confidence percentile are identified as the influential parameters. A similar sensitivity measure to that in Equation (3), based on the standard deviation of the input parameter, has been defined elsewhere [6]. The mean-based sensitivity has been applied to the analysis of maximum doses per realisation estimated with the Total-system Performance Assessment code for the Yucca Mountain system [6].

Remarks

Three sensitivity-uncertainty methods are presented. All of them are efficient in the sense that a single multiple-realisation Monte Carlo run is sufficient to generate results. Multiple methods are intended to complement the analyses of complex models for risk assessment to develop confidence that components most important to system safety are identified. The three methods discussed in this paper were created to support development of risk insights for the potential repository system at Yucca Mountain, Nevada, in the United States.

Acknowledgments

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References

[1] U.S. Nuclear Regulatory Commission (2001), Disposal of High-Level Radioactive Wastes in a Proposed Geologic Repository at Yucca Mountain, Nevada: Final Rule, *Federal Register*, vol. 66, No. 213. p. 55732. November 2, 2001.

[2] Jarzemba, M.S. and B. Sagar (2000), A Parameter Tree Approach to Estimating System Sensitivities to Parameter Sets. *Reliability and System Safety*. Vol. 67. pp. 89-102.

[3] Pensado, O., V. Troshanov, B. Sagar and G. Wittmeyer (2002), A Partitioning Method for Identifying Model Parameters. Probabilistic Safety Assessment and Management (PSAM6). Vol. 1. E.J. Bonano, A.L. Camp, M.J. Majors, and R.A. Thompson, eds. Kidlington, Oxford, United Kingdom: Elsevier Science Ltd. pp. 827-833.

[4] Pensado, O. and B. Sagar (2004), Sensitivity Analysis of an Engineered Barrier System Model for the Potential Repository System in the United States. Paper to be presented at the 7th Probabilistic Safety Assessment and Management (PSAM7). Berlin, Germany. June 14-18, 2004.

[5] Mohanty, S. and Y-T. Wu (2001), CDF sensitivity analysis technique for ranking influential parameters in the performance assessment of the proposed high-level waste repository at Yucca Mountain, Nevada, USA, *Reliability Engineering and System Safety*, vol. 73, No. 2, pp. 167–176.

[6] Mohanty, S. and Y-T. Wu (2002), Mean-based Sensitivity or Uncertainty Importance Measures for Identifying Influential Parameters, Probabilistic Safety Assessment and Management (PSAM6), vol. 1. E.J. Bonano, A.L. Camp, M.J. Majors, and R.A. Thompson, eds. Kidlington, Oxford, United Kingdom, Elsevier Science Ltd, pp. 1079–1085.

