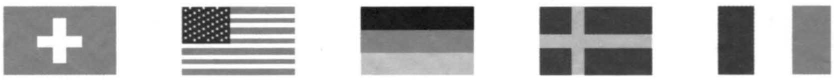
IEG

International Expert Group Gorleben

Repository Project Gorleben - Evaluation of the Present Situation



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Zusammenfassung

(Übersetzung der *Executive Summary*)

Hintergründe für die Studie

Ende 1998, als die neu gewählte Bundesregierung beschloss, aus der Kernenergie auszusteigen und ein neues nationales Entsorgungsprogramm aufzustellen, war eine Schlüsselfrage die, ob die Qualität der wissenschaftlichen Untersuchungen des Salzstocks von Gorleben und deren bis heute vorliegenden Ergebnisse die Weiterführung des Projekts rechtfertigen. Die Internationale Expertengruppe Gorleben (IEG) wurde gegründet, um den deutschen Stromversorgungsunternehmen eine objektive wissenschaftliche Beurteilung der Untersuchungen des Salzstocks von Gorleben als potentieller Endlagerstandort zur Verfügung zu stellen.

Im Laufe des Jahres der IEG-Tätigkeiten veröffentlichte die Regierung Behauptungen, dass es wesentliche "Zweifel" an der potentiellen Eignung des Salzstocks von Gorleben gebe. Daraus zog sie den Schluss, dass die untertägige Erkundung einzustellen sei. Der Umfang der Arbeiten der IEG wurde daraufhin erweitert, um auch Kommentare zu diesen Zweifeln zu erarbeiten. Die Schlussfolgerungen der IEG zum Gorleben-Programm und zu den aufgeworfenen Zweifeln sind in diesem Bericht dokumentiert.

Die Ursprünge des Konzepts eines Endlagers im Salz

Das Konzept der Nutzung tiefliegender geologischer Formationen für eine dauerhafte Isolierung von radioaktiven Abfällen von der Umwelt entstand, als die National Academy of Sciences (Nationale Akademie der Wissenschaften) der USA 1957 eine Endlagerung in tiefen geologischen Formationen empfahl und insbesondere Salz wegen seiner verschiedenen festgestellten Vorteile als bevorzugtes Medium nannte. Wissenschaftler aus Deutschland beteiligten sich an Experimenten in den USA. Die günstigen Ergebnisse führten zu einer Unterstützung der deutschen Entscheidung, mit den Arbeiten im Salzbergwerk Asse, in Morsleben und im Salzstock von Gorleben zu beginnen. Andere europäische Länder haben eine Endlagerung im Salz ebenfalls geprüft. Alle diese verschiedenen Studien in Ländern, die an einer Endlagerung im Salz interessiert waren, führten zu der Schlussfolgerung, dass Salz ein vorteilhaftes Wirtsgestein und in der Lage ist, die langfristige Isolierung von Radionukliden zu gewährleisten.

Das Gorleben - Programm

In den frühen 70er Jahren beschlossen die Bundesregierung und die kerntechnische Industrie, in Deutschland ein nukleares Entsorgungszentrum einschließlich eines Endlagers zu errichten. Nach einem internen Auswahlverfahren gab die Bundesregierung drei mögliche Standorte im Bundesland Niedersachsen bekannt. Die Regierung des Landes Niedersachsen war jedoch mit dieser Auswahl nicht einverstanden und schlug – basierend auf wissenschaftlichen, technischen und infrastrukturellen Gründen – selbst den Standort Gorleben vor. Die Bundesregierung akzeptierte diesen Vorschlag im Juli 1977.

Die Hauptergebnisse der Standortuntersuchung von Gorleben wurden von der BGR dokumentiert. Die Wissenschaftler kamen darin zu dem Schluss, dass die Prognosen für das geologische Modell in einem weitreichenden Umfang bestätigt wurden, obwohl festgestellt wurde, dass die Strukturen teilweise komplizierter waren als ursprünglich angenommen. Sie stellten fest, dass durchgeführte Permeabilitätsmessungen die Dichtigkeit des Salzes bestätigen und dass die hohen Konvergenzraten innerhalb des Salzes die Erwartung einer guten Isolationsfähigkeit untermauern. Wie vorhergesagt, wurden keine bedeutenden Einschlüsse von Lösungen, Gas oder Kondensat im Staßfurt-Halit gefunden. Große Sicherheitsabstände zum Rand des Salzstocks wurden bisher ermittelt, um dort ein Endlager einrichten zu können.

Die im Jahr 1998 neu gewählte Bundesregierung hat entschieden, dass

- ein Moratorium für die untertägige Erkundung des Salzstocks von Gorleben für einen Zeitraum von drei bis zehn Jahren erlassen werden soll,
- basierend auf den Ergebnissen einer neu eingerichteten Beratungsgruppe der Regierung, dem „Arbeitskreis Auswahlverfahren Endlagerstandorte (AkEnd)", weitere mögliche Standorte in Deutschland gefunden und untersucht werden sollen,
- die Ergebnisse der Untersuchungen der verschiedenen Standorte anschließend miteinander sowie auch mit denen des Salzstocks von Gorleben verglichen werden sollen. An Hand dieser Vergleiche soll dann der geeignetste Standort ausgewählt werden.
- der Betrieb des Endlagers etwa um das Jahr 2030 aufgenommen werden soll.

In einer Veröffentlichung des BMU von Mai 2000 im Internet nannte die Bundesregierung weitere Einzelheiten zu ihrer Argumentation für die Unterbrechung der Erkundung des Standorts von Gorleben. Die Liste der erhobenen Zweifel wird in diesem Bericht wiedergegeben. Einige davon sind allgemeiner Natur, einige betreffen die Eignung von Salz als Wirtsgestein und einige sind auf Gorleben bezogen.

Erläuterungen der IEG zu den Zweifeln

Die Mitglieder der IEG diskutierten der Reihe nach jeden Zweifel, stellten ihn dem derzeitigen Kenntnisstand oder dem akzeptierten Bewertungsstand der internationalen wissenschaftlichen Gemeinschaft gegenüber und besprachen anschließend die Relevanz für das Projekt Gorleben. Allgemeine Aussagen, die zu den Zweifeln gemacht werden können, sind folgende:

- Bei den meisten handelt es sich um Themen, die offen in der internationalen Gemeinschaft diskutiert wurden.
- Bei keinem dieser Themen handelt es sich jedoch um neue Aussagen; alle sind schon seit Jahren in Veröffentlichungen beschrieben und kontrovers diskutiert worden. Tatsächlich waren auch deutsche Wissenschaftler in diese Diskussionen direkt mit einbezogen und einige Themen wurden sogar explizit im Rahmen der Gorleben-Erkundung behandelt.
- Kein Punkt schließt eine sichere untertägige Endlagerung im Salz im allgemeinen oder in Gorleben im besonderen aus. Für die Fragen und Probleme, die einer weiteren Klärung bedürfen, können, wie die IEG darlegt, Programme entwickelt und durchgeführt werden.
- Es fehlen genau definierte Bedingungen für eine Wiederaufnahme der Arbeiten oder für eine Aufgabe des Standortes.

Eine klare wissenschaftliche Beurteilung der Sicherheit eines potentiellen Endlagers in Gorleben könnte viel transparenter sein, wenn die derzeitigen Untersuchungen abgeschlossen und alle standort-spezifischen Ergebnisse in einer vollständigen Langzeitsicherheitsanalyse (Total System Performance Assessment, TSPA) bewertet würden.

Erläuterungen der IEG zu Auswahl und Charakterisierung des Standorts Gorleben

Struktur und Durchführung des Auswahlverfahrens für Gorleben waren nicht transparent in dem Sinne, wie dies heute in den meisten Ländern für die Standortsuche empfohlen wird. Die Auswahl erfolgte jedoch vor 23 Jahren, zu einer Zeit, in welcher die jetzt empfohlenen Ansätze nicht angewendet oder gerade erst in verschiedenen Ländern entwickelt wurden. Zum anderen ermöglichen die heutigen Methoden eine wissenschaftlich/technische Bewertung der Eignung eines Standortes unabhängig davon, wie der betreffende Standort ursprünglich ausgewählt wurde. Des weiteren waren die rigorosen technokratischen Verfahren, die in den 80er Jahren entwickelt wurden, um aus einer Reihe von potentiellen Standorten einen einzelnen Kandidaten einzugrenzen, in der praktischen Anwendung international kein uneingeschränkter Erfolg.

Es gibt keine allgemein gültige Antwort auf die Frage, wie viele Standorte in die jeweiligen Schritte der Untersuchungen einzubeziehen sind. Die unterschiedlichen Entscheidungen, die in nationalen Programmen getroffen wurden, basieren auf Überlegungen und Untersuchungen zur geologischen Vielfältigkeit, zu den wirtschaftlichen Rahmenbedingungen und zur sozialen Gerechtigkeit. Alle diese Fragen müssen angesprochen werden, wenn der AkEnd seine Standortkriterien formuliert haben wird. Aus dem technischen und wissenschaftlichen Blickwinkel kommt die IEG zu dem Schluss, dass der Standort Gorleben zusammen mit weiteren Vorschlägen, die auf Grund der Ergebnisse des AkEnd gefunden werden, betrachtet werden soll.

Das Untersuchungsprogramm, das bisher in Gorleben durchgeführt wurde, ist umfassender als bei irgendeiner anderen Erkundung eines potentiellen Endlagerstandortes weltweit, ausgenommen die beiden Projekte WIPP und Yucca Mountain in den USA. Eine umfangreiche Datenbasis für Gorleben wurde zusammengestellt. In ihrer Gesamtbeurteilung hat die IEG keine wissenschaftlichen oder technischen Argumente gefunden, die den Salzstock von Gorleben als potentiellen Standort für ein Endlager disqualifizieren. Das bedeutet nicht, dass alle für ein Genehmigungsverfahren erforderlichen Daten schon erarbeitet wurden. Weitere Untersuchungen sind notwendig, wie in dem Programm zur Charakterisierung des Standorts, das durch die Verhängung eines Moratoriums abgebrochen wurde, festgelegt. Die IEG ist der Ansicht, dass sich durch den Abschluss der ursprünglich geplanten Erkundungsarbeiten eine vollständige Grundlage für die Bewertung der Eignung von Gorleben als HAW-Endlager ergeben würde. Diese verbesserte Datenbasis könnte auch zu dem Zeitpunkt von Nutzen sein, wenn ein Vergleich von Gorleben mit anderen zusätzlich ausgewählten Standorten angestellt wird, wobei dazu Kriterien genutzt werden, die sich aus dem AkEnd ergeben.

Besondere Empfehlungen der IEG für das deutsche Programm

Es ist notwendig, einen klareren Rahmen für die zuständigen Institutionen und deren Entscheidungen zu entwickeln. Organisatorische Strukturen und Zuständigkeiten, Programmstrategien und Meilensteine sind für eine transparentere Abwicklung der Arbeiten und Entscheidungen, die bisher in Deutschland nicht deutlich ist, neu zu definieren. Alle relevanten Interessengruppen müssen ermutigt werden, interaktiv an dem Prozess mitzuarbeiten. Eine ernst zu nehmende Unterlassung im deutschen Netzwerk der Interessengruppen und Verbindungen erscheint der IEG das Fehlen von direkten Beziehungen zwischen den Abfallerzeugern und den Ausführenden des BfS zu sein. Derzeit sind die Elektrizitätsversorgungsunternehmen nur zuständig für die Finanzierung des Endlagerungsprogramms. Wertvolle technische Beiträge könnten jedoch von der Versorgerseite dem BfS und umgekehrt zur Verfügung gestellt werden. Eine engere Kommunikation könnte das Verständnis bei den Versorgungsunternehmen für die von den Regierungsbehörden gewählten Verfahren und Strategien verbessern. Die IEG ist auch der Ansicht, dass die Verteilung der Zuständigkeiten des BMU für den Antragsteller (BfS) und für die Genehmigungsbehörden (Behörden von Niedersachsen) klarer definiert und öffentlich transparenter gemacht werden könnten. Weiterhin stellt die IEG fest, dass in verschiedenen Ländern die Einrichtung unabhängiger und hochrangiger wissenschaftlich/technischer Expertengremien, die die Tätigkeiten der Endlagerverantwortlichen und die der Aufsichtsbehörden bewerten, der Öffentlichkeit die zusätzliche Sicherheit gibt, dass die Entscheidungen bei der Endlagerung auf den besten verfügbaren wissenschaftlichen Erkenntnissen basieren. Die IEG stellt außerdem fest, dass eine Langzeitsicherheitsanalyse (TSPA) für das geplante Endlager in Gorleben bisher nicht systematisch und nach dem neusten Stand der Erkenntnisse erarbeitet worden ist. Die IEG erachtet es daher für außerordentlich wichtig, mit dieser Art von TSPA für Gorleben zu beginnen. Nach ihrer Fertigstellung muss eine Überprüfung in Form eines unabhängigen „Peer Review“ durchgeführt werden.

Für die Erkundung und Entwicklung eines Endlagers sollte ein phasenbezogenes oder schrittweises Verfahren entwickelt werden. Prinzipiell sollten alle Phasen möglichst weitgehend so flexibel abänderbar sein, dass die Langzeitsicherheit nie gefährdet wird. Außerdem sollte eine Regelung gefunden werden, die verlangt, dass eine Zustimmung benötigt wird, um von einer Phase in die nächste überzutreten. Diese Entscheidung könnte einer Institution übertragen werden, die nicht im direkten Zusammenhang mit dem Endlagerverantwortlichen steht. Sicherheitsberichte einschließlich der Langzeitsicherheitsanalyse (TSPA) würden eine Grundlage für formelle Überprüfungen der aufeinanderfolgenden Phasen durch die Sicherheitsbehörden ergeben.

Schlussfolgerungen der IEG zu der derzeitigen deutschen Entsorgungsstrategie

Die neuen Grundsatzentscheidungen der Bundesregierung basieren nicht allein auf wissenschaftlichen und technischen Argumenten. Wie in allen Ländern müssen gesellschaftliche und politische Aspekte ebenfalls berücksichtigt werden. Dennoch ist es wichtig, so genau wie möglich zwischen den Gründen zu unterscheiden, an Hand derer Entscheidungen legitim getroffen werden können. Wissenschafter, die sich mit der Endlagerung beschäftigen, so wie in anderen Bereichen mit weitreichenden Auswirkungen auf die Gesellschaft auch, haben eine Verantwortung, sich objektiven Argumenten zu widersetzen, die in Entscheidungsprozessen zu früh mit politischen Gesichtspunkten vermischt werden.
Für ein Land wie Deutschland, das noch für viele Jahre von der Kernenergie abhängig sein wird, wäre es unverantwortlich, die Erkundung für ein sicheres Endlager in tiefen geologischen Formationen unnötig zu verlangsamen. Auch mit einer verlängerten Zeitplanung (2030), wie sie nun von der Bundesregierung in Betracht gezogen wird, besteht die Notwendigkeit weiterzumachen, wenn man hofft, zu diesem Zeitpunkt ein Endlager in Betrieb nehmen zu können, das nachweisbar sicher und für die Gesellschaft akzeptabel ist.

Eine strukturierte und in geeigneter Weise schrittweise ausgeführte Strategie ist notwendig. Die IEG ist jedoch der Ansicht, dass ein schrittweises Verfahren zur Errichtung eines Endlagers ernsthaft nur erreicht werden kann, wenn ein wichtiger Anfangsschritt gemacht wird. Dieser erste Schritt ist die volle Zustimmung – auch auf politischer Ebene – zum Konzept der Endlagerung in tiefen geologischen Formationen. Dazu gehört die Bestätigung, dass ein solches Endlager am richtigen Standort, das richtig ausgelegt und betrieben wird, eine sichere Lösung des nuklearen Abfallproblems ermöglicht. Es wurden Vorbehalte von den politisch Verantwortlichen über die Durchführbarkeit der Errichtung eines sicheren Endlagers vorgebracht; es wurde darauf hingewiesen, dass die Endlagerung in geologischen Formationen die zweitbeste Lösungsmöglichkeit wäre, die vielleicht ersetzt werden könnte durch eine zukünftig noch zu entwickelnde Technologie. Dies ist keine Grundlage für die Umsetzung eines glaubwürdigen Programms, das von motivierten Wissenschaftlern und Ingenieuren ausgeführt werden soll. Die öffentliche und politische Unterstützung für die Endlagerung in geologischen Formationen muss in einem ausreichenden Maß gewonnen werden, um Fortschritte zu ermöglichen.

Fortschritte sind wichtig. Die IEG ist der festen Ansicht, dass die derzeitigen Entwicklungen in der deutschen Atompolitik nicht zu unnötigen Verzögerungen bei den technischen Anstrengungen zur Erreichung einer gesellschaftlich akzeptierten Lösung für die Endlagerung radioaktiver Abfälle führen dürfen. Wir sind verantwortlich für den Schutz der Umwelt für die jetzige und für künftige Generationen. Diese Verantwortung darf von den politischen Tagesproblemen nicht beiseite geschoben werden.

Executive Summary

The Gorleben programme

In the early 70's the Federal Government and the Nuclear Industry decided to construct in Germany a "Nuclear Fuel Cycle Centre", including a deep geological waste repository. After an internal selection process, the Federal Government announced in July 1975 the selection of three possible locations in the State of Lower Saxony. The Government of this State, however, did not agree with the specific choices and itself proposed – based on scientific, technical and infra-structural grounds - the site of Gorleben. The Federal Government accepted this proposal in July 1977.

The main results from the Gorleben site exploration have been documented by BGR. The scientists there concluded that the prognosis for the geological model had been confirmed to a large extent, although the structures were partly more complicated than originally expected. They found that the permeability measurements performed confirm the tightness of the salt and that the high convergence rates within the salt give reason to expect a good isolation capability. As predicted no significant inclusions of brine, gas, or condensate were identified in the Staßfurt halite. Large safety distances to the border of the salt dome were found so far to locate a repository.

The feasibility of using the assembled data in a technical judgement on the potential suitability of the Gorleben site became an important question in 1998, when the newly elected Federal Government decided that:

- A moratorium on the underground exploration of the Gorleben salt dome shall be established for a time span between three and ten years.
- Based on the results of a newly established Government advisory group, AkEnd, further possible sites in Germany shall be found and investigated.
- The results of investigations at the different sites shall then be compared with one another, and also with those achieved for the Gorleben salt dome. Based upon this comparison, the most suitable site shall be selected.
- Operation of the repository shall start around the year 2030.

In a statement of BMU of May 2000 the Federal Government gave more details of its reasoning for interrupting the exploration at the Gorleben site. The list of issues raised is reproduced in this report. Some are of a very generic nature, some concern the suitability of salt as a host rock, and a few are Gorleben specific.

IEG observations on the problematic issues

The IEG members addressed each issue in turn, weighing it against the current body of evidence or the consensus judgements of the international scientific community and then commenting upon the relevance to the Gorleben programme. General observations which can be made on the problematic issues are that:

- They mostly represent topics which are being actively discussed in the international community.
- None of them, however, are new issues; all have been studied, debated and reported upon in the open literature for many years. In fact, German scientists also have been directly involved in these discussions and some of the issues have even been addressed directly in the Gorleben programme.
- No issue in the list gives compelling technical grounds for breaking off field investigations aimed at improving the scientific decision basis concerning disposal in salt in general, or at Gorleben in specific.
- None of the issues preclude a safe, deep geologic repository in salt in general, or at Gorleben in particular. For those issues that require further clarification, programmes can, as the IEG has indicated, be developed and carried out.
- The IEG could not identify any obvious scientific arguments for the three tro ten year time frame chosen for the break in the field work and there are no defined conditions for resuming work or abandoning the site.

A sound scientific judgement on the safety of a potential repository at Gorleben could be achieved much more transparently if the current phase of exploration were completed and all the site-specific results were to be used in a complete "Total System Performance Assessment (TSPA)".

Observations of the IEG on Gorleben site selection and characterisation

The structure and the performance of the Gorleben selection process was not transparent in the way which is recommended for siting in most countries today. The events took place, however, 23 years ago, at which time the presently recommended approaches had not been applied or even developed in any country. Furthermore, current assessment methodologies allow a scientific/technical judgement on site suitability independently of how the site in question was originally selected and, in practice, the rigorous procedures developed in the 80's for narrowing in from a range of potential sites to a single candidate have not been an unqualified success internationally. The question of how many sites to consider at each step has no single answer. The differing decisions made in national programmes are based on considerations of geologic diversity, economic constraints and social justice. These issues will all have to be addressed when the AkEnd has produced its siting criteria. From a scientific and technical angle, the IEG has concluded that the Gorleben site should be considered along with any further proposals based on the work of AkEnd.

The investigation programme that has been carried out at Gorleben is more extensive than at any geological repository site world-wide, with the exception only of the US projects at WIPP and Yucca Mountain. An extensive database has been assembled. In its overall assessment, the IEG has not found any scientific or technical arguments which would disqualify the Gorleben salt dome as a candidate site for a repository. This does not imply that all data needed for a license application have been gathered. More investigations are needed, as defined in the site characterisation programme that was broken off by imposing a moratorium. The IEG considers that completing the planned activities would provide a more complete database for judging the suitability of Gorleben as a HLW repository site. This improved database would be valuable also when the time comes to prepare a comparison of Gorleben with additional sites chosen using criteria derived by the AkEnd.

Specific IEG recommendations for the German programme

There is a need to develop a clearer institutional and decision framework. This means defining organisational structures and responsibilities, programme strategies and milestones in a transparent manner not previously obvious in Germany. All relevant stakeholders must be encouraged to participate interactively in the process. A serious omission in the German network of stakeholder connections appears to the IEG to be the lack of direct interactions between waste producers and the implementers at the BfS. Currently, the utilities are responsible only for financing the disposal programme. However, valuable technical input could be provided from the utility side to BfS and, conversely, closer communication could improve understanding in the utilities of the policies and strategies chosen by government authorities. The IEG also believes that the allocation of BMU-responsibilities between implementers (BfS) and regulator (Lower Saxony authorities) could be more clearly defined and made more publicly transparent. Furthermore, the IEG notes that several nations have found that establishment of an independent technical review body to assess and evaluate the activities of the implementing group and the regulatory bodies provides the public with an added measure of assurance that decisions are being based upon the best-available scientific knowledge. The IEG notes that TSPA has not been applied for the planned Gorleben repository in a systematic state-of-the-art manner. The IEG therefore considers it to be important that this type of formal analysis for Gorleben is initiated and that, on its completion, an independent peer review be performed.

A phased or stepwise procedure towards repository implementation should be mapped out. In principle all the steps should be as reversible as is feasible without compromising the long-term safety. Further, some kind of approval to proceed from one step to the next is generally delegated to some authority external to the implementing organisation. Safety reports including TSPAs would provide a basis for the formal reviews by the safety authorities of the successive steps.

IEG conclusions on current German waste management strategy

The new key decisions of the Government are not based purely on scientific and technical arguments. As in all countries, societal and political aspects must also be considered. However, it is important to distinguish as clearly as possible the grounds on which decisions can be legitimately taken. Scientists involved in waste disposal, as in other areas with large impacts on society, have a responsibility to resist objective arguments being mixed too early in the decision process with political viewpoints. It would be irresponsible for a country like Germany, which will continue to rely on nuclear energy for many years, to unnecessarily slow down the progress towards safe deep geologic disposal. Even with the extended time-scales (2030) now considered by the Government, there is a need to move ahead if one hopes to implement by then a deep repository which will be demonstrably safe and societally acceptable.

A structured and appropriately phased strategy is necessary. The IEG believes, however, that a stepped procedure towards repository implementation can be seriously pursued only if one important initiating step is taken. This key step is a full commitment – also at the political level – to the concept of deep geological disposal. It involves an acknowledgement that a deep repository which is properly sited, designed and operated can provide a safe solution to the nuclear waste problem. Reservations have been expressed at the level of those politically responsible about the feasibility of implementing a safe repository; indications have been made that geologic disposal may be a second-best solution which could perhaps be replaced by some yet-to-be invented technology. This is no basis for initiating a credible programme to be run by motivated scientists and engineers. Public and political support for geological disposal must be won in sufficient measure to allow progress.

Progress is important. The IEG believes firmly that current developments in German nuclear policy must not result in unnecessary delays in technical efforts to move ahead towards an accepted societal solution to waste disposal. We have a responsibility to protect the environment for current and future generations. This should not be pushed aside by political problems of the day.

REPORT

1 Introduction

In Germany the disposal of radioactive waste is governed by the Atomic Energy Act. According to the Act, the Federal Government must establish and operate facilities for accepting and disposing of radioactive waste. The government has allocated this responsibility to the Bundesamt für Strahlenschutz (BfS; Federal Office for Radiation Protection), a federal authority under the Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU; Federal Ministry for the Environment, Nature Conservation and Nuclear Safety). The licence applicant for a repository is BfS and the licensing bodies are the state authorities of the state in which the site is located. BfS may make use of the capabilities of other bodies in order to carry out its functions. It has been supported primarily by work done by the Bundesanstalt für Geowissenschaften und Rohstoffe (BGR; German Geological Survey), the Deutsche Gesellschaft zum Bau und Betrieb von Endlagern für Abfallstoffe (DBE; German Company for the Construction and Operation of Repositories for Waste Materials), research centres and universities.

Since 1979 an extensive exploration programme has been underway at the Gorleben site in the Federal State of Lower Saxony. The objective is to evaluate the suitability of the Gorleben salt dome as a repository for all types of radioactive wastes. The salt dome and the surrounding area have been studied from the surface and from underground in considerable detail, in a lengthy field programme, the aim of which was to complete the underground exploration around 2003 [Thomauske, 1998]. The responsibility for developing the exploration concept and for assuring the proper performance of the work lies with BfS.

Prior to the change of the Government in late 1998, BMU and BfS had not expressed any doubts about the potential suitability of the salt dome of Gorleben for a repository. On the contrary, in a document [BMU, 1998] published then the opinion given is that:

> *"... The results obtained until now prove, that there exists a well founded chance for success for the (Gorleben site's) suitability as a repository, especially for highly radioactive, heat producing waste and spent fuel...."*

This position is in agreement with the widely accepted view that, to date, no results have been obtained during the surface and underground exploration which rule out Gorleben as a potentially suitable site. This is documented in numerous published reports. It is acknowledged, however, that the underground exploration has to be completed and all the results obtained have to be evaluated in a safety analysis in order to arrive at a final judgement on site suitability.

Despite the generally positive assessments of Gorleben's potential suitability within the scientific-technical communities, there have always been divergent opinions. Since the start of the Gorleben site evaluation, a small group of geologists have expressed their doubts about the suitability of the Gorleben salt dome as a repository for nuclear wastes. Their arguments have been discussed at length in public [e.g. seven expert reports prepared for the State of Lower Saxony] and the counter-evidence was published in a response by the scientists from the Geological Survey [BGR, 1995]. In 1998, the opponents to the Gorleben site again expressed their reservations [Gruppe Ökologie, 1998], which led BMU to publish its view quoted above [BMU, 1998] that to date there exists no evidence that the Gorleben salt dome is unsuitable for a repository.

In late 1998, when the newly elected Government of Germany resolved to phase out the use of nuclear power and to restructure the national waste management programme, the future of the Gorleben potential site for a deep geologic repository became a particularly prominent issue. A key question was whether the quality of the scientific work done at the site and the results of the characterisation to date justified proceeding with the project. The International Expert Group Gorleben (IEG) was established by the Gesellschaft für Nuklear-Service (GNS) in order to provide the German electricity utilities with an objective scientific judgement on the site investigations at Gorleben.

The members of the IEG were chosen because they have direct extensive experience in a number of national waste management programmes, including those of Germany, France, Sweden, Switzerland and the USA and also a broad knowledge of other world-wide efforts in this field. They also include members who have worked in repository projects in which salt is the proposed host rock, as is the case for Gorleben. Appendix 1 gives short curricula vitae for the IEG, illustrating the relevant aspects of their professional careers.

During the course of the year of the IEG's main activities, several developments in the German waste management programme had a major effect on the work of the Group. In June 2000, the Government and representatives of the utilities issued a "so-called" Consensus paper [BMU 1, 2000]. The Gorleben Project was also affected by this agreement. In Annex 4 to the paper, the Government claimed that there exist substantial (mainly non site-specific) problematic issues (referred to as "Zweifel" or "doubts") about the potential suitability of the Gorleben salt dome and concluded that one should stop the underground exploration and the relevant site-specific R & D work at Gorleben. Future work for Gorleben should be restricted to answering the questions raised by the so-called doubts. The technical arguments put forward by Government scientists to justify the change in policy were published in May 2000 by the BMU on its web site [BMU 2, 2000].

Because of these developments, the scope of work of the IEG was extended to include commenting on the waste management aspects of the Consensus paper and the BMU publication. During the year 2000, the moratorium on work at Gorleben was subsequently, in October, put into force. Key questions were whether and when work can be resumed, or whether the results of an exploration programme which up to the end of 2000 has cost around 2.5 billion DM have no further value. (These costs were prepaid by BMU, which has sole responsibility for the planning and execution of the exploration programme, but BMU is refinanced by contributions from the waste producers.) The answers to these questions must depend, amongst other aspects, on the quality and completeness of the scientific results obtained to date. Thus, reviewing the Gorleben work and commenting upon the scientific and technical issues raised by BMU/BfS have been the tasks on which the IEG has concentrated.

The work of the Group was performed through the year 2000. Four meetings were held in Germany, each lasting several days. At these meetings, the Gorleben site was visited and discussions were held with technical representatives of BGR and with one member of the AkEnd Working Group set up by the BMU, but not directly with the scientists at BfS. The interim conclusions of the IEG were made public at a series of press conferences following each of its meetings [Endlagerung 2000]. The final conclusions are documented in the present report which has been jointly drafted, reviewed and formally agreed upon by all IEG members.

The report is intended to be readable as a stand-alone document. Accordingly, it begins with a brief overview in Chapter 2 of work performed to date on deep disposal in salt – both in Germany and elsewhere in the world. This is followed in Chapter 3 by two sections which summarize objectively the specific status of the German waste disposal concept and the Gorleben Project. Thereafter, i.e. from Chapter 3.3 onwards, the emphasis shifts towards giving the opinions of the IEG on this status, together with appropriate justification for these views. In particular, the IEG responses to the "problematic issues" raised by BMU concerning disposal in salt are addressed in Chapter 3.3 and in an extended appendix in the light of international experience in relevant areas. A Chapter is then devoted to specific IEG proposals in three key areas: establishing a national waste disposal framework, addressing open technical issues, stepwise progress towards disposal. Finally, the conclusions and recommendations of the Group are gathered under three headings: the Gorleben programme, the issues raised by the BMU and recommendations for a path forward. Appendices are included to cover in more detail the issues raised in the main text.

