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NATIONAL BOARD FOR SPENT NUCLEAR FUEL

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Technical and Socio-political Issues in Radioactive Waste Disposal

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Volume I

Safety, Siting and Interim Storage.

STATENS KÄRNBRÄNSLE NÄMND

NATIONAL BOARD FOR SPENT NUCLEAR FUEL

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TECHNICAL AND SOCIO-POLITICAL ISSUES IN RADIOACTIVE WASTE DISPOSAL 1986

Volume I

Safety, Siting and Interim Storage

The Beijer Institute
of
The Royal Swedish Academy of Sciences

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TABLE OF CONTENTS

LIST OF APPENDIXES

VOLUME IA

LIST OF FIGURES

LIST OF TABLES

PREFACE

This study has been undertaken by the Beijer Institute of the Royal Swedish Academy of Sciences at the request of the Swedish National Board for Spent Nuclear Fuel (Statens Karnbranslenamd-SKN) - formerly known as NAK (Namnden for Anvant Karnbransle). The purpose of the study was to provide an integrated technical and sociopolitical analysis of how six countries (Federal Republic of Germany, France, Sweden, Switzerland, United Kingdom and the United States of America) have responded to four key issues in radioactive waste management: a) What constitutes "safe" or "absolutely safe" disposal, b) site selection processes, c) timing and type of interim storage, and d) subseabed disposal. The first three issues were selected by SKN for study to aid in their review of the comprehensive research programme on strategies for the disposal of spent fuel to be proposed by SKB (Svensk Karnbranslehantering AB)(Swedish Nuclear Fuel and Waste Management Company). The fourth issue, subseabed disposal, is of interest because of the international aspects and could be useful to keep abreast of current developments in the waste disposal field. Subseabed is presently considered to be the only available alternative to land based geologic disposal.

The Beijer Institute - The International Institute for Energy and Human Ecology - assembled a team of Professor Frank L. Parker, Vanderbilt University, (USA), Professor Roger Kasperson, Clark University, (USA), and Tor Leif Andersson, Tellus Energi AB, (Sweden), to prepare the report. The team has reviewed the scientific literature available to it, which consisted primarily of the reports of the electrical power companies or consortium of the power companies, of the international organizations active in the disposal of radioactive wastes (e.g. IAEA, NEA, CEC, ICRP) and of the publications of the various technical societies, energy and regulatory agencies and environmental and ecological groups in the individual countries. The team in toto orin part made visits to all of the countries included in this review to meet with representatives of waste producers, energy and regulatory agencies and environmental groups. No separate formal visits were made in the USA because of the involvement of two of the authors in USA waste disposal activities.

This report is a study of four key topics in the radioactive waste disposal field where both technical and socio-political factors are of great importance. Accordingly, this study builds upon and extends the previous report on the topic by the Beijer Institute, The Disposal of High-Level Radioactive Waste - 1984 (Parker et al, 1984). For the present report to be a stand alone document, various sections of the previous report, suitably updated and augmented, have been included in the appendices as background information.

While it would have been useful to review how these issues are treated in other major nuclear energy countries, time and money constraints have not permitted this. We should also note that the field of radioactive disposal is evolving so rapidly that a periodic review of the topic is necessary if the information is to be timely.

The study has been a joint effort of the three senior authors and Stephan A. Parker and with the help of Jimmy Levy.

We want to thank the Beijer Institute, and particularly its Director, Gordon T. Goodman, and its Deputy Director, Lars Kristoferson, for making the study possible and for guidance during the course of our work. We also want to thank the Swedish National Board for Spent Nuclear Fuel (SKN) for sponsoring the study, and particularly its Director, Olle Soderberg, and Chief Engineer, Nils Rydell, for advice and comments.

We want to thank the many people (too numerous to cite individually here. but listed in Appendix L) in the various countries and organizations that we contacted and visited for the great investment of their time and resources. Without their help, this report would not have been possible. We hope that the information contained in this report will be sufficiently useful to them to partially compensate for their help.

We would like to acknowledge the helpful comments and suggestions of the Beijer Institute Internal Review Group for this report. The members of the review group were:

Dr. Ghislain de Marsily of the Paris School of Mines, France
Dr. Reiner Papp of the Karlsruhe Nuclear Research Center, Federal Republic of Germany
Dr. Lewis Roberts of the University of East Anglia, England
Dr. Torbjorn Westermark of the Royal Institute of Technology, Sweden

This report, however, represents our views and interpretations, and any errors or misinterpretations are our own.

Frank L. Parker
Roger Kasperson
Tor-Leif Andersson
Stephan A. Parker

Stockholm, September 26, 1986

CHAPTER 1

INITIAL CONSIDERATIONS

From the background obtained from the previous Beijer Institute report on High-Level Radioactive Waste (Parker et al, 1984) it appeared that the views of the six countries surveyed (Federal Republic of Germany, France, Sweden, Switzerland, United Kingdom and the United States of America) on the four topics, a) what constitutes "safe" disposal, b) waste disposal site selection processes c) timing and type of interim storage and d) subseabed disposal, which are the subject of this study would be quite different. Our studies and our visits have confirmed these expectations. As pointed out in the previous report the views on each of these topics are coloured and tempered by a number of characteristics that are peculiar to each country. Among these are the size of the nuclear energy programme, the legal system, political culture, regulatory system, cultural heritage, public concerns, size of the country, geology and topography, scientific sophistication of the populace, energy resources, energy needs, fraction of energy supplied by nuclear power, wealth of the country, trust of authority and the politicization of nuclear energy development and waste disposal siting. Nevertheless, there is a degree of commonality among the technical views because all or most of the countries are members of many of the international bodies that are concerned with radioactive waste. All six, for example, are signatories of the Convention of the Organization for Economic Cooperation and Development (OECD) and members of its Nuclear Energy Agency (NEA), all are members of the International Atomic Energy

Agency (IAEA), three are members of Commission of the European Communities (CEC), and all subscribe to the principles of the International Commission on Radiological Protection (ICRP). In addition, there are wide ranging bilateral and multilateral agreements, exchanges of personnel and information, and personal communications among both the scientists and nuclear critics of these countries.

Consequently, while we have found good agreement, in general, among the scientists of the various countries on technical matters, we have found often divergent responses to these questions by governments and other political groups. For example on the technical side all of the countries are pursuing deep mined geological disposal. In contrast, on the socio-political side the USA is committed by law to final disposal by 1998, with a detailed sequence of steps to be followed in this process, whereas the United Kingdom is delaying the process for many decades. Sweden has successfully sited two radioactive waste facilities, whereas the progress on siting in the U.K. has encountered volatile and determined opposition. As indicated above there is no single "correct" answer to any of these questions any more than there is to what constitutes a "good" life. In the succeeding chapters we shall detail how the commonalities as well as the differences affect the solution reached in each of the countries.

To make our understanding of the problems within the individual countries more complete, we visited not only the producers of nuclear waste, (which, depending upon the country, are state-owned, privately-owned, or some combination thereof) but also the agencies which regulate the disposal of nuclear waste (which, again, depending upon each country, may be the federal government, or be highly dependent upon local governments). In some countries, even though there is no legal requirement for the local political unit to make a decision, in fact, because of the power or influence of those units, it would be very difficult for the central government to establish a repository without the concurrence or at least the tolerance of the local governmental unit.

In addition, we interviewed members of the environmental and ecological movements and/or political opposition or proponents in each of the countries. Because of the immediacy of the Chernobyl accident (April 26, 1986), some of our meetings during our first visit in the week of May 5 were cancelled and all (including those in our second visit, June 2-13) were affected. It is too soon yet to see all of the ramifications of the accident but distrust of the nuclear energy option and all activities related to it has increased markedly in several of the countries. As examples of the effects already felt, the Energy spokesman for the Social Democrat Party (SPD) in The Federal Republic of Germany, Volker Hauff, has called for the phasing out of nuclear energy and the elimination of reprocessing in the FRG; the Italian government has cancelled its tests of hole closure-emplacement in the NEA subseabed programme; and the Government of Denmark has called for the shutdown of the Barseback reactor in Sweden. The effects of the Chernobyl accident on the four topics of this report can only be speculated upon but at this time it is clear that a) What constitutes safety and what is satisfactory proof of that safety will be different. b) Siting of any nuclear facilities can only become much more difficult as a result of the accident (and consideration of international repositories is in abeyance. c) Pressure for interim storage until the previous two questions are resolved is more intense and d) Subseabed disposal consideration can only become more difficult.

Prior to our visits to each country we had updated the previous country reports (Parker et al, 1984) and sent each person we proposed to interview a letter explaining the purpose of our visit and a list of specific questions on each of the four topics. Both are included in Appendix K. After our visit, we pooled our notes and assigned topics to be addressed by each researcher, reflecting areas of expertise. One author was then assigned the responsibility for preparing each country report, or for integrating the literature and information gathered during the interviews and the interpretation of that information.

I.A. Technical

As indicated in the correspondence, our intentions had been to investigate the four topics from a high level waste disposal point of view. It quickly became apparent, however, that there are differences in classifications among the countries and about their decisions on the disposal route for each of the classifications. The classifications used by each country and the disposal proposed for each is shown in Table 1-1. As was shown in the previous report, and now updated for this report in Table 4-2, some countries have chosen to delay burial of reprocessed fuel or spent fuel until well into the next century. Consequently, actual siting of waste disposal facilities is mostly confined to low and intermediate level wastes. In any case, for all countries there is much more experience in siting disposal facilities for low and intermediate level wastes. Though this experience may not be completely applicable to high level waste disposal siting it is the best available and will also be reviewed in the chapter on siting.