RISK AND UNCERTAINTY ASSESSMENT FOR A POTENTIAL HLW REPOSITORY IN KOREA: TSPA 2006

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KAERI has worked on the concept development on permanent disposal of HLW and its total system performance assessment since 1997. More than 36 000 MT of spent nuclear fuel from PWR and CANDU reactors is planned to be disposed of in crystalline bedrocks. The total system performance assessment (TSPA) tools are under development. The KAERI FEP encyclopedia is actively developed to include all potential FEP suitable for Korean geo- and socio conditions. The FEPs are prioritised and then categorised to the intermediate level FEP groups. These groups become elements of the rock engineering system (RES) matrix. Then the sub-scenarios such as a container failure, groundwater migration, solute transport, etc are developed by connecting interactions between diagonal elements of the RES matrix. The full scenarios are developed from the combination of sub-scenarios. For each specific scenario, the assessment contexts and associated assessment method flow charts are developed. All information on these studies is recorded into the web based programme, FEAS (FEP to Assessment through Scenarios.) KAERI applies three basic programmes for the post closure radionuclide transport calculations; MASCOT-K, AMBER, and the new MDPSA under development. The MASCOT-K originally developed by Serco for a LLW repository has been extended extensively by KAERI to simulate release reactions such as congruent and gap releases in spent nuclear fuel. The new MDPSA code is dedicated for the probabilistic assessment of radio-nuclides in multi-dimensions of a fractured porous medium. To acquire input data for TSPA domestic experiment programmes as well as literature survey are performed. The data are stored in the Performance Assessment Input Data system (PAID.) To assure the transparency, traceability, retrievability, reproducibility, and review (T2R3) the web based KAERI QA system is developed. All tasks in TSPA are recorded under the concept of a "Project" in this web system. Currently, FEAS, PAID, the web based QA system in associated with documentation system and the visual MASCOT-K programme are integrated into the new system, CYPRUS. Once completed the CYPRUS system will be a platform not only for the daily R&D but also as the information provider for general public. The issues of stakeholders are the key for the successful TSPA. At this moment, KAERI is working on understanding characteristics of stakeholders and the optimum solution to accommodate opinions of stakeholders over TSPA. To illustrate the safety of a Korean reference disposal system (KRDS) some specific scenarios are identified. Results show that under given conditions the safety of the KRDS suits the guidelines given by Korea Institute of Nuclear Safety (KINS), the sole regulators in Korea. Results clearly point out that the future R&D in data acquisition should be focused on the understanding of the major water conducting features (MWCF.) The integrated results of TSPA and the KRDS development will be published in 2006.

PHYSICALLY BASED PROBABILITY CRITERION FOR EXCEEDING RADIONUCLIDE CONCENTRATION LIMITS IN HETEROGENEOUS BEDROCK

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Introduction

A significant problem in a risk analysis of the repository for high-level nuclear waste is to estimate the barrier effect of the geosphere. The significant spatial variability of the rock properties implies that migrating RNs encounter a distribution of bedrock properties and mass-transfer mechanisms in different proportions along the transport paths. For practical reasons, we will never be able to know exactly this distribution of properties by performing a reasonable amount of measurements in a site investigation.

On the contrary, recent experimental studies reveal that crystalline bedrock can possess a marked heterogeneity of various physical and geochemical properties (Hakami and Barton, 1990; Siitari-Kauppi *et al.*, 1997; Xu and Wörman, 1998) that potentially may have a certain impact on the transport of RNs in fractured bedrock. Also current field investigation techniques provide only fragmentary information of the properties of the geosphere. This is a basic motivation for treating flows of water and solute elements in groundwaters by means of stochastic continuum models (Gelhar *et al.*, 1974; Dagan, 1989; Gutjahr *et al.,* 1978; Gelhar *et al.*, 1979; Gelhar and Axness, 1983).

The stochastic analysis is based on the idea that we know only certain point values of the property fields and use this information to estimate intermediate values. The probabilistic properties of the stochastic analysis are suitable input variables for risk analyses of the relevant sequence of extreme events for which empirical observations are rare or non-existing.

The purpose of this paper is to outline the implications of the stochastic approach for estimating probabilities that certain concentration limits are exceeded at discharge points from the bedrock in case of a leakage from the waste repository. The analysis is restricted to the water flow and solute transport in the bedrock alone without consideration of the full sequence of events in a full risk analysis and the Baysian statistics involved in such conditioned (and cross-correlated) event series. The focus is on the implication for the risk analysis of the auto-covariance structure in bedrock properties and uncertainty in the associated site data.

Formulation of probability criterion

The three-dimensional nature of the mass flow involves uncertainties related both to the water flow and the geochemistry of the solute transport. A possible and relevant starting point for a probability analysis is the expected value of the solute concentration at a certain control section (Dagan, 1989; Rodriguez-Iturbe and Rinaldo, 1997).

$$< \mathrm{c}(\mathrm{t}) >= \int_0^\infty \mathrm{c}(\mathrm{t},\tau)\mathrm{g}(\tau)\mathrm{d}\tau \qquad (1)$$

in which g(τ) is the travel time probability density function (PDF) for water parcels travelling from an imagined leakage zone to the control section, τ is the residence time of an inert water parcel travelling along one of the trajectory paths, and c(t, τ) is the concentration of solute per unit volume of fracture water [kg/m^3] and t is the time [s].