2 Development of concepts and projects for deep geological disposal in salt

2.1 The Origins of the Salt Repository Concept

The concept of utilising deep geological rock formations to provide permanent isolation of radioactive wastes from the environment arose when in 1955, the United States Atomic Energy Commission (AEC) asked the National Academy of Sciences (NAS) to examine the radioactive waste disposal issue and recommend how to proceed. The NAS report [National Academy of Sciences, 1957] recommended deep geologic disposal and, in particular, cited salt as a preferred medium because of its several perceived advantages. These advantages included the natural creep properties of salt, which would act to seal any man-made openings and prevent natural fractures from developing through the salt. This process prevents water from moving through and dissolving the salt and carrying radioactivity to the biosphere. Other positive attributes cited were the widespread occurrence of salt formations and the high thermal conductivity of salt. High thermal conductivity allows a denser thermal loading, that is heat-generating wastes can be disposed of more compactly than is appropriate for other rock types. Another advantage is the ease of mining salt as compared with harder rock. The NAS continued to examine the radioactive disposal issue and issued subsequent reports culminating in a report [National Academy of Sciences, 1970] that supported the use of bedded salt for solid radwaste disposal.

Acting on the 1957 NAS recommendation, the AEC asked the Oak Ridge National Laboratory (ORNL) to begin evaluation of the suitability of natural rock salt as a host medium for radioactive waste disposal. ORNL conducted laboratory studies on salt and in 1963 implemented in situ tests in a salt mine at Lyons, Kansas. These tests utilised irradiated fuel elements supplemented with electric heaters to simulate both the radiation and thermal fields that could be expected from high-level waste. These tests confirmed that salt could be an effective disposal medium. In 1970 the AEC proposed that the Lyons facility be used as a high-level waste disposal facility. Lyons was abandoned as a potential repository site in 1972 when issues of unknown boreholes through the salt and water loss in nearby salt dissolution activities made the location untenable. The United States Geological Survey (USGS) conducted an extended search for a new bedded salt site and in 1973 identified an area in southeast New Mexico as having a high potential for satisfying the site selection criteria. In 1975 the present location of the Waste Isolation Pilot Plant (WIPP) was identified and detailed site characterization studies began. An initial acceptance of the WIPP site was determined in 1980 and underground exploration confirmed by 1983 that the site met all geological and geo-technical requirements. More information on WIPP is given in Chapter 2.3.

Scientists from Germany participated in the experiments being conducted in the salt mine at Lyons, Kansas. The favourable results coming from these tests provided support for the German decision to begin experimental emplacement of radioactive waste in Asse facility (Germany) in 1967. Many experimental studies were conducted in the Asse and non-radioactive rock mechanics studies continue to this date.

The Netherlands also expressed keen interest in utilising salt domes for waste disposal and participated in many of the Asse tests. Although they conducted many studies and conceptual repository designs, they did not progress to the stage of specific site selection and repository studies are on hold at the present time. Over quite a period of time, ANDRA, France, also participated in the Asse experiments.

Meanwhile, former East Germany was actively pursuing disposal of low- and intermediate-level wastes in salt. In 1970 the former Morsleben salt and potash mine was selected for detailed characterization and refurbishing as a repository. Waste emplacement on a pilot scale began in 1978 and full-scale disposal was authorized in 1981.

Other countries, such as Russia, France, and Spain, have also studied salt to some degree but none of the investigations have as yet resulted in an identified salt repository site for high-level waste. Other nations in Europe and elsewhere are considering repositories in rocks that are more readily available to them, notably crystalline rock, clay and tuff.

In this context it is worth recollecting that the favourable properties of salt were highlighted already in Europe in the catalogue of host rocks published by the EU [EUR, 1981]. All the bedded and domed salt deposits are indicated and the large number of salt domes in northern Germany are obvious.

All the various studies by the countries interested in a salt repository have confirmed the conclusion that salt is an advantageous host rock capable of safely providing long term isolation from the biosphere of radioactive waste materials. It is worth noting that salt beds and salt domes also serve as a host rock for other purposes that require isolation and confinement. Caverns in salt are used for storage of oil, methane and hydrogen in the United States. Also in Germany, caverns in salt are used for storage of oil and natural gas. Excavations in salt, often in old mines, are used for isolation and disposal of toxic wastes, most notably in Germany. This practical experience supports the concepts behind the use of salt as a radioactive waste repository host rock.

2.2 The Gorleben programme

2.2.1 Site selection

In the early 70's, the Federal Government and the Nuclear Industry decided to construct a "Nuclear Fuel Cycle Centre" in Germany. The core of this centre was to be a 1,400 t HM/year reprocessing plant. The centre was also to include all facilities for radioactive waste management and for fuel fabrication. The site was to be chosen so as to allow construction of a waste repository directly beneath the centre.

After an internal selection process, the Federal Government announced in July 1975 the selection of three possible locations with underlying salt domes: Börger (salt dome Wahn), Faßberg (salt dome Weesen-Lutterloh), and Ahlden (salt dome Lichtenhorst), all three located in the Federal State of Lower Saxony. The Government of this State, however, did not agree with these choices and itself proposed in February 1977 – after a State-internal selection process – the site of Gorleben. The Federal Government accepted this proposal in July 1977.

After many political, public, and scientific/technical discussions and after a major international public hearing [Niedersächsische Landesregierung, 1979], the State Government of Lower Saxony decided in May 1979 to refuse permission for the construction of the planned reprocessing plant at Gorleben. It decided, however, to allow investigations of the Gorleben salt dome in order to gather data needed for judging its potential for use as a repository for radioactive waste.

The selection processes for the sites described above have not been publicly documented. It is, therefore, not apparent whether geological or other arguments led to the specific preferences of the Federal or State Governments. Given that the original project was for a complete Nuclear Fuel Cycle Centre, arguments concerning costs, infrastructure, socioeconomic aspects etc. presumably were all weighted along with geological criteria. In any case, it is a documented fact that the Niedersächsische Landesamt für Bodenforschung (NLfB; Lower Saxony State Geological Survey) and the state mining authorities were directly involved. All potential fuel cycle centre sites nominated were certainly intended to be capable of hosting a deep geological repository. The process used for the selection in 1977 did not, however, include the transparency and public interactions which are the norm for site selection today [IAEA, 1995]. Comments on modern site selection approaches are included later in this report. For the specific Gorleben issues, upon which the report centres, it is important to note that site selection and site suitability assessment can, to some extent, be separately treated. The same IAEA guidance document acknowledges that the methodologies which have been developed over the past decades allow a scientific/technical judgement on site suitability independently of how the site in question was originally selected.

2.2.3 Site investigation

Site investigation from the surface started immediately after the Lower Saxony State Government decision and it lasted until 1986. In order to investigate the geological and hydrogeological situation of the strata above and adjacent to the salt dome, the following programme was carried out over an area of about 300 km^2 south of the river Elbe:

- 145 reconnaissance bore holes
- 322 monitoring holes
- 3 wells for pumping tests
- 150 km of seismic profiles

For the exploration of the salt dome itself

- 44 bore holes penetrating the caprock and reaching into the salt
- 4 deep bore holes on the flanks of the salt dome to a depth of about 2,000 m
- 2 shaft exploration bore holes to a depth of 880 m

were drilled.

After reunification in 1990, the surface investigations were extended to include an additional programme (performed between 1996 and 1998), covering the 80 km^2 area of Dömitz-Lenzen north of the Elbe river. Studies of the geological and hydrogeological situation included:

- 112 km of seismic profiles
- 22 reconnaissance bore holes
- 75 monitoring bore holes
- 5 bore holes penetrating the caprock and reaching into the salt

In addition to the drilling programme, state-of-the-art geological, hydrogeological, and geophysical investigation methods were employed in bore hole measurements, and sampling, laboratory analyses, data evaluation and interpretation, and modelling were carried out. An extensive laboratory programme, especially on rock mechanics and thermo-mechanic modelling, backed the field investigations.

Based on the results of the surface site investigation programme, the Federal Government decided to start an extensive underground exploratory programme. The two shafts Gorleben 1 and 2 were sunk between 1986 and 1995. After having reached the defined exploratory level at 840 m depth, mining of the necessary infrastructure area around the two shafts followed. Thereafter, drift mining started for the reconnaissance of exploratory area 1 (Erkundungsbereich 1 = EB 1).

A total length of 6800 m of drifts were mined for the infrastructure area and for EB1. This was complemented by drilling about 10,000 m of geological reconnaissance and about 1,500 m of geotechnical bore hole length from the exploratory level. Geological mapping on a scale 1:50 covered a surface area of about 50,000 m^2 during sinking the two shafts Gorleben 1 and 2. Mapping for the exploratory area EB1 on a scale 1 : 100 covered a surface area of roughly 94,000 m^2. In both shafts, five horizons each were installed with instruments for geotechnical measurements below 350 m depth. In addition three of them were installed in EB 1. From these stations, a total amount of 24,000 readings are taken per month.

When the moratorium was imposed on October 1, 2000, the drift intended to fully encircle EB1 was 100 m short of its planned final length.

2.2.3 Current status

As outlined above, the site investigation programme from the surface is complete. It has resulted in an extensive database on the geological, hydrogeological, and hydrochemical situation of the overburden strata, the caprock, and the top part of the salt dome as well as of the regional groundwater regime. Three-dimensional geological and hydrogeological models were constructed based on the results.

The general structure of the salt dome was deduced from the results of the investigation from the surface, using also valuable experience gained from the German potash and salt mining industry. The detailed knowledge of the complicated internal structure of the Gorleben salt dome, which is needed for a final decision on its suitability as a repository host formation, however, can only be achieved by underground exploration. The main objectives of this underground exploration are:

- determining the detailed geometry of the salt dome
- clarifying the complex internal tectonic structure
- finding large homogeneous blocks of rock salt, especially Staßfurt-Hauptsalz (z2HS) and Leine-Salz (z3LS)
- determining the location of possibly occurring interbeds of Main Anhydrite (z3HA) and of potash seam Staßfurt (z2SF)

These results are needed in order to locate and to dimension suitable areas for radioactive waste emplacement. Locations of anhydrite and potash seams must be known in order to establish an outer boundary for waste emplacement that is sufficiently removed from these minerals.

Reconnaissance of exploration area EB 1 successfully located a suitable area of 450 by 500 meters. As already mentioned, about 100 meters of drift have still to be mined in order to close the planned loop. EB 1 is the first of the five foreseen exploration areas in the northeastern part of the salt dome. The detailed investigations in EB 1 are regarded as an example for the exploration of the following EBs. The exploration is planned to be performed in a stepwise manner and in an iterative process, taking into account the results and experience gained during investigations in the previous

EBs. Only when the entire potential siting area has been explored to the same level of detail as EB 1, it will be possible to make a final decision on the suitability of the Gorleben salt dome to host a repository.
Four figures are reproduced in Appendix 3 to illustrate the status of the exploration.

Fig. 1: Hydrogeology of the Gorleben Site – Hydro-stratigraphic profile
Fig. 2: Hydrogeology of the Gorleben Site – Hydro-chemical profile
Fig. 3: Vertical cross-section of the Gorleben salt dome
Fig. 4: Horizontal cross-section of the exploration area EB 1

The main results deduced by the BGR from the underground exploration are:

- The extensive area of Staßfurt halite (z2HS) (no faults, no pathways) which is especially suited for the emplacement of high-level waste, was found to be larger than originally expected. Consequently, the northern pilot heading could be moved 100 m further north (Fig. 4). According to the results achieved up to now, the Staßfurt halite will continue in similar form also to the east of cross-cut 1 East, possibly including some inter-folding of younger sequences. EMR-measurements in bore holes indicate that the undisturbed Staßfurt-Hauptsalz (z2HS) also continues in the vertical direction. The prognosis for the geological model and for the extension of the Hauptsalz within exploration area EB 1 was so far confirmed to a large extent. The geological situation within the infrastructure area located south of EB 1 between shaft No. 1 and shaft No. 2 has been found to be more complicated than originally expected.

- As predicted, no inclusions of brine, gas, or condensate worth mentioning were found in the Staßfurt halite. It was proved by bore holes and by electromagnetic measurements (EMR) that beside the central series of Main Anhydrite (z3HA) also that at the border of the salt dome north of the explored area is broken into single fault-blocks. Areas of potential pathways (seams of anhydrite) which were postulated in some scenarios only occur in the form of isolated blocks at the border and especially in the central area and thus do not have any connection to groundwater in the overburden strata. The occurrences of brine so far are isolated and bound to jointed sulphate rocks (Main Anhydrite, Gorlebenbank).

- The high convergence rates met within EB 1, especially in the Knäuelsalz (z2HS1), give reason to expect a good isolation capability for radioactive waste canisters in the Staßfurt halite.

- On February 4, 2000, impregnation of condensate were found in the Knäuelsalz during an inspection of cross-cut 1 West with an ultraviolet lamp (UV-light). The respective evaluation with regard to safety is still pending. BGR is involved. One third of the Hauptsalz within EB 1 consists of Knäuelsalz.

- The permeability measurements performed confirm the presumed tightness of the native rock and thereby also the intact barrier function of the salt. The expected excavation disturbed zone (EDZ) can be mastered.

- Numerous analyses of Hauptsalz samples resulted in water contents which are lower (by about 50 %) than those known from the Asse mine which amount to 0.04 vol.-%

- According to the results achieved so far there exists a barrier of rock salt of 600 m thickness to the overburden.

2.3 Other specific projects in salt

Section 2.1 discussed the origins of the salt repository concept and mentioned some other projects. In this section we discuss in more detail three past or current projects that involve disposal of radioactive waste in salt.

WIPP:

The most advanced of these projects is the Waste Isolation Pilot Plant WIPP repository at Carlsbad in New Mexico, USA. The WIPP is a licensed facility, currently accepting defence programme transuranic waste (TRU). Most of this waste is similar in radiation flux to the German categories of low- and intermediate-level waste. Thermal output from the physical decay processes, which must be considered for spent fuel or high-level waste disposal, is too low to be of significance for these wastes. The WIPP is excavated at a depth of 665 m within a 1000 meter thick bedded salt formation.

Extensive in situ tests were conducted in the WIPP from 1984 to 1995, examining the details of rock mechanics behaviour and the interaction of simulated waste emplacements, both transuranic and high-level, with the salt environment. Although WIPP will not accept spent fuel or high-level waste, an extensive series of full-scale heater tests were conducted fully simulating defence high-level waste disposal in salt. At the time these tests were implemented, the United States was still considering a bedded salt HLW repository in Texas. All these experiments confirmed the suitability of salt as a host rock for the WIPP TRU waste repository and confirmed the conclusions reached with the Lyons, Kansas, experiments that salt could also provide a good host rock for a high-level waste repository.

These data, together with all the geotechnical information from site characterization, were utilised in Total System Performance Assessment (TSPA) modelling. This modelling was conducted annually between 1987 and 1995 to determine what new information was needed to provide the desired degree of confidence in the long-term compliance prediction. A final TSPA was completed in 1995 and formed the basis of the EPA certification of the WIPP. The WIPP repository is now in operation for disposal of defence programme transuranic waste. The WIPP, in addition to complying with EPA standards for radioactive waste disposal, must also conform to separate regulations governing disposal of the toxic materials in the transuranic mixed waste. The State of New Mexico administers this regulation and it has granted WIPP a separate permit confirming the safe isolation of these chemotoxic materials.

Asse:
The previously existing potash and rock salt mine Asse close to Wolfenbüttel, first began accepting radioactive waste in 1967 on an experimental basis. Approximately 125,000 drums of low-level waste (LLW) were emplaced up to 1978. In addition, about 1,300 drums of intermediate-level waste (ILW) were disposed of between 1970 and 1977. Emplacement of waste in Asse was stopped at the end of 1978 for legal and political reasons. The site continued, however, to give an international R&D facility for studying issues affecting waste disposal in salt.

Numerous in situ rock mechanics tests, backfill studies and heated canister experiments have been conducted. Physics processes important to the salt disposal concept, such as brine migration and storage of energy following salt irradiation have been studied by the project. Many of these studies had international participation, especially from the Netherlands, the United States, and France. At the present time, only some non-radioactive rock mechanics tests are continuing at the Asse. In addition to the in situ tests, numerous laboratory studies helped to develop the physical understanding necessary to develop the chemical and rock mechanics models.

Asse was never designated or licensed as a final disposal facility. Nevertheless, the L/ILW wastes emplaced underground during nearly 12 years of operation will not be retrieved. Instead, rooms and galleries are being back-filled with crushed salt in order to prepare the final closure of the facility. Although Asse is no longer an active research facility, it served an extremely valuable role as one of the key underground research laboratories for developing and confirming our understanding of processes important to salt repositories.

Morsleben:
The Bartensleben mine at Morsleben (ERAM) was chosen from a group of ten candidate sites in 1970 for further site characterization and refurbishing as a potential repository for low- and intermediate-level waste. Morsleben was a former salt and potash mine with vast excavations, many of which were considered suitable for disposal of radioactive waste. In 1978, pilot scale emplacement of waste began on an experimental basis. The first license for full-scale operation was granted in 1981. After German reunification in 1990, GRS conducted a safety evaluation of the facility [GRS, 1991]. Operations were suspended for three years. After asserting Morsleben's safety as a repository, disposal operations resumed in January, 1994. The operating license for Morsleben will expire in June, 2005; waste emplacement, how-

ever, was stopped in September, 1998, due to a court decision. Present government's policy is to decommission and close this facility consistent with safe practises. Backfill studies have been and are being conducted as part of the safe decommissioning of the facility, consistent with safe practises.

3 The current situation concerning Gorleben

3.1 The new Government concept

After the elections in September 1998, a coalition between the Social Democratic Party SPD and Bündnis 90/Die Grünen formed the new Federal Government. In the chapter on nuclear energy of their "Coalition Agreement" [Bundesregierung, 1998], the two parties declared, amongst many other statements on nuclear policy, that they agreed that "the radioactive waste management concept followed thus far in Germany has failed in its content and no longer has a relevant basis". Furthermore, they asserted that there exist doubts with regard to the suitability of the salt dome at Gorleben. For this reason, they concluded, the exploration should be interrupted and further sites in different host rocks investigated for their suitability.

The statements in the coalition agreement relating to radioactive waste management are based upon a report of the Heinrich-Böll-Stiftung which was published in August 1998 [Gruppe Ökologie, 1998].

In February 1999, BMU established a new advisory committee to start a new site selection procedure. The committee's title is "Arbeitskreis Auswahlverfahren Endlagerstandorte (AkEnd)" [AkEnd, 1999]. The task of AkEnd is to define a complete set of criteria and a new procedure, including public participation, for site selection within the territory of Germany. It is not the task of AkEnd to search for new sites. The final report of the committee shall be published at the end of 2002. Consideration of Gorleben does not lie within the purview of the AkEnd. However, the intention of the Government is ultimately to include Gorleben along with a further list of potential sites derived using AkEnd criteria, before making a final choice of site for a repository.

The present Federal Government put its doubts on the Gorleben salt dome in concrete terms in May 2000, when the BMU posted a paper on the Internet, entitled "Topical Questions on Radioactive Waste Management" [BMU 2, 2000]. In this paper, eleven problematic issues ("Zweifel") are raised. These are commented on briefly in section 3.3 and in detail in Appendix 2 of the present report.

On June 14, 2000, a contract ("Consensus Paper") [BMU 1, 2000] between the Federal Government and the four largest utilities in Germany was initialled. This paper and the BMU internet publication will be commented on in detail in Chapter 3.2 and 3.3.

Annex 4: Declaration of Federal Government on Exploration of Gorleben Salt Dome: According to Title 9a para. 3 of the Federal Nuclear Law, the Federal Government is responsible for establishing installations for disposal of radioactive materials. The Federal Government commits itself to this responsibility and declares it will take up the appropriate measures irrespective of the phase-out of nuclear energy to make sure that the appropriate capacities for disposal of waste are provided in a timely manner.

As potential host rock media, salt, as well as granite, clay, and other formations may be considered. In 1979 it was decided to explore the Gorleben salt dome as a possible repository site. The geological results thus far attained may be summarised accordingly: the area consisting of older rock salt, which is foreseen for storing high-level waste (HLW), has been shown to be greater than expected during the course of excavation of excavation area 1 (EB-1). However EB-1 does not suffice to store the predicted waste volume.

The analytically determined rate of rise of the salt dome permits the expectation that, with regard to possible rises it is not likely there will be any related dangers even in long-term time horizons (in the order of 1 million years). No appreciable pockets of solutions, gas, or condensates have been found. The previous findings, suggesting that the area is a tight formation have been confirmed, including the expected function of the salt as a barrier. To this extent the obtained geological findings do not contradict the thesis that the Gorleben dome is a suitable site.

However the Federal Government believes it necessary, in the light of ongoing international discussion, to rework and develop further the suitability criteria and the concept for disposal of HLW. The state of science and technology and the general risk evaluation have developed substantially during recent years; this has consequences for the further exploration of the Gorleben salt dome.

Above all, the following question marks pose doubts:

- *The management of gas which may built up in dense rock salt as a result of corrosion and decomposition of the waste poses a special problem.*
- *The requirement that repositories allow retrievability of the radioactive waste is growing internationally.*
- *The suitability of salt as a medium should be compared with others, such as clay and granite, in the light of findings in other countries.*
- *For the geological disposal of spent fuel, additional criteria must be fulfilled, in order to exclude long-term recriticality.*
- *The International Commission on Radiological Protection will likely soon make public recommendations which for the first time include a radiation protection goal for non-intentional human penetration of a repository.*

A further exploration of the Gorleben salt dome cannot contribute to the clarification of these outstanding questions. For this reason, the exploration of the Gorleben salt dome will be interrupted for at least three, and at most ten years; a clarification of the above questions will follow.

The moratorium does not imply that Gorleben will be given up as a site for a repository. But, during the clarification of conceptual and safety-technical questions, no investments will be made which cannot contribute to clarification of these questions.

The Federal Government will take necessary measures to maintain the Gorleben site during the moratorium. This will include the necessary legal steps to secure the position of the Federal Government as licensee and to secure the project from intervening third parties. The Federal Government will take necessary measures such that the applied for 10-years extension of the concept operations plan for the exploration project will be approved. The Federal Government will ensure the plan is legally protected by an appropriate action according to Title 9 of the Federal Nuclear Law."

In the statement of BMU of May 2000 [BMU 2, 2000] the Federal Government points out in more detail its reasoning for interrupting the exploration at the Gorleben site. The main problematic issues ("Zweifel") are listed there in Chapter II. Final Disposal, Gorleben, Assessment of the Gorleben Site – Purpose of, and Rationale for, a Moratorium: which are listed below:

1. Gas generation
2. Human intrusion
3. Criticality/direct disposal
4. Safeguards
5. Time frame for isolation and assurance
6. Protection goals and safety indicators
7. Observations from nature
8. Multiple barrier concept
9. Retrievability / revision of safety assessment
10. Chemo-toxic constituents of waste matrix/packaging
11. Model calculations

The comments of the IEG on the issues raised by BMU are summarized in the following Chapter of this report.

3.3 IEG Comments on problematic issues raised by BMU and on their technical consequences for Gorleben

In the documentation produced by the BMU [BMU 2, 2000] a series of problematic issues are put forward as technical justification for decisions being taken in the waste disposal programme. Some of these are of a very generic nature, some concern the suitability of salt as a host rock, a few are Gorleben specific.

In Appendix 2 of the present report, the IEG members have addressed each issue raised by BMU. The approach taken is to consider each BMU argument in turn, weigh it against the current body of evidence or the consensus judgements of the international scientific community and then comment upon the relevance to the Gorleben programme. In the present Chapter, a brief summary of the Government's position and of the IEG's response is presented for each item:

1. Gas generation

"... In gas-tight rocks, e.g. salt, gas - which can be generated in low- and intermediate-active wastes essentially by anaerobic corrosion of metallic constituents - can accumulate under high pressure with the danger of creating pathways for water by inducing fractures. No convincing solution for this issue has yet been found for gas-tight rocks. ...

... It is not clear, which magnitude gas pressure can reach during the disposal of heat-generating wastes, assuming fast convergence and whether this pressure built up compromises the desired tightness of the rock salt. ..."

The problem of gas generation and transport in geological repositories has been studied for many years. The results allow an inference that gas generation in the Gorleben repository, whether used for disposal of spent fuel or high-level waste or for low- and medium-activity waste, will not pose a threat to repository integrity and long term safety. However, bounding calculations, which are presently well within the current state of knowledge and capability, should be conducted to address the specific Gorleben parameters. If these calculations do not provide the desired margin of confidence, there are remedies that may be readily applied.

Consequently, gas generation does not present either a new or an insurmountable issue and should not be used as a technical argument against the Gorleben site.

2. Human intrusion

"... The most recent international initiatives to include human interference in considerations have not been comprehensively incorporated in Gorleben's suitability assessment so far. ..."

The Gorleben site and the design of any repository proposed there should be evaluated for its resilience against the impacts of future intrusion. The salt-dome feature of Gorleben is common to this part of Germany so that it is no more likely than other formations to be selected for future development of resources that may be found throughout the area. No evidence of oil, gas, or mineral deposits adjacent to Gorleben has been reported. A representative scenario involving potential future inadvertent human intrusion should be evaluated but there is no reason to believe that predicted future consequences would exceed protection standards being proposed and evaluated throughout the international community.

3. Criticality / Direct disposal

"The question of criticality of nuclear fuels in a repository has not been answered satisfactorily for any repository for spent fuel elements. ...

... It has not been demonstrated that technical means can ensure below-critical conditions or the containment of the effects (- of criticality events). ...

... Further, a series of questions need to be resolved about concepts and methods of long-term safety considerations at the Gorleben site. ..."

Conceivable means for creating a risk for unintentional criticality have to be addressed for any repository for disposal of large amounts of fissile material. The assessment has to be done for each specific geologic environment and repository design. There are, however, means to avoid such a risk. The studies made for proposed repositories in granite and in tuff show that the criticality scenarios are indeed very improbable. There are good reasons to believe that for a properly designed salt repository, like the one planned for Gorleben, the probabilities of criticality are even less. The studies also show that the consequences of postulated critical excursions in a repository would be small, both with respect to the integrity of the repository and to the amount of fission products in the repository.

4. Safeguards

"... Direct disposal increases the inventory of fissionable material (U-235, Pu-239,...). We must examine whether the measures investigated so far as part of R&D programmes can be sufficient even then to safeguard against undeclared removal of disposed fuel elements ...

... The requirements derived from safeguards issues are possibly inconsistent with the demand that wastes should remain recoverable. No concept has yet been developed that reconciles the two opposing aspects in a satisfactory way."

From the scientific and technical viewpoint, confidence in the long term safety of a repository should be so high before disposal commences that retrieval for safety reasons is a scenario of vanishingly small probability. In this case, the plastic properties of salt, which enhances the isolation of the radioactive wastes whilst making retrieval more difficult – although not unfeasible – are positive host rock characteristics. Should a future society knowingly choose to retrieve spent fuel for other reasons (e.g. the un-used energy producing potential) then they should also be willing to undertake the more complex, more expensive retrieval methods, which would be necessary.

In summary, safeguards issues have been studied for repositories for many years and the international consensus is that these facilities present a lower risk than surface facilities. In a salt dome clandestine retrieval of fissile material would not be radically harder or easier than in other repository host media.

5. Time frame for isolation and assurance

"... RSK and SSK recommend (1988) that the required assurance about the safety of a repository needs to be demonstrated through a safety analysis for a period of about 10,000 years. ...

... Experts nowadays point out that it is not possible to conduct a strict demonstration of long-term safety assurance up to the time that the radioactive wastes present no danger any more; this point in time could lie well beyond 10,000 years. ...

... It is internationally considered an open question whether or how it might be possible to demonstrate safety assurance for even longer (- than 1 million years -) periods of time that approach the main long term risk to be taken into account ..."

It is true that there is an active debate at present on the time scales to be considered in safety assessments. The scientific community recognizes clearly that calculations of individual dose or risk should be used only as safety indicators after a relatively short time compared to the toxic lifetime of the wastes. The time at which to cease using quantitative assessments based on calculations of dose or risk is a policy rather than a scientific decision. However, by calculating out to long times, by considering a range of scenarios and by using complementary safety indicators such as the flux of radionuclides, it is possible to build confidence that a repository system will provide passive safety for very long times into the future. No approach other than geologic disposal can offer this at present. In all countries pursuing geologic disposal, scientists from the implementing and regulatory sides have sought and found a consensus on valid approaches.

For a repository in salt at Gorleben, the question of relevant time scales may be less troublesome than for many other concepts in hard rock or in other saturated media. For disposal in salt, the normal scenario is zero release for all conceivable times in the future, and the safety assessment of the repository system will focus on low probability disruptive processes. From experience at WIPP, it seems that human intrusion may be the main long term risks to be taken into account.

6. Protection goals and safety indicators

"... Compared to (- some other -) countries the national (- upper dose -) limit value of 0.3 mSv/a ... is three times higher; these countries show a tendency toward a limiting dose value of 0.1 mSv/a. Non-radiological protection goals are also required on the national level, ... In accordance with today's state of technology it is to be assumed that a different system of safety assessment needs to be established which rests on additional safety criteria and indicators."

In practice, all of the areas touched upon by BMU are indeed the subject of active discussion in the waste management community. These discussions have not, however, prevented progress being made towards geologic disposal. In fact, three of the countries mentioned above (USA, SF, S) are those world-wide which are closest to implementing deep geologic repositories. The commonly applied dose constraint for a waste repository in a number of national regulations is 0.1 mSv/a, although ICRP propose a maximum of 0.3 mSv/a as appropriate. In practise, the facts that dose estimates are not precise and that large margins of safety are always sought in safety assessments together make the question of the exact figure chosen in regulations of little importance. The difference between the 0.1 mSv and 0.3 mSv values discussed by BMU is largely irrelevant from a safety angle. ICRP 81 suggests that radiological performance goals could be either risks or disaggregated dose/likelihood. Both should be regarded only as performance measures or safety indicators. A safety case should be supported and justified by other evidence. Measures that are being suggested to complement dose or risk include fluxes of radionuclides from the repository into the environment, comparisons with fluxes of natural radioactivity, toxicity indices for the waste, and sub-system criteria, such as container lifetimes and radionuclide fluxes through specific engineered barriers. All of these should be regarded as complementary indicators which will add to the information base used by decision makers. ICRP 60 states that 'the standard of environmental control needed to protect man to the degree thought desirable will ensure that other species are not put at risk'. The IAEA, however, has recently produced a discussion report that notes that there is now sufficient information to be able to move forward to serious consideration of an approach to protection. In summary, the BMU has correctly identified that the development of dose and risk criteria, the value of other safety indicators and broader protection of the environmental arena merits further attention. The issue involved affect all programmes, not just those in Germany and not just those in salt. In all other countries examining these issues, the waste management programmes are being advanced in parallel with the continuing scientific discussions.