In the technical aspects, it is striking that the questions being asked are technical problems at the frontiers of knowledge (e.g. long term behavior of materials, effects of glaciation, predictive geology, flow in fractured material, chemical speciation, partitioning of radionuclides between solute and medium, etc.) These questions are being asked in the course of the optimization of design of the disposal system because the basic questions of the possibility of "safe" disposal have already been answered affirmatively, (sometimes by designs with large safety factors) in most of these countries, as shown in Table 2-1. The information being developed in this search for a disposal site and

TABLE [illegible]. WASTE CLASSIFICATION AND DISPOSAL BY COUNTRY

Country	Deep Geological Disposal Type C Repository (High Level Waste)	Mined Geological Repository Type B Repository (Intermediate Level+TRU Waste)	Shallow Land Type A Repository (Low Level Waste)	Other Options
FRG	Site-specific Gorleben Salt Dome* For all kinds of solidified Waste HAW, MAW, LAW vitrified Designed to accommodate HLW	Site-Specific Konrad Iron Ore Mine Disposal of waste with negligible thermal impact on the host rock LAW, MAW decommissioning waste	None	
France	Category C Wastes High-level activity and Long-Lived nuclides high amount of beta-gamma emitting high heat output Significant amount of long lived radionuclides		*Category A Wastes Low-level and intermediate activity with short-lived nuclides Nuclides with half-lives less than 30 years Insignificant or low level heat output Insignificant amount of long-lived radionuclides (Alpha activity less than 0.1 Curie (3.76 Bq) pg tonne, per waste average) (In exceptional cases up 0.5 curie per tonne per waste container)	
	Category B wastes Low-Level and Intermediate Level Activity with long-lived nuclides Significant amount of long-lived nuclides, mainly alpha-emitters Low or intermediate level amount of both gamma emitters low or intermediate heat output			

TABLE 1-1 - (Continued)

Country	Deep Geological Disposal Type C Repository	Mined Geological Repository Type B Repository	Shallow Land Type A Repository	Other Options
Sweden	High Level waste (Cateogries 1a and 1b) Category 1a Spent fuel Category 1b Vitrified High level Waste Category 2 Trans-uranic-bearing wastes Category 3 Core components and intervals	Repository for LLW and ILW short-lived radionuclides Intermediate Level Waste (Some in each category 2-5) requires shielding but no cooling. Low Level Waste (some in each category 2-5) requires neither shielding nor cooling. Category 4 Reactor Waste Category 5 Decommissioning waste Swedish Final Repository For LLW and ILW	Shallow Land Burial Only LLW with specific Activity below 8×10^{-6} Ci Total Activity at burial site should be less than 2.7 Ci.	
Switzerland	HLW High concentrations of short- and long-lived radionuclides Vitrified HLW and/or Spent fuel Activity 10 years after discharge from reactor __Vitrified__ less than 4400 MCi __Spent Fuel__ less than 4500 MCi Alpha-containing IL wastes whose radionuclide concentrations exceed the maximum concentration values for the planned Swiss repository for ILW and LLW.	LLW & ILW Low and medium concentrations of short-lived radionuclides, limited proportion of long-lived radionuclides At time of emplacement __With Reprocessing__ less than 150 MCi __Without Reprocessing__ less than 50 MCi LLW (Note - eligible for disposal in Type A Repository) Low Concentrations of short-lived radionuclides, only traces of long-lived radionuclidos Activity of radioactive substances 10 years after discharge from reactor __With reprocessing__ Less than 0.01 MCi __Without reprocessing__ Less than 0.01 MCi	None	

TABLE I-1 - (Continued)

Country	Deep Geological Disposal Type C Repository	Mined Geological Repository Type B Repository	Shallow Land Type A Repository	Other Options
United Kingdom	HLW Wastes in which the temperature may rise significantly as a result of their radio-activity.	ILW Wastes in between HLW and LLW	LLW Wastes, whose activity is above VLLW (and thus unacceptable for dustbin disposal) but less than 4GBq tonne beta/gamma	VLLW Wastes, whose very low level of activity means that they can be safely disposed of without specific authoritzation under the Radioactive Substances Act of 1960. Can be disposed of with household refuse (dustbin disposal). Less than 400 kBq beta/gamma activity and less than 0.1 m^3 in volume or less than 40 kBq beta/gamma for single items
USA	10 CFR 60.2 in effect: spent fuel, solidified reprocessing wastes "High level radioactive waste" or "HLW" means: 1. irradiated reactor fuel, (2) liquid wastes resulting from the operation of the first cycle solvent extraction system, or equivalent, and the concentrated wastes from subsequent extraction cycles, or equivalent, in a facility for reprocessing irradiated reactor fuel, and (3) solids into which such liquid wastes have been corrected.	Disposal Route not specified 40 CFR 191 TRU (Transuranic) Wastes ILW - not defined Waste containing more than 100 nanocuries of alpha-emitting transuranic isotopes, with half-lives greater than twenty years, per gram of waste, except for (1) high-level radioactive wastes; (2) waste that the Department [of energy] has determined, with the concurrance of the Administrator, do not need the degree of isolation required by [40 CFR 191]; or (3) wastes that the [Nuclear Regulatory] Commission has approved for disposal on a case-by-case basis in accordance with 10 CFR 61.	LLW Policy Act Radioactive Waste Not classified as high-level radioactive waste, transuranic waste, spent nuclear fuel, or by-product materials as defined in Section 11e(2) of the Atomic Energy Act of 1954. and Wastes that the Nuclear Regulatory Commission classifies as low-level radioactive wastes.	

optimization is greatly improving our understanding of our environment and how it functions (e.g. the Permocarboniferrous trough in Switzerland, flow through fractures, water dating etc.).

I.B. SocioPolitical Issues

Although sociopolitical issues lie at the heart of the difficulties experienced in implementing radioactive waste management programmes in the six countries, they are at an earlier stage of analysis and understanding than the technical problems. A variety of factors contribute to the slower engagement of the social and political obstacles, including the greater complexity of such issues, the weaker state of applicable theory, the evident differences in social and political systems, the tendency to conceive of waste management as a technical activity, and in some countries, the lack of funds to support sustained research on these questions. Whatever the reasons, radioactive waste management has emerged as an important public policy problem, one which has elicited quite different national responses and which is straining established institutional mechanisms and roles in a number of countries. In this respect, the countries studied are addressing quite basic questions concerning viable institutional responses and approaches which command public confidence. In the chapters to follow we identify the major sociopolitical issues which are at stake in four areas of radioactive waste management, how they are experienced in each country, what responses have emerged and with what apparent success or failure.

This assessment has indicated two basic properties of radioactive waste disposal which need to be addressed in understanding national responses. The first relates to the sharp divergencies which are characteristically present in the social experience of coping with radioactive wastes. It is not unusual, for example, for the views of technical experts and those of the public to be at great variance. This is particularly evident in the way that judgements over risk and safety arise and the degree to which the task of safe disposal is seen as tractable or intractable. There are, of course, clear divergencies also within the public, centered on such larger questions as the role of technology in the creation of the "good" life, the contributions and dangers of nuclear power in energy solutions, and the political ramifications of alternative paths to technology management. There are also conflicts between the politicians who fashion the laws and policies which set the structure of waste management, and the scientists who work in the day to day efforts of assessment and prospective solutions, with differing objectives, conceptions of the problem and reward systems. Finally, it is quite apparent that effective responses to the same problems vary from country to country, what works in one nation sometimes does in another but often does not. The evident difficulty in transferring the meaning of social and political experience across political cultures poses substantial burdens on increased understanding that is not present in the technical realm.

The second basic property apparent in our reviews and interviews is the extent to which technical and sociopolitical issues intermingle in basic questions of policy and management. Decisions on the length of time which wastes must be sequestered and populations protected are in one part technical -- what is possible and with what asssurance -- and in one part philosophical -- what is our responsibility to the future and how is it best exercised? Or in searching for sites for radioactive waste disposal facilities, how do we integrate the technical properties needed to assure a sound site with broader questions of social equity and political bargaining? Responding to the multi-dimensional nature of these issues challenges existing methodologies of analysis and processes for making decisions and resolving conflicts.

I.C. Structure of the Report

In order to make the report more readable we have divided it into two volumes. The first volume dealing with concepts of safety, siting of nuclear waste disposal sites, and interim storage of spent fuel and high level radioactive waste is divided into two parts. The second volume is a review of subseabed disposal.

In volume one the first part contains the analysis comparing practices in the various countries, determining trends and drawing conclusions and the second the background material on a country by country and by organization basis. Chapter one gives some initial background material on the technical and sociopolitical aspects of the problem. Though concepts of safety, siting considerations and means of interim storage all interact, each of the chapters as much as possible are stand alone chapters with their own introductions and conclusions. Chapter two explores the meaning of safety as related to high level waste and tries to put it into perspective, details how safety is defined by the various national and international authorites and the sociopolitical difficulties in resolving the questions. Chapter three deals with siting considerations, how they are applied in each country, the knowledge gained from experience with siting of low-level waste disposal sites, the sociopolitical considerations and conclusions. Chapter four deals with interim storage, the technology, its use in the various countries, and the influence of the technology on the timing for disposal. Chapter 5 gives our overall conclusions.

Part two contains background material and more detailed discussion on the programmes of the various international agencies, Commission of the European Communities, International Atomic Energy Agency, International Commission on Radiological Protection and the Nuclear Energy Agency and within the six countries surveyed, Federal Republic of Germany, France, Sweden, Switzerland, United Kingdom and the United States of America.

Volume two covers subseabed disposal from the concept to the national programs and the multinational studies to special institutional and regulatory problems.

I.D. References

Parker, Frank L., Broshears, Robert E., Pasztor, Janos, 1984

The Disposal of High-Level Radioactive Waste - 1984

The Beijer Institute, The Royal Swedish Academy of Sciences

CHAPTER II

SAFETY

In his role of administrator of the U.S. Environmental Protection Agency, W. D. Ruckleshaus (1985) sought to separate risk assessment from risk management. He hoped in this way to decrease the contentiousness in risk assessment as it would be without some of the emotional content inevitable in risk management. Unfortunately for that concept, those who do risk assessment in high level nuclear waste disposal must make judgments as to the probability of events in the far distant future, the likely distribution and habits of humans at that time and the state of knoweldge in a wide variety of fields. These judgments can vary so greatly that it is obvious that there will not be scientific concensus on the risks involved. Even more certain is the likelihood that there will be neither scientific nor societal concensus on the appropriate risk management. Risk management, of course, means reducing the level of risk until it is societably acceptable, i.e. safe. It is this question of acceptable risk that is dealt with in this chapter.

II.A. Risk

The lack of experience with high level radioactive waste disposal over the long time periods involved and the subjective nature of safety in contrast to risk makes this discussion difficult. It is partly for these reasons, as well as the more general emerging use of risk analysis techniques in nuclear plant safety assurance, that the approach to demonstrating the safety of radioactive waste management is increasingly a risk based one. Risk broadly refers to the probability of harm to people or the things they value associated with particular events. The International Commission on Radiological Protection (1985) has defined risk somewhat more specifically (and narrowly) as "the probability that a serious detrimental health effect will occur in a potentially exposed individual or his descendants". (Health effect is frequently used as an euphemism for fatality). Risk may be thought of as composed of stages, involving

events → releases → exposures → consequences

Safety deals with the level of acceptance of the consequences and therefore varies according to the culture and the circumstances.