A physically based analysis of the travel time PDF for water, g(τ), and the solute response function, c(t, τ), will be associated with uncertainties due to the discrete collection of data and the heterogeneous environment. According to the central limit theorem, the deviation of the estimated (sampled) expected value, $< \bar{c} >$, from the true expected value, E[<c(t)>], of an ensemble of outcomes (realisations) is normally distributed with the standard deviation Std[<c>]/$n^{0.5}$, where n is number of samples. Hence, the probability that $< \bar{c} >$ exceeds a certain limit ***C*** can be expressed as

$$p(< \bar{c} > \geq \boldsymbol{C}) = p(z \geq Z) = erfc[Z] \qquad (2)$$

in which the standardised variable z = [$< \bar{c} >$- E[<c>]]/ Std[$< \bar{c} >$], Z = [***C*** - E[<c>]]/ Std[$< \bar{c} >$]. The probability that an individual realisation exceeds the limit ***C*** can be expressed analogous to (2) under the assumption that the distribution of <c> is normal.

In this study, we will assume normal distribution of <c> and stationarity in the sense that Std[<c>] = constant regardless of time and physico-chemical processes. Hence, (2) is the criterion from which we will express the probability that the estimated concentration exceeds a certain limit, in which z = [<c>- E[<c>]]/ Std[<c>],. Furthermore, from Gauss approximation formula one may show from a discrete form of (1) and independence between g and c that

$$Var[< \mathrm{c}(\mathrm{t}) >] \cong \int_0^\infty Var[\mathrm{c}(\mathrm{t},\tau)]\mathrm{g}^2(\tau)\mathrm{d}\tau + \int_0^\infty \mathrm{c}^2(\mathrm{t},\tau)Var[\mathrm{g}(\tau)]\mathrm{d}\tau \qquad (3)$$

in which the variance operators are evaluated over the ensemble of random realisations (not e.g. the temporal variance of g and c, respectively). Consequently, the probabilistic problem is decomposed into problems of estimating the uncertainties as well as the expected values of the solute response curve on one hand and the water residence PDF on the other hand. Those problems are practically feasible based on statistical data of physical and chemical parameters of the system. Particularly, if the cross covariance between g and c can be neglected the stochastic analysis of the solute transport and the water flow can be done independently.

Stochastic -physically based formulation of flow and transport processes

Both the water flow and the solute transport are analysed based on stochastic continuum and a combination of numerical techniques and closed-form solutions. The water flow can modelled based on a discrete fracture network that is generated with known statistically properties as well as deterministic features such as observed fracture zones (Geier, 1992, 1996 and 2004). The statistical nature of the procedure calls for a need to employ Monte Carlo simulations to resolve Std [g(τ)] and E[g(τ)]. These calculations are relatively "heavy" and form a practical point of view the computer capacity sets significant limits to be noted.

The solute transport is formulated based on partial, differential equations that represent advection, matrix diffusion and sorption in the solid rock surfaces. The most relevant rock properties including fracture aperture and several matrix properties as well as flow velocity are assumed to be spatially random along transport pathways. Perturbations (random spatial variability in bedrock properties) are introduced in the coefficients to reflect an uncertainty of the exact appearance of the bedrock associated with the discrete data collection.