7. Observations from nature

"... Appropriateness and prerequisites for the application of natural analogues are still subject to quite varied assessments. Problems stem from the site specific application of observations from nature against the background of anthropogenic disturbance of the system and from transfer of observations from A to B."

In practice, the direct use of parameter values from natural analogues in repository safety assessments has been extremely limited (mainly to corrosion rates for waste matrix and container materials). On the other hand, the value of analogues in raising technical and public confidence in the scientific understanding of deep repositories has been significant. Various national programmes have produced special publications on the topic and an internationally sponsored film was produced for public viewing (Nagra 1994). The biggest challenge has been to extract "hard" scientific data, which can be used in rigorous testing of safety assessment models. This has been achieved, however, in some cases, particularly those relating to the thermodynamic models predicting solubility of specific nuclides in ground waters.

For the case of salt repositories there have been few specific analogue studies. Germany does however, participate in an international Natural Analogue Working Group of the European Communities and recently efforts have been made in Germany to establish a more active national programme in this area.

8. Multiple barrier concept

"... The geologic barriers rock salt and overburden have a decisive impact on Gorleben... It cannot be precluded that in the future the failure of one barrier will not be allowed to lead to non-compliance with the protection goals. Consequently, the suitability of Gorleben is in doubt if compliance with the protection goals needs to be demonstrated at this site even for the case that the salt dome barrier fails, according to the state of science and technology. ..."

The use of multiple safety barriers is common in repository designs. These barriers are partly overlapping and partly complementary. It is generally expected that full safety is guaranteed even when a barrier fails completely. In practise, complete failure of any single barrier in a geologic repository is barely credible; at most, individual barriers lose their efficiency and overall system safety is still guaranteed by the combined functionality of all remaining barriers. The Gorleben project does include multiple barriers. The salt dome itself is the strongest geological barrier. The surrounding and overlying geologic media provide an environment that permits proper functioning to the salt barrier. They are not expected on their own to provide a fully functioning redundant barrier.

9. Recoverability / revision of the safety assessment

"Disposal in Gorleben has not so far been designed for recoverability. ...
Recoverability of heat generating wastes and especially of spent fuel elements, planned from the beginning, has become the prevailing international state of technology. It must therefore also be considered, dependent on the site and host rock, in the Gorleben concept. ..."

Deep geologic repositories will be constructed and operated over many decades and will be sealed only after a long monitoring phase. Accordingly, there is little operational pressure to finalize retrievability concepts. However, disposal systems are being actively planned and designed, so that retrievability features must be discussed now. During the last decade there has been an intensive international debate on this issue. More importantly, the whole issue of retrievability is irrevocably linked to the question of public confidence in the safety of geologic repositories – and this fundamental issue is directly linked to the ethical and environmental questions concerning continued use of nuclear technologies.

Retrieval is always possible in principle. Engineering methods to allow retrievability are available, even though they become more complex and expensive as the step-wise closure of the repository progresses and with increasing time after closure of the repository. This conclusion must be demonstrated to the public on the basis of specific studies on retrieval concepts and techniques. Specific German studies have been done for the Gorleben site. For HLW without significant content of fissile materials, retrievability arguments are related mainly to the confidence of different groups in the long-term safety performance of the repository. For fissile materials, the prime arguments for and against retrievability concern resource conservation and weapons safeguards. The fact that retrievability in salt is more problematic than in other host rocks is a result of the excellent sealing and isolation properties of salt.

10. Chemo-toxic constituents of waste matrix/packagings

"... These constituents have not received close attention so far. Internationally, consideration of chemically toxic constituents in safety assessments is being discussed and demanded even more vigorously. Besides, the issue of colloid migration of constituents that are radio-toxic as well, e.g. Pu, during the post-operational phase, has recently become a focal point of geochemical safety research. ..."

In some national programmes, the chemo-toxic components of radioactive waste repository inventory were considered already many years ago. Although some analyses still need to be done to address the case of chemo-toxic constituents in low- and medium-activity waste disposed in Gorleben, there is every reason to believe, based upon completed studies in Sweden, the United States (WIPP) and indeed, for the Konrad repository, that the Gorleben repository will perform satisfactorily also with respect to chemo-toxic waste components. The information and capability now exists to conduct conservative site-specific bounding calculations. These calculations should be carried out as soon as possible to determine if the uncertainties are acceptable or whether more research needs to be conducted to better define the relevant mechanisms.

11. Model calculations

"The development of probabilistic analyses for application to, for example, the modelling of groundwater movement and transport processes has only just begun. The impact of these basic research efforts on statements about the uncertainties in the models and scenarios used remains unknown.

... the future requirements for such a repository, which may become the prerequisites for such a repository, must be anticipated today already to the greatest extent possible."

Probabilistic analyses were introduced in some programmes (e.g. Canada) around 20 years ago. The proposed repository in Gorleben is located in a salt dome. Due to its physical properties this is a more homogeneous medium than crystalline rocks. The necessity for extensive use of probabilistic methods for calculation of groundwater flow thus seems to be less than for other host rocks such as crystalline rock. The brief review suggests however that the probabilistic methodology has been developed and is available for application when needed.

Some general observations can be made on the problematic issues, based upon the above summaries and the more extensive discussions in Appendix 2. These are:

- They mostly represent topics which are being actively discussed in the international community.
- None of them, however, are new issues; all have been studied, debated and reported upon in the open literature for many years.
- German scientists also have been directly involved in these discussions; personnel from BfS, technical experts from institutes such as GSF-IfT (Institut für Tieflagerung), BGR, FZK (Forschungszentrum Karlsruhe) and scientists from German universities have all contributed to advancing knowledge in the areas mentioned.
- Some of the issues have been already specifically addressed in earlier Gorleben studies (like e.g. collecting data for gas generation, modelling gas generation, probabilistic safety analyses and evaluations of criticality).
- None of the issues preclude a safe, deep geologic repository in salt in general, or at Gorleben in particular. For those issues that require further clarifica-

tion, programmes can, as the IEG has indicated, be developed and carried out.

3.4 IEG assessment of the current situation in the German radioactive waste disposal programme

3.4.1 General

As explained earlier, the IEG assessment is based upon its study and discussion of the following input material:

- the Consensus Paper [BMU 1, 2000] drafted by the Federal Government and utility representatives
- the further documentation included in the BMU web-site [BMU 2, 2000]
- study of selected technical reports on the Gorleben project
- presentations by various technical experts in Germany

The IEG was established originally specifically for the purpose of reviewing the quality and relevance of scientific work performed to date at Gorleben. The publication during this year of the above mentioned wider documentation on disposal strategies in Germany has, in practice, led the group to consider also further issues of relevance for deep geological disposal of HLW or spent fuel. However, closely related topics (such as the future of the Konrad facility) and also broader policy issues (such as the future of nuclear energy, the use of reprocessing, the safety of transport) have not been addressed.

The IEG recognizes that the Consensus Paper is largely a political document aimed at reaching a compromise agreement on the future of nuclear power in Germany. Nevertheless, it contains some statements on waste disposal, and (in its Annex 4) on Gorleben in particular, which we comment upon here.

The IEG is gratified to see that the Federal Government:

- recognizes that repositories are needed, irrespective of the future of nuclear power,
- accepts that geological findings to date do not contradict the thesis that Gorleben could be a suitable site,
- wishes to retain Gorleben as a potential repository site.

However, the IEG does not believe that the technical issues raised in the Consensus Paper Annex 4 are new, nor that they preclude a safe repository in salt in general or at Gorleben specifically. The group could not identify any obvious scientific arguments for the break in the field work and there are no defined conditions for resuming work or abandoning the site. Completing the current phase of exploration would improve the technical decision basis.

Furthermore, carefully designed in-situ experiments at Gorleben could perhaps help clarify some open technical issues (e.g. gas production and transport).
The Consensus Paper Annex 4 raised technical issues, which are expanded upon and dealt with in more detail in BMU documentation. As described above in section 3.3 and in Appendix 2, these issues – whilst scientifically important – are not new. They have been worked on for years in many countries (including Germany). A structured programme for further scientific work on each topic should be prepared. This programme could include German studies (in particular safety assessments), laboratory work in Germany or in the scope of international collaboration and also in situ investigations. There are no technical reasons why those additional studies that are judged worthwhile could not be initiated in parallel with continuing field work at Gorleben.

Finally, in the following section, the IEG makes some comments on the present situation concerning the specific field work to date at Gorleben. These are based on the study of detailed documents and on discussions with experts from BGR. The activities outlined earlier in this report indicate that the surface-based exploration programme at Gorleben has been one of the most comprehensive in the world.

3.4.2 Gorleben

The geoscientific site investigation of the Gorleben salt dome was planned and executed by BGR with the assistance of many contractors. The most important of these was DBE which is the operator of the exploratory mine at Gorleben. Both entities have contracts with BfS.

Site investigation at the Gorleben site started as early as 1979 as already mentioned in Chapter 2.2. The quality-assured results of site investigation are documented at length in detailed reports. BfS and BGR published three summary reports in May 1982, April 1990, and February 1996, respectively [PTB, 1983; BfS, 1990; BGR, 1996]. In addition, a large number of articles were published in the scientific literature. A further BGR-report [BGR, 1995], commented on and answered six expert reviews which were performed earlier on behalf of NMU (Niedersächsisches Umweltministerium).

Staff members of BGR presented results of the Gorleben site investigation programme to the IEG during its second meeting in March 2000 and discussed with the Group. The IEG also visited the Gorleben site in November 1999 including an underground tour through the exploration mine.

The general IEG assessment of the site investigations at Gorleben – both, from the surface and underground – is that virtually no other potential HLW repository site worldwide has been investigated and characterized more comprehensively than the Gorleben salt dome. The investigation methods, tools, instruments, and models including evaluation, interpretation, and presentation of the large amounts of data, were all state-of-the-art or even at the forefront of science and technology when they were applied.

Naturally the state-of-the-art has moved on during the years since investigations began at Gorleben. However, German scientists have followed these developments by being members of the different international bodies at work and by participating in scientific exchanges. They have therefore been in a position to take account of such developments during the on-going Gorleben programme.

In its overall assessment, the IEG has not found any scientific or technical arguments, which would disqualify the Gorleben salt dome as a candidate site for a repository. There are therefore no compelling scientific reasons for interupting investigations.The more fundamental question of the suitability in principle of salt as a repository host rock has also been raised. The IEG considers that the arguments originally used to justify the choice of salt (lack of groundwater, good sealing properties, radiation resistance etc.) are still valid today. From the issues which have been raised during the decades of repository development, the two which may be most relevant for salt are gas transport and retrievability. As the considerations in section 3.3 show, however, the former of these is not judged to rule out salt and the latter is significant mainly because the good sealing properties of salt make retrieval more difficult but not impossible.

This does not mean that the Gorleben site has yet been proven suitable. The underground exploration is still to be completed, as outlined in Chapter 2.2. Only when the complete northeastern part of the salt dome has been investigated to the same degree as EB 1, can a definitive judgement on the suitability be made. In addition, this judgement could be achieved much more transparently if all the site-specific results were to be used in a complete Total System Performance Assessment (TSPA) for the planned repository in the Gorleben salt dome.

4 IEG suggestions on the path forward

The IEG felt it appropriate to extend its mandate somewhat beyond commenting upon the technical work at Gorleben and on the scientific validity of the doubts raised by the BMU concerning Gorleben and salt host rocks. Based upon the long experience of the members in different disposal programmes, some constructive suggestions are made for the German case. These range from general recommendations on the overall framework of the German programme and on the broad procedures most likely to lead to successful repository siting through to specific proposals for further activities which may help clarify some of the problematic issues raised by BMU.

4.1 Recommendations on the German national framework

The international community has established communication and co-operation in nuclear waste programmes through agencies such as the International Atomic Energy Agency (IAEA) and the Nuclear Energy Agency (NEA) of the Organisation for Economic Co-operation and Development (OECD). In addition, scientists and engineers from member nations participate in international peer reviews and technical exchanges. The IEG is an example of such a group; all members are from participating member nations of the NEA. The international organisations also facilitate co-ordination of waste policies and strategies. For example, an IAEA publication describes those activities and elements considered necessary for national programmes to provide radioactive waste disposal [IAEA, 1995].

The IEG has not only reviewed the current status of the German waste disposal programme. It has also attempted to make constructive suggestions which might help to prevent the programme from stagnating. The suggestions fall into three areas for progressing further:

- develop a clearer institutional and decision framework
- work directly on addressing the BMU problematic issues
- map out a phased or stepwise procedure.

An essential element of the way forward for the German programme will be to review its national programme for decision-making. Guidance can be obtained from the cited IAEA publication.

Nations with programmes for radioactive waste disposal have each developed processes for national decision-making that assign specific roles in the process to different organisations. Table 1 illustrates the role of different organisations in a number of representative nations conducting nuclear waste disposal programmes. These rational processes have many common elements. Redefinition or modification of such a process in Germany can take advantage of the experiences made and lessons learned in other nations.

The ultimate decision on whether and how to proceed with development of a radioactive waste repository usually resides at the highest level of the national government. An implementing body is commonly chartered to locate and investigate sites for a facility, to recommend development at a specific site and to be responsible for developing any facility. This body may be part of a ministry or department of the national government (e.g. the USDOE) or an organization established by the electric utility companies (e.g. SKB in Sweden) or a mixed group (e.g. Nagra in Switzerland or Nirex in the UK). This role is conducted in Germany by the Federal Office for Radiation Protection (BfS) which is directly responsible to the BMU.

It is generally agreed that the funding for waste disposal activities must be obtained from those organisations that are responsible for generating the radioactive wastes. In some countries this requirement is met by directly assigning responsibility for implementing the disposal scheme to the utility companies that have generated electricity using nuclear power plants. In the United States, this requirement is met by a fee imposed by the government for each unit of electricity sold from a nuclear power plant, a fee that the utilities then pass through to their consumers. Co-disposal of waste generated by government agencies must however be paid for separately from government funds. In Germany, the BfS determines what investigations are to be performed and the utility companies reimburse as "payments in advance" the funds expended by the government each year as the work is performed.

Even when the determination of the siting strategy is formally within the responsibility only of the implementing organisation, history has shown that the technical, social, and political issues surrounding the siting of radioactive waste disposal facilities demand participation by a wide range of interested parties or "stakeholders". Repository siting is now recognized as an interdisciplinary task requiring not only technical experts who can evaluate the predicted integrated performance of a facility in meeting the requirements for adequate safety, but also generalists who can integrate the input from scientific, political, legal, financial, and public communication specialists. Other organizations beyond the implementing organization need to be consulted in the site evaluation process if agreement is to be reached that a site should be developed. Some nations have had success with seeking volunteer communities to put forward their site for consideration.

The most serious omission in the German network of stakeholder connections appears to the IEG to be the lack of direct interactions between waste producers and the implementers at the BfS. Currently, the utilities are responsible only for financing the disposal programme. However, valuable technical input could be provided from the utility side to BfS and, conversely, closer communication could improve understanding in the utilities of the policies and strategies chosen by government authorities.

There is an international consensus that approval or "licensing" of repository construction and operation must be obtained from an independent regulatory authority. In some nations, the agency that establishes regulatory standards is separate from the agency that develops and administers regulations. In the USA, for example, the Environmental Protection Agency (EPA) is responsible for establishing "generally applicable standards for protection of the general environment from offsite releases from radioactive materials in repositories" (Section 121 (a) Nuclear Waste Policy Act) while the Nuclear Regulatory Commission (NRC) is responsible for the licensing process. It is extremely important for public acceptance that the implementing and regulatory organizations be totally independent with common accountability only at the very highest levels of the national government.

The IEG believes that the allocation of BMU-responsibilities between implementers (BfS) and regulator (Lower Saxony authorities) could be more clearly defined and made more publicly transparent. In countries where the direct responsibility for disposal is not assumed by the Government, the definition of roles is more straight forward. In the USA where the Government, as in Germany, has assumed responsibility, implementer and regulator roles are allocated separately already at the federal level to DOE and NRC.

Several nations have found that establishment of an independent technical body to assess and evaluate the activities of the implementing group and the regulatory bodies provides the public with a measure of assurance that decisions are being made based upon the best-available scientific knowledge. Some examples are given here:

KASAM, the Swedish National Council for Nuclear Waste is an independent scientific committee attached to the Ministry of the Environment. KASAM's mandate is to study issues related to nuclear waste and the decommissioning of nuclear installations, including an independent review of the research and development programme presented by the implementing organisation, SKB. Eleven experts are appointed to the council representing technology, science, ethics, psychology and the social sciences.

In the USA final approval of the Waste Isolation Pilot Plant (WIPP) facility was aided considerably by the existence and the activities of the Environmental Evaluation Group (EEG), a body paid for by the USDOE, staffed by the State of New Mexico, but given the freedom to express technical opinions without interference from either organization. Similarly, the US has established the Nuclear Waste Technical Review Board (NWTRB) to provide independent and expert technical review of the DOE programme at Yucca Mountain and to report at least twice a year to the US Congress and the Secretary of Energy on scientific issues facing the nation's spent fuel disposal programme. Eleven members eminent in the fields of science and engineering are appointed by the US President from candidates recommended by the National Academy of Sciences and are confirmed by the US Senate. Finally, in the USA the National Research Council has for many years supported the Board on Radioactive Waste Management (BRWM). This is a body of independent scientists and engineers who advise the Government and others on waste management issues, and participates in organizing the production of reports by specially chosen volunteer subcommittees.

In Switzerland, a Commission on Nuclear Waste Management (KNE) advises the government and regulators with regard to the geological work being conducted by the implementing organisation, NAGRA. In addition, the Department for the Environment, Transport, Energy, and Communication established an Expert Group on Disposal Concepts for Radioactive Waste (EKRA), consisting of eight members with expertise in science and engineering, to advise on policy and strategy for waste disposal.

In France, the Government has established an independent review Commission on Nuclear Waste Management (Commission Nationale d'Evaluation CNE). The members are chosen from scientific institutions and two members from outside France are included.

Consideration should be given to establishing an advisory group in Germany, composed of eminent experts, representing technical and social sciences deemed appropriate, to provide independent advice to the Government with continuing review of the programme. This could be viewed by the German public as providing the highest levels of independent information, unaffected by political and economic pressures. Since BMU is the implementing body in Germany, one possibility would be to have the members of an advisory group (including some representatives of other countries) nominated by professional academic institutions (Deutsche Forschungsgemeinschaft/DFG, Wissenschaftsrat, or Max-Planck-Gesellschaft) and appointed by the Chancellory or BMWi (Ministry of Economics).

Table 1: Key Nuclear Waste Organisations in Representative Nations

NATION	Implementing Agency	Standards Body	Regulatory Review	Permit Authority	Advisory Body
Canada	Utility Group	CNSC	CNSC	CNSC	Seaborn Commission (temporary)
Finland	POSIVA (utility)	STUK	STUK	Council of State	
France	ANDRA	DSIN	IPSN	Ministry of Industry	CNE
Germany	BfS	BMU with RSK, SSK	Länder (with TÜV, SGS, MA)	Länder	none
Sweden	SKB (Utility)	SSI	SKI	Cabinet	KASAM
Switzerland	NAGRA, GNW	HSK, BAG	HSK	Ministry of Energy	KNE EKRA
USA Yucca Mt.	US DOE	EPA	NRC	NRC	NWTRB BRWM
USA WIPP	US DOE	EPA	EPA	EPA	EEG BRWM
UK	Nirex	EA	NII, EA		RWMAC

Implementing Agency: Organization responsible for identifying a site, preparing for and seeking a permit to construct and/or operate a facility, and for operating the facility.

Standards Body: National body responsible for setting environmental *radiological standards required to be met by a repository* and associated facilities.

Regulatory Review: Organisation that verifies the technical adequacy of analyses provided by the implementing organisation in support of permit or license application.

Permitting Authority: Organisation that issues permit or licence for activities related to disposal facility.

Advisory Body: Any independent (of licensing authority and implementing agency) body created to advise national or local governments on nuclear waste issues.

ANDRA	National Agency for Radioactive Waste Management
BAG	Federal Office of Health
BfS	Federal Office for Radiation Protection
BMU	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
BRWM	Board on Radioactive Waste Management, National Research Council, U. S. National Academies
CNE	National Commission of Evaluation
CNSC	Canadian Nuclear Safety Commission
EA	Environment Agency
DSIN	Direction of Safety of Nuclear Plants
EEG	Environmental Evaluation Group
EKRA	Expert Group on Disposal Concepts for Radioactive Wastes
EPA	Environmental Protection Agency
GNW	Co-operative for waste management, Wellenberg
HSK	Swiss Nuclear Inspectorate
IPSN	Institute for Protection and Nuclear Safety
KASAM	Swedish National Council for Nuclear Waste
KNE	Commission on Nuclear Waste Management
MA	Mining Authorities
NAGRA	Swiss Co-operative for radioactive waste disposal
NAS	National Academy of Sciences
NII	Nuclear Installations Inspectorate
NIREX	United Kingdom Nirex Limited
NRC	Nuclear Regulatory Commission
NWTRB	Nuclear Waste Technical Review Board
POSIVA	Posiva OY Finland
RSK	Reactor-Safety Commission
RWMAC	Radioactive Waste Management Advisory Committee
SGS	State Geological Surveys
SKB	Swedish Nuclear Fuel and Waste Management Company
SKI	Swedish Nuclear Power Inspectorate
SSI	Swedish Radiation Protection Institute
SSK	Radiation Protection Commission
STUK	Finnish Centre for Radiation and Nuclear Safety
TÜV	Technical Inspection Association
US DOE	United States Department of Energy

4.2 Suggestions for addressing technical issues, including those raised by BMU

The German programme should consider some additional activities for the evaluation of Gorleben that would provide better-structured information to German decision-makers and the public concerning the suitability of this site as a proposed repository for disposal of high-level waste. Future work can be divided into general studies and experimental investigations at the Gorleben site. Work in the latter category is currently ruled out by the imposed moratorium. Despite this, the IEG has made scientific and technical suggestions.

As discussed in the following section 4.3, consideration should be given to the development and publication of a general design concept for a HLW repository at the Gorleben site. This would describe specifically the design and construction of the facility and how it might be expected to perform. Some programmes which have found early and clear definition of a reference disposal concept to be a very valuable aid to focusing discussion and debate are Sweden, Switzerland (NAGRA, 1985) and Finland [TVO 1982, 1985]. The USA kept many options open for a long time but ultimately the publication of a reference concept in the "Viability Assessment" for a repository at Yucca Mountain in the USA in 1998 [USDOE, 1998] proved useful in helping people to understand exactly what was being proposed and how it might be expected to perform. The WIPP bedded salt repository established a reference design early in the programme. It proved valuable in assessing operational and long-term performance issues and allowing performance assessment of proposed modifications to address areas of concern. For France, the situation is described in ANDRA [1997].

Using the knowledge previously acquired of the past evolution of the salt formation and of its regional geological environment, it would be useful to try to predict, with reasonable confidence, the future evolution of the salt dome during the various time periods that would be considered for the safety assessments: regional geologic stability, potential effect of the next glaciation, effect of erosion and subrosion would be among those potential processes to be evaluated.

Consideration should also be given to preparing a publicly accessible comparison of different geologic media summarising the results of surface and underground studies in foreign countries, and comparing the advantages and disadvantages of a salt medium with other geologic formations being considered for possible placement of a geologic repository.

As recommended by the ICRP [ICRP, 2000] site-specific assessments are an essential tool in the development of a radioactive waste repository. These assessments are referred to as Total System Performance Assessments (TSPA). An assessment typically consists of the following elements: system understanding, scenario analysis, development of conceptual and detailed systems models, consequence analysis, uncertainty and sensitivity analysis, and interpretation of the calculated results. The scenarios describe a possible combination of specified features, events, and processes (FEPs) affecting the disposal system that could lead to radiological consequences. Analysis of these scenarios helps to understand the role and relative importance of each of the different barriers of the disposal system. This understanding then supports the development of a safety case for analysis and review by the regulatory authorities and helps to establish priorities for research programmes and to define the experiments to be performed in surface laboratories and/or in situ underground. TSPA is used not only for final assessment of radiological safety but also for guiding R&D work and for optimising repository design.

The IEG notes such TSPA has not been applied for the Gorleben salt dome and the planned repository in a systematic state-of-the-art manner. The IEG therefore considers it to be important that this type of TSPA for Gorleben be initiated.

National programmes have found it useful to submit the results of their TSPA to the critical examination of external review groups, consisting of either independent scientists from prestigious scientific organisations within a nation or of international groups co-ordinated through the OECD/NEA or the IAEA or by invitation to international experts. When a TSPA for Gorleben is available, an independent peer review should be performed.

Specific activities at Gorleben that would be useful to improve the decision basis on site suitability include the following:

- Continuation of the circular drift excavation around EB 1 with the aim of assessing the homogeneity of the salt formation and identifying any major negative features in the formation (e.g. anhydrite and potash seams or blocks, large brine pockets)
- Completion of the exploration of the north-eastern part of the salt dome including exploration areas EB 3, 5, 7, and 9.
- Definition of the outer boundaries of the south-western part of the Gorleben salt dome that could accommodate the major extension of the repository.
- Assessment of the time-dependent thermal effect of waste packages emplaced in the repository-near field. This kind of experiment can be conducted in situ with the emplacement of samples of real packages, or by the implementation of simulated packages, artificially heated. However, this type of experiment has already been performed in the Asse mine and it may not be necessary to repeat them in Gorleben.
- Consideration should be given to the feasibility of conducting experiments on the gas transport properties of bulk rock salt and of backfilled bore holes and drifts.

If the moratorium on Gorleben cannot be lifted, then the time during the Moratorium could be used for experimental work at another location along the following lines.

4.3 Stepwise progress towards repository implementation

The development and implementation of a deep repository for long-lived and/or high-level radioactive wastes is a process that will last for many decades. This process affects and involves different organisations and groups in society and is subject to several laws, regulations, and rules. The rules vary from nation to nation and may also change with time during the implementation of any specific repository. These circumstances make it prudent, or even necessary, to proceed in steps. The steps that are necessary will, of course, vary from place to place and from time to time depending on the local ground-rules. The following list contains possible operational steps included in the process of establishing a (national) deep repository. All national programmes, however, do not include all the steps included in this list.

- Selection of a disposal concept - generic safety report
- Finding a site
  - screening
  - selection of sites (one or several)
  - preliminary site investigations – preliminary site-specific safety report
  - detailed site surface investigations – updated site-specific safety report
  - detailed site characterization from underground at selected site(s) – main site specific safety report, site suitability and confirmation report
- Repository construction, first stage - first stage as built safety report
- First stage operation
- Additional construction stages - updates of safety report
- Additional operation stages (for some concepts, construction and operation may proceed in parallel – but spatially separated)
- Final repository safety report – as deposited and operated safety report
- Closure
- Post closure surveillance (and monitoring)

In principle all these steps should be as reversible as is feasible without compromising long-term safety in order to correct or "repair" things that may go wrong. Further, some kind of approval to proceed from one step to the next is generally delegated to some authority external to the implementing organization. The safety reports including TSPAs listed would be bases for the formal reviews by the safety authorities of the successive steps.

A very important point to note in the Gorleben context is that the logical, technocratic process of narrowing in from a set of potential sites to a single candidate (as described above) has not been an unqualified success since its development in the 80's. Other approaches are also recognized as valid, and the IAEA broad siting guidelines for a deep waste repository give some points of guidance [IAEA, 1994].

Relevant quotes from this document are as follows:

"A suitable site can be identified either by narrowing down from a group of candidate sites or by objective evaluation of one or more designated sites.
Existing nuclear sites (or adjoining land) may be worthy of special consideration owing to the potential benefits in relation to reduced waste transport requirements.
It may be possible to solicit volunteer sites from communities or owners.
It is not essential or possible to locate the best possible site.
The approach to assessing safety should be similar, regardless of how the site is chosen.
At each stage of a siting process, societal, ecological and legislative issues should be evaluated and addressed according to national policies.
The regulatory body should be kept informed of and involved in decisions at relevant stages of the process.
A QA programme should be established early in the siting process.
Throughout the siting process, data should be collected, presented and archived in a standardised fashion: this needs to be established early in the siting process."

In the case of Gorleben the above-described process has been followed in principle up to the current stage (underground exploration) but with less transparency in siting than it would be expected today. There is, however, one conspicuous omission – so far no site-specific assessment of the long-term safety has been reported. Although, this is not required under the applicable laws but it would be valuable. Such safety reports are indispensable tools in the recurrent evaluations of such a long-term and large-scale project.

The number of sites selected for underground exploration varies from country to country and from time to time. In the early 1980s the USA and Switzerland were both aiming at underground examination of three sites for a high-level waste repository for a geological repository. The Swedish programme at that time indicated that two sites would be investigated from underground. As the programmes developed and matured it did however become clear that the time and resources required for underground exploration would be extensive. Thus, USA, Switzerland and Sweden have all decided to explore only one site (at a time) from underground. The same is true for Finland. In France the plan is still to build two underground laboratories in different types of host rocks. In Germany the Gorleben site was planned to be the only HLW site that would be explored from underground.

The conditions for starting surface and underground explorations are different in different countries. In some countries permits are required under the environmental as well as the nuclear laws, whereas in other countries only permits according to the mining laws are needed. The applicable law for permission of investigation Gorleben was the mining law. In some instances, the underground explorations at a potential site are described as underground laboratories of the second generation. This to distinguish them from the underground research laboratories at sites that are not intended for a future repository.

The purpose of the underground exploration is to confirm the suitability of the site. The information and data gathered during exploration is used for the "main" safety report that is a key document supporting an application for a repository construction permit. Start of underground exploration also means the start of construction of some underground areas that will be part of the planned repository. This implies that these activities have to be assessed and evaluated in this context in order to avoid future problems if and when a construction permit for the repository is granted. The underground exploration at Gorleben has been going on since 1986 and about three years remain before scheduled completion.