Portraying risk involves assessing the array of events possible for a nuclear waste repository and its propagation through each of the subsequent stages. In most technological activities, defining the range of events which may occur and their evolution into consequences is done experimentally, drawing upon actuarial data and observed or scientifically established evidence on the relationships among stages in the evolution of consequences. For nuclear waste disposal, this is strictly impossible, as noted above, because repository performance experience does not exist, the lengthy time periods involved make potential events difficult to gauge, and human factors make completeness of analysis intrinsically impossible. In this situation, risk provides a more useful approach than the more traditional means of conservative engineering judgements and margins of safety. Key to this approach is the use of probabilistic assessments of events and their likely propagation into releases, exposures, and consequences. Risk analysis specifically calls for distinctions among probabilities occuring at each stage of events. The analysis also allows for the expression of consequences in some comparable metric, for discounting the consequence according to the probability of its occurrence, and for summing the array of risks for a particular repository system at a specific site. The use of the risk-based approach has particular merit for radioactive waste disposal in that it allows internalization and comparison of very low probability events which may occur over the long time periods as well as those which may be more routine in occurrence. Finally, specific statements of uncertainty levels and the use of sensitivity analysis provide guidance as to the confidence which should be placed in the results.

It is not surprising, in view of this, that the approach to safety in most countries makes extensive use of the risk concept. This approach has also been endorsed by the International Commission on Radiological Protection (1985), and by the Nuclear Energy Agency

(1984) in its treatment of Long-term Radiation Protection Objectives for Radioactive Waste Disposal.

While none of the countries employs a purely probabilistic approach (due to data limitations and incomplete modelling and validation) a general endorsement of risk-based approaches is apparent. While this development represents an important step in progress over earlier deterministic approaches, the use of the risk concept is not without its share of problems and unresolved issues. Consider, for example, the following.

* The very long time periods of potential hazard of high level radioactive wastes makes identification of all possible events impossible. Moreover, quantifying the probability of unlikely events occurring from geologic and climatic changes and from human intrusion requires subjective judgements which, while not inappropriate as an element of risk analysis, inevitably have large uncertainties associated with them. This has led experts in at least one country (the Federal Republic of Germany) to handle the low probability component of the risk analysis by more qualitative means.

* The long time periods have produced controversy over the length of time for which risk should be calculated. Most European countries currently calculate risk for time periods up to 10^6 years or more, whereas the United States has chosen to limit at least the period of regulatory protection (and thus much assessment of effects) to 10,000 years, (although U.S. Department of Energy Siting Guidelines (US DOE, 1984) do require that natural events likely to occur over the next 100,000 years be taken into account when choosing a site). However, the Swedish National Institute for Radiation Protection (SSI) has recommended that calculations be made only for the time period till the next ice age, approximately 10,000 years (Bergman et al 1984). This choice can be quite important depending upon how the results are expressed as the accumulated effects over long time periods could represent large collective risks absolutely.

* The use of conservatism and worst case analyses in risk estimation can have substantial effects on the results and their safety implications. Protection analyses in

regulatory settings have generally employed intentional conservatisms in estimated probabilities and sizes of potential consequences. Such conservatism can, however, skew the analysis and lead to misleading results. This has led the International Commission on Radiological Protection, among others, to call for "best" estimates rather than conservative estimates. Regulators, however, have a long tradition of the use of conservatism in analysis as a means of protection against uncertainty.

* Risk analysis techniques, while very useful in depicting risk, provide no intrinsic guidance on two critical value questions -- how low the risk must be to provide an appropriate level of safety, and how the risk should be geographically distributed over the existing population and temporally distributed over generations now and in the future. Although various recommendations have been made as to appropriate objectives for risk standards and some emerging technical consensus is apparent (see below), this has not yet had the test of public acceptance over time.

* Related to the above are two other nagging questions in the search for safety. The first is whether the risk standard should address individual risk, as employed in the various European countries, or whether it should aim at both a collective and individual risk as in the United States. Second, should levels of <u>de minimis</u> risk (that risk which is sufficiently low that it does not merit regulatory attention) be recognized and incorporated into assessments and regulatory approaches. And how will both these issues be rationalized to often fearful and distrustful publics? (Cf International Commission on Radiological Protection -46 which has adopted exemption quantities which would have a similar effect).

II.B. "Demonstration of Safety"

II.B.1. <u>International</u>

II.B.a. <u>Nuclear Energy Agency (NEA)</u>

The Nuclear Energy Agency has led in trying to reach multi-national consensus on what constitutes proof ("demonstration") of long term safety. "Demonstration" is the "verification by experiment of one or a set of assumptions" (Nuclear Energy Agency, 1983).

The Nuclear Energy Agency has defined what it viewed as constituting a "demonstration" of the safe long-term management of high level radioactive waste:

Direct -- is the short-term demonstration and proof that a "facility could be built, operated and closed safely and at acceptable costs, using available mining and engineering experience".

Indirect -- is "by preparing a convincing evaluation of the systems' performance and long-term safety on the basis of predictive analyses confirmed by a body of varied technical and scientific data, much of it derived from experimental work." (Nuclear Energy Agency 1983).

Since the risks from radioactive waste disposal in a repository are expected to occur in the far future, predictive modelling subjected to extensive peer review is the dominant means of demonstrating compliance with the safety goal. Such predictive models should include:

1. Scenarios with Repository with present geology constant.

(i.e., constant properties of the medium evolution scenario).

This could permit a detailed study of the consequences of repository construction, including:

- heat output, thermo-hydromechanical effects,
- geochemical modification
- efficiency of sealing materials

Large-scale experiments are needed to address these questions.

2. Retrospective scenarios. Can we determine what would have happened if waste had been disposed of at the site 10,000 or 1,000,000 years ago? The study would take into account changes due to the waste and due to the recorded geologic changes. This of course requires a detailed study of the historical evolution of the site, which is what geologists traditionally have been trained

to do. Would the natural evolution have breached the barriers?

3. Extrapolation of the observed evolution. Several such scenarios can be studied, making some assumptions on the causes of the natural evolution (e.g., climatic, internal, geodynamic, etc.). The objective is not to "predict" the geology, but to determine if the efficiency of the barriers is not significantly reduced for a set of plausible, natural slow evolutions of the medium. The effect of the presence of the waste itself is, of course, added to each of these scenarios.

4. "Accident" scenarios. These include consequences of inappropriate human action, added to the previous evolution scenarios at different dates (e.g., 500, 5000, 500,000 years), both for direct contamination and for perturbed evolution of the barriers. Although unlikely, the consequences of catastrophic mechanisms such as faulting, meteorite impact, magmatic activity, etc., need to be assessed, and, if possible, upper bounds should be placed on their probability of occurrence. Both their direct consequence in terms of releases, and indirect consequence in terms of barrier efficiency reduction, should be assessed. Such scenarios need also to be added at distant dates on normal evolution scenarios. (Nuclear Energy Agency, 1985a)

The U.S. Environmental Protection Agency (EPA, 1985) has stated that events or processes having less than 1 chance in 10^8 occurring each year need not be considered.

The Swedish National Institute for Radiation Protection (SSI) (Bergman 1984) has recommended that in these "accident" scenarios the non-radiological consequences of such events should also be assessed so that the radiological consequences may be put in perspective.

As predictive models evolve, there is a particular need to develop (and demonstrate) the links between particular elements of system performance assessments. These include: (1) the link between the outputs from performance assessments and the needs of regulators; (2) the links between various mathematical models used in performance assessments and (3) the link between model development and field/laboratory observations.

Because of the uncertainties in consequences of events likely to occur in the far distant future, for repositories "absolute safety does not exist and ... safety goals must be seen in the context of other human activities" (Nuclear Energy Agency, 1983). To provide this indirect "demonstration" one must resort to mathematical modelling of the chemical, biological and hydrogeological environments of the repository, and its contents and their interaction. To provide guidance on what it considered "demonstration", the Nuclear Energy Agency (1985a) published a catalogue of current efforts in "demonstration". They noted there is consensus that "development of detailed physical, geochemical and mathematical models is now of less concern than the coupling between the models and the adequacy of the data used". The data is obtained from laboratory and field studies and natural or manmade analogues, with underground laboratories being constructed to try to obtain more valid and relevant in-situ data. An appraisal of the programme was also published in 1985 (Nuclear Energy Agency 1985b). This data will be used in predictive risk assessment methodologies. Because mathematical model validation in the usual sense cannot be had, one can obtain some confidence in the results if different models (analytical solutions and numerical codes) give similar results (verification) for the same scenario (Andersson, 1986). Consequently such comparisons have been made through HYDROCOIN (ground water flow computer codes), INTRACOIN (nuclide migration computer codes) to better understand "the influence of various strategies for geosphere modelling on the safety assessments", and BIOMOVS (Biological pathways computer codes).

The three methods -- laboratory experiments, field tracer experiments and natural analogues -- considered for validation of the performance assessment models each have specific drawbacks. Laboratory experiments are short time experiments with the rock and water not at their normal state or altered as a result of the repository conditions. Field experiments do not usually define the flow paths and the geochemical conditions under which flow occurs. Moreover, unique solutions to the results obtained are not usually available. Natural analogues have difficulties in defining initial and interim conditions, geohydrological flow and characterization of the samples. Consequently, the best that can be hoped for is that within 10 to 15 years it would be "possible to reach consensus about the range of applicability of different modelling approaches and important assumptions in the applications" (Andersson, 1986).

These results lend further credence to the beliefs expressed by the Subcommittee of the U.S. Environmental Protection Agency's Scientific Advisory Board in its review of High Level Radioactive Waste Regulations, that, in general, repositories were likely to be designed to meet standards far more stringent than the regulations (SAB, 1985). This is because the licensing regulations will set certain standards, say 100 μSv per year to a member of the critical group, the licensee (because of the difficulties described above) will therefore have to pick sites that are relatively easy to characterize (which is difficult in the real world) or else will make such conservative assumptions to be sure to meet the standards, that the expected dose values will be well below those standards.

IIB.1.b. Safety defined by International Commission on Radiological Protection

The International Commission on Radiological Protection felt that its previous recommendations could be used to handle normal development but that special guidance was required for probabilistic events. The Commission agrees that the use of "best estimates" or "engineering judgements" (subjective probability) "is an appropriate method to determine probabilities for use in waste disposal analyses". On dealing with uncertainties about the future, the Commission states that these "can only be dealt with by making assumptions and recognizing that these may, or may not, correspond to a future reality". They also note that the assumptions should be such that individuals in future generations will be "accorded a level of protection consistent with that applied today". (ICRP, 1985) Because of the large uncertainties in events and processes "estimates of the order of magnitude of probabilities and radiation impacts will often be the best that can be achieved". The Commission also finds that restricting average annual doses over a lifetime to 1 mSv implies an annual risk limit of less than 10^{-5} for all probabilistic events, and therefore some fraction of that for the source under consideration will meet safety guidelines. The Commission, of course, still adheres to the ALARA principle (as low as reasonably achievable, economic and social factors being taken into account) and the no-threshold, linear relationship between dose and effect. However, it does give guidance on low individual and collective doses "below which there would be no further need for radiation protection concern" because the costs incurred "to evaluate the collective dose in detail, or to consider the implementation of additional radiation protection measures, could, in itself, outweigh any potential reduction in health detriment costs". These dose limits were set at an annual individual dose of 0.01 mSv to members of the critical group and a collective dose of 1 man Sv caused by a practice or source over a defined period of operations. Reservations about the ability to define the collective dose lead some to fear that this may vitiate the use of exempt doses.