The mass transport is first solved in a general form along one-dimensional pathways, but the results is extended to multi-dimensional flows simply by substituting c(t, τ) in (1). A solution can be obtained in the Laplace domain for a Dirac pulse that is released at the up-stream boundary in the form of (Wörman *et al.,* 2003, Wörman *et al.*, 2004)

$$E[\bar{c}] = \frac{M_0}{Q}\exp\left[\left(-E[\tilde{\beta}] + \sum_{i=1}^{N} a_i \frac{\ell_i}{E[\tilde{\beta}]\ell_i + 1}\right)x\right] \qquad (4)$$

where the auxiliary variables $\tilde{\beta} = c_1\eta_u + c_2\eta_u\eta_h\eta_M$, $\eta_u \equiv u/\tilde{u}$, $\eta_h \equiv h/\tilde{h}$, $\eta_M \equiv \tilde{M}/M$, $M = (D_p\varepsilon_t\varepsilon(1+K_D))^{0.5}$ [m s$^{-0.5}$], $c_1 = p/u$, $c_2 = -[(2\varepsilon_t D_p)/(hu)]\alpha[1 - 2/(1+\exp(-2Z\alpha))]$, $\tilde{\alpha} = \sqrt{p(1+K_D)/[(p+k_r)(\varepsilon_t/\varepsilon D_p)]}$ and p is the Laplace variable. The series expansion method of De Hoog *et al*. (1982) by means of the MATLAB® code of Hollenbeck (1998) to numerically invert (4) to the real domain. For the solution in a network of fractures representing the bedrock, the summation is performed over 26 terms (N=26) and the variance factor a_i as well as the correlation factor l_i are defined in Table A3-1 in Wörman *et al.* (2004). The second term on the right-hand side of (4) represents the effect of the parameter variability on the expected value of c. Both a_i and l_i can be determined from statistical evaluation of data on the physico-chemical parameters of the system as demonstrated in the next section.

The variance of c can be evaluated in the Laplace domain as the square-root of the expected value E[c´c´], where c´ is the perturbation (deviating from E[c]). Wörman *et al.* (2003) showed that

$$\bar{c}' = \frac{M_0\beta'}{Q\sum_{i=1}^{N} a_i \frac{\ell_i}{E[\beta']\ell_i + 1}}\exp\left(-E[\tilde{\beta}]x\right)\left(1 - \exp\left(\sum_{i=1}^{N} a_i \frac{\ell_i}{E[\tilde{\beta}]\ell_i + 1}\right)\right) \qquad (5)$$

$$\begin{aligned}\beta' = {} & c_1\eta'_u + c_2E[\eta_u]E[\eta_M]\eta'_h + c_2E[\eta_u]E[\eta_h]\eta'_M + c_2E[\eta_M]E[\eta_h]\eta'_u + c_2E[\eta_u]\eta'_M\eta'_h + \\ & + c_2E[\eta_M]\eta'_u\eta'_n + c_2E[\eta_u]\eta'_u\eta'_M + c_2\eta'_u\eta'_M\eta'_h - c_2E[\eta_u]Cov[\eta_M\eta_h] - c_2E[\eta_M]Cov[\eta_u\eta_h] \\ & - c_2E[\eta_h]Cov[\eta_u\eta_M] - c_2Cov[\eta_u\eta_h\eta_M] \qquad (6)\end{aligned}$$

Consequently, we now have a complete coupling between statistical treatment of data, physically based analyses of the flow and transport processes as well as the probabilistic criterion subject to the risk assessment.

Application to site specific data

The empirical basis for site specific example is taken with respect to geology and geohydrology from the safety assessment exercise performed by the Swedish Regulatory (SKI, 1996) with the use of data from Äspö Hard Rock Laboratory. The flow analysis follows the approach described in Wörman *et al.* (2004). Data on parameter variability on a fracture scale in the Äspö bedrock was taken from the studies of Xu and Wörman (1998; 1999) and Hakami (1995). The expected values of the parameters were:

$D_e = 10^{-13}$	$[m^2/s]$
$D_p = 10^{-10}$	$[m^2/s]$
$\varepsilon = 0.004$	[-]
$k_d = 0.008$	$[m^3/kg]$
$k_r = 10\text{-}10$	[1/s]
$x = 500$	[m]
$h = 0.0064$	[m]
$u = 50$	[m/y]
$L = 0.1$	[m]