In order to construct and operate a repository, permits are required according to the nuclear law(s). In this respect the rules are also different in different countries. In countries like Germany and USA the aim is having one permit (= the licence) issued at one time when a complete safety case can be made. This can only be done after the underground exploration. In other countries also the licensing process proceeds in steps. In Switzerland a permit is required from the nuclear regulator even for surface drilling, the rationale being that even the exploration activities might affect the future characteristics of the site. In Finland and Sweden the first major (nuclear) permit (licence) is required before underground exploration starts. The rationale is that the underground exploration requires shafts, drifts and/or tunnels which, if the site is later confirmed, will be part of the repository, i.e. a nuclear facility. Furthermore, under the environmental laws, the local municipalities must approve the siting and the start of underground explorations. In order to agree to that they will need reasonable assurance from the nuclear authorities that it will be a safe facility. Although the safety case will not be complete with all site specific data at this stage a (preliminary) safety review will be conducted by the authorities before the permit to go underground is granted. The safety case, the review and the permit will then be amended as additional information becomes available from underground exploration until the licence also includes permit to start depositing waste packages, i. e. start of operation.

The actual construction of a repository itself is also often planned to be made in stages. The first construction stage may be set up as a testing and demonstration stage. In such cases the first construction stage will be followed by an as-built safety report to support a permit for first-stage operation. Then follows waste emplacement and operation of the first-stage and after that the full evaluation. Phased repository

construction, or construction in parallel with operation will in any case be appropriate for a disposal process which takes place over decades and it seems unlikely that the repository construction will be fully completed before start of operation.
The site confirmation, the construction and the operation of a deep repository for long-lived nuclear wastes thus constitutes a long chain of steps covering several decades in time. There are several major interim decisions to be taken and these should be supported by relevant and updated assessments of the long-term safety (TSPAs). The final safety report will not come until it is time for closure of the repository. This final report must account for all information, data and experiences gathered throughout the construction and operation of the facility.

The chain of processes described above is reflected in the recently proposed regulation from the Swedish Nuclear Power Inspectorate (SKI) [SKI, 2000]:

> *"Features, events and processes that are of importance for the safety of a repository after its closure shall be analysed before the construction of the repository, before the start of its operation and before its closure. The safety assessment shall be kept updated as long as the repository is kept under operational surveillance and maintenance." (§1, Chapter 4)*

4.4 IEG recommendations

The IEG would recommend that the following steps should be implemented for the continuation of the Gorleben programme:

- Perform a comprehensive Total Systems Performance Assessment (TSPA) using the currently available site-specific data for the Gorleben site. Evaluate the current status of the problematic issues identified by BMU as part of the assessment.
- Identify any possible experimental programme that should be performed at Gorleben or elsewhere in order to resolve any of the problematic issues.
- Develop a stepwise programme for the further implementation of a deep geologic repository in Germany (at Gorleben) and identify in particular the key decision points in this programme where external, independent review would be prudent.
- Complete the exploration programme at Gorleben as revised, carry out the experimental programme, update the Total Systems Performance Assessment as needed considering the results from explorations and experiments.

5 Overall IEG observations and conclusions on Gorleben and Germany's disposal programme

5.1 Gorleben site selection and characterization

The safety of a repository at any site is determined ultimately by the characteristics of the site (and of the repository design). It is not determined by the process used to select the site. Accordingly, it is possible to address separately the two questions: Was Gorleben properly chosen? and: Can it provide the required levels of safety? The former question cannot be addressed purely scientifically, since societal, economic and political issues also affect site selection. The latter question can, in principle, be answered using the safety assessment methodology which has been developed internationally over the past 25 years – provided that the data necessary for the assessment are available in sufficient quantity and quality.

The choice of Gorleben in 1977 was based on a research programme which began about 10 years before then. The structure and the performance of the selection process was not transparent in the way which is recommended for siting in most countries today. The public was not included and there is little or no open documentation available. The events took place, however, 23 years ago, at which time the presently recommended approaches had not been applied or even developed in any country. It has been suggested by opponents of Gorleben that the selection process itself disqualifies the site. The same argument has been made in the USA by opponents of the Yucca Mountain site in Nevada which was selected from a short list of candidates by the US Congress. These arguments are not scientific and it remains a political or societal decision whether the investment in investigating a potentially suitable site can or should be written off for societal or political reasons.

After the selection of Gorleben as a potential repository site, the investigation programme which was carried out from the surface and from underground was more extensive than at any geological repository site world-wide, with the exception only of the US projects at WIPP and Yucca Mountain. An extensive database has been assembled. The results to date provide no technical grounds for ruling out the site. This does not imply that all data needed for a licence application have been gathered. More investigations are needed, as defined in the site characterization programme which was broken off by imposing a moratorium. The IEG considers that completing the planned activities would provide a more complete database for judging the suitability of Gorleben as a HLW repository site. This improved database would be necessary also when the time comes to prepare a comparison of Gorleben with additional sites chosen using criteria derived by the AkEnd.

5.2 IEG conclusions on current German waste management strategy

The original aim of the IEG was to review only the Gorleben site investigation programme. However the far-reaching decisions taken in the German national waste management programme make it imperative to set the Gorleben developments in a wider context. Accordingly, the IEG has considered also the overall German waste management strategy. The Group has, however, restricted its detailed discussions and conclusions to the area of HLW or spent fuel disposal.

One important issue in this area should be noted: No other country has aimed at disposal of all its radioactive wastes in a single repository, which is the declared objective of the German Government. There are sound scientific reasons for segregating waste types with differing radioactivity, heat generation and (most importantly) chemical characteristics. Naturally, in a single, sufficiently large salt dome all types of wastes can be safely emplaced at separate locations. It is then a purely financial question whether one wants to implement deep disposal not only for HLW but also for L/ILW. In the German case, this decision has been taken already and the Konrad facility has been proposed.

Returning to the central topic of disposal strategy for HLW or spent fuel, the IEG notes that the new key decisions of the Government are:

- to initiate new work on siting criteria, leading eventually to alternative potential sites for a deep geologic repository
- to postpone the target date for repository operation from "as early as possible" to around 2030.

These decisions are also not based purely on scientific and technical arguments. As in all countries, societal and political aspects must also be considered, and the IEG agrees that this must be so. However, it is important to distinguish as clearly as possible the various types of grounds on which decisions can be legitimately taken. Scientists involved in waste disposal, as in other areas with large impacts on society, have a responsibility to resist objective arguments being mixed too early in the decision process with political viewpoints.

Only part of the justification for suspending work is technical, in that the BMU documents a list of problematic issues which it believes should be clarified before proceeding with Gorleben – or indeed, even with salt as a potential repository host rock. The IEG, as documented in this report, has looked at each of the issues and has reviewed the relevant international literature. The Group concluded that none of the points raised are new. Virtually all of them have been discussed in the international arena for decades. Most of the issues have also been worked upon by scientists in Germany. None of the issues preclude a safe, deep geologic repository in salt in general, or at Gorleben in particular. For those issues which require further clarification, programmes can, as the IEG has indicated, be developed and carried out. There are no scientific reasons for stopping work at Gorleben during these investigations. Indeed, it would be logical to consider whether experiments at the site could yield scientific input.

5.3 IEG recommendations for the way forward

It would be irresponsible for a country like Germany, which will continue to rely on nuclear energy for many years, to delay unnecessarily the progress towards safe deep geologic disposal. Even with the extended time-scales (2030) now considered by the Government, there is a need to move ahead if one hopes to implement by then a deep repository which will be demonstrably safe and societally acceptable.

Today, it is internationally recognized that a successful programme of this scope and duration can be initiated only if a clear framework is established. This means defining organizational structures and responsibilities, programme strategies and milestones in a transparent manner were not previously obvious in Germany. All relevant stakeholders must be encouraged to participate interactively in the process. Many of the problems are not peculiar to the German programme. There are some special features, however, which are more obvious in Germany. There is a relatively loose inclusion of the waste producers in the disposal issue while assigning all responsibilities (other than financing) to the Government and authorities related to it. In the USA, where a similar organizational structure is used, this has also led to disputes over responsibilities. Recently, the IAEA [IAEA, 1995] has published guidelines on structuring national disposal programmes and it could be useful to compare these with current or future proposals for Germany.

At the next level down, a specific technical strategy leading to an acceptable repository is needed. This strategy should be flexible and should aim at stepwise or phased progress as outlined earlier in this report. Many national programmes have found that the tool of "Total System Performance Assessment (TSPA)" can be extremely valuable here. The methodology has been developed over decades and – whilst not perfect – it can give reliable input to decision making throughout the programme. In Germany, total assessments have been made of the Konrad facility in the scope of the licensing process. For Gorleben, there has been too little use of TSPA. It is important to realize that the technique can be used not only to give a final measure of repository safety, but also to guide R&D work and to define appropriate data collection programmes.

As sketched in Chapter 4.3 above, the crucial question of siting strategy is also a part of the stepwise procedure towards a deep repository. It was pointed out, however, that the question of how many sites to consider and to investigate to differing levels of detail has no single answer. The differing decisions made in national programmes are based on considerations of geologic diversity, economic constraints and social justice. These issues will all have to be addressed when the AkEnd has produced its siting criteria. From a scientific and technical angle, the IEG has concluded that the Gorleben site must be considered along with any further proposals based on the work of AkEnd. The large investments already made at Gorleben will, unavoidably, play a role in the final evaluation. This has been used as an argument for stopping work at Gorleben in order not to further increase investment there. The IEG believes that the value of extra knowledge gained by completing the planned programme will outweigh the relatively modest further investment needed.

The IEG believes that it is necessary to point out clearly that a stepped procedure towards repository implementation can be seriously undertaken only if one important initiating step is taken. This key step is a full commitment – also at the political level – to the concept of deep geologic disposal. It involves an acknowledgement that a deep repository which is properly sited, designed and operated can provide a safe solution to the nuclear waste problem. Reservations have been expressed at the level of those politically responsible about achievable repository safety; indications have been made that geologic disposal may be a second-best solution which could perhaps be replaced by some yet-to-be invented technology. This is no basis for initiating a credible programme to be run by motivated scientists and engineers. Public and political support for geological disposal must be won in sufficient measure to allow progress.

Progress is important. The IEG believes firmly that current developments in German nuclear policy must not result in unnecessary delays in technical efforts to move ahead towards an accepted societal solution to waste disposal. We have a responsibility to protect the environment for current and future generations.

6 References

AkEnd (1999): Internet-Address: http://www.akend.de

Andra (1997): Synthèse des choix de concepts de stockage des déchets de haute activité à vie longue. ANDRA CDO A HVh 97.047, 1997.

Bundesregierung (1998): Aufbruch und Erneuerung auf Deutschlands Weg ins 21. Jahrhundert, Koalitionsvereinbarung zwischen der Sozialdemokratischen Partei Deutschlands und Bündnis 90/Die Grünen vom 20. Oktober 1998

Bundesregierung (2000): Antwort auf die kleine Anfrage ... der Fraktion der F.D.P: (2000), Drucksache 14/4588, 08.11.2000

BfS (1990): Fortschreibung des zusammenfassenden Zwischenberichtes über bisherige Ergebnisse der Standortuntersuchung Gorleben vom Mai 1983, BfS ET-2/90, 299 p., April 1990

BGR (1995): Projekt Gorleben – Stellungnahme zu Gutachten, die im Auftrag des NMU zur Eignungshöffigkeit des Standortes Gorleben angefertigt wurden, BGR-Archiv-Nr. 114026, 134 p, Oktober 1995

BGR (1996): Standort Gorleben – Zusammenfassung von Erkundungsergebnissen 1990 – 1995, BGR-Archiv-Nr. 114484/96, 35 p, Februar 1996

BMU (1998): Deutschland bei der Endlagerung radioaktiver Abfälle weltweit führend – Bundesministerium weist Einwände der Heinrich-Böll-Stiftung zurück. UMWELT, 10, p. 494 – 496, 1998

BMU 1 (2000): Vereinbarung zwischen der Bundesregierung und den Energieversorgungsunternehmen vom 14. Juni 2000, http//www.bmu.de/ sachthemen/konsens01.htm (Haupttext); ...02.htm (Anhang I – III); ...03.htm (Anhang IV – V), 2000

BMU 2 (2000): Aktuelle Entsorgungsfragen, 2000
http://www.bmu.de/atomkraft/entsorgung.htm

Bornemann, O. & Bräuer, V. (1999): Results of Geological Investigations at the Gorleben Salt Dome, the Potential Repository Site for Radioactive Waste in Germany.- Proc. 7th Int. Conf. On Radioactive Waste Management and Environmental Remediation (ICEM 99) 26-30 Sept. 1999; Nagoya/Japan, 1999

EUR, (1981): Confinement géologique des déchets radioactifs dans la Communauté Européenne, EUR 6891 FR, Bruxelles, 1981

GRS (1991): Sicherheitsanalyse des Endlagers für radioaktive Abfälle Morsleben (ERAM) – GRS – 79, Köln, 1991

Gruppe Ökologie (1998): Analyse der Entsorgungssituation in der Bundesrepublik Deutschland und Ableitung von Handlungsoptionen unter der Prämisse des Ausstiegs aus der Atomenergie. Auftraggeberin: Heinrich-Böll-Stiftung, Hannover, 248 p, 1998

IAEA (1995): Establishing a National System for Radioactive Waste Management, Safety Series No. 111-S-1, International Atomic Energy Agency, Vienna, 24 p, 1995.

IAEA (1994): Siting of Geological Disposal Facilities, Safety Series No. 111-G-4.1, IAEA, Vienna, 32 p, 1994.

ICRP (2000): Radiation Protection Recommendations as Applied to the Disposal of Long-Lived Solid Radioactive Waste", Annals of the International Commission on Radiological Protection , Publication 81, Elsevier Science, Oxford, U.K., 2000.

Nagra (1985): Project Gewähr 1985: Nuclear Waste Management in Switzerland: Feasibility Studies and Safety Assessment, Nagra Project Report, NGB 85-09E, Wettingen 1985.

National Academy of Sciences/National Research Council (1957): The Disposal of Radioactive Wastes on Land: Report of the Committee on Waste Disposal of the Division of Earth Sciences. Publication 519, Washington, D.C., 1957

National Academy of Sciences/National Research Council (1970): The Disposal of Radioactive Wastes in Bedded Salt Deposits. Washington, D.C., 1970

Niedersächsische Landesregierung (1979): Rede - Gegenrede, Wortprotokoll des Gorleben-Hearings vom 28. 3. bis 3.4.1979; als Manuskript veröffentlicht; 7 Bände, Hannover, 1979

PTB (1983): Zusammenfassender Zwischenbericht über bisherige Ergebnisse der Standortuntersuchung in Gorleben, PTB-Bericht, 153 p, Mai 1983

SKI (2000): Kommentarer till SKI:s föreskrifter om säkerhet vid slutförvaring av kärnavfall. Preliminär version för remiss. (Comments to SKI:s regulation on safety at final disposal of nuclear waste. Preliminary version for review.) SKI-PM 5.1-990760 dated 2000-07-20. In Swedish, 2000

Thomauske (1998): B.: Realization of the German Repository Concept - Status and Prospects. Proc of DisTec '98 – International Conference on Radioactive Waste Disposal, Hamburg, p. 193 – 200, 1998

TVO (1982): Final disposal of spent nuclear fuel into the Finnish bedrock. Nuclear Waste Commission of Finnish Power Companies, Report YJT-82-46 In Finnish, 1982

TVO (1985): The repository programme for spent nuclear fuel disposal inFinland. Nuclear Waste Commission of Finnish Power Companies, Report YJT-85-30. In Finnish, 1985

USDOE (1998): Viability Assessment of a Repository at Yucca Mountain, DOE/RW 0508, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, December 1998

Appendix 1

IEG Work Programme and Curricula Vitae of the Members

IEG Work Programme

After the election of the new Government in September 1998, the new coalition between SPD and Bündnis 90/Grüne produced the "Coalition Paper" [Bundesregierung, 1998] in which the new policy for radioactive waste management including waste disposal was defined:

- *"the radioactive waste management policy of the previous Government has failed and a new national plan for the management and disposal of the inherited burden of radioactive waste has to be formulated"*
- *"one repository for all types of radioactive wastes is sufficient"*
- *"such a repository is needed around 2030"*
- *"there are doubts about the suitability of the Gorleben salt dome as a repository site. Therefore, the underground exploration has to be suspended until new disposal criteria have been formulated and further sites in different geological host rocks have also been selected and investigated. After comparison of different sites a decision shall be made in favour of the site to be selected.*

After this statement of the new Government the waste producers realized that BfS, which is responsible for the management and execution of radioactive waste disposal in Germany, may now be required under the newly established policy to formulate a completely new waste disposal programme for radioactive wastes, despite the scientific and technical achievements of the past thirty years.

Therefore the main waste producers decided to invite internationally recognized experts in the field of radioactive waste management and disposal from different countries. They were asked to find an independent expert opinion on the situation at Gorleben. The following scientists have accepted an invitation to join the International Expert Group Gorleben (IEG):

- Per-Eric Ahlström, Sweden
- Denis Alexandre, France
- Dr. Colin Heath, USA
- Prof. Dr. Klaus Kühn, Germany
- Dr. Charles McCombie, Switzerland
- Dr. Wendell D. Weart, USA

The original goal set for the IEG was to reach a consensus regarding the following main questions:

- Is salt a suitable host rock for a repository, judged on the basis of current international knowledge?

- Is the work performed at Gorleben in agreement with the nationally and internationally accepted radioactive waste disposal methodologies or are there significant deficiencies in the Gorleben evaluation programme?
- Finally, can the present Government's approach (and that of its executing body BfS) actually make a positive contribution towards improving the quality of the exploration work currently in progress? If so, should the new conceptual ideas of BfS be incorporated in the originally defined exploration programme defined years ago?

This list of issues to be addressed was extended in May 2000, when BMU published its reservations, described as "doubts" [BMU, 2000] in respect to the Gorleben site. BMU states:

> *"...The basis for the selection of the Gorleben site was an early determination in favour of disposal in deep geologic salt formations (domes) as host rock. Its (Gorleben's) suitability for disposal of radioactive wastes is in dispute. The (former) views of the responsible federal agencies about the prospective suitability of the Gorleben salt structure were based on the safety criteria of the Reactor-Safety Commission (RSK) from 1982. These views need to be re-evaluated against the background that the international expertise of today considers these criteria insufficient. The Federal Office for Radiation Protection (BfS) shares the view that a new assessment basis must be generated for the Gorleben site...*
>
> *Some aspects have already been basically known for some time, but a new plateau of knowledge has recently evolved, especially based on discussions on the international stage. These developments must now be taken into account in Germany as well. Some of those aspects have already been incorporated e.g. into the planning for the Konrad repository and must likewise be considered in the assessment and planning for Gorleben. In response to the questions about the suitability of the Gorleben salt dome, it needs to be resolved whether, in conformance with the state of science and technology, the required long-term protection against environmental harm can be ensured and a positive licensing decision can realistically be expected. Against the background of the findings, developments, and assessments detailed in the following sections, it is questionable to what extend the previous plans for Gorleben rest on a basis that can still be relied upon. Against this background the suitability of the Gorleben site is at considerable risk...*
>
> *...That means that essentially the following issues need to be studied: (see list given in Chapter 3.2 of this report)"*

The question list put to the IEG, therefore, was amended to include the BMU issues in the context of the international experience:

- Are the so called "doubts" really new issues which were not known before 1998? Are such doubts directly related to the underground exploration programme and do such doubts necessitate breaking off investigations on scientific grounds or even preclude a safe repository in salt in general or at Gorleben in specific?

In total, four meetings of the IEG have taken place, one at Gorleben, one in Hannover and two in Berlin. The Gorleben exploration mine has been visited by the members of the IEG where geoscientists of BGR explained the results obtained until now. Each meeting of the IEG was followed by a press conference in Berlin to inform the public about the work of the Group.

Curricula vitae of the members of the IEG

Per-Eric Ahlström, Senior Consultant, Swedish Nuclear Fuel and Waste Management Co (SKB), graduated as MSc in Engineering Physics in 1956. From 1956-1984 Mr. Ahlström was with Vattenfall working in nuclear engineering, reactor physics, reactor safety, nuclear fuel management, nuclear waste management. From 1984-1992 he was research director of SKB, and from 1993 until his retirement in 1997 Vice President of SKB. Under his leadership at SKB, the Swedish waste management programme ran international R&D programmes in underground laboratories, sited and constructed a centralized fuel storage facility and a final repository for reactor wastes, and maintained one of the world's most advanced deep geological repository development programmes.

D. C. Alexandre, chemist and geologist, entered the French CEA (Atomic Energy Commission) in 1961, when he was put in charge of studies on uranium ore treatment and uranium processing. In 1983 he became head of the Cadarache Research Centre, department of R&D on radioactive waste (treatment, conditioning and characterization for the French territory). In 1987 he became Deputy Director of ANDRA (French Agency for Radioactive Waste Management) where he remained until in 1990 he returned to CEA as Research Director for the programme on direct disposal. Dr. Alexandre was representative of France at the EC for many years. He retired in October 1996.

Dr. Colin Heath is an Assistant General Manager for TRW Environmental Safety Systems, the contractor which has performed extensive studies at the Yucca Mountain site for the US Department of Energy (DOE) where he has worked since 1993. He received a PhD in nuclear engineering in 1964 after graduating with a BS in chemical engineering in 1960. From 1977 to 1981 Dr. Heath was Director of the US DOE's initial siting investigations for radioactive waste repositories; he has been closely involved with all aspects of the US spent fuel storage and disposal for 25 years.

Professor Dr.-Ing. Klaus Kühn, graduated as a mining engineer from the Bergakademie Clausthal (Clausthal School of Mines) and received his doctorate from the Technische Universität Clausthal. In 1965, he joint the national research centre GSF (then named Gesellschaft für Strahlenforschung, today GSF – Forschungszentrum für Umwelt und Gesundheit). After founding the GSF - Institut für Tieflagerung (Institute for Underground Disposal), he was its director from 1973 until 1995. Since then, he works as scientific advisor for GSF and as Professor at the Technische Universität Clausthal. He was and is a member of many national and international committees, e.g. the German Reaktor-Sicherheitskommission (RSK – Reactor-Safety Commission) from 1983 until 1998, as an expert in radioactive waste management.

Dr. Charles McCombie received a PhD Degree in Physics in 1971. From 1970-74, he worked at the United Kingdom Atomic Energy Authority, England and from 1974-79 at the Swiss Institute for Reactor Research, now the Paul Scherrer Institute. Dr McCombie is an independent advisor in international nuclear waste management. His principal role at present is as Head of Science, Technology and Engineering for Pangea Resources Australia. Prior to this he was Director of Science & Technology at Nagra (National Co-operative for the Disposal of Radioactive Wastes) in Switzerland for almost 20 years. He is retained as Executive Advisor to Nagra, has directly advised waste management projects in various other countries (e.g. Japan, Canada, Germany) and for the OECD/NEA. He is currently Vice Chairman of the Board of Radioactive Waste Management of the National Academies of the USA and a member of the Nuclear Research Advisory Committee of the National Paul Scherrer Research Institute.

Dr. Wendell D. Weart, is a Senior Fellow at Sandia National Laboratories in Albuquerque, New Mexico. He possesses a Doctorate in geophysics with undergraduate degrees in geology and mathematics. He was the scientific programme manager for the Waste Isolation Pilot Plant (WIPP) from its inception in 1975 until 1995 when he became senior scientist and Laboratory Fellow advising on Nuclear Waste Management issues. WIPP, a custom built deep geological repository for long-lived transuranic wastes, is the first facility of this type to have successfully gone through a formal permitting procedure leading to active operation.

References

BMU, (2000): Aktuelle Entsorgungsfragen; http://www.bmu.de/atomkraft/entsorgung.htm

Bundesregierung (1998): Aufbruch und Erneuerung auf Deutschlands Weg ins 21. Jahrhundert, (1998): Koalitionsvereinbarung zwischen der Sozialdemokratischen Partei Deutschlands und Bündnis 90/Die Grünen vom 20. Oktober 1998

Appendix 2

The Problematic Issues

The present Federal Government expressed its doubts on the Gorleben salt dome in concrete terms in May 2000, when the BMU posted a paper on the Internet, entitled "Topical Questions on Radioactive Waste Management". In this paper eleven problematic issues ("Zweifel") are raised. These are commented on in detail on the following pages.

A 2.1 Gas Generation and its Implications for Gorleben

The BMU paper presents gas generation as one of the reasons for doubts about Gorleben's ability to perform safely over long periods of time. The concern focuses around the generation of gas in low- and intermediate-activity level, not spent fuel or high-level waste. The statement is made that: "*No convincing solution for this issue has yet been found for gas-tight rocks.*"

The potential for generation of significant quantities of gas in nuclear waste repositories has been recognized and investigated at least since the mid 1970s. Among the early studies were those conducted for the Waste Isolation Pilot Plant (WIPP) and reported by Molecke [Molecke, 1979 and 1980]. These early studies focused on the bacteriological degradation of organic material in low- and intermediate-level waste. Studies of gas generation intensified in the decades of 1980 and 1990. Investigations expanded to include the anoxic corrosion of iron and aluminium that resulted in release of hydrogen. A literature review of the state of gas generation knowledge was presented in a report to the DOE in November 1987, and in a NIREX [1994] report which examined the issue for a planned LLW/ILW repository near Sellafield [Norris, 1987]. The topic was the subject of NEA workshops in September 1991, [NEA/ANDRA, 1991] and as recently as June, 2000 [NEA/EC/ANDRA, 2000]. The international nuclear waste management community has addressed this issue with both experimental programmes and mechanistic and/or empirical modelling. The international waste management community agrees that the general mechanisms for generation of gases in nuclear waste repositories are now well understood. Because repository-specific environments and designs may interact with waste contents in different ways and to differing degrees, each repository must conduct experiments or do modelling apropos to its environment to ascertain rates and volumes of gas production. The important thing to recognize is that the process of gas generation and the concerns it may raise for repository safety have been known and factored into repository performance for many years.

Once the gas generation mechanisms in a repository are applied and the rates and volume of gas production are determined, the remaining issue that must be addressed is the consequence of the generated gas on the repository integrity and safety. There are significant differences in behaviour between repositories in fractured rock, such as granite, and those in rocks such as salt. In general, fractured host rocks have enough permeability that gases may escape from the repository before building up to high pressure. The gas may, however, affect the flow properties of the fluids in and around the repository and may act as a carrier for the relatively small volume of radioactive gases that could be released from spent fuel. In very low permeable host rocks, such as salt, the gases cannot readily escape the repository, and this leads to a concern that high pressures may be created in the repository and that those pressures may lead to a breach of repository integrity.

Consequences of Gas Generation for Gorleben

Since the permeability of the Gorleben salt is so low ($\sim 10^{-21} m^2$ to $10^{-23} m^2$), gases that are created within the tightly sealed repository may not be able to migrate through the salt as fast as they can be generated. The ultimate question then is whether gases will be created in sufficient volume and at such a rate as to create cracks through the salt barrier, thereby posing a threat to repository integrity. It is generally accepted that for the case of high-level waste or spent fuel, the gas potential derives from corrosion of iron and not from decomposition of organics since very little organic matter occurs in this type repository. The low brine content of the Gorleben salt, coupled with the creep of the salt to virtually eliminate any open volume around the spent fuel, tends to remove the possibility of substantial corrosion of the iron because of limited water availability.

To examine the gas generation question for low- and medium-activity waste, which does generally contain organic material, two basic scenarios may be postulated. The first possibility (Scenario 1) is that no human intrusion occurs and the water for corrosion of the iron and degradation of the organics must come from the brine content of the surrounding salt and backfill material. The second possibility (Scenario 2) is that water is introduced by future human intrusion into the repository. In this latter case, the intrusion may provide access for enough water to carry the corrosion of all the iron to completion and allow microbial degradation of the organics. Even though a large volume of gas may be produced in this scenario, the same intrusion that allowed water to access the waste will also provide a relatively permeable path for gas to escape. Consequently, pressure build ups that could fracture the salt are not expected to occur and the only release path to be modelled is the one created by the human intrusion, a scenario that must be modelled in any event. To provide assurances that fracturing of the salt is not a probable consequence for this scenario, the processes involved may be modelled by using conservative (bounding) assumptions for borehole permeability and rates of hydrogen generation from corrosion and organic decomposition. This conservative approach was used by the WIPP performance assessment modelling to show that no unacceptable consequences occurred.

Scenario 1, which depends on water from the surrounding salt and/or backfill for gas generation, is also unlikely to cause gas pressure induced fracturing of the salt sufficient to breach the repository. There are two reasons for this conclusion. First, the quantity of brine available from the Gorleben salt is not believed sufficient to carry the gas generation process to completion, thereby limiting the volume of gas necessary to cause the extensive fracturing required to breach the salt barrier. Second, the porosity in the backfill and in the disturbed rock zone surrounding the excavated waste rooms will accommodate a large volume of the gas that is generated. Calculations could be readily carried out for the specific situation at Gorleben by suitably bounding the mechanisms and parameters involved. The recent papers [Müller, 2000 and Müller-Lyda et al., 2000] illustrate that the German programme has an understanding of gas generation necessary to carry out this gas generation modelling. Similarly, the extensive history of salt rock mechanics research in Germany can provide the necessary knowledge of the appropriate salt properties.

By analogy to the WIPP, which is also a repository in salt (albeit bedded salt), one may infer that gas fracturing will not be a threat to the integrity of the Gorleben repository. The WIPP regulator (Environmental Protection Agency (EPA)) and several technical oversight groups thoroughly examined the gas generation threat to WIPP, as modelled by performance assessment for the compliance application, and concluded the generated gas would not breach the salt barrier or the shaft seals. The WIPP situation may be summarized as follows: intra-crystalline brine will migrate to the WIPP waste rooms from the disturbed rock zone until the brine is depleted or pore pressure gradients are equalized. In the most extreme case, only 60 percent of the iron in the repository was corroded due to limited availability of brine. No more than half of the organic material was expected to decompose. For most realizations much less brine was available and far less gas was generated. For this extreme condition, however, gas pressures were calculated to reach lithostatic pressure and enter, and possibly enlarge, natural pre-existing fractures and planes of weakness and to occupy pore volume near the room surfaces. As gas continued to be generated, it was accommodated in the expanding volume of the opening created, thus limiting the pressure increase to no more than lithostatic levels. The volumes of gas, for even the extreme case, were never sufficient to extend fracture openings through the salt barrier. For most of the model realizations, the brine volume was so small the generated volumes of gas never approached lithostatic pressure. This conclusion and the supporting arguments are presented in the Compliance Certification Application for the WIPP [DOE, 1996].