II.B.2. National Programmes

Demonstrating the safety of the repository is a political and institutional as well as a scientific quest, for it must be broadly convincing if public confidence is to be won. Here we begin by examining the safety goals which have emerged in the six countries, the *major approaches to demonstrate that the safety goal will be achieved*, and the areas of contention and debate.

II.B.2.a. Safety Goals

All six countries proceed from a common consensus over safety goals--that radiation exposure resulting from a nuclear waste repository should be a small fraction of that occurring from natural background sources. Current International Commission on Radiological Protection dose recommendations suggest a maximum risk objective of

10^{-5} per year, corresponding approximately to 1 mSv per year for those scenarios where exposure is expected to persist for a decade or more in the lifetime of individuals in a "critical group". The "critical group," in turn, is a hypothetical population group defined on the basis of human behavior using pessimistic but not unrealistic assumptions. The probability of exposure is assessed assuming that an exposed individual of the hypothetical critical group is present at the time and place where maximum risk arises. In addition, the International Commission on Radiological Protection system of dose limitation incorporates the principle that "all exposures should be kept as low as reasonably achievable (the ALARA principle), economic and social factors being taken into account."

All nations have chosen an individual dose limit for safety goals except the United States, which has a collective dose limitation together with an individual dose limitation for the first 1000 years after disposal. But the countries with individual dose limits show considerable variation (Table 2-1). Switzerland and the United Kingdom have adopted a standard of 0.1 mSv yr^{-1} for a member of a critical group. While the Federal Republic of Cermany has a limit of 0.3 mSv yr^{-1} coupled with an ALARA requirement. Sweden uses a more qualitative approach, without a quantitative goal and with regulators deciding judgementally on the acceptability of the projected safety performance but bearing in mind that 0.1 mSv yr^{-1} is the limit at power plants and is used as a guide here. France has not yet adopted a quantitative dose limit but proceeds from three general objectives:

Table 2-1

SAFETY GOALS IN THE SIX COUNTRIES

Country	Type of Dose Limit	Safety Goal (Dose Limit)	Time Period Covered	Major Demonstrations	Decision Making Authority
Federal Republic of Germany	Individual	0.3 mSv yr^{-1} for most exposed group; ALARA	No time limit; seeking consensus on a 10,000 yr limit	Project Andere Entsorgung International Review (Partial) ASSE mine	Ministry of Environment Radiation Protection and Reactor Safety Federal Cabinet Heads of State, Governments, Sept. 23, 1979 (2) Minister of States
France	Individual	No decision yet (1 mSv yr^{-1}) most likely	No time limit	None	Ministry of Health Institute for Nuclear Protection and Safety
Sweden	Individual	No quantitative limit; ALARA 0.1 mSv yr^{-1} power plants	No time limit	KBS Reports International Review	Government Ministry of Industry
Switzerland	Individual	0.1 mSv yr^{-1}	No time limit	Gewähr Project	Federal Council (Bundesrat) Pending Federal Dept of Transportation, Communication and Energy
United Kingdom	Individual	0.1 mSv yr^{-1} a person in the critical group	No time limit	None	Department of Environment
United States	Individual	1,000 deaths maximum over 10,000 years 0.25 mSv yr^{-1} whole body body, 1000 years	10,000 yrs	Waste Confidence Rule Making Hearing	Environmental Protection Agency; Nuclear Regulatory Commission

*to guarantee the protection from radioactivity of present as well as future generations

*to minimize constraints on future generations

*to preserve the quality of the environment and to prevent restriction on the present or future exploitation of natural resources

The United States, unlike the other countries, has a collective risk limit of 1,000 deaths attributable to a repository during the first 10,000 years of operation and an individual whole dose limit fo 0.25 mSv for the first 1000 years after disposal, but adds to this specific performance criteria for each barrier, including limits on nuclide release rates, canister lifetimes, and water travel times. The 1000 deaths in 10,000 years is a risk comparable to the risk from the unmined uranium ore in the United States which would produce the amount of waste (100,000 mthm) in the repository).

The time period over which the safety goal applies also varies. The U.S. Environmental Protection Agency has adopted 10,000 years as the period for dose limitation. The 10,000 year cutoff represents the period in which basic geology and climate may reasonably be expected to remain stable and beyond which uncertainties become very large. Other countries generally have not accepted such a time limit and have projected effects up to 10^7 and 10^8 years in the future (even though the expected lifetime of the earth is estimated at only 3.5×10^9 years).

II.B.2.b. Approach to Implementation and Demonstration.

All six countries in the study have adopted a common approach to meeting the safety goal, namely deep geologic disposal with a system of multiple barriers for waste isolation. In some cases, such as in the United States of America, specific quantitative performance criteria have been formulated for each of these barriers. The Nuclear Energy Agency in 1985 created the Probabilistic Systems Assessment Codes (PSAC) User Group for the purpose of exchanging codes, information and experience, and providing for peer reviews and discussion of specific technical issues.

Several important national efforts at demonstrating safe long-term management of radioactive wastes consistent with the Nuclear Energy Agency guidelines have been made. Each reflects the culture and institutions of the particular country. In the Federal Republic of Germany a lengthy public proceeding aimed at assessing the integrated waste disposal concept at Gorleben touched only peripherally on the safety demonstration issue. The conclusion reached by the Minister President of Lower Saxony, Mr. Albrecht at the end of the Gorleben International Review of the safety report of the Entsorgung Center of the German Fuel Reprocessing Company (DWK) and the judgments of both the RSK (Reaktor Sicherheit Kommission) and the Commission for Radioactive Protection (Strahlenschutzkommission) was that all aspects, including waste disposal, of a "nuclear Entsorgungszentrum is, in principle, realizable under consideration of all relevant technical safety aspects ..." (Albrecht, May 16, 1979), though he rejected the

the establishment of an Entsorgungzentrum at Gorleben. Then, the Heads of Federal and State Goverments on September 28 1979 (Heads, 1980) agreed on revised Entsorgung guidelines where they found that disposal of reprocessed wastes is realizable.

Following the publication of the Andere Entsorgung Reports (Project Group Alternative Entsorgung, 1985) with 25 technical appendices, the Federal Cabinet on January 23, 1985 held that disposal of reprocessed wastes is feasible and that though direct disposal is suitable for fuel elements for which the development of a special reprocessing technique is economically not justifiable and direct disposal of spent fuel seems technically feasible, in principle it still requires further research and development work. Sweden used the KBS reports of the Swedish Nuclear Fuel Supply Company and the associated extensive international review to convince the responsible authorities that it had met the requirements of the law. In Switzerland NAGRA (National Cooperative for the Storage of Radioactive Waste) in Project Gewähr, produced a series of reports to show that safe disposal is possible. A Parliamentary decision is pending. In the United States, a judicial decision suggested that the Nuclear Regulatory Commission conduct a public proceeding (rule making hearing) to determine whether it had confidence in the feasibilty and safety of radioactive waste disposal. It concluded after 5 years of testimony and deliberations in 1984 that it had such confidence. The U.K. and France have not yet had similar proceedings.

II.B.2c. Country Approach

Our interviews with responsible officials in the six countries indicate general adherence to the general approach outlined above, with some variations in emphases.

In the Federal Republic of Germany Safety criteria for disposal of radioactive wastes in an underground repository have been issued by the Federal Ministry of the Interior (BMI, 1983). These are shown in Table 2-2. The recommendations are roughly equivalent in scope and intent to the NRC's 10 CFR 60. But specific numerical design, retrieval, and marking criteria are not provided. Probabilistic analysis will play a partial role because, as noted above, low probability events cannot be calculated with any confidence. Safety determinations will be conducted by the state authority, using technical consultants, in a public proceeding which will require 2-3 years. The Ministry for Environment, Radiation Protection and Reactor Safety, after discussions with its reactor safety division, will make a final decision, including an assessment of the ALARA principle.

In France, no precise values have been set for the performance of individual barriers, although the integrity of the vitrified waste glass must be maintained during the thermal period. Safety will be demonstrated by: (1) the quality of calculations, (2) the performance of various barriers, and (3) the strength of the proof offered to the Ministry of Health and others. The actual process will involve demonstration of safety through the traditional three reports: the preliminary safety report (at the time of the construction permit), a

TABLE 2-2

TOPICS DISCUSSED IN SAFETY CRITERIA
FOR DISPOSAL OF RADIOACTIVE WASTES

Contents

provisional safety report (at the commissioning period), and the final safety report (at the operating license stage). The Institute for Nuclear Protection and Safety (IPSN) will review ANDRA's (National Agency for the Management of Radioactive Waste) assessment. Considerable emphasis is placed upon retaining flexibility in the roles of individual barriers. For low level waste the French envisage a 300-year period of monitoring and surveillance, a figure derived from the durability of the public service in France. No time period has been yet determined for high level waste.

In Sweden, no specific safety goal or quantitative criteria for the performance of components of the safety system are recognized. Rather the approach is to have the system as safe as possible, within reasonable limits. Key to the demonstration of safety will be the required safety analysis by the SKB, (Swedish Nuclear Fuel and Waste Company) with the SKI (Swedish Nuclear Power Inspectorate) performing its own analysis. Particular attention will be given to completeness and the degree of integration achieved.

In Switzerland, officials saw a proof as consisting of (1) technical consensus on the adequacy of predictive modelling, (2) natural analogues, and (3) experimental evidence. NAGRA (National Cooperation for Storage of Radioactive Waste) has, through the Gewahr proceeding and through subsequent safety analyses, to demonstrate compliance with the Guideline R-21 which states that individual doses will not exceed 10 mrem per year and that after the repository is sealed, no safety nor surveillance measures will be required. After scrutiny by a wide variety of bodies, including some international credibility. As an example, one Swedish critic argued that "the method of waste disposal presented in KBS was not absolutely safe -- yet was declared so by the Government. The risk number was stated to be low and acceptable but the Government never said what the number should be." Either broad approach to a safety demonstration, it is clear, will run its own particular sociopolitical risks.

A final burden which institutional demonstration must face is that critics will always be able to point to assumptions that could be different or uncertainties that cannot be removed. Representing the view of many critics, one West Germany opponent argues that ".... a safety analysis can only give meaningful results if the system under study is perfectly well known and if its behavior can be predicted for the relevant period of time" (Hirsch 1983). In his view, because of the lack of sufficient "scientific armoury", "the long-term isolation of radioactive wastes is a problem which takes us beyond the boundaries of science" (ibid). Overcoming the scientific doubts raised by such critics will require an institutional process which inspires confidence in those who certify that the safety test has been met.