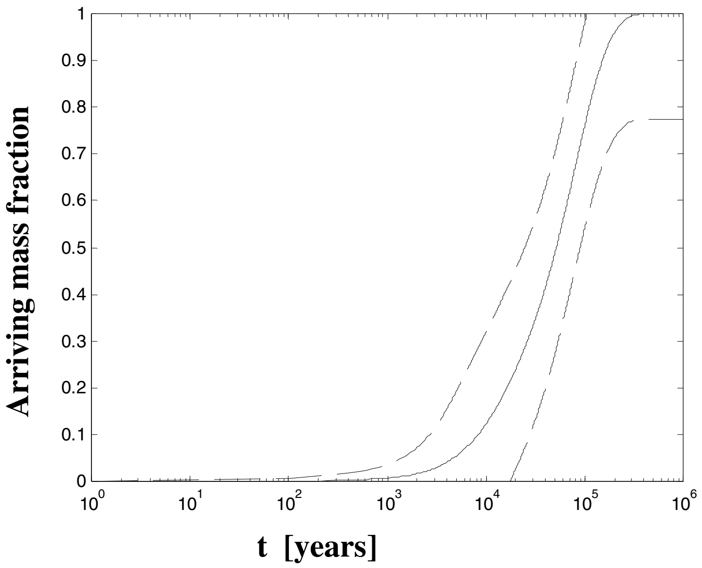
Geostatistics of the matrix property M, aperture and flow velocity for single fractures were obtained from Äspö crystalline rock in a one-meter scale (Xu and Wörman, 1998; Xu *et al.*, 2001; Hakami, 1995). The statistics of the matrix property are obtained from direct measurements, whereas the velocity and aperture variation are evaluated along flow trajectories arising in Monte Carlo flow analyses with fractures with spatially variable aperture (Xu *et al.* 2001). The information of both statistics and parameter values are summarised in Table 5 in Wörman *et al.* (2004).

From the flow analyses it was clear that there is a notable correlation length in both flow velocity and fracture aperture that is longer than the size of the fracture. However, due to limited computer capacity no Monte Carlo simulations were performed for the flow. In this illustrative example the probabilistic components are limited to the first term on the right-hand side of (3).

Figure 1 shows the mass fraction arriving (cumulative concentration) at the boundary surfaces of the 5 km x 5 km x 1 km calculation domain. As can be seen the confidence intervals defined in terms of ± one standard deviation is up to several hundred percents. Qualitatively, the first term on the right-hand side of (3) is $Std[\langle c\rangle]/E[\langle c\rangle] \approx 2$. Hence, as an example based on (2), the probability that the concentration exceeds one standard deviation is about 16%.

The time corresponding ton 50% mass recovery falls within the prediction interval 10^4-10^5 years and, in this interval, there is an uncertainty about timing of about one order of magnitude due to the uncertainty of the rock properties.

Figure 1. **Accumulated solute mass resulting from a pulse of a reactive solute traveling through a fracture network, in which the solid line denotes the expected cumulative breakthrough curve (BTC), the dash lines denote plus/minus one standard deviation**



Discussion

The exact concentration limit relevant in a risk analysis depends on several conditioned factors such as failure of repository canister as well as change of climate, hydrology and ecology. The aim of this tentative study is to demonstrate a methodology by which we can estimate the probability that concentration limits for radionuclides in heterogeneous bedrock are exceeded. The proposed method is based on a physical formulation of the under laying mechanisms of the water flow and solute transport, a stochastic representation of system properties and a geostatistical interpretation of site specific data. Such a combined theoretical and empirical approach is particularly recommendable as components of risk analysis involving events for which direct observations are rare or non-existing.

References

Dagan, G, 1989. *Flow and Transport in Porous Formations*, Springer-Verlag, Berlin.

De Hoog, F.R., J.H. Knight, A.N. Stokes (1982), An Improved Method for Numerical Inversion of Laplace Transforms, J. Sci. Stat. Comput., 3(3), 357-366.