The WIPP salt contains from 0.5 to 3.0% brine, on average more than ten times the Gorleben salt brine content. Consequently it may be surmised that since gas generation is dependent on water availability, gas generation in Gorleben will be more restricted than in the WIPP. Gas volumes produced from the limited amount of brine available from brine inclusion migration or from the salt backfill should not present a breach threat to the Gorleben repository. Modelling of the slow pressure increase due to gas generation, in the most realistic representation for WIPP, resulted in an increase in the repository pore space by enlarging pre-existing fractures in or along the anhydrite interbeds [De Vries et al., 1998]. In an assumed homogeneous salt and isotropic stress field, which is more nearly the case for Gorleben, the modelling of the very slow pressure build-up in WIPP stopped and/or reversed the creep closure process but did not result in propagating fractures.

As an additional assurance measure, WIPP added a backfill component consisting of MgO. This material was shown to interact with the CO_2 gas deriving from decomposition of the organic material to form a solid (magnesite), thus removing CO_2 from the gas volume. While compliance with the regulatory criteria did not depend on this feature, it did provide the additional assurance that the standard required. Should the Gorleben specific modelling require an additional safety measure, such remedies are available.

The above observations allow an inference that gas generation in the Gorleben repository, whether used for disposal of spent fuel or high-level waste or for low- and medium-activity waste, may not pose a threat to repository integrity and long-term safety. However, bounding calculations, which are presently well within the current state of knowledge and capability, should be conducted to address the specific Gorleben parameters. If these calculations do not provide the desired margin of confidence, there are remedies that may be readily applied.

Consequently, gas generation does not present either a new or an insurmountable issue and should not be used as a technical argument against the Gorleben site.

References

DeVries, K.L., Callahan, G.D. and Munson, D. E. (1998): WIPP Panel Simulations with Gas Generation. Proc. 4th Conference on Mechanical Behaviour of Salt, Rotterdam, Netherlands, p. 537-550, 1998.

DOE (1996): WIPP Compliance Certification Application, October, 1996, Chapter 6.2-6.5, Appendix MASS, Sections 3.2 and 8.0, October 1996.

Molecke, M.A. (1979): Gas Generation from Transuranic Waste Degradation: Data Summary and Interpretation, 1979 SAND79-1245, 1979.

Molecke, M.A. (1980): Degradation of Transuranic Contaminated Waste under Geologic Isolation Conditions, 1980, SAND79-2216A, 1980.

Müller, W. (2000): Gas Generation, Presented at NEA/EC/ANDRA Workshop on Gas Generation, Accumulation and Migration in Underground Repository Systems for Radioactive Waste: Safety-Relevant Issues, Reims, France, 26-28 June 2000.

Müller-Lyda, I., Javeri, V. and Müller, W. (2000): Strategy for the Treatment of Gas-Related Issues for Repositories Located in Rock Salt, Presented at NEA/EC/ANDRA Workshop on Gas Generation, Accumulation and Migration in Underground Repository Systems for Radioactive Waste: Safety-Relevant Issues, Reims, France, 26-28 June 2000.

NEA/ANDRA (1991): Gas Generation and Release from Radioactive Waste Repositories, NEA/ANDRA Workshop, 2000.

NEA/EC/ANDRA (2000): Gas Generation, Accumulation and Migration in Underground Repository Systems for Radioactive Waste: Safety-Relevant Issues, NEA/EC/ANDRA Workshop, Reims, France, 26 - 28 June 2000

Nirex (1994): Post-Closure Performance Assessment: Gas Generation and Migration, United Kingdom Nirex Ltd., Report Ni:S/94/003, 1994.

Norris, G.H. (1987): A Review of Literature Relevant to Gas Production in Radioactive Waste, 1987, DOE Report No. DOE/RW/87.109, 1987.

A 2.2 Human Intrusion

The BMU has raised questions as to whether consideration of disposal in a salt dome, or in salt in general, is problematic because of the possibility that inadvertent human intrusion at some time in the future might result in unacceptable consequences. A further claim is that new criteria of the ICRP may soon change the state-of-the-art in this area.

As pointed out in a recent publication of the International Commission on Radiological Protection [ICRP, 2000], *"The possibility of elevated exposures from disruptive events is an inescapable consequence of the decision to concentrate waste in a disposal facility rather than diluting or dispersing it."* This issue has been central to consideration of siting of geologic repositories in any geologic medium, and is not limited to salt formations. In June 1989, the Radioactive Waste Management Committee of the Nuclear Energy Agency (NEA) of the Organization for Economic Co-operation and Development (OECD) organized a workshop on "Assessment of the Risks Associated with Human Intrusion at Radioactive Waste Disposal Sites" held in Paris, France [OECD/NEA, 1990]. Discussions at this workshop recognized that, while one cannot scientifically predict how man and society will develop, it is possible to discuss in a meaningful way how man might interfere in the future with a repository and to develop waste disposal practices that can be considered sufficiently invulnerable to human intrusion.

One paper presented at this workshop of the GSF-German Institut für Tieflagerung [Hirsekorn, 1990], considered the impact of possible future solution mining in a radioactive waste repository in a salt dome. Calculations presented in this paper predicted consequences from human intrusion well within the proposed standards for allowable impacts from repositories to protect people and the environment. This provides evidence that the German programme for repository development has long considered human intrusion as an issue to be addressed in establishing facilities.

Following this workshop, the NEA established a working group on Assessment of Future Human Actions at Radioactive Waste Disposal Sites. This working group included three representatives from Germany. This group met during the period 1991 - 1993 [Andersen et al., 1994] and produced a final report [OECD/NEA, 1995] which presented a framework for the evaluation of future human actions and discussed means to reduce the associated risks. As pointed out in the NEA report, radioactive wastes are not special with regard to predicting the impacts of human intrusion. There are many other human activities that may have consequences for the future that are difficult or impossible to predict.

All national programmes agree, however, that measures need to be taken to limit the chance that future human intrusion will occur. Sites are to be chosen so as to minimize resource conflicts (e.g. minerals, or oil and gas deposits). Salt is, of course, itself a raw material; but salt deposits are relatively common in Germany so that no severe restrictions are introduced. The burial of high-level radioactive wastes should be sufficiently deep so as not to be affected by surface activities, such as large construction activities or surface explosions, and to make any future excavation and recovery a significant undertaking. Every effort must be made to communicate information about the location and nature of waste disposal sites through dissemination and conservation of records and by the construction of physical markers at the sites.

All agree, however, that the prediction of human behaviour for long times into the future is not possible nor can any guarantee be given that information will be retained for the future. Deliberate or knowing human intrusion is not considered an important issue since any future society that deliberately opens a waste disposal site must be considered responsible for and capable of protecting itself properly. But all agree, also, that the consequences of inadvertent human intrusion into a repository site must be considered prior to establishing such facilities.

For possible repositories in salt formations, human intrusion may be the only mechanism by which radionuclides can be postulated to escape from a repository and pose a threat to humans and the environment. For example, the US Environmental Protection Agency (US EPA) established a specific human intrusion scenario in its criteria for certifying the Waste Isolation Pilot Plant (WIPP) in New Mexico (see Chapter 40, Code of Federal Regulations, Part 194). These criteria required the evaluation of the rate of resource drilling in the vicinity of the WIPP site over the past 100 years and use of this drilling rate in a performance assessment of activities over the 10,000 year regulatory period. A similar assessment conducted for the Gorleben salt dome could provide an appropriate evaluation as to whether future human intrusion is significant to the suitability of Gorleben as a repository.

Other national programs are also evaluating potential human intrusion events. A Canadian report [Wuschke, 1996] concluded that the estimated risks from four postulated intrusion scenarios into a repository in plutonic rock of the Canadian shield would be several orders of magnitude below established risk criteria. More recently, the Swedish Nuclear Fuel and Waste Management Company (SKB) report on post-closure safety in a deep repository [SKB, 1999] concluded that the future doses could be 0.1 to 10 times the natural background radiation but with risk to individuals being much less than one chance in one million per year.

An international consensus is developing that, although it is not possible to forecast future human actions and their impact on a repository, some representative scenarios should be considered to test the resilience of the repository site and design against future unanticipated events. As stated by the ICRP, [ICRP, 2000]:

> *"Because the occurrence of human intrusion cannot be totally ruled out, the consequence of one or more typical plausible stylised intrusion scenarios should be considered by the decision-maker to evaluate the resilience of the repository to potential intrusion.... However, any projections of the magnitude of intrusion risks are by necessity dependent on assumptions that are made about future human behaviour. Since no scientific basis exists for predicting the nature or probability of future human actions, it is not appropriate to include the probabilities of such events in a quantitative performance assessment that is to be performed with dose or risk constraints."*

The US EPA and the US Nuclear Regulatory Commission are proposing standards and regulations pertaining to a site at Yucca Mountain to require performance of a consequence analysis that includes a specified assumed scenario. This proposed scenario assumes that, 100 years after closure of the repository, a drilling event results in a single, nearly vertical, borehole that penetrates a waste package and extends to the saturated zone below the Yucca Mountain repository. DOE would be required to show, through a performance assessment, that, in the words of EPA, *"the conditional risk as a result of the assumed intrusion scenario should be no greater than the risk levels that would be acceptable for the undisturbed repository case"*. This very rigorous requirement goes beyond the recommendations of the ICRP and places possible future unintentional human intrusion in the same category as all other future impacts on a repository.

The Gorleben site and the design of any repository proposed there should be evaluated for its resilience against the impacts of future intrusion. The salt dome feature of Gorleben is common to this part of Germany so that it is no more likely than other formations to be selected for future development of resources that may be found throughout the area. No evidence of oil, gas, or mineral deposits adjacent to Gorleben has been reported. A representative scenario involving potential future inadvertent human intrusion should be evaluated but there is no reason to believe that predicted future consequences would exceed protection standards being proposed and evaluated throughout the international community.

References

Anderson, D. R., Galson, D. A. and Patera, E. S. (1994): The Assessment of Future Human Actions at Radioactive Waste Disposal Sites: An International Perspective, Proceedings of the Fifth Annual International Conference on High-Level Radioactive Waste Management, Las Vegas, Nevada, May 22-26, 1994.

Hirsekorn, R.-P. (1990): Post-operational leakage of a storage cavern constructed by solution mining in a former HAW repository area in a salt dome; in: Risks Associated with Human Intrusion at Radioactive Waste Disposal Sites, Proc. NEA-Workshop, OECD/NEA, Paris, 1990, p. 159 - 170

ICRP (2000): Radiation Protection Recommendations as Applied to the Disposal of Long-Lived Solid Radioactive Waste, Annals of the International Commission on Radiological Protection, Publication 81, Elsevier Science, Oxford, U.K., 2000.

OECD/NEA (1990): Risks Associated with Human Intrusion at Radioactive Waste Disposal Sites, Proceedings of a NEA Workshop, OECD/NEA, Paris, 1990.

OECD/NEA (1995): Safety Assessment of Radioactive Waste Repositories: Future Human Actions at Disposal Sites, Report of the NEA Working Group on Assessment of Future Human Actions at Radioactive Waste Disposal Sites, OECD/NEA, Paris, 1995.

SKB (1999): Deep Repository for Spent Nuclear Fuel, SR 97 – Post-Closure Safety, Technical Report TR-99-06, SKB, Stockholm, Sweden, November 1999.

Wuschke, D. M. (1996): Assessment of the Long-Term Risks of Inadvertent Human Intrusion into a Proposed Canadian Nuclear Fuel Waste Disposal Vault in Deep Plutonic Rock – Revision 1, AECL-10279, Rev. 1, Whiteshell Laboratories, Pinawa, Manitoba, Canada, 1996.

A 2.3 Criticality in a Deep Repository

One of the concerns raised by BMU is the risk for criticality in a repository with spent nuclear fuel. It is claimed that criticality might compromise the entire integrity of a repository. Aspects of criticality must be further investigated in the case of non-reprocessed spent fuel elements and, if the occasion arises unused plutonium in Gorleben because these means of disposal may become the more favoured or even the exclusive method [BMU, 2000].

The potential risk for the occurrence of criticality cannot be immediately dismissed for a deep repository containing substantial amounts of fissile material. The issue has been the subject of numerous studies in countries planning for disposal of spent nuclear fuel.

Nuclear fuel for a LWR typically contains some 3 - 4% of fissile material (uranium-235) in the fresh fuel and about 1.5% fissile material (uranium-235 plus plutonium-239 and -241) after a burnup of about 40 MWd/kg. LWR-fuels with plutonium (MOX-fuel) may have slightly higher content of fissile isotopes – up to 5.5% for fresh fuel and up to 3% for burned fuel. Spent fuels from other types of thermal power reactors have similar fissile contents in the fuel. One exception is natural uranium fuel (e.g., from HWR) where the fissile content is of the order of 0.5%. Fuel for fast reactors typically have much higher fissile content up to about 25% for the fresh fuel and fuel for research reactors may have even higher enrichments – up to 93% (uranium-235).

The used fuel is proposed to be encapsulated in canisters with a content of a few tonnes (uranium weight) of fuel before disposal. This means that one canister with spent enriched nuclear fuel may contain more fissile material than the theoretical minimum critical mass. A whole repository will contain many times more. The disposal of spent nuclear fuel thus means that the potential for an unintended critical configuration of the fissile material has to be addressed in the safety analysis.

Two main cases have to be addressed:

- potential risk for criticality of the fuel as deposited in the canister,
- reconfiguration of the fissile material to a critical configuration, e. g. by selective leakage and precipitation of fissile elements.

The fuel will (in many proposed cases) be encapsulated in the same geometrical configuration as used in the reactor, i.e. a close to optimum configuration from the reactor physics point of view. The temperature in the repository is ambient (much lower than in a reactor) and the short-lived strongly neutron-absorbing radionuclides (like xenon-135 and samarium-151) have decayed. This means that criticality is conceivable with only a limited number of fuel assemblies if a moderating material is added. A spent fuel canister must therefore be designed in such a way that criticality is not achieved even if the canister is filled with fuel that for some reason not has reached full burnup and starts taking in groundwater from the surrounding repository formation. In practice this is achieved by rearranging the fuel in a non-critical configuration, by having strict administrative control of the fuel burnup and other important parameters in the encapsulation plant and/or by mixing the fuel with some neutron-absorbing material e.g., an insert with walls between each fuel assembly [SKB, 1995]. Removal of the fuel rods from the assembly skeleton and tight packaging – often referred to as rod consolidation - is another way to eliminate the risk of inadvertent criticality for LWR-fuel. This is planned for the German spent fuel to be directly disposed of. Still another way is to mix fuel with high residual concentration of fissile nuclides with other fuel having high burnup (i.e. low fissile concentration). In the design and safety analysis several real or potential phenomena must be accounted for, as e.g. long-term reactivity changes, any dissolution of neutron absorbing material or any reconfiguration of fuel rods.

The issue of reconfiguration of the fissile material was addressed already in the 1970s [Behrenz and Hannerz, 1978] and has recently been revisited [e.g. Bowman and Venneri, 1994, Konynenburg, 1996, Ahn, 1997, Sanchez, 1998]. The issue has two aspects - one is the probability that some process will redistribute the fissile material into a configuration that might develop and sustain a neutron chain reaction - and the other is the probable and/or possible consequence of such a chain reaction if it occurs. The early studies of a repository for LWR fuel in granitic bedrock [Behrenz and Hannerz, 1978] concluded that the reconfiguration of plutonium from several canisters is an extremely unlikely event due to the very slow chemical processes in the prevailing geochemical environment as compared to the half-lives of fissile plutonium. Reconfiguration of uranium from LWR-fuel is also very unlikely because (due to the low uranium-235 content) several tonnes of uranium must be assembled in proper concentration and configuration. Criticality with uranium could for geometrical reasons only occur in the back-filled excavations of the repository and would involve the movement of uranium from several canisters to the same spot during a very long time. The consequence of a hypothetical criticality by plutonium or uranium from spent LWR fuel was furthermore judged to be very limited.

A recent analysis of the criticality issue for the disposal of different types of spent fuel (research reactors, commercial LWR's and others) has been reported by [Sanchez et al., 1998] for the proposed Yucca Mountain repository in the USA. The principal findings from that study are that:

- Internal or near-field criticality is only possible if significant separation of fissile material and neutron absorbers occur by chemical processes and/or other mechanisms. The probability of such separation is very small.
- Low enrichment fissile materials (less than 2% enrichment) do not achieve delayed criticality in far-field geometries even for infinite geometry. Even with higher enrichments criticality is only possible if significant quantities of fissile material is accumulated in one single far-field location. The probability of such an accumulation is also very small.
- The consequences of any critical excursion, should such an event occur, are very small indeed both concerning thermal effects to the repository and generation of additional fission products. In terms of additional annual effective dose they are estimated to be less than the round off of the computed values in other performance assessment scenarios.

It should be pointed out that in an environment containing significant amounts of salt or iron the fissile concentrations and mass quantities of fissile material must be very large in order to achieve criticality [Sanchez et al., 1998, vol. 2, p 2-6]. This means that e.g. for a repository in salt the potential occurrence of criticality should have an even smaller probability than for the cases studied in granite or tuff.

Some analyses [Bowman and Venneri, 1994] point out that fissile material in certain concentrations and configurations could impose a risk for divergent neutron chain reactions (autocatalytic criticality) with considerable energy release as a result. Vitrified weapons' plutonium is pointed out as particularly sensitive in this respect. No real analysis to assess the probability for creation of such a configuration is however done. Other analyses [Konynenburg, 1996] challenge the aforementioned scenario and point out a number of factors that will make the scenario very unlikely indeed for a spent fuel repository. A study [Ahn, 1997], also for the proposed Yucca Mountain repository, concludes that the concentrations reached for plutonium-239 (or later in time for uranium-235) from vitrified weapons-grade plutonium are too low for an autocatalytic criticality.

In conclusion - all conceivable mechanisms for creating a risk for unintentional criticality have to be addressed for any repository for disposal of large amounts of fissile material. The assessment has to be done for each specific geologic environment and repository design. There are however means to avoid such a risk. The studies made for proposed repositories in granite and in tuff show that the criticality scenarios are indeed very improbable. There are good reasons to believe that for a properly designed salt repository, like the one planned for Gorleben, the probabilities are even less. The studies also show that the consequences of postulated critical excursions in a repository would be small both with respect to the integrity of the repository and to the amount of fission products in the repository.

References

Ahn, J (1997): Transport of weapons-grade plutonium and boron through fractured geologic media, Nuclear Technology 117, p 316, March 1997.

Behrenz, P. and Hannerz, K. (1978): Criticality in a spent fuel repository in wet crystalline rock. KBS Technical Report 108, 1978.

BMU, (2000): Current issues in closing the nuclear fuel cycle. Status: May 2000. Translation of Aktuelle Entsorgungsfragen: http://www.bmu.de/atomkraft/entsorgung.htm, 2000.

Bowman, C. D. and Venneri, F. (1994): Underground Supercriticality from Plutonium an Other Fissile Material, Los Alamos Report LAUR-94-4022A (1994); also in Science and Global Security, 5, p 279, 1996.

Konynenburg, R. A. (1996): Comments on the draft paper "Underground Supercriticality from Plutonium and Other Fissile Material", Science and Global Security, 5, p 303, 1996.

Sanchez, C. et al. (1998): Nuclear Dynamics Consequence Analysis (NDCA) for the Disposal of Spent Nuclear Fuel in Underground Geologic Repository. V.1-3, Sandia report SAND98-2208; INEEL/EXT-98-00996; DOE/SNP/REP-0033. October 1998.

SKB (1995): SKB: RD&D – Programme 95, p 78, 1995

A 2.4 Safeguards

In government documentation [BMU, 2000], the suitability of Gorleben is questioned on the grounds of "new findings and assessments relevant to Gorleben". In the list of findings the issue of safeguards is raised. The assertions made are that:

- direct disposal instead of reprocessing increases the inventory of fissionable materials so that the adequacy of existing safeguards R&D must be checked

- neither the IAEA nor the EU has safeguards concepts for direct disposal of plutonium
- no concept has been developed to reconcile the conflicting demands of safeguards and retrievability.

In this section responses to these issues are offered.

Firstly, the impact of direct disposal of spent fuel on safeguards issues is by no means a new issue which has been raised by German government intentions to cease reprocessing. The IAEA organized a series of advisory and consultant group meetings [IAEA, 1991; IAEA, 1995; IAEA-1, 1997; IAEA, 1998] all on the issue of safeguards for disposal of nuclear materials including spent fuel. In these meetings the German delegation, commonly consisting of five persons from various organizations, was always amongst the largest. In addition, there was a special German Support Programme for the IAEA in the safeguards area. Despite these existing activities, when the IAEA initiated in 1994 the Programme for Development of Safeguards for the Disposal of Spent Fuel in Geologic Repositories (SAGOR), Germany joined the eight full members (B, CDN, SF, F, H, S, UK, USA) as an observer with three delegates from government, research and industry participating. The SAGOR programme published its five volume final report in 1998 [IAEA, 1998]. In addition to these international activities, specific German studies have been devoted to the situation at Gorleben [Biurrun et al., 2000], and the safeguards issue has been directly addressed in special reports prepared by industry [GNS, 2000]. It is clear that the issue of safeguards in spent fuel repositories has been examined worldwide for at least ten years.

The conclusions reached by experts were that existing safeguards concepts and methods are applicable to spent fuel disposal facilities such as conditioning plants and "are capable of being adapted to cope with the unique aspects of final disposal" [IAEA-2, 1997]. Further R&D was recommended – but with the objective of optimizing safeguards measures at facilities rather than clarifying any outstanding fundamental issues.

There are some specific issues related to disposal in salt domes. For example, the precise layout of the safeguarded areas underground is constantly changing as disposal rooms are excavated and then backfilled. Clandestine removal of disposed fuel from a repository at some later date when the radiation field has reduced in intensity has also been studied [Peterson, 1999]. Although this might be technically easier in salt than in hard rock, simple surveillance measures can continue the safeguards regime effectively. While, however, retrieval might be easier in salt than hard rock, the fact that mining would be required for removal of waste from salt repository and not from an unbackfilled, hard rock repository implies that a salt repository is more secure from the safeguards standpoint.

Disposal of unwanted plutonium has been a much discussed issue of late 90's [CSIS, 2000]. Using the plutonium to fabricate MOX fuel is one obvious option and this is being done with both civil stocks and surplus military plutonium. A further option is immobilization of the plutonium [NRC, 1996] using the can-in-canister approach developed by USDOE [NRC, 1996; Carter and Pigford, 1999] or else newer technologies based on SYNROC materials. In all cases, the objective is to ensure that the conditioned plutonium meets the spent fuel standard – in other words to ensure that the safeguards problems are no larger than for the spent fuel case dealt with above. It is worth noting that disposing of fissile materials in geologic repository, whether spent fuel or conditioned plutonium, and therefore making them extremely inaccessible, is recognized as an effective way of reducing the nuclear threat [CSIS, 2000; Carter and Pigford, 1999]. Delaying repository implementation for decades would mean living with the greater threat during this time.

The last issue raised by the German government on safeguards – the conflict between safeguards and retrievability – is indeed a point worthy of discussion. It is, however, not a salt-specific issue, nor a Gorleben-specific issue. In principle, safeguards are maximized if retrieval is made as difficult as possible whereas options for future alternative methods of dealing with spent fuel are most open if retrievability is simple. All societies implementing geologic disposal will have to weigh these conflicting goals against one another before choosing a disposal route.

From the scientific and technical viewpoint, confidence in the long-term safety of a repository should be so high before disposal commences that retrieval for safety reasons is a scenario of vanishingly small probability. In this case, the plastic properties of salt, which enhances the isolation of the radioactive wastes whilst making retrieval more difficult – although not unfeasible – are positive host rock characteristics. Should a future society knowingly choose to retrieve spent fuel for other reasons (e.g. the un-used energy producing potential), then they should also be willing to undertake the more complex, more expensive retrieval methods, which would be necessary. [Biurrun et al., 2000] concluded that retrievability in salt is possible when rock temperatures are below 100°C but that the scale of operations needed *"makes an undetected retrieval of disposed fuel elements impossible"*.

In summary, safeguards issues have been studied for repositories for many years and the international consensus is that these facilities present a lower risk than surface facilities. In a salt dome clandestine retrieval of fissile material would not be radically harder or easier than in other repository host media.

References

Biurrun, E., Engelmann, H.J., Brennecke, P. and Kranz H., H-J., (2000): Safety and safeguards aspects of retrievability: A German Study, in IAEA Tecdoc 1187, Retrievability of high level waste and spent fuel, Proceedings of an international seminar organized by Swedish National Council for Nuclear Wastes (KASAM), October 1999, IAEA, Vienna, 2000.

BMU 1 (2000): Vereinbarung zwischen der Bundesregierung und den Energieversorgungsunternehmen vom 14. Juni 2000, http//www.bmu.de/ sachthemen/konsens01.htm (Haupttext); ...02.htm (Anhang I – III); ...03.htm (Anhang IV – V)

Carter, L. and Pigford, T. (1999): Confronting the Paradox in Plutonium Policies, Issues in Science and Technology, Winter 1999-2000

CSIS (2000): Managing the Global Nuclear Materials Threat: Policy recommendations, CSIS Panel Report, CSIS Press, Washington DC, 2000.

GNS, (2000): Beschreibung des Entsorgungspfades Langfristzwischenlagerung/Direkte Endlagerung abgebrannter Brennelemente aus deutschen Kernkraftwerken, GNS, 2000.

IAEA (1991): Consultants' report on safeguards for final disposal of spent fuel in geological repositories, Report STR-274, IAEA, Vienna, 1991.

IAEA (1996): Issues in Radioactive Waste Disposal: 2nd Report of the Working Group on Principles and Criteria for Radioactive Waste Disposal, IAEA-Tecdoc-909, IAEA, Vienna, 1996.

IAEA-1 (1997): Report of the Advisory Group Meeting on safeguards for final disposal of spent fuel in geological repositories, Report STR-309, IAEA, Vienna, 1997.

IAEA-2 (1997): Safeguards for final disposal of spent fuel in geological repositories, Safeguards Policy Series, Number 15, entry into force on 19/6/97, 1997.

IAEA (1998): Safeguards for the Final Disposal of Spent Fuel in Geological Repositories, STR-312, IAEA, Vienna (5 vols.) 1998, SAGOR final report, 1998.

NRC (1996): Nuclear Wastes: Technologies for Separation and Transmutation, National Research Council Committee Washington DC, 1996.

Peterson, P. (1999): Issues for detecting undeclared post-closure excavation at geologic repositories, Science and Global Security 1999, Volume 8 pp 1-39

A 2.5 Time Frames for Isolation and Safety Demonstration

The BMU points out that earlier work in Germany restricted quantitative analyses of repository behaviour to a period of 10,000 years. They claim that it is internationally an open question whether, or how, one can extend these times to the longer periods for which the HLW remains significantly radio-toxic. In the following text, the IEG gives some more extended background to the current international debate on these issues.

It is recognized throughout the scientific community that the long-term safety of a repository will never be proven by means of a strict demonstration in the mathematical sense. Responsible scientists and technologists rely on safety assessments which they realize do not yield precise predictions of events, but rather scope the potential range of future system behaviour. The assessments deliver broad estimates, with confidence levels which decrease as the time period considered becomes longer. These estimates quantify the bounding behaviour of different evolution scenarios representing the main features, events and processes (FEPs) that might affect the repository evolution. A key part (but not the only part) of the safety demonstration is thus a repository safety assessment, or total system performance assessment (TSPA) which is conducted with models, applied to selected FEPs. The various parameters introduced in the models result from measurements of physical, mechanical, chemical and geochemical processes. There are of course uncertainties in these measurements but the parameters do not normally change rapidly with time and confidence in the values can sometimes be increased by experiments simulating the processes of long-term evolution and by natural analogues' studies. The longer the simulation of system evolution is conducted, the greater become the uncertainties in results – but, in parallel, the radioactivity of the waste will decrease with time.

Key time dependent processes:

Before reaching conclusions on timescales which can be considered in an overall assessment, it is useful to consider the relevant timescales for individual processes and system components.

- The evolution of radiotoxicity with time:
  Waste radioactivity or radiotoxicity decreases with time. A useful reference time is when the activity or toxicity of the wastes reaches the same value as that of the

original uranium ore. The resulting time scale differs, depending upon the normalization adopted (e.g. per unit of mass or per volume) and upon values used for radiotoxicity. As a round number conservatively chosen on the high side, this time scale is of 10,000 years for fission products glasses and of 100,000 years for spent fuel. Nevertheless, at this time the repository will still contain some radionuclides with longer half lives (e.g. Tc-299, Np-237, I-129).

- The time dependence of the evolution of engineered/technical barriers:
  Studies made on waste forms such as ceramic matrices in spent fuel, or borosilicate glasses, demonstrate a resistance to water dissolution for ten of thousands of years. Metallic containers such as those intended to be used in the Gorleben concept have a lifetime of at least several thousand years in a water saturated environment. In a normal evolution scenario, there will be no water in contact with the waste packages in the Gorleben repository.
- The evolution of the geological formation:
  The Gorleben salt dome has been estimated to have been stable since the Tertiary (about 65 million years) with little significant evolution or change in the geochemical conditions.
- The time dependence of the evolution of the biosphere:
  The biosphere changes on much shorter timescales. This is the fundamental reason for wishing to dispose of long-lived wastes in deep geological formations. For safety evaluations, the stylized assumption is often made that the biosphere conditions remain the same as those today. Variations with extreme climate change scenarios have also been made.
- Evolution of human society:
  This is obviously the fastest changing element. It is recognized that it is impossible to predict the changing habits of man and the development of society. Again stylized assumptions based on today's lifestyles are mostly assumed.
- The time of peak release:
  For typical release scenarios, even in saturated fractured rocks, the peak releases are calculated at 100,000 years or more into the future. In a salt medium the normal evolution scenario implies zero release for all conceivable times in the future. Attention at Gorleben may therefore be focussed on disruptive human intrusion scenarios, as was the case for the WIPP repository.

Treatment of timescales in safety assessments and in regulations:

The challenge of dealing with the long timescales treated in repository assessments have long been recognized in national programmes. Positions taken in some countries are summarized below.

- Canada [AECB, 1987]: Time frame for quantitative compliance: 10,000 years; requirement that longer periods be addressed quantitatively to ensure that no sudden increase in risk would occur.
- Finland : Up to "reasonably predictable time periods" (~ 10,000 years), dose constraint from expected evolution; beyond, quantities of nuclides migrating to be below specified limits (derived from natural background).
- France : Stability of geologic barrier to be demonstrated for a period of at least 10,000 years; calculations of doses for normal evolution extend to 100,000 years; thereafter the situation is hypothetical.
- Sweden ; The safety standard is given as a risk limit with the risk associated to a dose calculated by the current dose/risk relation recommended by ICRP. The compliance must be demonstrated fully for the first 1,000 years. For the time after 1,000 years the safety of the repository shall be assessed using safety indicators of which the calculated dose may be one. The assessment shall be made for at least 10,000 years and up to 1 million years depending on the radiotoxicity of the waste [SSI, 1998, SKI, 2000].
- Switzerland [HSK, 1993]: Doses and risks shall "at no time " exceed specified values.
- UK: The official guidelines specify a risk target for the post-closure period which is of undefined duration. The advisory body, NRPB, has proposed different approaches for different time periods.
- USA [EPA, 1993]: 40 CFR 191 specifies dose limits for 1,000 years, cumulative release limits for 10,000 years, ground water permissible concentrations for 1,000 years. The 1000 year limit assumes an absence of human intrusion.
- USA: Draft 40 CFR 197 [EPA, 1999] requires compliance demonstration for 10,000 years, presentation of results to peak dose or risk.