II.D. Conclusions

With the inherent uncertainty in calculating far distant events, even with the knowledge that designers purposefully incorporate extra factors of safety in their designs, it is evident that there can be no absolute guarantee of absolute safety. Rather, as indicated in the discussion above and by International Commission on Radiological

Protection in its analysis, safety (i.e. acceptable risk) is what meets community norms or standards and proof is what reasonable, impartial people would agree is the preponderance of the evidence.

Risk assessments that have been reviewed by international group of experts appear to invoke greater confidence than those reviewed by another body of the same government which in turn appear to invoke greater confidence than those have been reviewed by a different group within the same governmental body. There appears to be some movement toward truncating the analyses at a point in time or at a dose level where the uncertainty is so great that it gives no guidance between alternatives or the cost of the evaluation or remedial action would outweigh the benefits of such actions.

II.D. REFERENCES

Albrecht, Ernst, 1979, Statement to Parliament of Lower Saxony, May 16.

Andersson, K. 1986, "Prospects of Model Validation. Against Field/Laboratory Observations" in NEA System Performance. Assessments for Radioactive Waste Disposal.

Bergman, C, et al., 1984. Review of KBS-3. SSIa 84-05, Stockholm, Sweden.

BMI, 1983. Sicherheitskriterien Fur die Endlagerung Radioactive Abfalle in Einem.

Bergwerk. Federal Ministry of the Interior (Ed). Bundesanzeiger 35, No. 2, 45-46.

CEA, 1985 Commissariat a L'Energie Atomique, Institute de Protection et de Surete Nucleaire. French regulations and waste management (Revision 1). Paris: CEA. August.

Heads of the Federal and State Governments, 1980 Revised Basic Guidelines for Entsorgung of Nuclear Power Plants, 1980 Federal Ministry of the Interior Bundesanzeiger No. 58 22, March.

Hirsch, Helmut, 1983. Nuclear waste management in West Germany -- The Battle continues. The Ecologist 13 4-15.

International Commission on Radiological Protection, 1985 Radiation Protection Principles for Disposal of Solid Radioactive Waste. ICRP 46.

Nuclear Energy Agency, 1983. Long-Term Management of High-Level Radioactive Waste - The Meaning of a Demonstration

Nuclear Energy Agency, 1984. Long Term Radiation Protection Objectives for Radioacative Waste Disposal.

Nuclear Energy Agency, 1985a. The Management of High-Level Radioactive Waste - A Survey of Demonstration Activities, April.

Nuclear Energy Agency, 1985b. Technical Appraisal of the Current Situation in the Field of Radioactive Waste Management.

NEA

Project Group Alternative Entsorgung, 1985
Systems Study Alternative Entsorgung Executive Summary
March, KWA 2190/1

Ruckleshaus, W. D. 1985. "Risk, Science and Demoncracy", Issues in Science and Technology 1(3) (19-38).

U.S. Department of Energy, 1984. "10 CFR Part 960 Nuclear Waste Policy Act of 1982; General Guidelines for the Recommendation of Sites for the Nuclear Waste Repositories 49 Federal Register 47714-47770, Dec. 6.

U.S Department of Energy, 1985. 40 CFR Part 191 Environmental Standards for the Management and Disposal of Spent Unclear Fuel, High Level and Transuranic Radioactive Wastes. 50 Federal Register 48066-38088, September, 19__

U.S. Scientific Advisory Board (SAB), 1985. Environmental Protection Agency's Science Advisory Board Subcommittee on High Level Waste Standards.

CHAPTER III

SITING

III.A. Introduction

Siting radioactive waste facilities is a crucial need in the timely deployment of the back end of the nuclear fuel cycle. In a number of countries, the accumulation of spent fuel at nuclear power plants could become a significant problem if storage, reprocessing, and/or disposal facilities do not become available. All countries except the United Kingdom are now involved in active siting programmes, seeking sites with sound attributes of geology, geohydrology, seismicity, accessibility, and local planning considerations.

Siting radioactive waste facilities has encountered significant, frequently volatile, public response, producing changes in programmes, political controversy, and delays in implementation. The countries studied have responded to this situation in a variety of ways, often beginning with traditional institutional processes but then being forced to utilize extraordinary measures to overcome sociopolitical obstacles. In this chapter we review the siting methodologies which have emerged and their technical bases, overview the characteristics of the national programmes, and assess the major sociopolitical issues (and responses to them) which currently exist.

III.B. Generic Site Selection Methodology

Before a site is developed into a mined geologic repository, it must be characterized. Choosing one or more sites for characterization requires identifying desirable and undesirable attributes for candidate sites, and subsequently eliminating unsuitable candidates through a screening and assessment procedure.

Only countries with large nuclear waste programmes require more than one final repository. Given the expenses involved in characterization, countries with no pressing urgency (e.g. legal requirements) for an operational repository might identify a few sites and characterize them serially, as is the case in France, rather than in parallel, as is the case in the United States. From a technical point of view, the logic of serial characterization is impeccable; after all, only one site needs to be characterized <u>if it turns out to be suitable for development into a repository</u>. Political uncertainties, public opposition, equity considerations and the cost of delay in establishing a repository, however, may make it necessary to characterize, and even to build, more than one repository.

The most cost-efficient method for site selection is to pick one site and then develop it into a repository. This can most easily be done if large geological formations are known to be sufficiently thick and laterally extensive to house a repository, and possess all suitable characteristics. Without subsurface exploration and experimentation this cannot be certain. In the characterization phase it must be shown that the repository and its contents meet appropriate standards and guidelines. Candidate sites for characterization may be chosen based on generic rock type, as in the Gorleben salt dome of the Federal Republic of Germany, or on previous land use, as at the Hanford and Yucca Mountain sites in the United States (in basalt and tuff, respectively). In both instances it still must be shown that the sites are suitable.

III.B.1. Screening

When there is a choice of repository sites, a screening methodology is employed. The complexity of the screening (and its costs) relates to the number of steps taken and the number of sites considered. Large-scale screening activities have been coordinated in Europe by the Commission of the European Communities (CEC), and in the United States by the Department of Energy (DOE). The CEC (1979) Catalogue of Geological Formations Having Favorable Characteristics for the Disposal of Solidified High Level and/or Long Lived Radioactive Wastes considered three types of geological formations: crystalline rocks, argillaceous formations, and saliferous formations.

Each nation was responsible for surveying its own territory. The objective of the Catalogue was "to provide the CEC and its member states with information on the geographical distribution of rocks and formations likely to justify more extensive investigation with a view to determining their suitability for the reception of solidified highly-active and/or long-lived radioactive wastes and consequently for the prevention of any return of radioactivity into the biosphere in amounts constituting a biological risk. "(CEC, 1979).

The Catalogue constitutes a desk study that identified candidates for a screening process. As such, it depends on published literature; no new studies were carried out for the catalogue. It is also concerned with only three rock types. Nonetheless, it is valuable as an international consensus on those attributes considered important in a final repository for high level waste in all geologic media. These are shown in Table 3.1. The conclusion of that study was that "the compilation of the European Catalogue has shown the relative abundance, both in number and extent, of geological formations which, judged on the selection criteria adopted, have favorable characteristics for the disposal of highly active solid radioactive waste".

For the three countries (Sweden, Switzerland, and the United States), not members of the CEC, the search for suitable geologic formations for repositories has enlarged the suite of rocks deemed suitable. In addition to bedded salt, both basalt and tuff sites in the United States have been nominated for characterization for possible selection as the first high level waste repository location. Sites in shale (Pierre) have also been investigated.

Based upon the criteria shown in Table 3-1, only a few classes of rocks were eliminated a priori in the CEC sponsored search. Extrusive volcanic rocks (i.e. including basalts and tuffs) were eliminated, though the rationale is not given. In addition, with minor exceptions only exposed rock masses and their

TABLE 3-1

SUMMARY TABLE OF CRITERIA

	Criterion	Limiting values (or Assessment value) of criterion	Observations
Rock-linked criteria and limiting values	Sorption capacity	(high)	
	Thermal conductivity	(high)	
	Permeability	(low)	
	Geomechanical properties	(good)	- good mechanical behavior (stability of cavities) - high plasticity
	Solubility	(low)	
Basically formation-linked criteria and limiting values	Thickness . salt . clay . crystalline	 . ≥ 200 m . ≥ 100 m . ≥ 500 m	cf. paragrah 212.21 for variation
	Homogeneity and uniformity	(very high)	- little or no fracturing - little or no change in facies
	Minimum depth from which formation must extend downwards	200 - 300 m	
Formation environment-linked criteria and limiting values	. Hydraulic gradient . Abnormally high geothermal conditions	. (zero or very low) . (absent)	
	Seismicity	I ≤ IX (MKS international scale, 1964)	
	Tectonics	- (simple) - (little activity)	

extensions under cover were studied. Among the evaporites, only halite and anhydrite were studied. Gypsum, sylvine, carnallite and a number of others were eliminated on the basis that they are chemically unstable, at least to some extent.

An earlier set of factors that should be considered was formulated by the IAEA (1977). These are shown in Table 3-2. The report also mentions that the host environment-waste interaction must also be considered. All factors, however, can only be considered as guides as IAEA said in its Forward:

> "The extreme complexity of many geological environments and of the rock features that govern the presence and circulation of groundwater does not make it feasible to derive strict criteria for the selection of a site for a radioactive waste repository in a geological formation. Each potential repository location must be evaluated according to its own unique geological and hydrological setting."

In the next section the factors are examined in the context of which are most important during the operational phase and those which are important during the post-closure period.

In those cases where performance assessments have been carried out, it was found that repositories sited in appropriate locations in bedded and domal salt, crystalline rock, and clays, the doses incurred have easily met the recommended international safety standards. In no case where such assessment studies have

TABLE 3-2

SITE SELECTION FACTORS FOR REPOSITORIES

Group I - Inherent geological and hydrogeological safety

1. Spatial distribution of the rocks - characteristics of the containing rocks
   - (a) Homogeneity of the rock mass
   - (b) Three-dimensional geometry
   - (c) Geological structure
2. Fluid-flow factors - the possible mechanisms for transport of nuclides away from a repository.
   - (a) Rock parameters, including permeability[1], porosity[1] and dispersiveness[1]
   - (b) Regional hydrological and hydrogeological conditions.
3. Long-term stability of the rocks - integrity of the repository and containment of the wastes.
   - (a) Solubility
   - (b) Plasticity
   - (c) Mechanical integrity
   - (d) Thermal integrity
   - (e) Radiation integrity
   - (f) Diapirism
   - (g) Geodynamic conditioning
   - (h) Seismicity
   - (i) Operational safety and stability.
4. Geochemical parameters - influenced by the operation of the repository and influencing the effectiveness of the containment.
   - (a) Sorption properties (adsorption and absorption)
   - (b) Thermal effects
   - (c) Gas and liquid inclusions
   - (d) Mineral sources of water.