Geier, J.E. (1996), Discrete-Fracture Modelling of Äspö Site: 3, Predictions of Hydrogeological Parameters for Performance Assessment, (SITE-94) SKI Report 96:7, Swedish Nuclear Power Inspectorate, Stockholm, Sweden.

Geier *et al.* (1992), Discrete-fracture network modelling, Finnsjön, Phase 2, SKB Technical Report 92-0x.

Geier, J., (2004), "Discrete-Feature Model for Flow and Transport in Fractured Crystalline Rock: DFM Code Version 1.0 Technical Description and User Documentation," SKI Report 03:xx.

Gelhar, L.W., P.Y. Ko, H.H. Kwai and J.L. Wilson (1974), Stochastic Modelling of Groundwater System, Rep. 189, R.M. Parsons Lab. for Water Resour. and Hydrodyn., Mass. Inst. of Technol., Cambridge.

Gelhar, L.W., A.L. Gutjahr, R.L. Naff (1979), Stochastic Analysis of Macrodispersion in a Stratified Aquifer, Water Resources Res., 15(6), 1387-1397.

Gelhar, L.W., C.L. Axness (1983), Three-dimensional Stochastic Analysis of Macrodispersion in Aquifers, Water Resources Res., 19(1), 161-180.

Gutjahr, A.L., L.W. Gelhar, A.A Bakr, and J.R. MacMillan, (1978), Stochastic Analysis of Spatial Variability in Subsurface Flows, 2. Evaluation and Application. Water Resources Res. 14(5), 953-959.

Hakami, E. (1995), Aperture Distribution of Rock Fractures. Doctoral Thesis, Department of Civil and Environmental Engineering, Royal Institute of Technology, Stockholm.

Hakami, E., N. Barton (1990), Aperture Measurements and Flow Experiments Using Transparent Replicas of Rock Joints, Proc. Int. Symp. Rock Joints, Loen, Norway, Eds. Barton and Stephansson, Balkema, Rotterdam, The Netherlands, 383-390.

Hollenbeck, K. J. (1998), INVLAP.M: A Matlab Function for Numerical Inversion of Laplace Transforms by the De Hoog Algorithm, http://www.isva.dtu.dk/staff/karl/invlap.htm

Rodriguez-Iturbe, I., A. Rinaldo, (1997), *Fractal River Basins*, Cambridge University Press, Cambridge, United Kingdom.

Siitari-Kauppi, M., A. Lindberg, K.H. Hellmuth, J. Timonen, K. Väätäinen, J. Hartikainen and K. Hartikainen (1997), The Effect of Microscale Pore Structure on Matrix Diffusion æ a Site-specific Study on Tonalite. J. Contaminant Hydrology, 26, 147-158.

SKI (1996) SKI SITE-94, Deep Repository Performance Assessment Project. SKI Report 96:36. Swedish Nuclear Power Inspectorate, Stockholm, Sweden.

Wörman, A., S. Xu, B. Dverstorp (2003), "Kinematic Analysis of Solute Mass Flows in Rock Fractures with Spatially Random Parameters", Journal of Contaminant Hydrology, 60: 2003, 163-191.

Wörman, A.; J. Geier, S. Xu, (2004), "Modelling of Radionuclide Transport by Groundwater Motion in Fractured Bedrock for Performance Assessment Purposes", SKI technical report, in press.

Xu, S.; A. Wörman (1999), Implications of Sorption Kinetics to Radionuclide Migration in Fractured Rock, Water Resources Research, 35(11), 3429-3440.

Xu, S.; A. Wörman (1998), Statistical Patterns of Geochemistry in Crystalline Rock and Effect of Sorption Kinetics on Radionuclide Migration, SKI Report 98:41, Stockholm, Sweden, ISSN 1104-1374.

Xu, S.; A. Wörman, Dverstorp, B., (2001), "Heterogeneous matrix diffusion in crystalline rock – Implications for geosphere retardation of migrating radionuclides", Journal of Contaminant Hydrology, FEB 2001: 47(2-4) 365-378.

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