Typical suggestions for treatment of long timescales involve to subdividing the future into various time slices and using different safety indicators in a complementary fashion for judging the repository acceptability in each time frame. For example:

- calculating doses using a rigorous analysis with the present day biosphere for 1,000 years
- calculating doses using a reference biosphere out to 10,000 years
- calculating doses using a reference biosphere out to peak dose
- using comparisons with natural radionuclides fluxes in the geosphere out to the period of geological stability, e.g. 100,000 to a million years or more.

It is true that there is an active debate at present on the timescales to be considered in safety assessments. The scientific community recognizes clearly that calculations of individual dose or risk should be used only as safety indicators after a relatively short time compared to the toxic lifetime of the wastes. The time at which to cease using quantitative assessments based on calculations of dose or risk is a policy rather than a scientific decision. However, by calculating out to long times, by considering a range of scenarios and by using complementary safety indicators such as the flux of radionuclides, it is possible to build confidence that a repository system will provide passive safety for very long times into the future. No approach other than geologic disposal can offer this at present. In all countries pursuing geologic disposal, scientists from the implementing and regulatory sides have sought and found a consensus on valid approaches.

For a repository in salt at Gorleben, the question of relevant timescales may be less troublesome than for many other concepts in hard rock or in other saturated media. For disposal in salt, the normal scenario is zero release for all conceivable times in the future, and the safety assessment of the repository system will focus on low probability disruptive processes. From experience at WIPP, it seems that human intrusion may be the main long-term risks to be taken into account.

References

AECB (1987): Regulatory Policy Statement. Regulatory Objectives, Requirements and Guidelines for the Disposal of Radioactive Wastes - Long-Term Aspects, Atomic Energy Control Board, Document R 104, Ottawa, 1987.

EPA (1993): US Environmental Protection Agency, 40 CFR191: Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Wastes, Final Rule (Fed. Register Vol. 58, No 242), December 1993.

EPA (1999): US Environmental Protection Agency: Environmental Radiation Protection Standards for Yucca Mountain, Nevada, Proposed Rule (Fed. Register Vol. 64, No 166), August 1999.

HSK (1993): Protection Objectives for the Disposal of Radioactive Waste, Guideline HSK R 21/R, Swiss Federal Nuclear Safety Inspectorate, Würenlingen, 1993.

SKI (2000): Statens Kärnkraftinspektions föreskrifter om säkerhet vid slutförvaring av kärnavfall. (SKIFS 2000:x). Preliminär version för remiss. 2000-07-20. (The Swedish Nuclear Power Inspectorates regulation on safety at final disposal of nuclear waste. Preliminary version for review. 2000-07-20.) (Only available in Swedish.)

SSI (1998): The Swedish Radiation Protection Institute's Regulation (SSI FS 1998:1) on the Protection of Human Health and the Environment in connection with the Final Management of Spent Nuclear Fuel and Nuclear Waste: September 28th. In force

from February 1, 1999. English translation. Separate document with Background and Comments to the regulation is available in English.
http://www.ssi.se/fortattning/index.htm.

A 2.6 Protection Goals

The question requiring to be resolved concerning protection goals are, according to the BMU analyses:

- the discrepancy between current German dose limits (0.3 mSv/y) and those in other countries such as CDN, S, SF, CH and the USA where the tendency is to make the limit about 0.1 mSv/y
- the definition of non-radiological national goals
- the use of safety indicators other than individual dose estimates.

In practice, all of the areas touched upon by BMU are indeed the subject of active discussion in the waste management community. These discussions have not, however, prevented progress being made towards geologic disposal. In fact, three of the countries mentioned above (USA, SF, S) are those worldwide which are closest to implementing deep geologic repositories. The comments below indicate that the issues are being addressed and that they are not specific to salt or to Gorleben.

Radiation doses and risks

International recommendations concerned with the safe disposal of radioactive waste are based on the principles of radiological protection. These principles derive from recommendations issued from time to time by the International Commission on Radiological Protection (ICRP) and encapsulated in the IAEA Basic Safety Standards [IAEA, 1996]. These form the obvious basis for national regulatory criteria. Because people will be subject to a number of sources of radiation exposure, the individual dose constraint for exposures resulting from a waste repository should only be a fraction of the overall recommended radiation dose limit. The ICRP's recommended dose limit for members of the public (for all exposures to man-made, non-natural sources of radiation; i.e. doses that can be controlled) is 1 mSv/a, and this figure has been incorporated into the IAEA Basic Safety Standards. ICRP note that the application of dose limits to waste disposal has intrinsic difficulties, as dose limits for public exposure are rarely limiting in practice [ICRP, 1998]. They thus recommend that emphasis is placed on dose constraints.

The commonly applied dose constraint for a waste repository in a number of national regulations is 0.1 mSv/a, although ICRP propose a maximum of 0.3 mSv/a as appropriate. In assessing the safety of a waste repository, a common view is that individual dose constraints should be applied to the maximum value of the average dose in the maximally exposed group (i.e. that is representative of those individuals expected to receive the highest dose). ICRP emphasizes that dose constraints are prospective: i.e. they are calculated, future doses (from performance assessments: PAs) used 'exclusively in the optimization of protection' [ICRP, 1998]. In practice, the facts that dose estimates are not precise and that large margins of safety are always sought in safety assessments together make the question of the exact figure chosen in regulations of less importance. The current debate in the USA between USNRC and US EPA about whether 0.15 or 0.25 mSv/y should be used in regulation is widely regarded as largely irrelevant from a safety angle and the same applies to the difference between the 0.1 mSv and 0.3 mSv values discussed by BMU.

Potential Exposure and Risk

Before the integrated system of radiological protection was brought together in ICRP 60 [ICRP, 1991], recommendations with respect to solid radioactive waste disposal were contained within ICRP 46 [ICRP, 1985], which itself was based on the underlying system of dose limitation recommended in ICRP 26 [ICRP, 1977]. ICRP 46 dealt specifically with the issue of long timescales, and with the uncertainties involved in identifying if, and how, radiation exposures might occur in the distant future. In doing this, it introduced the concept of potential exposure to cover the uncertain possibility that some scenarios for the future evolution of a repository may expose people to radiation. It recommended that dose limitation be applied to the 'normal evolution' of a repository, but introduced the concept of risk limitation to protect future generations (analogous to dose limitation for people living today) in respect of probabilistic events (and environmental changes) and potential exposures. It also introduced the concept of scenario analysis into safety assessments of waste disposal.

Since ICRP 46 and 60 were published there have been several important areas of discussion, and developments with respect to their application to long-lived waste disposal. In 1998 the ICRP issued a new policy document (ICRP 77) concerned with the disposal of all types of radioactive waste, which clarified some of these issues. However, the ICRP currently feels that all three of these publications need to be supplemented, updated and clarified, and ICRP Committee 4 issued draft recommendations now published as ICRP 81 [ICRP-1, 1999], which are discussed below. This is complemented by a report ICRP 82 [ICRP-2, 1999] on situations involving prolonged public exposures.

A key issue ICRP 81 addresses is the use of dose and risk in the assessment of potential exposures, since this is especially relevant for the human intrusion scenario of great importance in salt repositories.

Use of Dose and Risk in the Assessment of Potential Exposures

Potential exposures are those which are not certain to occur but which can be assigned a probability of occurrence. ICRP acknowledges that there are methodological problems and uncertainties in modelling potential exposures for radioactive waste repositories.

When the concept of potential exposures was first applied to deep repositories, it was generally assumed that there was some category of behaviour that could be termed 'normal evolution', analogous to 'normal exposure' in present day practices, in radiological protection parlance. Other exposures resulting from natural environmental events, could be classed as probabilistic. ICRP now accepts that their previous recommendation (in ICRP 46) to treat normal and probabilistic situations separately may not be practicable [ICRP-2, 1999]. Instead, they have moved towards two new categories of exposure pathway: natural and human intrusion.

Although ICRP 77 (1998) recognized that the role of potential exposure in risk assessment for long-lived radionuclides is not yet clear, it continued to recommend that the annual individual risk to a critical group for potential exposure (combined with annual individual dose to a critical group for normal exposure) would be adequate for comparing the limiting detriment to future generations with that currently applied to the present generation. ICRP 81 [ICRP-1, 1999] suggests that the constrained optimization process could calculate either risks or disaggregated dose/likelihood. Either approach can provide the same degree of protection. The latter approach is particularly useful for examining, in detail, those scenarios, which have low probability, but high potential consequences.

To summarize, the latest ICRP guidance can be taken to envisage a long-term radiological safety assessment calculating disaggregated doses under reasonable, selected test conditions, as if they were doses as defined in the normal ICRP dose constraint framework. However, these should be regarded as performance measures or safety indicators (which could be complementary to other indicators: see below). Demonstration of 'compliance' is not as simple as straightforward comparison of doses with the ICRP constraints, as proof that the system satisfies such criteria cannot be absolute. A decision on acceptability should be based on reasonable assurance rather than absolute demonstration of compliance, and will require a latitude of judgement. A safety case should be supported and justified by other evidence to see whether additional measures could reasonably improve protection.

Other Performance Measures

The limitations of dose and risk with increasing time into the future have led to other repository performance measures being suggested. An underlying feature of several of these measures is comparison with natural systems. Qualitative arguments, based on natural analogues, can be used by the implementing agencies to build up a robust case to support compliance calculations. This approach has been used in several national programmes, although it is usually applied at a subsidiary level, rather than being presented as the backbone of a safety case.

More specifically, measures that are being suggested to complement dose or risk include:

- Fluxes of radionuclides from the repository into the environment, averaged over long time periods.
- Comparisons with fluxes of natural radioactivity (and other toxic substances) through the environment: essentially a comparison with natural background radioactivity or chemotoxicity.
- Toxicity indices for the waste itself.
- Sub-system criteria, such as container lifetimes and radionuclide fluxes through specific engineered barriers.

At the outset, it is important to note that the list above does not identify alternative measures. These should be regarded as complementary indicators which will add to the information base used by decision makers. The challenge is to identify how to calculate them, how to use them and how to adjust the weight given to all the measures at different times in the future.

Radiological Protection of the Natural Environment

The framework for radiological protection of people works in exactly the opposite way to that used for protecting from most other environmental hazards. Commonly, society tries to adopt measures for protecting the environment, since that is then assumed to protect humans also. In radiological terms it is always stated that, if people are adequately protected, then the environment is adequately protected. ICRP 60 (1991) states that *'the standard of environmental control needed to protect man to the degree thought desirable will ensure that other species are not put at risk'*. Some commentators say that this is a largely empirical belief, unsupported by any substantial body of evidence, which may not always be the case, particularly when all time and space scales are considered: for example, possibly high doses to benthic fauna from historic seabed disposal, but only minute doses to people [Pentreath, 1998]. The IAEA has recently produced a discussion report [IAEA, 1999] that notes that there is now sufficient information to be able to move forward to serious consideration of an approach to protection of the natural environment.

Although there is a large amount of information on radiation effects on the environment [UNSCEAR, 1996], there is no internationally recognized way to use this to reconcile and develop the two approaches, and certainly no agreement on how to incorporate such considerations into regulations for waste disposal. Based on the UNCED Convention on Biological Diversity (part of the UNEP Rio Conference of 1992), Larsson and Sundell-Bergman [Larson and Sundell-Bergmann, 1999] suggest that a general regulatory objective could be formulated in terms of:

- protection of biological diversity: identifying real or generic critical populations in different ecosystems and ensuring that these populations are not significantly threatened by releases of radionuclides;
- protecting biological resources by ensuring that critical organisms with economic or cultural value are not threatened.

In summary, the BMU has correctly identified that the development of dose and risk criteria, the value of other safety indicators and broader protection of the environmental arena merits further attention. The issue involved affect all programmes, not just those in Germany and not just those in salt. In all other countries examining these issures, the waste management programmes are being advanced in papallel with the continuing scientific discussions.

References

IAEA (1996): International Basic Safety Standards for Protection against Ionising Radiation and for the Safety of Radiation Sources. International Atomic Energy Agency, Vienna, 1996, Safety Series No. 115, 353 p, IAEA, Vienna, 1996.

IAEA (1999): Protection of the environment from the effects of ionizing radiation. IAEA-TECDOC-1091, 53 p, IAEA, Vienna, 1999.

ICRP (1977): Recommendations of the International Commission on Radiological Protection. ICRP Publication 26. Pergamon Press, Oxford, 53 p, 1977.

ICRP (1985): Radiation Protection Principles for the Disposal of Solid Radioactive Waste. ICRP Publication 46. Pergamon Press, Oxford, 23 p, 1985.

ICRP (1991): 1990 Recommendations of the International Commission on Radiological Protection. ICRP Publication 60. Pergamon Press, Oxford, 201 p, 1991.

ICRP (1998): Radiation Protection Policy for the Disposal of Radioactive Waste. ICRP Publication 77. Pergamon Press, Oxford, 21 p, 1998.

ICRP-1 (1999): ICRP Committee 4: Task Group on Radiation Protection Recommendations as Applied to the Disposal of Long-Lived Solid Radioactive Waste. Draft Version 24/2799 (published in ICRP 81), 1999.

ICRP-2 (1999): Protection of the Puclic in Situations of Prolonged Radiation Exposure, ICRP Publication 82, Pergamon Press, 1078, 1999.

Larsson, C-M. and Sundell-Bergman, S. (1999): Protection of the natural environment - philosophy and criteria. In: 'Health and Environmental Criteria and Standards', Stockholm Environment Institute, p 170 - 174, 1999.

Pentreath, R.J. (1998): Radiological protection criteria for the natural environment. *Rad. Prot. Dosimetry* 75, p 175 - 179, 1998.

UNSCEAR (1996): Effects of Radiation on the Environment. UN Scientific Committee on Effects of Atomic Radiation, 1996 Report to UN General Assembly: Annex 1, 7-86. UN, New York, 1996.

A 2.7 Observations from Nature; Natural Analogues

The BMU recognizes that observations from nature can give indicators of salt dome stability and can support safety analyses. It also points out, however, that proper use of analogue evidence is difficult, that anthropogenic disturbances make things even more complicated and that extrapolation of results to other sites is problematic.

All of the above points are valid. They are not new and have been addressed in natural analogue studies for more than 20 years. Some of the earliest studies were on integrated analogues of complete disposal systems. The best known is that of the natural reactors at Oklo in Gabon [Walton and Cowan, 1975]. Subsequently interest also grew in studying more specific process analogues (e.g. of radionuclide migration) and in archaeological analogues of value for understanding the behaviour of the engineered barrier system. This increased interest led to foundation in 1986 of the Natural Analogue Working Group of the EU [Côme and Chapman, 1986a, 1986b, 1989, 1991] This group is still in existence and has generated a wealth of literature on natural analogues. The most comprehensive overviews of natural analogue studies are in the two books by Miller et al. [Miller et al., 1993, 2000]

Analogue systems can be studied for a variety of reasons:

- to build conceptual understanding of the processes governing the long-term behaviour of a geologic repository

- to measure specific parameters for use in safety assessments
- to measure parameters for comparison with estimates derived from calculational models, thus helping to build confidence in these models
- to illustrate to a wide range of audiences, including the general public, that deep geological media can provide a stable environment, which can prevent mobilization and transport of radionuclides for extremely long times.

In practice, the direct use of parameter values from natural analogues in repository safety assessments has been extremely limited (mainly to corrosion rates for waste matrix and container materials). The value of analogues in raising technical and public confidence in the scientific understanding of deep repositories has been significant. Various national programmes have produced special publications on the topic and an internationally sponsored film was produced for public viewing [Nagra, 1994]. The biggest challenge has been to extract "hard" scientific data, which can be used in rigorous testing of safety assessment models. This has been achieved, however, in some cases, particularly those relating to the thermodynamic models predicting solubility of specific nuclides in groundwaters [Linklater et al.,1996].

For the case of salt repositories there have been few specific analogue studies. One important example, however, is a Sandia investigation of igneous intrusion into salt. This gave valuable confirmation that the heat did not affect the salt properties over any significant distance. Germany does however, participate in the Natural Analogue Working Group mentioned above and recently efforts have been made in Germany to establish a more active national programme in this area [Steininger, 2001].

In summary, the value of natural analogue studies, and also the difficulties in quantitatively interpreting these have been long recognized. The challenge to any waste disposal programme is to make best use of the available natural analogue evidence. Serious programmes are addressing this challenge; studies to date have yielded valuable evidence on the reliability of scientific modelling concepts for various host rocks; further creative work for the medium salt may be possible.

References

Côme, B. and Chapman, N.A. (eds) (1986a, 1986b, 1989, 1991): Natural Analogue Working Group; First Meeting, Brussels, November 1985. Second Meeting, Interlaken, June 1986. Third Meeting, Snowbird, June 1988. Fourth Meeting, Pitlochry, June 1990. CEC Nuclear Science and Technology Reports, EUR 10315, 10671, 11725, 13014. Commission of European Communities, Luxembourg.

Linklater, C.M., Albinsson, Y., Alexander, W.R., Casas, I., McKinley I.G. and Sellin, P. (1996): "A natural analogue of high pH cement pore waters from the Maqarin area of Northern Jordan: comparison of predicted and observed trace element chemistry of U and Se", Jour. Contam. Hydrol. 21, p. 59 - 69, 1996.

Miller W.M., Alexander W.R., Chapman N.A., McKinley I.G. and Smellie J.A.T. (1993): Natural Analogue Studies in the Geological Disposal of Nuclear Wastes", Elsevier, Amsterdam, 1993.

Miller W.M., Alexander W.R., Chapman N.A., McKinley I.G. and Smellie J.A.T., (2000): The geologic disposal of radioactive wastes and natural analogues: lessons from nature and archaeology, Elsevier, Amsterdam, 2000.

Nagra (1994): Traces of the Future: A video film produced by Nagra with international sponsorship. Nagra, Wettingen, 1994.

Steininger W. (2000): German Natural Analogue Research Activities; Proceedings of the 8th EC Natural Analogue Working Group Meeting, 23-25 March 1999, Strasbourg, EC Nuclear Science and Technology 2001 (in press).

Walton R.D. and Cowan G.A. (1975): Relevance of nuclide migration at Oklo to the problem of geologic storage of radioactive waste, in "the Oklo Phenomenon", IAEA, Vienna, 1975, p. 499-507, 1975.

A 2.8 Multiple Barrier System

The concept of a Multiple Barrier System (MBS) as applied to repositories for radioactive waste is nothing new. It is applied in many industries, especially in nuclear installations like nuclear power plants or reprocessing plants for spent fuel. The basic idea of the MBS is that a series of different barriers enhances the safety of the respective facility, plant, or installation. The core of the assertions made by BMU is that it is "controversial whether barriers should be fully independent" and that if full independence is aimed at, then it is doubtful whether Gorleben will function if the salt dome fails.

Compared to any other nuclear or industrial plant, a repository for radioactive waste in geological formations is a passive system. There are no high pressures and/or temperatures and there are no fast occurring reactions or processes. The features, events and processes (FEPs), which have to be taken into account for the long-term safety of a repository, are extremely slow, apart from a very limited number of examples, like an earthquake. On the other hand, the safety of a repository system has to be evaluated for extremely long time periods, in some countries in the order of some hundred thousand years even up to one million years depending on the national regulation.

During more than 40 years of research and development including design and safety assessments, international agreement has been reached that the MBS for repositories in geological formations comprises two different groups of barriers:

- engineered (technical) barriers
- geological (natural) barriers

Engineered barriers are:

- the waste form (ceramic fuel pellets, HLW glass)
- primary containers (fuel cladding, HLW stainless steel canister)
- specifically designed containers (overpacks) for the long-term containment of spent fuel or HLW (made from copper, steel, cast iron, specific alloys, or combination of these)
- buffer materials for waste containers (e.g. compacted bentonite blocks or bentonite granules)
- backfill materials (e.g. sand or rock/bentonite mixtures, crushed rock salt, rock/cement mixtures)
- specifically designed seals for boreholes, drifts, and shafts

Geological barriers are:

- the host rock in which the repository is located
- geological formations neighbouring the host rock (adjacent, underlying, overburden)
- a favourable hydrogeological situation with no or very slowly moving groundwater and with low hydraulic gradients
- a favourable geochemical situation with regard to technical and geotechnical barrier lifetime as well as radionuclide retention.

As mentioned in the beginning there is complete international agreement to apply the MBS for radioactive waste repositories in geological formations. Well advanced examples are:

- The Yucca Mountain project in welded tuff in the United States [DOE, 1999]
- The Olkiluoto repository project in granite in Finland [Posiva, 1999]
- The repository project in granite or sedimentary rock in Japan [JNC, 2000]
- The repository project in granite in Sweden [SKB, 1999]
- The repository project in Opalinus clay in Switzerland [Nold, 2000]

Besides these projects there is one repository already in operation, namely the Waste Isolation Pilot Plant (WIPP) in the State of New Mexico in the US. This repository successfully went through a complete licensing procedure performed by the

US Environmental Protection Agency [USEPA, 1998]. WIPP is located in a bedded salt formation. Within its MBS the most important barrier is the Salado salt formation. Other barriers are favourable aspects of the overlying aquifers, their transport characteristics, the MgO used as a chemically and mechanically functioning backfill and the waste form itself (mostly cemented matrixes).

The total effectiveness of a MBS for radioactive waste repositories has to be assessed with the tool of a "Total System Performance Assessment (TSPA)". Within this TSPA all realistic scenarios, derived from a logical screening of all FEPs, are assessed for their consequences. Within this process, also failure of one or more barriers is evaluated. For the specific example addressed by the German Government, namely the long-term safety of a repository for radioactive waste located in the Gorleben salt dome, a TSPA also has to address the failure of the most important barrier in the MBS, namely of the host rock salt. Only if it can be shown by the repository's safety case that the repository with its MBS is able to meet the regulatory safety standard it has a chance to be licensed. The safety case for a repository in Gorleben also has to include some possible failure of the geological barrier "rock salt" if the FEP-screening and the scenario analysis should result in such a possible failure.

In all projects mentioned the combination of engineered and geological barriers, working together, is intended to give a high level of safety and high confidence in the functioning of the overall system. The weights given to different individual barriers vary from concept to concept. In fractured rocks, for example, access of groundwater to the repository is the normal case and hence a larger burden of isolation falls on the buffer and/or the overpack. For salt, the normal case is effectively total exclusion of circulating groundwaters at the repository. Thus the geological medium provides an extremely powerful isolation barrier. Scenarios in which this isolation is compromised by various low probability scenarios must also be examined. None of these will totally remove the salt barrier, but some may compromise its efficiency. Experience with WIPP has indicated that human intrusion may be the most significant scenario for analyses. Hypothetical scenarios in which the total geological barrier is removed from the MBS system cannot be expected to lead to satisfactory performance in any geological disposal concept.

In summary, the use of multiple safety barriers is common in repository designs. These barriers are partly overlapping and partly complementary. It is generally expected that full safety is guaranteed even when a barrier fails completely. In practice, complete failure of any single barrier in a geologic repository is barely credible; at most, individual barriers lose their efficiency and overall system safety is still guaranteed by the combined functionality of all remaining barriers. The Gorleben project does include multiple barriers. The salt dome itself is the strongest geological barrier. The surrounding and overlying geologic media provide an environment that permits proper functioning to the salt barrier. They are not expected on their own to provide a fully functioning redundant barrier.

References

DOE (1999): Viability Assessment of a Repository at Yucca Mountain.- Department of Energy, Office of Civilian Radioactive Waste Management, 1998, 4 volumes, Washington D.C., December 1998.

EPA (1998): Certification Decision for the Waste Isolation Pilot Plant's Compliance with EPA's Radioactive Waste Disposal Standards, March 1998.

JNC (1999): H 12: Project to Establish the Scientific and Technical Basis for HLW Disposal in Japan – Japan Nuclear Cycle Development Institute, April 2000, 4 volumes, 1999.

Nold, A.L. (2000): The Swiss HLW/ILW Repository in Opalinus Clay – Programme, Layout and Emplacement of Spent Fuel Canisters – DisTec 2000, 143 - 152, 2000.

Posiva (1999): Safety assessment of spent fuel disposal in Hästholmen, Kivetty, Olkiluoto and Romuvaara – TILA-99, Posiva OY, March 1999.

SKB (1999): Deep Repository for Spent Nuclear Fuel – SR 97 – Post Closure Saftey, Technical Report TR – 99 – 06, Stockholm, November 1999

A 2.9 Retrievability

The reasons given by BMU for including retrievability in their list of problematic issues are that the Gorleben disposal concept was not designed for recoverability and that the international state-of-the-art now includes explicitly planning for retrieved operations.

There is a general agreement in the technical community that the safest way to dispose of long-lived wastes is by geological disposal. That means emplacement of the waste in a repository built deep underground in a suitable geologic formation. The safety of the repository is then assured by multiple passive barriers (engineered and geological), in such a way that after closure there is no need for any further action by future generations. It is true that during the development of the geologic disposal concept (in all types of host rocks) retrievability was not an issue.

Retrieval of wastes for safety reasons was reckoned to be a scenario of such low probability that little effort was devoted to its study. Retrieval for other reasons, such as recovery of usable raw materials (fissile isotopes, precious metals etc.) was treated under the heading of deliberate human intrusion. The philosophy which was commonly followed was that no measures should be taken to ease such retrieval and that any future society deliberately embarking on this course is itself responsible for any risks arising. The responsibility of today's society is to maximize the safety of future generations whilst imposing minimum future burdens.

However, the debate on retrievability has been active now for several years [IAEA, 1997; Euratom, 2000; KASAM, 1988; KASAM, 2000, Petersen, 1998]. (The OECD/NEA working group mentioned by BMU follows on a series of other meetings on retrievability during the last few years).

As arguments for retrievability, two major reservations have been expressed in social and political circles:

- The closure of a repository appears to many as too final and irrevocable. There is a desire to be assured that things can be corrected if the science and technology experts after all haven't got it quite right.
- More from an ethical point of view, irreversible geological disposal is seen by some as denying future generations the opportunity to choose to recover the waste. This may be to reuse some components or else because the advancement of technology may allow better conditioning of the wastes in the future or other solutions for waste management better suited than geological disposal.

Of course, the simplest way to ensure total reversibility and to leave open all future potential options would be to delay geological disposal and to store the waste in a surface or subsurface facility. This solution, however, would pass to future generations the burden and responsibility of waste management and also implies increased risks.

There are different possible levels of retrievability:

- Reversibility:
  Denotes the ability to reverse one or a series of steps in repository planning and development at any stage of the programme. This implies the review, and if necessary re-evaluation of earlier decisions, as well as the technical means to reverse a step. A programme may be planned to facilitate reversibility, for example by adopting small steps and frequent reviews in the programme as well as by engineering measures. In the early stages of a programme, "reversal" of a decision regarding site qualification, or the adoption of a particular design option, may be considered. At later stages, during construction and operation, or following em-

placement of the waste, reversal may involve engineering measures, such as the modification of one or more components, or even retrieval of waste packages.

- Retrievability:
  This is a special case of reversibility, being the ability to reverse the action of waste emplacement. Retrieval, the action of recovery of waste or waste packages, may be considered at various stages after emplacement, including after final sealing and closure. In discussing retrievability, it is important to specify what is to be retrieved, since this affects the implementation and technical feasibility. Retrieval could, for example, refer to recovery of individual waste packages, identified as faulty or damaged, even as emplacement of other packages continue; retrieval of some or all of the waste packages at some time after emplacement, or retrieval of the waste materials if the packages are no longer intact. Retrievability may be facilitated by the repository design and operational strategies, e.g. by leaving underground access ways open and emplacement / retrieval systems in place until a late stage, and through the development and use of durable containers and easily excavated backfill.

- Recoverability:
  This term is sometimes used to describe retrieval operations aimed at recovering the waste itself, e.g. to recover reusable fissile materials in spent fuel, to submit the waste to a new conditioning process or to submit the waste to a new treatment with the aim of decreasing its long-term radiotoxicity (partitioning / transmutation). Such an action would depend on a careful cost/benefit analysis, balancing the operational risks incurred by workers during the retrieval, recovering and treatment operations against the benefits of material reuse or the decrease of the long-term risk if there is any.

Positions on retrievability taken in selected countries

The earliest formal position taken on retrievability was in the USA where a 50-year period of retrievability was required in regulations as a guarantee that recovery options were possible should some unforeseen problem occur during the operational period of a geologic repository. As the debate on retrievability intensified over the last ten or more years, the implementing organizations of some national programmes voluntarily built into their concepts easier retrievability. In Sweden, SKB amended its strategy to include a demonstration disposal phase and specific studies were performed to provide evidence that wastes could be retrieved after this period if this choice were made. For a Swedish type repository with long-lived containers embedded in soft bentonite clay within a stable hard crystalline host rock, this is a relatively straightforward matter. Some other countries also directly addressed the technical feasibility of retrieving emplaced wastes (e.g. UK Nirex studied the removal of soft grouts from around ILW containers in a deep repository). In Switzerland, Nagra, in response to public opinion in the wake of the referendum on the Wellenberg repository, introduced design and operational features to allow easier monitoring and retrieval of wastes for decades or even centuries. Recently the USDOE OCRWM organization has altered the reference design of the proposed Yucca Mountain repository to make direct control of wastes and easy retrievability for up to three hundred years.

At a regulatory level, the tendency was still to warn against the possible negative safety effects of easy retrievability rather than to require that retrieval be possible. For example the Swiss regulations [HSK/KSA, 1993] state that, whilst retrievability is not forbidden, any measures intended to ease retrievability may not have a detrimental effect on long-term safety. The regulatory situation changed when the authorities in the Netherlands forbid any geologic disposal which was not shown to be retrievable. This tendency of authorities to respond to public pressure requiring retrievable disposal has grown stronger with time. France requires retrievability now [CNE, 1998]; the latest report of Government experts in Switzerland proposes long-term underground retrieval disposition for a portion of HLW emplaced in a special part of the repository called pilot repository [EKRA, 2000].