Group II - Major operations and construction constraints

1. Social and political aspects
2. Ecological effects
3. Economic aspects
4. Civil engineering, mining, and engineering geology
5. Protection against voluntary and involuntary access.

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[1] Subject to modification by secondary thermal and mechanical effects.

been carried out has it been shown that a particular rock type is unsuitable for a repository. This is not surprising since if it were obvious that the rock types were unsuitable, then a performance assessment would not be carried out.

The U.S Department of Energy has two screening programmes. The first, nearing completion, considered sites in salt, basalt, and tuff. The second, recently deferred, considered crystalline rock formations.

The methodology is laid out clearly and is generically applicable to all national screening programmes. At the screening phase, potential sites for characterization are identified. Up to four stages are involved, depending on the size of the country, in narrowing the study area to smaller land units. First geologic provinces are identified, which are believed to have rocks of sufficient size to host a repository, within which are regions (which may occupy tens of thousands square kilometers). Regional screening narrows to areas hundreds to thousands square kilometers. Within an area, screening reveals locations, usually smaller than 300 square kilometers. Within the location only one or two potential repository sites need to be identified, although the location may be large enough to contain several sites. Sites tend to be smaller than 30 square kilometers in total area.

The survey of provinces and regions is basically a paper study based on maps showing land use, geology, and earthquake epicenters, plus relevant information available in the open literature. Area and location studies involve field exploration and laboratory studies to reveal pertinent information concerning subsurface hydrology, stratigraphy, and geochemistry, plus the potential host rock's engineering and waste-isolation characteristics.

National surveys can reveal hundreds of potential sites (as in Switzerland and the United Kingdom, in search of sites for low level waste disposal). Application of progressively narrower screens of eligibility weed out from further scrutiny sites not likely to meet criteria, and lead to a number of sites that are very likely to be suitable for development. In some countries, there may be many potentially suitable sites whereas in others, due to size, geology, and population density, there may be only a few potentially suitable sites. Nationally screened sites, like those chosen directly, may then be characterized in detail. Final development into a repository is not planned to take place, however, until extensive underground testing and in-situ experiments have been carried out.

III.B.1.a. <u>Post Closure</u>

A mined geologic repository (MGR) would be operational for 100 years or less, during which time activities would be supervised and radioactive releases monitored. After backfilling and plugging of shafts and boreholes, surface facilities would be decommissioned, decontaminated, disassembled, and disposed of at a suitable repository facility. As discussed below it would be necessary to isolate the wastes from the accessible environment for long periods of time; 10,000 years has been suggested as a minimum. Because isolation during most of those years must be without human supervision, inherent geological and hydrogeological safety considerations are given greater weight than operational and construction considerations, largely because containerized waste is essentially retrievable in the short term. Nine site characteristics considered most important in the long post-closure period, largely adapted from guidelines of the U.S.Department of Energy (1984) (10 CFR 960), are reviewed below. Naturally, they are important in the short term as well.

Each aspect is considered on an historical basis. Projecting possible problems 10,000 to tens of millions of years in the future can only be done by looking at the past. By and large the technical criteria suggested below are considered over the Quaternary period, which covers the last 3.5 million years.

(1) Geohydrology. The most likely mechanism for the release of radionuclides from a repository to the accessible environment is transport by ground water. To evaluate this potential for release, it is necessary to estimate the paths, quantities, and times of ground water flow in order to determine the fastest path of likely radionuclide travel to the accessible environment.

(2) Geochemistry. It is important to ensure that the present and expected geochemical characteristics of the site are compatible with waste containment and isolation. This is considered in two steps: (1) conditions that affect the release of radionuclides from the engineered barrier system, and (2) the

conditions that affect the release of radionuclides into the biosphere (e.g., the conditions related to radionuclide precipitation and sorption and the formation of complexes or physical states that increase the mobility of radionuclides).

(3) Rock Characteristics. Basic rock characteristics to consider are: that the host rock be sufficiently thick and laterally extensive to allow for considerable flexibility in locating the underground facility to ensure isolation, and that it be resilient or extensive enough that the safety of the repository will not be compromised through its response to the thermal, chemical, mechanical, and radiation stresses induced by repository construction, operation, and closure. Similarly, characteristic rock responses to interactions between the waste, the host rock, the ground water, and the engineered barrier system need to be evaluated.

(4) Climatic Changes. After closure, severe climatic changes could affect the ability of the repository to isolate waste. Changes in precipitation can result in changes in infiltration, which in turn may affect the groundwater regime. Changes in run-off and stream flow would affect the rates of erosion. All other things being equal, sites where the predicted climate would not be likely to encourage radionuclide releases would be preferred over sites where releases would be likely.

(5) Erosion. The goal in situating the repository deep underground is to keep the wastes underground for millions of years. Predicting the likelihood of the wastes being uncovered in

the next millions of years can only be done by considering evidence of what happened in the last millions of years (the Quaternary Period), though of course this is no guarantee of what will occur in the future. Climatic, tectonic and geomorphic evidence of the rates and patterns of erosion must be examined.

(6) Dissolution. Chemical weathering of the rock is a concern because it might expose the waste package to corrosive fluids, or open a hydraulic path between the host rock and the immediately surrounding rocks, or, worse yet, open a hydraulic path directly to the biosphere.

(7) Tectonics. Since one of the most likely ways for radionuclides to enter the accessible environment is transport by groundwater, areas where major tectonic events (i.e. uplift, subsidence, faulting, and folding) that could change the groundwater flow regime must be avoided. Evaluation of tectonic and igneous activity in the Quaternary period, if continued in the future, should show little likelihood of leading to premature radionuclide release.

(8) Human Interference. There are three aspects to controlling human interference with the repository: directly by continued government ownership and control of the site, warning systems to alert potential intruders, and indirectly by the presence or lack of exploitable resources. The first aspect can be depended on only as long as there is competent continuous government authority, and therefore should be viewed as a short-to medium-term solution (100- 1000 years). Warning systems employ

markers or monuments with symbols and information but their effectiveness over very long periods is highly uncertain. Choice of a site should take into consideration natural resources at or near the site, addressing historical, current, and potential future exploration for, and uses of, those resources.

(9) Unnatural Resources. A further consideration is the creation of a potentially exploitable resource. Once site control passes from a competent authority, the resources placed in the repository, where they differ from natural resources in the vicinity of the repository, in effect create a mine. Spent fuel creates a plutonium mine; copper canisters a copper mine. No aspect of the multi-barrier system is immune from consideration as a concentrated resource, from the waste form, overpack and back-fill to the plugging materials. If the repository so much as appears to hold valuable resources, ease of access after closure needs to be impeded.

b. Pre Closure

The protection of future generations starts with protection of the present one. A repository is built for the protection of public health and safety. The indirect impacts of the siting of such a large industrial project must be considered parochially with respect to the environment, socioeconomics, and transportation, whereas the national interest calls for an evaluation of cost-effectiveness and consideration of the ease and cost of siting, construction, operation, and closure.

(1) Health and Safety. Site selection should protect the health and safety of repository workers and the public. To that end, local weather conditions, population density and distribution, site ownership and control, and offsite installations and operations must be taken into account. For example, a site with great frequency of atmospheric temperature inversions could increase the danger to workers in case of accidents; prevailing winds should ideally flow away from densely populated areas.

(2) Environment, Socioeconomics, and Transportation. Siting will have strong impacts, direct and indirect, on the environment. Construction on or near archeological, historical, and scenic areas could diminish or spoil unique resources. Aesthetic considerations aside, some countries have laws that protect threatened or endangered species and their critical habitats.

Since constructing a repository is such a large project and involves radioactive materials, it may have substantial impacts, both beneficial and adverse, on host communities and regions. The nature of the project, the length of the site selection and construction periods, numbers and characteristics of in-migrants, the size and rurality of the host community, and the degree of public participation and technical assistance will also shape the type and magnitude of impacts. Well developed efforts will be needed to identify and assess such effects, and programmes to minimize adverse impacts and to compensate affected persons for unmitigated impacts may be required.

The local transportation and other infrastructure and service systems may require upgrading to handle the movement of workers, supplies, and waste, with minimal conflict with prior users. This is considered in further detail in the next section.

(3) <u>Cost of Siting, Construction, Operation and Closure.</u> At the simplest level, the less that has to be changed to accommodate the repository and its support facilities, the lower the cost. Items to be considered are: surface characteristics of the site, characteristics of the host rock and surrounding strata, hydrologic conditions, and tectonics.

Ideal surface characteristics would include flat terrain, with good drainage and no flooding problems, large enough to accommodate surface facilities. A site should provide easy access to the local, regional, and national transportation networks, and would ideally be located close to waste-producing facilities so as to minimize transportation costs. Studies have shown that greater transportation distances do not significantly affect radiological risks. Surrounding terrain should require minimal road and bridge improvement or construction. Severe weather conditions can compromise the safety of transportation workers, as well as hindering the safe and timely unloading of transported wastes.

Desirable rock characteristics from the siting perspective are that the rock mass be sufficiently thick and laterally extensive, easily mapped and characterized, and present few irregularities. In construction it is desirable that the host rock be readily accessible, easily excavated, and require little or no shaft support. In operation it should require minimal maintenance, and it should seal itself soon upon closure. In practice this is not possible, as rocks that require minimal maintenance (like crystalline) do not seal themselves, and those that seal quickly (like salt) require maintenance. At all stages the rock's integrity should not be compromised due to stresses incurred.

Surface characteristics should encourage drainage away from the repository. Surface streams should present no threat of entering the access shafts or of cutting off the repository from its transportation network. Nor should severe rainfall and its attendant runoff contribute to flash flooding or land slides.

Hydrologic and tectonic threats are considered in great detail for post-closure effects. However, local tectonic activity too small to represent a long-term threat must be carefully considered in terms of its possible adverse effects during the construction and operation of the repository even though effects below ground are usually minimal.

III.B.2. Technical Methodologies and Related Research in the Six Countries

The features and criteria discussed above are generic to preliminary site identification. In the discussion below we examine the technical siting methodologies and related research which have evolved for choosing radioactive waste disposal sites. Such approaches address a combination of legal requirements, technical aspects and potential social impacts.

III.B.2.a. <u>The Federal Republic of Germany</u>

The overall strategy in the FRG is to identify a promising site, characterize it, and submit the site-specific safety analysis to the state authorities. In September 1986 construction of the first exploratory shaft was started at the proposed waste repository in the Gorleben salt dome.

More than any other nation, the Federal Republic of Germany is committed to the geological disposal of heat-producing radioactive wastes in deep salt formations. From 1967 to 1978, the abandoned salt mine at Asse, near Braunschweig in Lower Saxony, was used for the disposal of low level and most of the medium level wastes produced in the FRG during that period, and for experimental purposes (Merz 1986). The operating permit expired in 1978. Since that time no final disposal of any radioactive waste has occurred in the FRG. The Asse mine now serves as a test facility for experiments relevant to radioactive waste disposal in the salt dome at Gorleben.

The technical suitability of the Gorleben site depends on the results of an extensive underground exploration programme, which will not be completed before the early 1990s. No other site is currently being considered for the disposal of high level waste. In case Gorleben is not found suitable, it is argued that it will be possible to locate and evaluate another site relatively rapidly, because the lessons learned from Gorleben would be applied in another salt dome. Pursuing another site now in parallel with Gorleben, it is argued, would either double the annual costs (which are already considered high) or would at least slow the speed of evaluation.

In the FRG, the federal government has the responsibility for disposing of nuclear waste. Nuclear sites are licensed by the individual states. A survey of 200 salt domes showed that 20 to 50 of those were technically potentially acceptable for development into a repository, most of which were located in the state of Lower Saxony. The federal government nominated three sites to the Governor of Lower Saxony. Gorleben, one of the largest potentially acceptable domal sites, was not originally nominated due to its proximity to the border of the German Democratic Republic. However, the Governor recommended it, and the site was officially designated in 1977.

III.B.2.b. France

There is no legally specified list of technical requirements that a high-level waste repository must meet in France. But French experts have participated in developing the Commission of the European Communities' and the International Atomic Energy Agency's list of siting criteria. Since 1985, a temporary group of experts, headed by Professor Jean Goguel and named by the Ministry of Industry, has been developing technical criteria for the choice of an underground laboratory site, suitable for an alpha waste repository and later on for a HLW repository. This group will issue its report by mid-1987 which will contain safety and performance objectives. Under the licensing mechanism the approach is to find a geologically suitable site, establish an in-situ laboratory, and, if the results of the tests are favourable, apply for a license to develop it into a repository.

Site investigation for an underground laboratory is under way, and a site will be selected by 1989. Operation is expected to start in 1992. The Castaing Comission suggested that an underground laboratory be opened for each of the formations being investigated before a final decision is made on the host formation for the repository (Castaing Commission, 1983). In June 1984, ANDRA (National Agency for the Management of Radioactive Wastes) received a ministerial order to propose one site for the construction of an underground laboratory. Tests are already conducted in granite, in an uranium mine at Fanay-Augeres, whose purpose is mainly to examine generically the properties of granite/waste interactions.

France's role within the CEC (Commission of the European Communities) site investigation programme has been the study of granite media, and it is perhaps due to this that crystalline rock has been the major focus of its repository research until now. But this may change in the future. Sites will be examined in clay, granite, salt, or shale formations, but an underground laboratory will likely be built only in one.

The site selection procedure in France has three phases: inventory, preselection, and site characterization (Faussat 1986). The objective of the inventory is to select geographical zones where the hydrogeologic characteristics are favourable. During preselection a few zones or sites are selected based on existing data and on limited investigations. First, the unsuitable formations are eliminated. Second, an investigation programme will be carried out on a limited number of sites of different structures, in order to keep the final choice open as long as possible. The investigations will be conducted using classical methods of geophysics and prospection, such as area exploration, collection of hydrogeologic data, mappings, seismic and gravimetric prospecting and deep test boreholes. The geologic and hydrogeologic investigations will be completed in the underground laboratory. If the results are satisfactory, this facility may be developed into the national final repository for alpha wastes, and a retrievable demonstration final storage facility for high level wastes. If the results are unsatisfactory, the facility will be decommissioned and the exercise repeated elsewhere.

The first national survey of approximately 1000 sites showed about 100 that were not disqualified. Some numerical criteria were applied in the site selection process, but qualitative criteria were favoured. The major technical objective is geological simplicity. At the preselection stage, 10 sites were designated. The generic criteria apply here, but no methodology for their application or weighting has been made public.

III.B.2.c. Sweden

Sweden has no special legal requirements for selecting a radioactive waste site. Like Germany, France, and Switzerland, when a site has been thoroughly characterized an application is made to the proper authorities, who decide whether the applicant's safety report demonstrates an adequate degree of safety (see chapter II). Since the decisions to grant construction and operating licenses are qualitative, the applicant has an incentive to optimize the overall safety of the repository, rather than meet certain limits for each barrier. Licensing of radioactive waste sites is made by the Swedish Government upon recommendations from the safety authorities.

The search for potential sites for a high level waste repository started in 1977. The siting programme to 1990 is divided into four serial phases: reconnaissance, surface investigations, borehole investigations, and evaluation and modelling.

Phase 1: The reconnaissance phase involves a desk study of available data, maps, and satellite images, followed by field inspection for preliminary assessment of promising sites. The list of 4-6 km^2 sites recommended for further investigation is carried into the second phase.

Phase 2: Surface investigations seek to define major fracture zones and other geological characteristics of sites through geological mapping and geophysical ground measurements. Significant features near the site area are also mapped, and taken into account in planning the third phase.

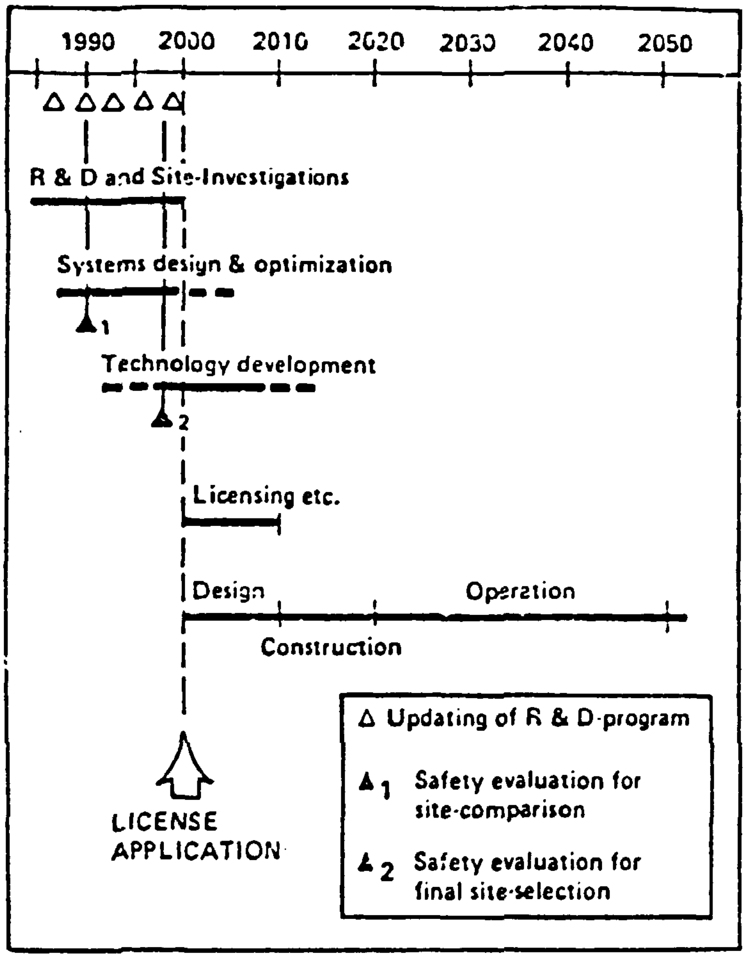
Phase 3: The drilling programme seeks to confirm the results of the surface investigations; define the fracture zones in three dimensions; measure the hydraulic properties, and determine the chemical conditions of both bedrock and groundwater. Cores are taken from a 1000m vertical borehole to determine the rock type(s) at repository depth. Additional cores are taken from ten to fifteen angled boreholes aimed at intersecting fracture zones mapped from the surface. Up to twenty percussion boreholes are drilled to supplement the surface geophysical mapping of fracture zones, etc.

Phase 4: Information gathered in the preceding phases will be synthesized into mathematical models that will seek to predict radionuclide migration routes and rates for each site. The most important component, of course, is the calculation of groundwater flow from the repository. These activities are part of a broader set of repository development activities (Figure 3-1).

The initial search for high-level waste repository sites was confined to large industrial land holdings owned by lumber companies, utilities, or the government. Drilling was carried out, and three sites were chosen for further investigation (SKBF, 1977).

A nation-wide search was conducted to seek the best geology. A desk study of a few hundred rock formations revealed 25 that looked promising enough to send geologists in for a closer look. Geophysical mapping was made at a number of these sites. Four of them were eventually chosen for further investigations according to phases 2-4 of the site investigation programme. Results from the seven sites were reported in KBS-3. (SKBF, 1983).

Figure 3-1. Overall time-schedule for realization of a HLW-repository in Sweden.
Source: Ahlstrom 1986.



Since then, one more site has been studied, bringing the total number of sites for detailed borehole drilling investigation to eight. At least four of these sites show good enough characteristics from a geological point of view to host a repository of the KBS-3 type. Before the final selection, detailed site investigations will be made on a couple of sites during the 1990s. All these eight sites have gneiss or granite rock. Reconnaissance studies have also been made on gabbroic rock. Pilot boreholes were drilled on two sites, which then were abandoned. Drilling on the third gabbro site (Almunge) was blocked by protesting opponents.

The Swedish Final Repository (SFR) for low and intermediate level, non-heat bearing wastes is under construction below the Baltic sea at the Forsmark nuclear power station. The site was already licensed for nuclear activities. Therefore it was possible to take advantage of the unique transportation situation (all nuclear fuel, new and spent, is transported by a single purpose ship). In June 1983, a construction license was granted, and construction commenced in autumn that same year. The SFR features land-based tunnel access to the mined tunnels and silo, which are covered by more than 50m of rock topped by the sea water, which above the repository is 5 to 6 meters deep. The stated design goal is to limit the radiation dose to the local population to less than 10 percent of natural background radiation(SKB, 1985). Construction of the first phase should be completed in 1988, with an operating license and commissioning later that year.

III.B.2.d. <u>Switzerland</u>

NAGRA (National Cooperative for Storage of Radioactive Waste) is responsible for disposing of all nuclear wastes in Switzerland, and must show in a safety analysis that its proposed solution(s) will meet the stipulations of the Swiss Safety Authority Guideline R-21. In effect the proposed repository must be shown to limit exposures to below 10 mrem per year. No particular host rock is mandated, and no sub-optimization or intermediate barrier safety requirements are required. In fact, no repository is required to be built. R-21 requires only that safety objectives be met under realistic conditions and no safety measures or surveillance of a repository be required after closure. The applicant at each of the four stages of licensing must show the need for a repository. Switzerland, while enthusiastic about possible international repositories (including subseabed), is nonetheless searching for sites to dispose of wastes within Swiss borders in the event that the international option fails to materialize.