The current situation in Sweden is that the authorities are neutral with respect to retrieval. They say, however, in the proposed regulation that if measures are taken to simplify or facilitate retrieval the consequences of these measures must be analyzed in the safety assessment. The thought behind is that the measures must not impair safety. (It is also interesting to note that the municipality council of Oskarshamn in their review comments to the proposed SKI regulation say that: The municipality wants to point out that it has not been expressed during the current feasibility study that the public would endorse specific measures to facilitate retrieval.)

The current situation worldwide concerning retrievability is that virtually all countries will expect a proof that retrieval is feasible if required. The question of financial responsibility for any retrieval operations has not been finally cleared up in all countries. Ultimately, the long time scales of relevance imply that responsibility must pass to the state. At any time, the liability is obviously with the state should retrieval be undertaken for reasons other than protecting public health and safety.

The specific case of the Gorleben repository

In salt, retrievability will be technically somewhat more difficult to implement than in other geological media such as crystalline rocks and even clay formations, due to the plasticity of the salt and its natural ability for creeping still increased by the thermal output of high-active wastes. On the other hand, in a salt medium, after backfilling of the repository works the creeping of the surrounding rock means there will never be a significant risk of water ingress. The only credible reason for possible waste retrieval would be to recover the spent fuel for reprocessing and reuse of fissile materials, or, for vitrified wastes, (very improbably) to carry out new conditioning. Although difficult, retrievability is possible, as acknowledged by BMU. Specific techniques have also been planned for this in Germany [Buirrun et al., 1995, 2000] and for the WIPP repository in USA. For Gorleben the conclusions drawn were that retrieval is possible if the rock temperature is below 100°C and that this will occur after a time period depending on the repository layout and the spent fuel cooling time prior to disposal.

Deep geological repositories will be constructed and operated over many decades and will be sealed only after a long monitoring phase. Accordingly, there is little operational pressure to finalize retrievability concepts. However, disposal systems are being actively planned and designed, so that retrievability features must be discussed now. More importantly, the whole issue of retrievability is irrevocably linked to the question of public confidence in the safety of geologic repositories – and this fundamental issue is directly linked to the ethical and environmental questions concerning continued use of nuclear technologies.

Retrieval is always possible in principle. Engineering methods to allow retrievability are available, even though they become more complex and expensive as the stepwise closure of the repository progresses and with increasing time after closure of the repository. This conclusion must be demonstrated to the public on the basis of specific studies on retrieval concepts and techniques. Specific studies on retrieval procedures in Gorleben have been done within the German disposal programme. For HLW without significant content of fissile materials retrievability arguments are related mainly to the confidence of different groups in the long-term safety performance of the repository. For fissile materials, the prime arguments for and against retrievability concern resource conservation and weapons safeguards. However, the public desire to have reversibility as such - without specifying the reason or giving any justification - needs to be acknowledged. Retrieval in salt is feasible if steps are taken to restrict maximum temperatures. The relative complexity of retrieval in salt relative to other host rocks is a direct result of the excellent sealing and isolation properties.

References.

Biurrun, E., Engelmann, H.J., Hubert, R., Lommerzheim, A. und Pöhler M. (1995): Untersuchung zur Rückholbarkeit von eingelagertem Kernmaterial in der Nachbetriebsphase eines Endlagers, DEAB T 57, BMBF Förderkennzeichen 02E8371, Februar 1995.

Biurrun, E., Engelmann, H-J., Brennecke, P. und Kranz, H. (2000): Safety and safeguards aspects of retrievability: a German study in IAEA Tecdoc 1187, Retrievability of high level waste and spent fuel, Proceedings of an International Seminar organized by Swedish National Council for Nuclear Wastes (KASAM), October 1999, IAEA, Vienna, 2000.

CNE (1998): Réflexions sur la réversibilité des stockages; CNE Report, Paris, June 1998.

EKRA (2000): Disposal Concepts for Radioactive Wastes, Final Report, Expertengruppe Entsorgungskonzepte für radioaktive Abfälle, January 2000

Euratom (2000): Concerted action on the retrievability of long-lived radioactive waste in deep underground repositories – Final Report; EU Project report series Nuclear Science and Technology, EUR 19145 EN, 2000.

HSK/KSA (1993): Protection Objectives for the Disposal of Radioactive Waste; Regulatory Guideline R-21 of the Swiss Federal Nuclear Safety Inspectorate (HSK), November 1993.

IAEA (1997): Issues in radioactive waste disposal; 2nd Report of the Working Group on Principles and Criteria for Radioactive Waste Disposal, Chapter 2, p. 9ff, IAEA-TECDOC-909, IAEA, Vienna, 1997.

KASAM (1988): Ethical aspects on nuclear waste – Some salient points discussed at a seminar on ethical action in the face of uncertainty in Stockholm, Sweden, September 1987; Statens Kärnbränsle Nämnd/National Board for Spent Nuclear Fuel, SKN Report 29, April 1988.

KASAM (2000): Retrievability of high-level waste and spent nuclear fuel, Proceedings of an International Seminar in Saltsjöbaden, Sweden, October 1999, IAEA-Tecdoc-1187, Vienna, 2000.

Peterson, P.E. (1998): Post-closure repository safeguards – Comprehensive assessments of excavation methods; Proc. International High-Level Radioactive Waste Management '98, p. 735-737, 1998.

A 2.10 Chemo/toxic Waste Issues for Deep Geologic Repositories

The BMU paper raises the concern that chemo/toxic constituents in radioactive waste pose safety problems that "have not received close attention so far." It is true that the safety concerns related to chemo/toxic materials in Gorleben itself have not yet been evaluated. This is so because the issue of chemotoxicity is not of great importance for conditioned high-level wastes or spent fuel; the potential problem arises primarily with low- and medium-active wastes. The issue should therefore be evaluated in more detail for Gorleben. However, there is ample precedent, as shown in the following paragraphs, to believe that chemo/toxic materials to be found in low- and medium-active wastes will not pose a safety threat to the long-term behaviour of either salt or hard rock repositories designed to contain the radioactive components of the waste.

Deep disposal of non-radioactive chemo/toxic or hazardous wastes in mined repositories has been considered in many countries and practised in a few, most notably in Germany [Kühn and Hawickhorst, 2000]. In 1975 the United States Environmental Protection Agency (EPA) issued a report [Stone et al., 1975] which concluded that deep underground storage and disposal of chemo/toxic wastes would be an environmentally acceptable way of managing the wastes. This report especially commented on salt, potash, and gypsum mines as offering most suitable containment. Deep potash/salt mines have been used in Germany for hazardous waste disposal since the early 1970s. The Herfa-Neurode disposal facility has been used since 1972. A good summary of some of the chemo/toxic waste, deep repository operations in Germany is contained in a paper by [Rempe, 1995]. It is clear then that the issue here is not with the safety of chemo/toxic waste disposal in deep mined repositories in salt formations per se. Studies, as well as practical experience, show it can be done safely. So the question must be whether co-disposal of chemo/toxic wastes and radioactive wastes poses synergistic threats to containment.

Germany has disposed of low- and medium-level radioactive wastes containing hazardous material at the Morsleben repository since 1978 and only recently terminated operations at this facility. Studies of the effects that may occur from this waste after facility closure are now underway and these considerations have raised similar issues for Gorleben. The Konrad deep repository, which is currently in the final licence phase, satisfactorily addressed the issue of chemo/toxic safety. An evaluation of the Konrad repository with respect to chemo/toxic safety was documented in a paper by [Brennecke, 1999]. He concludes from his conservative evaluation that the criteria for chemo/toxic limits in water will not be exceeded and the "existence of danger can be excluded" for any postulated release from the repository. There is no reason why a properly designed salt repository, such as Gorleben, would not show a similar result when the calculations are performed.

The WIPP facility, a transuranic repository in bedded salt, disposes of waste that contains appreciable quantities of chemo/toxic materials ranging from heavy metals to volatile organic compounds. These materials are subject to regulatory criteria (RCRA) separate from those for radioactive material. The WIPP has been permitted for disposal of these materials by the State of New Mexico [WIPP, 1999] and is currently disposing of this mixed transuranic waste. This permit determined that the WIPP repository would safely contain these chemo/toxic constituents for at least 10,000 years, the time period required by the regulation.

Safety analyses have been recently published [SKB, 1999] for a deep geologic repository in hard rock for long-lived low- and intermediate-level wastes. This report addresses the chemo/toxic metals lead, cadmium and beryllium contained in the waste. The predicted accumulations of these metals for the scenarios that considered releases to coast and archipelago environments never reached current day levels. In agricultural and peat land environments, calculated values could reach present day values at times between 100,000 and 10 million years in the future but would not likely continue to increase in concentration due to long-term climatic changes.

When chemo/toxic wastes are commingled with radioactive wastes, there are factors that will have to be considered that may be ignored for radioactive waste alone. This has to do with the possibility for radioactive colloids to form in the presence of organics or for radioactive isotopes to become more readily solubilized if organic chelates are present in the waste. Also, the carbon dioxide generated by microbial degradation of the organic components in the waste can result in a lower pH environment. These chemical conditions can accelerate the corrosion of canisters, thereby increasing the corrosion gas generation rate, and increasing the solubility of certain isotopes in any water present. All these reactions require the presence of water. Again, lack of significant quantities of water in an unbreached salt repository is one of the favourable aspects of a salt host rock.

These aspects have been thoroughly studied by the WIPP Project and determined to not present a significant threat to the repository performance. Indeed, the fact that any water that could contact the waste would be in the form of a concentrated brine significantly reduces the potential for migration of radioactive colloids due to flocculation. One could anticipate a similar result for Gorleben. Nevertheless, these issues and calculations to resolve them are not minor and do have to be performed for the specific repository under consideration.

If the low/medium-level waste is close enough to the spent fuel to see elevated thermal conditions, then the effect of heat on the organics in the waste must also be considered. Extensive studies would be necessary to examine the nature and rate, at higher temperature, of all the processes enumerated earlier. These results would have to be considered in a performance assessment before the consequences of such close co-location could be determined. For this reason it would be highly desirable to keep the two waste forms thermally isolated from each other.

It should be noted, that to date, other nations contemplating disposal of spent fuel/high-level waste in deep geologic repositories do not plan to dispose of low/medium-level wastes in the same facility. There are several reasons for this decision. One of the principal reasons low- and medium-level waste is not contemplated as a component of high-level waste repositories is that deep geologic isolation is simply not required for satisfactory safety. Low-level waste radioactivity decays rapidly enough that very long-term isolation is not necessary for the radioactive component. The chemo/toxic constituents are generally in small concentration and are considered adequately isolated by shallow land burial. Additionally, the larger amounts of space required by the larger volumes of low/medium-level waste generally recommend the economies of near surface land burial if adequate sites are available.

The other common reasons for separating the L/ILW from the HLW/SF are to avoid having to consider the complex chemical interactions that are conceivable. Given the additional, though surmountable, concerns of gas generation, colloid potential and the prospect of increased solubilization by organic chelates, it makes sense to keep these two types of waste disposal separate to avoid the complications that would have to be addressed in a final performance assessment or safety evaluation for a combined facility.

One may conclude that other nations have not chosen to co-locate low- and medium active and spent fuel/high-level waste for good reasons. These reasons include:

- increased complexity of phenomena that would have to be considered in repository performance,
- the potential for known deleterious effects such as gas generation and increased solubility of isotopes,
- the lack of an objective, safety-related justification, for isolating low-/medium-activity waste in deep mines (and especially in HLW repositories) and
- the greater costs associated with deep disposal of chemo/toxic wastes for most nations.

The first two of these reasons lose their validity if the different waste types are disposed in the same salt dome - but fully separated.

Although some analyses still need to be done to address the case of chemo/toxic constituents in low/medium-level waste disposed in Gorleben, there is every reason to believe, based upon completed studies in Sweden, the United States (WIPP) and indeed, for the Konrad repository, that the Gorleben repository will perform satisfactorily. The information and capability now exist to conduct conservative site-specific bounding calculations. These calculations should be carried out as soon as possible to determine if the uncertainties are acceptable or whether more research needs to be conducted to better define the relevant mechanisms.

References

Brennecke, P. (1999): Safety-related Aspects due to Organic and Inorganic Waste Constituents, Waste Management '99 Proceedings, Feb. 28 – March 4, 1999, Tucson, Arizona, 1999.

Kühn, K. und Hawickhorst, W. (2000): Entsorgung und Endlagerung in Deutschland – inhaltlich gescheitert und ohne sachliche Grundlage? – Teil 2 – atomwirtschaft 45, Heft 8/9, p 540 – 545

Rempe, N.T. (1995): Deep Geologic Disposal in Germany—Models for Mixed Waste Disposal in the U. S., Proceedings of the Third Biennial Mixed Waste Symposium, Baltimore, MD, August 7-10, 1995.

SKB (1999): Deep repository for long-lived low- and intermediate-level waste. Preliminary safety assessment. SKB TR 99-28. Svensk Kärnbränslehantering AB, November 1999.

Stone, R.B., Aamodt, P.L., Engler, M.R., and Madden, P. (1975): Evaluation of Hazardous Waste Emplacement in Mined Openings, EPA-600/2-75-040, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1975.

WIPP (1999): Hazardous Waste Facility Permit NM 4890139088-TSDF, October 27, 1999 (URL: http://www.wipp.carlsbad.nm.us/library/caolib.htm#RCRA)

A 2.11 Modelling Calculations - Handling of Uncertainties

Different kinds of uncertainties

The basic knowledge, models and data for an assessment of the long-term safety of a deep repository are necessarily characterized by different types of imperfections and uncertainties. An important part of such an assessment is therefore the handling of these deficiencies. Modelling in general will by its nature have inherent uncertainties. Despite that, modelling can be used to assess the function of a system. Modelling is also an indispensable tool to describe a system and its uncertainties in a structured way.

The key statements in the BMU documentation that concerns modelling uncertainties are as follows [BMU, 2000]:

> *"The development of probabilistic (geostatistical) analyses for application to, for example, the modelling of ground water (movement) and transport (processes) has only just begun. The impact of these basic research efforts on statements about the uncertainties in the models and scenarios used remains unknown. Licensing procedures ... have so far required only deterministic safety assessments. It is necessary to firmly incorporate safety assessments and related safety goals based on probabilistic (methods) in the assessment basis for Gorleben."*

In practise, both probabilistic and deterministic methods have been used in repository modelling for many years and a broad scientific consensus on the relative pros and cons of each has been achieved. In this context it is relevant to note the following comments by the Swedish Nuclear Power Inspectorate (SKI) to their recently proposed regulations concerning safety at disposal of nuclear waste [SKI, 2000]. These comments give a good summary of the current thinking internationally on this issue.

> *"Lack of knowledge and other deficiencies in assumptions, models or data used in the performance assessment calculations are in this context called uncertainties. These uncertainties can be categorised into:*
>
> - *Scenario uncertainties; uncertainties in outer or inner conditions with respect to art, level and timing;*
> - *System uncertainties; uncertainties in completeness of description of the system of FEPs used for the analysis of single barrier functions as well as for the whole repository;*
> - *Model uncertainties; uncertainties in the calculational models used for the calculations;*
> - *Parameter uncertainties; uncertainties in the values of the parameters (input data) used for the calculations;*
> - *Spatial variability in the parameters used for describing the barrier functions of the geosphere (in particular concerning groundwater flow, mechanical and geochemical properties).*
>
> *There are often no clear borderlines between the different kinds of uncertainties; the important thing is that the uncertainties are described and handled in a consistent and structured manner.*
> *The evaluation of uncertainties is an important part of the safety case. This means that uncertainties must be thoroughly discussed and considered at the selection of cases for calculation, choice of calculation models and parameter values as well as at the assessment of calculation results.*
> *The assumptions and calculations models that are used must be carefully selected with due consideration to the application and the choice must be motivated by discussion of alternatives and*

with reference to scientific bases. In cases where there are doubts on which model to use several models should be applied in order to elucidate the uncertainties with respect to choice of model. Both the deterministic and probabilistic models should be applied in such a way that they supplement each other and thus give a broadest possible picture of the risks."

These comments are very much in line with the discussion and recommendations given by the so-called IPAG group set up by OECD/NEA Radioactive Waste Management Committee [NEA, 1997]. They point out that the benefits of a deterministic approach are that it gives a transparent treatment of the different kinds of uncertainties and often a clear presentation of the expert judgements involved. Further the results are relatively easy to understand and communicate. Also it is possible to employ rather complex mathematical models in the analysis. A major disadvantage is that it is often difficult to give a logical explanation of the selection of cases analysed and to demonstrate that adequate coverage has been given to combinations of uncertainties. Advantages of the probabilistic approach are that it provides an explicit representation of parameter uncertainty and derivation of a risk estimate for the whole system. Disadvantages with the probabilistic methods are the need to develop appropriate density functions for each parameter, to either ensure sampling of independent parameters or develop quantitative descriptions of correlations between non-independent parameters in order to avoid non-physical combinations of data. Further the methodology has an inherent difficulty in demonstrating an appropriate representation of low-probability/high-consequence "tails". It is often difficult to communicate the assumptions and results from probabilistic assessments.

Probabilistic analysis – historic development

The development of probabilistic methods for long-term safety assessment started about twenty years ago with the development of the SYVAC-code in Canada [Dormuth and Quick, 1980]. The Canadian approach was soon followed by similar developments in other countries and a special working group PSAC (Probabilistic System Assessment Code user group) was set up within OECD/NEA in order to facilitate international comparison of the developments in the participating countries. This group was active from the mid-1980's to the early 1990's and published a series of reports.

Development of the probabilistic modelling for groundwater flow in fractured crystalline rock resulted in the HYDRASTAR-code at SKB in Sweden [Norman, 1991]. This code applies a stochastic continuum approach. Parallel development of statistical discrete fracture flow modelling was conducted and applied by the international OECD/NEA Stripa project [Gnirk, 1993]. The codes thus developed have been applied in later Swedish safety assessments.

Thus it is not correct to assert that "the development has only just begun". On the other hand it must be kept in mind that the development of the probabilistic methodology continues and will continue. More and more data and experiences are gathered and this knowledge should be fed into improvements of the methods applied in safety analyses. This development is however not unique for long-term safety assessments of nuclear waste disposal. Another factor of practical importance for the development is that probabilistic methods are very dependent on large and fast computer capacity. This is a field where dramatic improvements have occurred and probably will continue. Thus we may expect continued increased use of the probabilistic methods.

Approach to safety assessment

The acceptance criterion for a deep repository is often formulated as a risk criterion. This means that both probability and consequence must be estimated for a conceivable sequence of events. The probabilistic element can be made larger or smaller in the consequence calculations in a safety assessment. Different countries and organizations have elected their specific approach, often as a reflection of the laws and regulations in each country.

The SYVAC-code was used extensively by AECL for the environmental impact assessment made for the Canadian disposal concept in the early 1990s [AECL, 1994].

In looking through recently published safety assessments for deep repository projects one finds that indeed a mixture of deterministic and probabilistic approaches have been applied. The viability assessment for the Yucca Mountain project in USA includes a fairly comprehensive use of the probabilistic methodology [DOE, 1998].

The work on WIPP, the US bedded salt repository, incorporated probabilistic performance assessment as a fundamental tool to direct the necessary project research and ultimately to demonstrate compliance with the regulatory standards. The analyses began in 1985 as an annual evaluation of WIPP's safety. They were critical in developing priorities for the various ongoing research efforts. Probabilistic methods allowed evaluation of sensitivity and uncertainty analyses for critical modelling parameters. Thus they permitted the work at WIPP to focus effort on those studies that would provide the greatest contribution to confidence in the final performance assessment.

Because of the self-healing characteristics of salt and the absence of natural geologic phenomena that could breach the site, the major focus of the performance assessment was on the likelihood and consequences of inadvertent human intrusion. The processes that proved to be most critical in this evaluation involved gas generation, actinide solubility and radionuclide transport, all of which proved to be important elements of the intrusion scenario. To address the inherent uncertainties in the hydrogeologic system, a geo-statistical model was developed to assure uncertainties were adequately covered.

Regulatory authority (EPA) certified WIPP in 1998 based primarily upon the performance assessment presented in the 1996 compliance application that documented WIPP's compliance with the regulatory criteria [DOE, 1996].

The Swedish SR-97 assessment includes a combination of methodologies [SKB, 1999]. In SR-97, detailed probabilistic distributions of parameter values have been derived for input primarily to probabilistic radionuclide transport calculations only where there is some kind of statistical material on which to base a distribution. This includes:

- Conditions in the geosphere that are determined by the spatial variability of the geosphere. These may include primary conditions such as fracture statistics or hydraulic conductivity, or data calculated on the basis of the spatial variability, e.g. water travel times.
- Positions for initially damaged canisters in the repository.
- Earthquake statistics for an earthquake scenario.

For other input parameters to the probabilistic radionuclide transport calculations, a more simplistic approach has been applied using a reasonable or best estimate value and a pessimistic value. These values have been selected and carefully justified by experts in the specific areas.

Risk calculations for a deep repository contrast here with calculations for many technical systems where statistics from operating experience, mainly from individual components or subsystems, can serve as a basis for a probabilistic analysis. In a safety assessment of, for example, the operation of a nuclear power plant, operating statistics for pumps and standby generators can provide data for a probabilistic analysis.

In safety assessments the use of pessimistic assumptions and bounding calculations applying deterministic models is often a valuable tool for some types of scenarios. The Finnish TILA-99 assessment almost entirely relies on a deterministic methodology [Posiva, 1999]. They use bounding calculations or worst case scenarios. This is also the case in the SITE-94 project conducted by SKI [SKI, 1996].

It is interesting to note that SKI in their proposed regulatory document [SKI, 2000] suggest what they call "remaining scenarios" should cover events and processes that are selected and studied independently from probabilities in order to illustrate the importance of single barriers or barrier functions.

The proposed repository in Gorleben is located in a salt dome. Due to its physical properties this is a more homogeneous medium than crystalline rocks. The necessity for extensive use of probabilistic methods for calculation of groundwater flow thus seems to us to be less than for other host rocks such as crystalline rock. The brief review above suggests however that the probabilistic methodology has been developed and is available for application when needed. Thus this issue does not constitute any major concern with respect to the Gorleben site.

References

AECL (1994): Environmental impact statement on the concept for disposal of Canada's nuclear fuel waste. AECL-10711, COG-93-1. September 1994.

BMU (2000): Current issues in closing the nuclear fuel cycle. Status: May 2000. Translation of: http://www.bmu.de/atomkraft/entsorgung.htm; Stand Mai 2000: Aktuelle Entsorgungsfragen.

DOE (1996): DOE Compliance Certification Application, 1996. http://www.wipp.carlsbad.nm.us/library/cca/cca.htm

DOE (1998): Viability assessment of a repository at Yucca Mountain. Total System Performance Assessment. US Department of Energy OCWRM DOE/RW-0508 Volume 3. December 1998.

Dormuth, K. W. and Quick, R. D. (1980): Accounting for parameter variability in risk assessment for a Canadian nuclear waste disposal vault. International Journal of Energy Systems 1, p. 125-127, 1980.

Gnirk, P. (1993): OECD/NEA International Stripa Project 1980-1992. Overview Volume II. Natural Barriers. (p 225 - 301 – Modelling of groundwater flow and solute transport), 1993.

NEA (1997): Disposal of radioactive waste. Lessons learnt from ten performance assessment studies. Nuclear Energy Agency Organization for Economic Co-operation and Development. OECD/NEA, 1997.
http://www.nea.fr/html/rwm/reports/1997/ipag.pdf.

Norman S. (1991): Verification of Hydrastar – A code for stochastic continuum simulation of groundwater flow. SKB TR-91-27, SKB July 1991.

Posiva (1999): Safety assessment of spent fuel disposal in Hästholmen, Kivetty, Olkiluoto and Romuvaara. TILA-99, Posiva OY, March 1999.

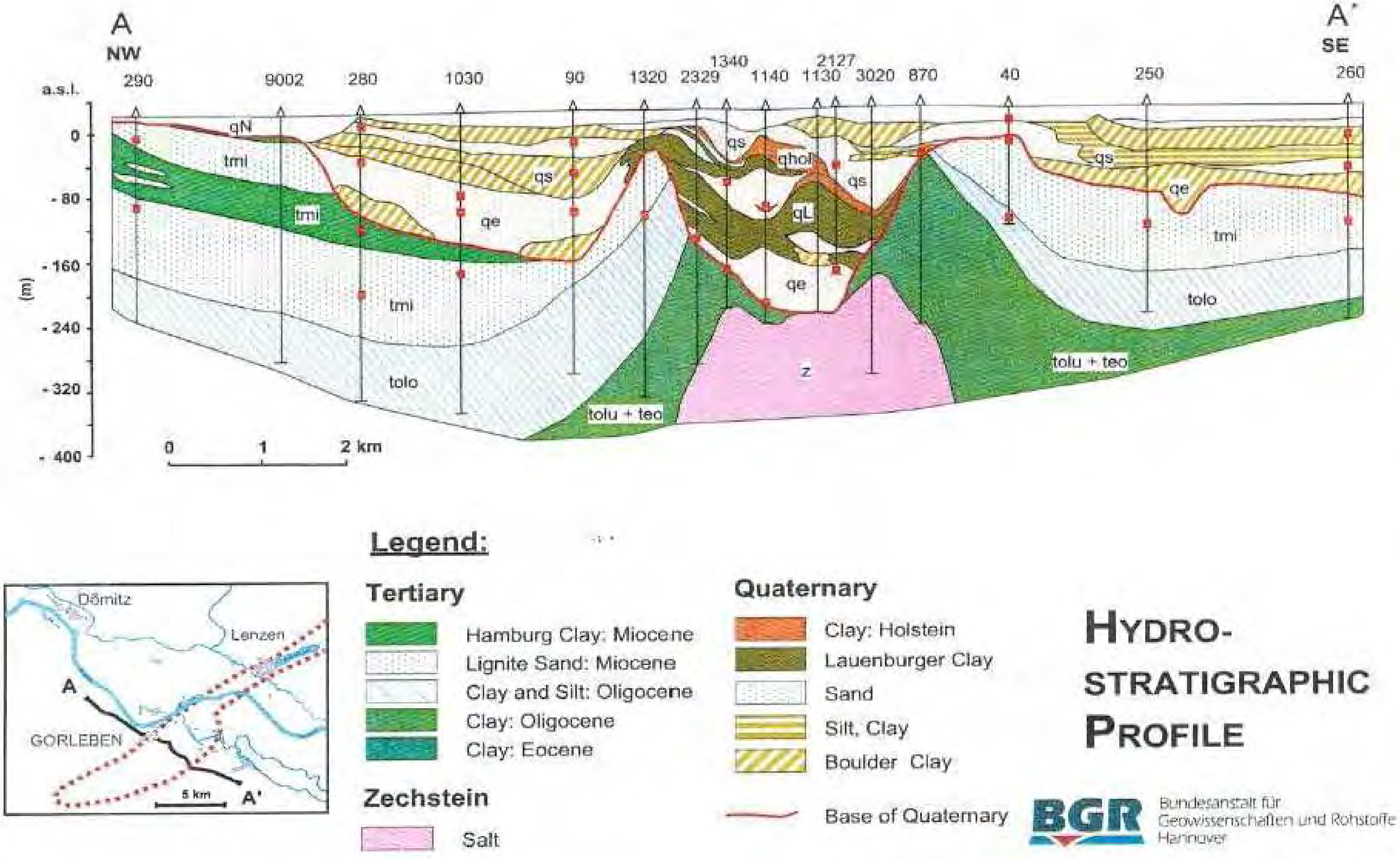
SKB (1999): Deep repository for spent nuclear fuel. SR-97 – Post-closure safety. Technical Report TR-99-06, Stockholm, November 1999.

SKI (1996): SITE 94, Deep Repository Performance Assessment Project, SKI Report 96:36 Vols. 1&2. Summary, SKI Report 97:5. Swedish Nuclear Power Inspectorate, Stockholm, 1996.

SKI (2000): Kommentarer till SKI:s föreskrifter om säkerhet vid slutförvaring av kärnavfall. Preliminär version för remiss. (Comments to SKI:s regulation on safety at final disposal of nuclear waste. Preliminary version for review.) SKI-PM 5.1-990760 dated 2000-07-20, in Swedish, 2000.

Appendix 3

Figures


A
NW
A'
SE
290
9002
280
1030
90
1320
2329
1340
1140
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870
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- 80
- 160
- 240
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- 400
(m)
qN
tmi
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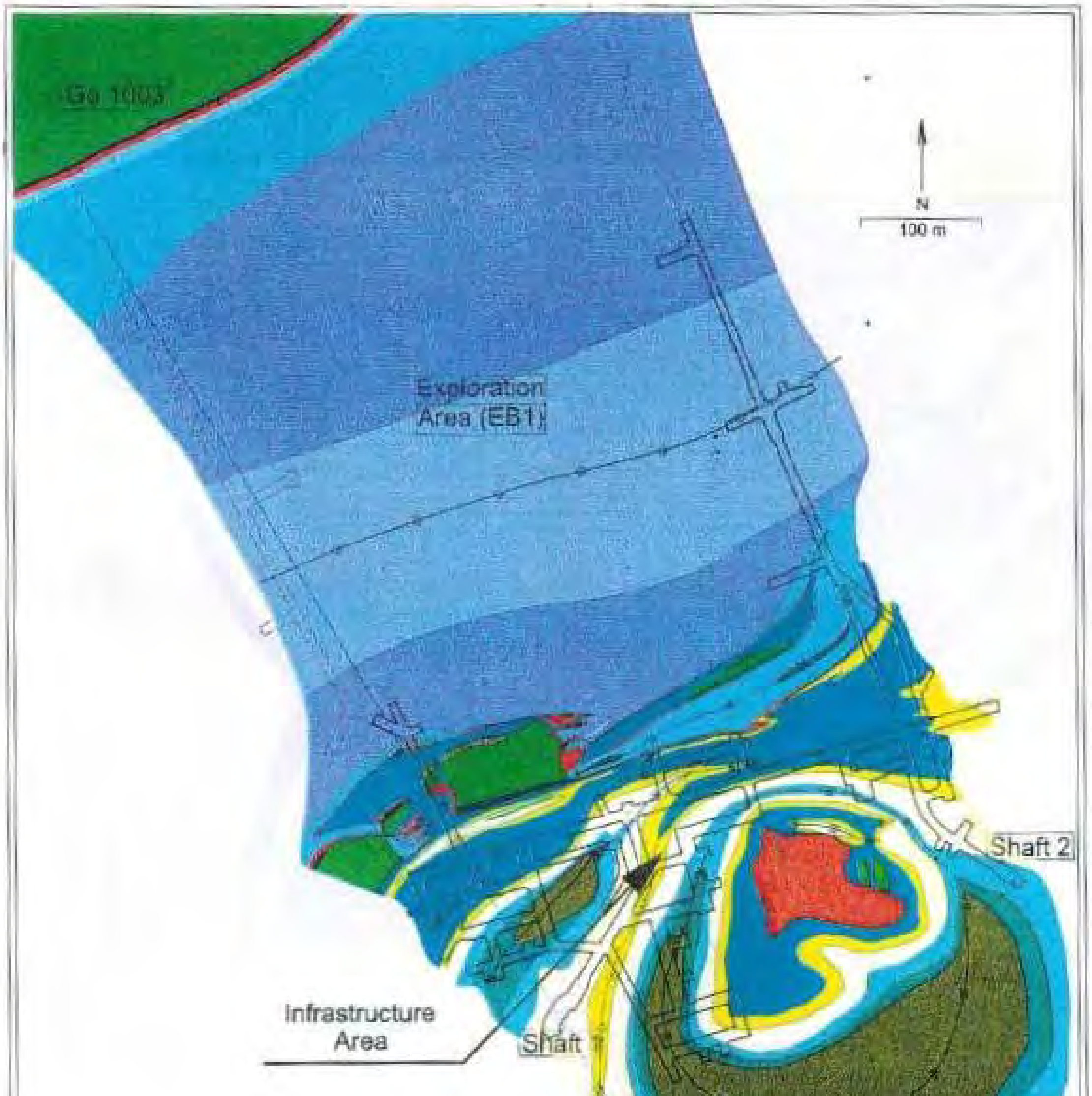
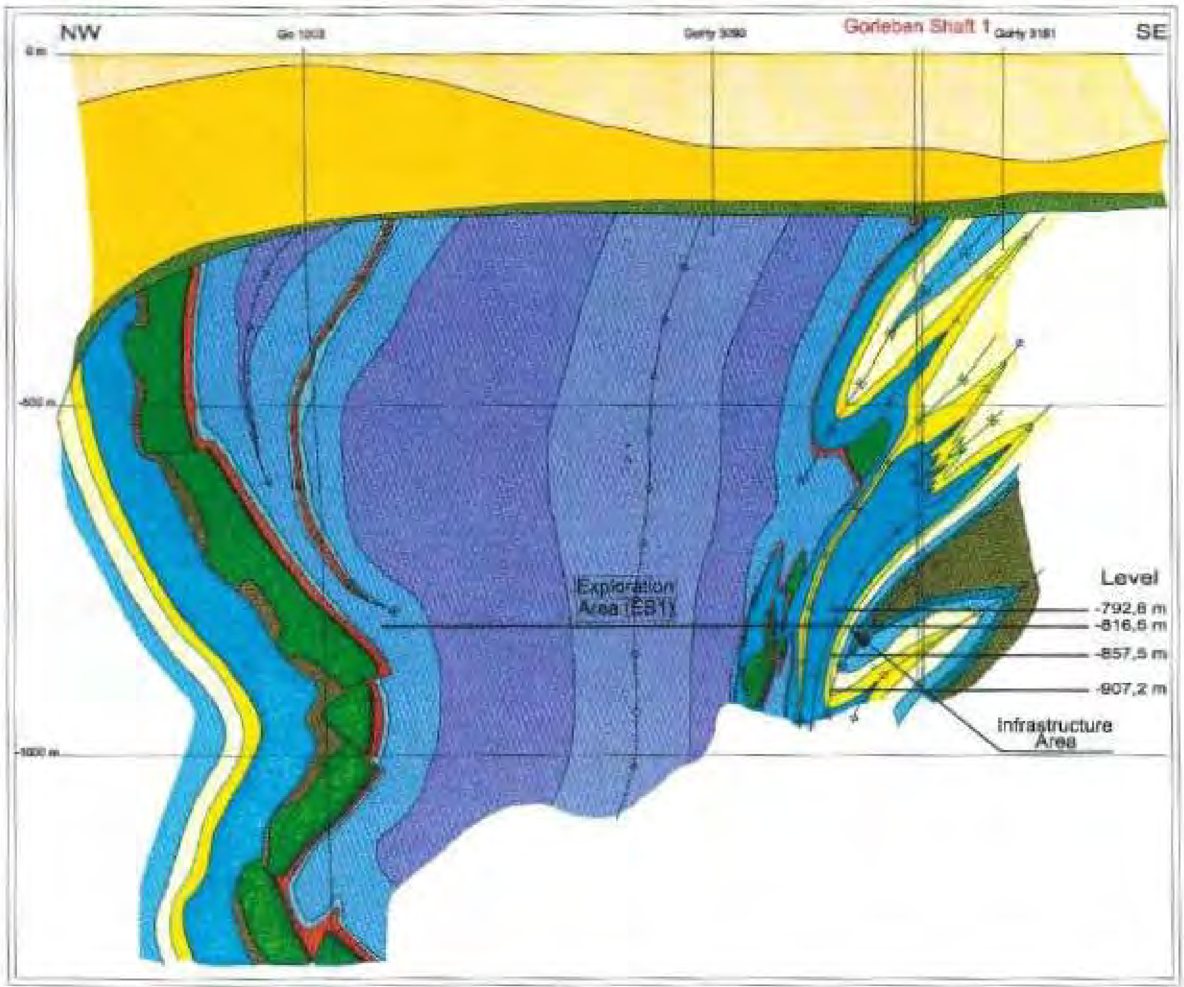
0
1
2 km
Legend:
Tertiary
Hamburg Clay: Miocene
Lignite Sand: Miocene
Clay and Silt: Oligocene
Clay: Oligocene
Clay: Eocene
Zechstein
Salt
Quaternary
Clay: Holstein
Lauenburger Clay
Sand
Silt, Clay
Boulder Clay
Base of Quaternary
Dömitz
Lenzen
GORLEBEN
5 km
HYDRO-
STRATIGRAPHIC
PROFILE
BGR
Bundesanstalt für
Geowissenschaften und Rohstoffe
Hannover

Geological Map of Exploration Area at 840 m Level



Vertical Cross-Section Exploration Area 1



Appendix 4

Übersetzung Kapitel 1 und 5

1 Einführung

In Deutschland wird die Endlagerung radioaktiver Abfälle durch das Atomgesetz geregelt. Nach diesem Gesetz muß die Bundesregierung Anlagen zur Sicherstellung und Endlagerung radioaktiver Abfälle errichten und diese betreiben. Die Regierung hat diese Aufgabe dem Bundesamt für Strahlenschutz (BfS) übertragen, einer Bundesbehörde, die dem Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU) untersteht. Das BfS beantragt die Genehmigung für ein Endlager, und die Behörden des Bundeslandes, in dem sich der jeweilige Endlagerstandort befindet, entscheiden über die Genehmigung. Das BfS kann sich zur Erfüllung seiner Pflichten Dritter bedienen. Eine Unterstützung erfolgte durch die Arbeit der Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), der Deutschen Gesellschaft zum Bau und Betrieb von Endlagern für Abfallstoffe (DBE), durch Forschungszentren und durch Universitäten.

Seit 1979 läuft in Gorleben im Bundesland Niedersachsen ein umfangreiches Untersuchungsprogramm zur Bewertung der Eignung des Salzstocks als Endlager für alle Arten radioaktiver Abfälle. Der Salzstock und der ihn umgebende Bereich wurden über Tage und unter Tage sehr detailliert untersucht. Ziel war es, die untertägige Erkundung bis zum Jahre 2003 fertigzustellen [Thomauske, 1998]. Die Verantwortlichkeit für die Planung und Entwicklung des Untersuchungskonzeptes sowie für die Sicherstellung der ordnungsgemäßen Ausführung der Arbeiten liegt beim BfS.

Vor dem Regierungswechsel Ende 1998 hatten BMU und BfS keine Zweifel hinsichtlich der Eignungshöffigkeit des Salzstocks von Gorleben als Endlager geäußert. Im Gegenteil, in einem entsprechenden Dokument [BMU, 1998] wird folgender Meinung Ausdruck gegeben:

> "... die hierbei gewonnenen Ergebnisse belegen nachvollziehbar, dass eine begründete Aussicht auf eine Eignung insbesondere für die Endlagerung hochradioaktiver, wärmeentwickelnder Abfälle und abgebrannter Brennelemente besteht ..."

Diese Position entspricht der weitverbreiteten Ansicht, die in zahlreichen veröffentlichten Berichten dokumentiert ist, daß während der Untersuchungen über und unter Tage bis heute keine Ergebnisse erzielt wurden, die Gorleben als potentiell geeigneten Standort ausschließen. Es wird jedoch eingeräumt, daß die Untersuchung unter Tage noch abgeschlossen werden muß und alle erzielten Ergebnisse in einer Sicherheitsanalyse bewertet werden müssen, um zu einer abschließenden Beurteilung hinsichtlich der Eignung des Salzstockes zu kommen.

Trotz der generellen positiven Bewertungen der Eignungshöffigkeit innerhalb der wissenschaftlichen Fachwelt gab es schon immer unterschiedliche Meinungen. Seit Beginn der Bewertung von Gorleben äußert eine kleine Gruppe von Geologen ihre Zweifel bezüglich der Eignung des Salzstocks von Gorleben als Endlager für radioaktive Abfälle. Ihre Argumente wurden in der Öffentlichkeit ausführlich diskutiert (z. B. sieben Gutachten, die für das Land Niedersachsen erstellt wurden). Gegenargumente wurden von Wissenschaftlern der Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) veröffentlicht [BGR, 1995]. 1998 haben die Gegner von Gorleben nochmals ihren Vorbehalten Ausdruck gegeben [Gruppe Ökologie, 1998]. Das führte dazu, daß das BMU seine oben zitierte Ansicht veröffentlichte [BMU, 1998]: bis heute gibt es keinen Beweis für die Nicht-Eignung des Salzstocks Gorleben als Endlager.

Ende 1998, als die neu gewählte Bundesregierung Deutschlands beschloß, aus der Nutzung der Kernenergie auszusteigen und das nationale Entsorgungsprogramm neu zu strukturieren, wurde die Zukunft von Gorleben als potentieller Ort für ein Endlager in tiefen geologischen Formationen zu einem wichtigen Thema. Eine Schlüsselfrage war, ob die Qualität der vor Ort ausgeführten wissenschaftlichen Arbeit und die bis dahin erzielten Ergebnisse der Standortuntersuchungen es rechtfertigen, mit dem Projekt fortzufahren. Die Gesellschaft für Nuklearservice (GNS) richtete die Internationale Expertengruppe Gorleben (IEG) ein, um den deutschen Elektrizitätsversorgungsunternehmen eine objektive wissenschaftliche Bewertung der Untersuchungen von Gorleben zu ermöglichen.

Die Mitglieder der IEG wurden ausgewählt, weil sie langjährige Erfahrung bei der Bearbeitung von nationalen Endlagerprojekten haben. Es wurden Fachleute aus Deutschland, Frankreich, Schweden, der Schweiz und den USA ausgewählt, die zusätzlich einen breiten Überblick über die Endlageraktivitäten weltweit haben. Einige Mitglieder haben in Endlagerprojekten gearbeitet, bei denen, wie im Fall von Gorleben, Salz als Wirtgestein genutzt wird. Appendix 1 enthält kurze Lebensläufe der Mitglieder der IEG, in denen die relevanten Aspekte ihres beruflichen Werdegangs beleuchtet werden.

Im Laufe des vergangenen Jahres, in dem die Hauptaktivitäten der IEG stattfanden, gab es neue Entwicklungen bei der Entsorgung radioaktiver Abfälle in Deutschland, die einen wesentlichen Einfluß auf die Arbeit der Gruppe nahmen. Im Juni 2000 paraphierten die Regierung und Vertreter der Elektritizitätsversorgungsunternehmen eine Vereinbarung, in der alle Aspekt einer Übereinkunft zum Ausstieg aus der Kernenergie in Deutschland abgedeckt wurden [BMU 1, 2000]. Auch das Projekt Gorleben wurde von dieser Vereinbarung beeinflußt. In Anhang 4 dieser Vereinbarung erklärte die Regierung, daß es hinsichtlich der potentiellen Eignung des Salzstocks Gorleben substantielle (überwiegend nicht standortspezifische) Zweifel gebe, und kam zu dem Schluß, daß die untertägige Erkundung und die relevanten ortsspezifischen Forschungs- und Entwicklungsarbeiten in Gorleben unterbrochen werden müssen. Die zukünftige Arbeit für Gorleben solle auf die Beantwortung der Fragen beschränkt werden, welche die sogenannten Zweifel aufwerfen. Die technischen Argumente der Wissenschaftler der Regierung, welche die Änderung der Politik rechtfertigen sollen, wurden im Mai 2000 vom BMU auf seiner Website veröffentlicht [BMU 2, 2000].

Als Folge dieser Entwicklung wurde der Umfang der Arbeit der IEG erweitert und schloß nun die Bewertung der endlagerrelevanten Aspekte der Vereinbarung und der BMU-Veröffentlichung ein. Im Laufe des Jahres 2000 wurde dann im Oktober die zeitweilige Unterbrechung der Erkundungsarbeiten (Moratorium) in Gorleben in Kraft gesetzt. Schlüsselfragen sind nun, ob und wann die Erkundungsarbeiten wieder aufgenommen werden können oder ob die Ergebnisse eines Untersuchungsprogramms, das bis Ende 2000 ungefähr 2,5 Milliarden DM gekostet hat, keinen weiteren Wert haben. (Diese Kosten werden vom BMU vorfinanziert, das für die Planung und Ausführung des Untersuchungsprogramms die alleinige Verantwortung hat, wobei sich das BMU anschließend durch Zahlungen von den vorausleistungspflichtigen Abfallerzeugern refinanziert.) Die Antworten auf diese Fragen sind, neben anderen Aspekten, von der Qualität und der Vollständigkeit der wissenschaftlichen Ergebnisse abhängig, die bis heute erzielt worden sind. Daher waren die Prüfung der Arbeiten in Gorleben und das Bewerten der wissenschaftlichen und technischen Aspekte, die von BMU/BfS zur Sprache gebracht wurden, die Aufgaben, auf die sich die IEG konzentriert hat.

Die Arbeit der Gruppe wurde während des gesamten Jahres 2000 ausgeführt. Es wurden vier Treffen in Deutschland abgehalten, wobei jedes mehrere Tage dauerte. Während dieser Treffen wurde auch eine Befahrung von Gorleben durchgeführt. Es wurde mit Wissenschaftlern der Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) sowie mit einem Mitglied der vom BMU eingerichteten Arbeitsgruppe AkEnd diskutiert. Die Zwischenergebnisse der IEG wurden in einer Reihe von Pressekonferenzen, die im Anschluß an jedes Treffen abgehalten wurden, öffentlich gemacht [Endlagerung, 2000]. Die Endergebnisse sind im vorliegenden Bericht dokumentiert, der von allen Mitgliedern der IEG gemeinsam entworfen, überarbeitet und formal bestätigt wurde.

Der Bericht soll als "Stand-Alone"-Dokument gelesen werden können. Daher beginnt er mit einem kurzen Überblick in Kapitel 2 über die bis heute – sowohl in Deutschland als auch an anderen Orten – durchgeführten Arbeiten im Zusammenhang mit der Endlagerung im Salz. Darauf folgen in Kapitel 3 zwei Abschnitte, in denen der spezielle Status des deutschen Endlagerkonzepts und des Projekts Gorleben zusammengefaßt werden. Danach, d.h. ab Kapitel 3.3, verschiebt sich die Betonung auf die Darstellung der Meinung der IEG, zusammen mit der angemessenen Rechtfertigung dieser Ansichten. Insbesondere in Kapitel 3.3 und in Appendix 2 werden die Antworten der IEG auf die vom BMU aufgeworfenen Zweifel bezüglich der Endlagerung in Salz im Licht der internationalen Erfahrung angesprochen. Anschließend ist ein Kapitel den speziellen Vorschlägen der IEG in drei Schlüsselbereichen gewidmet: Einrichtung eines nationalen Rahmenplanes für die Endlagerung, Ansprechen offener technischer Punkte und schrittweises Vorgehen bei der Endlagerung. Schließlich werden unter drei Überschriften die Schlußfolgerungen und Empfehlungen der Gruppe zusammengefaßt: das Gorleben-Programm, die vom BMU aufgeworfenen Zweifel und Empfehlungen für das weitere Vorgehen. Der Bericht enthält Appendices, welche die im Haupttext enthaltenen Punkte detaillierter behandeln.

5 Gesamtbetrachtung und Schlußfolgerungen der IEG zu Gorleben und zum Endlagerungsprogramm in Deutschland

5.1 Standortauswahl von Gorleben und dessen Charakterisierung

Die Sicherheit eines jeden Endlagers hängt letztendlich von den charakteristischen Merkmalen des Standorts (und des Endlagerkonzeptes) ab. Sie wird nicht durch das Verfahren zur Auswahl des Standortes bestimmt. Demzufolge kann man die beiden folgenden Fragen getrennt stellen:

Wurde der Standort Gorleben richtig ausgewählt?
Kann am Standort Gorleben der erforderliche Sicherheitsnachweis geführt werden?

Die erste Frage kann nicht unter rein wissenschaftlichen Gesichtspunkten beantwortet werden, da auch gesellschaftliche, wirtschaftliche und politische Gesichtspunkte die Auswahl eines Endlagerstandortes beeinflussen. Die zweite Frage kann, im Prinzip, unter Anwendung der Methoden zur Bewertung der Sicherheit beantwortet werden, die während der letzten 25 Jahre international entwickelt wurden – vorausgesetzt, die für die Bewertung notwendigen Daten sind in ausreichender Qualität und Quantität verfügbar.

Die Auswahl von Gorleben im Jahr 1977 basierte auf einem Forschungsprogramm, das ungefähr 10 Jahre zuvor begonnen hatte. Die Methodik und die Durchführung des Auswahlverfahrens waren nicht transparent, so wie es heute in den meisten Ländern für die Standortauswahl empfohlen wird. Die Öffentlichkeit wurde nicht einbezogen, und es ist wenig oder keine offene Dokumentation verfügbar. Die Auswahl fand jedoch vor über 23 Jahren statt, zu einer Zeit, als die derzeit empfohlenen Ansätze in keinem Land angewandt wurden. Sie waren noch nicht einmal entwickelt worden. Die Gegner Gorlebens behaupteten, daß das Auswahlverfahren selbst den Ort disqualifiziere. Das gleiche Argument wurde in den USA von Gegnern des Standortes Yucca Mountain in Nevada vorgebracht, der vom US-Kongreß aus einer kurzen Kandidatenliste ausgewählt wurde. Diese Argumente sind nicht wissenschaftlich, und es bleibt eine politische oder gesellschaftliche Entscheidung, ob die Investition in die Erforschung eines potentiell geeigneten Ortes aus gesellschaftlichen oder politischen Gründen abgeschrieben werden kann oder sollte.

Nach der Auswahl von Gorleben als potentieller Standort für ein Endlager in tiefen geologischen Formationen wurden das über- und untertägige Untersuchungs- und Erkundungsprogramm umfangreicher durchgeführt als an irgendeinem anderen Standort weltweit, mit Ausnahme der beiden US-Endlagerprojekte WIPP und Yucca Mountain. Es wurde eine umfassende Datenbasis zusammengetragen. Die Daten bieten derzeit keine technischen Gründe für eine Ablehnung des Standortes. Das bedeutet jedoch nicht, daß schon alle für ein Genehmigungsverfahren erforderlichen Daten erarbeitet worden wären, wie sie im Programm für die Standortcharakterisierung festgelegt wurden. Weitere Untersuchungen sind notwendig, die allerdings durch das Moratorium unterbrochen wurden. Die IEG ist der Auffassung, daß der Abschluß der geplanten Aktivitäten zu einer umfassenderen Datenbasis für die Beurteilung von Gorleben als Standort für ein Endlager für hochaktive Abfälle führen würde. Diese verbesserte Datenbasis wäre auch dann von Nutzen, wenn ein Vergleich von Gorleben mit weiteren Standorten erstellt werden sollte, die, unter Anwendung der vom AkEnd aufzustellenden Kriterien, in Zukunft ausgewählt werden.

5.2 IEG-Schlußfolgerungen zur aktuellen Entsorgungsstrategie Deutschlands

Das ursprüngliche Ziel der IEG war es, nur das Untersuchungsprogramm von Gorleben zu bewerten. Aufgrund der weitreichenden Entscheidungen im deutschen nationalen Entsorgungsprogramm war es jedoch erforderlich, die Entwicklungen in Gorleben in einem breiteren Kontext zu sehen. Daher hat die IEG auch die gesamte deutsche Strategie hinsichtlich der Entsorgung radioaktiver Abfälle behandelt. Die Gruppe hat ihre detaillierten Erörterungen und Schlußfolgerungen jedoch auf die Endlagerung hochaktiver Abfälle und abgebrannter Brennelemente begrenzt.

Darüber hinaus soll jedoch auf einen wichtigen Punkt hingewiesen werden: kein anderes Land verfolgt das Ziel, alle seine radioaktiven Abfälle in einem einzigen Endlager zu entsorgen; dieses ist aber das erklärte Ziel der deutschen Regierung. Es gibt vernünftige wissenschaftliche Gründe für die Trennung von Abfallarten mit unterschiedlicher Radioaktivität, Wärmeerzeugung und (und das ist am wichtigsten) chemischen Merkmalen. Selbstverständlich können auch in einem einzigen Salzstock von ausreichender Größe alle Arten von Abfall an getrennten Orten sicher untergebracht werden. Es ist dann eine rein finanzielle Frage, ob man nicht nur für hochaktiven Abfall, sondern auch für schwach- und mittelaktiven Abfall die Endlagerung in tiefen geologischen Schichten durchführen möchte. Im Fall Deutschlands wurde die Entscheidung bereits getroffen, und die Schachtanlage Konrad wurde vorgeschlagen.

Um zum zentralen Thema der Entsorgungsstrategie für hochaktive Abfälle oder abgebrannte Brennelemente zurückzukehren, bemerkt die IEG, daß die neuen Schlüsselentscheidungen der Regierung die folgenden sind:

- eine Aktivität zu Standortkriterien zu initiieren, die möglicherweise zu alternativen Standorten für ein Endlager in tiefen geologischen Formationen führen
- das geplante Datum für den Betrieb des Endlagers von "so früh wie möglich" auf "ungefähr 2030" zu verschieben.

Auch diese Entscheidungen basieren nicht ausschließlich auf wissenschaftlichen und technischen Argumenten. Wie in allen Ländern müssen dabei ebenso gesellschaftliche und politische Aspekte betrachtet werden. Von dieser Vorgehensweise ist auch die IEG überzeugt. Es ist jedoch wichtig, so klar wie möglich zwischen den unterschiedlichen Gründen zu unterscheiden, auf denen Entscheidungen legitim getroffen werden können. Wissenschaftler, die auf dem Gebiet der Abfallendlagerung oder auch in anderen Bereichen, die einen großen Einfluß auf die Gesellschaft haben, arbeiten, sind dafür verantwortlich, daß objektive Argumente nicht zu früh im Entscheidungsprozeß mit politischen Standpunkten vermischt werden.

Nur ein Teil der Rechtfertigung für das Moratorium sind technische Aspekte. Das BMU hat eine Liste aller problematischen Punkte erstellt, die nach seiner Meinung geklärt werden sollen, bevor die Untersuchungen in Gorleben – oder vielmehr sogar im Salz als potentiellem Endlager-Wirtgestein – fortgeführt werden. Die IEG hat sich, wie in diesem Bericht dokumentiert, mit jedem dieser Punkte befaßt und die relevante internationale Literatur herangezogen. Die Gruppe kommt zu dem Schluß, daß keiner der angeführten Punkte neu ist. Praktisch alle werden seit Jahrzehnten auf internationaler Ebene diskutiert. An den meisten Themen haben auch Wissenschaftler in Deutschland mitgearbeitet. Keiner dieser Zweifel schließt eine sichere geologische Endlagerung im Salz im allgemeinen oder in Gorleben im besonderen aus. Für die Themen, für die eine weitere Klärung erforderlich ist, können, wie die IEG zeigt, Programme entwickelt und durchgeführt werden. Es gibt keine wissenschaftlichen Gründe für eine Unterbrechung der Erkundungsarbeiten in Gorleben während dieser Untersuchungen. Es wäre folgerichtig zu überlegen, ob vor Ort durchgeführte Untersuchungen zu weiterem wissenschaftlichen Input führen könnten.

5.3 IEG-Empfehlungen für die nächsten Schritte

Für ein Land wie Deutschland, das noch viele Jahre auf die Kernenergie angewiesen sein wird, wäre es unverantwortlich, Fortschritte auf dem Weg zu einer sicheren Endlagerung in geologischen Formationen unnötig zu verzögern. Auch mit der nun von der Regierung geplanten Streckung des Zeitplanes (2030) ist es notwendig weiterzuarbeiten, wenn zu diesem Zeitpunkt ein Endlager in Betrieb genommen werden soll, das nachweisbar sicher und gesellschaftlich akzeptabel ist.

Heute ist international anerkannt, daß ein erfolgreiches Programm mit diesem Umfang und dieser Dauer nur dann begonnen werden kann, wenn ein klarer Rahmenplan vorhanden ist. Das beinhaltet die Definition organisatorischer Strukturen und Verantwortlichkeiten, Programmstrategien und Meilensteine in transparenter Weise, was bisher in Deutschland nicht immer offensichtlich war. Alle betroffenen Interessengruppen müssen dazu ermutigt werden, an dem Prozeß interaktiv teilzunehmen. Viele der Probleme sind nicht Deutschland-spezifisch. Es gibt aber einige besondere Merkmale, die in Deutschland offensichtlicher sind. Dazu gehört die nur lose Einbindung der Abfallerzeuger in das Thema "Endlagerung" durch die Zuordnung jeglicher Verantwortung (bis auf die Finanzierung) an den Staat und an die ihm angeschlossenen Behörden. In den USA, wo eine ähnliche organisatorische Struktur besteht, hat dieses System zu Meinungsverschiedenheiten über gerade diese Verantwortlichkeiten geführt. Kürzlich wurden von der IAEA Richtlinien zur Strukturierung nationaler Endlagerungsprogramme veröffentlicht [IAEA, 1995], und es könnte nützlich sein, diese mit aktuellen oder zukünftigen Vorschlägen für Deutschland zu vergleichen.

Auf der nächsten Stufe darunter ist eine spezielle technische Strategie, die zu einem akzeptablen Endlager führt, erforderlich. Diese Strategie sollte flexibel sein und, wie weiter oben in diesem Bericht aufgeführt, auf ein schritt- oder phasenweises Vorgehen abzielen. Viele nationale Programme haben gezeigt, daß das Instrument "Langzeitsicherheitsanalyse" (TSPA; Total System Performance Assessment) hier außerordentlich wertvoll sein kann. Die Methode ist über Jahrzehnte hinweg entwickelt worden, und – wenn auch nicht perfekt – kann sie einen zuverlässigen Beitrag dazu leisten, Entscheidungen während der Entwicklung des Gesamtprojektes zu treffen. In Deutschland wurde diese Methode im Rahmen des Genehmigungsverfahrens für das geplante Endlager Konrad genutzt. Für Gorleben wurde die TSPA nicht ausreichend genug angewandt. Diese Technik kann man nicht nur für eine endgültige Bewertung der Sicherheit von Endlagern nutzen, sondern auch, um Forschungs- und Entwicklungsarbeit zu leiten und um entsprechende Programme zur Datenermittlung zu definieren.

Wie in Kapitel 4.3 angedeutet, ist die wichtige Frage der Standortauswahl auch Teil des schrittweisen Vorgehens hin zu einem Endlager. Dabei wurde darauf hingewiesen, daß es auf die Frage, wie viele Standorte betrachtet und bis zu welchem Detaillierungsgrad sie untersucht werden sollen, mehr als eine Antwort gibt. Die sich in den verschiedenen Ländern unterscheidenden Entscheidungsmechanismen basieren auf Betrachtungen der geologischen Vielfältigkeit, wirtschaftlicher Rahmenbedingungen und sozialer Gerechtigkeit. Dies muß angesprochen werden, wenn der AkEnd seine Standortkriterien erstellt hat. Aus wissenschaftlicher und technischer Sicht hält es die IEG für notwendig, daß Gorleben bei allen weiteren, auf der Arbeit des AkEnd beruhenden Vorschlägen mit berücksichtigt werden muß. Es ist unvermeidbar, daß auch der bisherige große finanzielle Aufwand für Gorleben eine Rolle bei der endgültigen Bewertung spielen wird. Als Begründung für das Moratorium wurde das Argument "steigende Kosten für weitere Arbeiten" genannt. Die IEG ist der Überzeugung, daß der Wert zusätzlicher Erkenntnisse, die durch die Beendigung des geplanten Erkundungsprogramms erzielt werden, die relativ bescheidenen weiteren Investitionen aufwiegen wird.

Die IEG macht darauf aufmerksam, dass ein schrittweises Vorgehen hin zur Errichtung eines Endlagers nur dann ernsthaft unternommen werden kann, wenn ein wichtiger Anfangsschritt getan wird. Dieser bedeutende Schritt besteht in der vollen Hinwendung – auch auf politischer Ebene – zum Konzept der Endlagerung in tiefen geologischen Formationen. Ein solches Endlager am richtigen Ort, das richtig geplant und betrieben wird, stellt eine sichere Lösung für das Problem der Entsorgung von radioaktiven Abfällen dar. Auf der politischen Ebene sind Reservierungen gegenüber der erreichbaren Endlagersicherheit gemacht worden. Es sind Andeutungen gemacht worden, daß die Endlagerung in tiefen geologischen Formationen nur die zweitbeste Lösung sein mag und durch Techniken ersetzt werden kann, die in Zukunft erst noch zu entwickeln sind. Dies ist keine Basis für die Bearbeitung eines glaubwürdigen Programms, das von motivierten Wissenschaftlern und Technikern auszuführen ist. Um Fortschritte zu ermöglichen, muß in ausreichendem Maße öffentliche und politische Unterstützung für die Endlagerung in tiefen geologischen Formationen gewonnen werden.

Fortschritte sind wichtig. Die IEG ist der festen Ansicht, daß die derzeitigen Entwicklungen in der deutschen Atompolitik nicht zu unnötigen Verzögerungen bei den technischen Anstrengungen zur Erreichung einer gesellschaftlich akzeptierten Lösung für die Endlagerung radioaktiver Abfälle führen dürfen. Wir sind verantwortlich für den Schutz der Umwelt für die jetzige und für künftige Generationen.

Literatur, siehe englischer Text