Types of waste are defined in accordance with the maximum allowable radionuclide concentration permitted for the repository type, so as to allow the repository to meet the radiation protection objectives. What has emerged at NAGRA (National Cooperative for Storage of Radioactive Waste) is a plan to build two repositories: a deep geologic repository (type C) for high level waste and some alpha-containing intermediate level waste, and a less deep geologic repository (type B) for all remaining radioactive wastes. It has also reserved the option of a separate repository for low level wastes (Type A).

NAGRA is a consortium formed by private power companies and the Swiss Confederation to dispose of all of their nuclear wastes. By government decree, it must also provide disposal for radioactive wastes from medical, research, and other sources. NAGRA is charged with all management through construction of the necessary repositories. There is no required timetable for construction and operation.

Presently HLW disposal is not a problem, as under the reprocessing contracts wastes will not be returned until 2010 to 2020. The search for the type C repository is, therefore, not as far advanced as that for the type B repository. Although, as a private company, NAGRA is not required to make its site selection process public, it has chosen to publish the guidelines for Type B repositories (See Appendix H).

Type C Programme

The Type C programme anticipates mined galleries with vertical shaft access at a depth of about 1200 meters. First choice as host rock is the crystalline basement in northern Switzerland, which is covered with hundreds of meters of sediments, including clay and some thinner bedded salt layers. The siting programme is now divided into four phases:

Phase 1	1980-89	Regional investigation and site selection (screening)
Phase 2	1989-95	Detailed site investigations at 1-3 locations, selection of one site
Phase 3	1995-2005	Underground laboratory investigation at one site
Phase 4	2005-20	Development into repository.

These phases are tentative--it is possible that, for a variety of reasons, more than one site will be carried into Phase 3 (see discussion of the type B repository below).

The 1000 square kilometer regional investigation programme called for deep drilling at 12 sites to obtain information about the crystalline basement. Six deep boreholes have been drilled and investigated, but further work has stopped while a regional synthesis of available data is analyzed to determine whether it is worthwhile to continue. The area being investigated is bounded on the north by the border with the FRG, in an area of relatively low seismic activity between the more active areas near Basel and Schaffhausen. The recent unexpected (although it had been known in the FRG; see Buser + Wildi 1984) discovery of a large, deep Permo-carboniferous trough trending west-east below the mesozoic sediments has cast some doubts on the possibility of finding a suitable site. The trough itself is unsuitable, and the basement crystalline rock below it is considered too deep for a repository. While it is less certain that a site will be found in granite, interest in clay and salt formations has increased. It is possible that a national screening search will have to be instituted, and the research programme redesigned (Alder, 1986).

Type B Programme

The type B repository was planned as a horizontally accessed mine cavern system with a few hundred meters rock overburden when the site selection programme began in 1978. The timetable was:

1978	Potential host rock formations selected in marl; clay; crystalline rock; and limestone above the watertable, where covered by impermeable clay layers		
1981	100 sites identified: 20 selected for further investigation.		
1983	NAGRA ranks sites:	3	1st priority
		5	reserve
		12	disqualified

A detailed site selection methodology was employed to choose the three top sites. (NAGRA, 1981; NAGRA, 1983). The original 100 potential site areas were identified in five geologic formations, namely anhydrite (23 sites), alpine marl and claystone (15 sites), opalinius clay (25 sites), "isolated" formations above the water table (23 sites), and crystalline rock (14 sites). These sites were then assessed with respect to a number of spatial and geologic factors (e.g., water impermeability, hydrogeology, spatial extent of the host rock, etc.) as shown in Table 3-3. Each site, based on general criteria, then was judged "good," "average," "acceptable", or "unacceptable" on each factor. An additional assessment of non-geologic factors (e.g., proximity to

SUMMARY OF JUDGMENTS OF POSSIBLE SITES FOR A TYPE B REPOSITORY (SWITZERLAND)

		A Le Montet	B Val Canaria	C Glaubenbuelen	D Bois de la Glaive
	HOST	ANHYDRITE			
NUCLEAR SAFETY CRITERIA	1. Geological situation (Overall assessment)	2	2	3	1
	1.1 Available size of the host rock	2	1	2	1
	1.2 Geometrical forecastability	2	2	3	2
	1.3 Rock mechanical stability	1	1	1	1
	1.4 Complexity of the geology	2	3	3	2
	2. Hydrogeological situation (Overall assessment)	1	1	1	1
	2.1 Water flow through host rock	1	1	1	1
	2.2 Length of flow pathways	2	2	3	2
	2.3 Speed of flow	1	1	1	1
	2.4 High water flow zone	1	1	1	1
	3. Biospheric conditions (dilution)	1	2	2	1
	4. Predictability of Change (Overall assessment)	2	2	3	1
	4.1 Tectonic stability	1	1	1	1
	4.2 Exogenous change	1	1	1	1
	4.3 Hydrogeology	2	2	3	2
	5. Chemical properties of the geosphere (Overall Assessment)	3	3	3	3
	5.1 Nuclide retention	2	2	2	2
	5.2 Aggressivity of water	3	3	3	3
	6. Future use conflicts (Overall assessment)	2	1	1	1
	6.1 Raw materials use	3	2	2	2
	6.2 Water use	1	1	1	1
	6.3 Underground construction	1	1	1	1
	OVERALL VALUATION OF NUCLEAR SAFETY	2	2	3	1
EVALUATION CRITERIA	7. Extent of still needed classification (Overall assessment)	2	3	3	1
	7.1 Time and cost of siting	1	3	2	1
	7.2 Geological risk	2	2	3	1
	8. Time for creation of depository	1	3	2	1
	9. Costs for creation of depository	1	2	2	1
	10. Environmental acceptability (Overall assessment)	2	2	3	2
	10.1 Environmental impact	2	2	3	2
	10.2 Depository aspects	2	2	3	2
	10.3 Traffic	1	2	3	1
	10.4 Nature conservatory	2	3	3	2
	10.5 Water protection	2	2	3	2
	11. Economic significance	2	1	2	2
	12. Time needed for permit	1	3	1	1
	OVERALL EVALUATION	2	3	2	1
	OVERALL SUITABILITY	II	III	III	I

SOURCE: NAGRA, 1983.

settlements, risk of flooding, conservation) provided further perspective. This procedure allowed the qualitative designation of 20 sites which should be investigated further.

The second round of site selection involved:

*a more detailed study of the existing geological and hydrologic data

*extended design studies on the construction work

*new systematic considerations of regional and environmental planning

These further studies reduced the 20 sites to 11.

The third round involved assessment of the 11 site areas in terms of eight attributes: landscape, settlements, traffic, water protection, military installations, proprietory considerations, disposal of excavated materials, and mountain judicial licenses. Further assessments were also made of: ecological and hydrogeological aspects, construction techniques, and area planning. The sites were then each judgementally graded on a three-point scale for some 12 attributes, grouped (with six attributes each) into nuclear safety (post-closure) and development (pre-closure). The attribute scores were then combined, using an unspecified weighting procedure, into aggregate scores for the two broad factors and an overall site desirability score (see Table 3-3 for the methodology applied to anhydrite sites). In this last procedure, nuclear safety was awarded a higher priority than development. The evaluation produced three priority sites, five sites held in reserve, and 12 sites dropped from further analysis.

In September 1985, Government permission was granted to allow investigation of the three first-priority sites by borehole drilling and seismic geophysical surveys. In addition, investigation of a fourth site, with vertical access and below the water table, was proposed by the government as an alternative to the horizontal access sites. The broadening of the programme was motivated by one of the reserve sites volunteering to host the repository. All four sites are presently undergoing borehole and seismic investigation. The Government has withheld permission to excavate test galleries at the sites; since a test gallery could be developed into a repository, building one could be seen as the start of construction (which requires a separate license).

It is expected that one or more test galleries will be excavated in 1987 which, after geologic and hydrogeologic investigations and in-situ testing, will lead to application for a license for the repository site in 1989 or 1990, with operation of the repository commencing in 1995.

III.B.2.e. The United Kingdom.

During the 1970s the United Kingdom initiated a programme of geological and geophysical exploration to assess potential areas for a high level radioactive waste repository in granite. In December 1981, however, in the face of local political opposition this programme was suspended following a decision to store high level waste (HLW) for at least 50 years before disposal. It was considered that the feasibility of disposal had been proven in principle, but that HLW could be safely stored on or near the surface for a substantial time, and that a period of surface storage would allow the heat generation from high level wastes to diminish naturally. Safe disposal in a deep granitic repository is considered feasible by the British, but they deem premature any effort to begin construction of a facility at this time (Feates 1984). Final decisions on high level wastes disposal are not expected for several decades.

A 1976 report (Gray et al. 1976) from the Institute of Geological Sciences (IGS) (now the British Geological Survey) suggested criteria for the selection of potential areas for a high level wastes repository. This document distinguishes between area selection and site selection. The former, which applies only to broad geographical and geological zones, can be accomplished via the application of generic criteria, but site selection is a far more rigorous process requiring extensive geological exploration and a demonstration of the compatibility of site and disposal method. Uncertainties in the prediction of long-term geological and climatological events are emphasized, and to compensate a multi-barrier disposal concept is advanced as an adequate solution. A minimum depth of 300 m is suggested, with the entrances to shafts located at least 60 m above sea level (this elevation marks the projected shoreline if polar ice caps should melt). Backfilling and sealing these shafts are seen as potentially weak links in geological isolation. All existing surface flow features are to be avoided, particularly in view of the potential for rapid erosion should sea level drop another 100m during the next ice age. All human activities that strain the earth's crust (deep mining, dam construction, injection wells) are to be absent within a 15 km radius. Natural seismicity, however, is not regarded as a major problem provided that obviously active areas are avoided. Damage to waste packages from rock creep or subsidence is judged more likely than disruption from seismic events.

The original areal screening in the UK included offshore islands as well as mainland formations. Several geological media were surveyed, including anhydrite, clay, granite, and salt. Britain lacks mainland salt domes, but offshore sites have been considered. Bedded salt formations in the UK are rather thin and are heavily exploited commercially. Regions of interbedded salt and clay, however, have been suggested as repository sites; clay horizons might serve for waste emplacement with the adjacent salt seams providing a water tight barrier (Keen, 1984). Most high level waste work has centered on the U.K.'s substantial formations of granite. Within the CEC (Commission of the European Communities) crystalline rock studies have been carried out by the UK and France.

Before its termination, the field research programme conducted by the British Geological Survey inventoried over a hundred potential sites for the British repository. Eight areas of crystalline rock were selected for further investigation. Actual drilling was done at only one site, Altnabreac in northern Scotland. Here, three boreholes were sunk 300 m deep, and ground water was sampled from a network of shorter holes and natural springs.

Although the search for a specific repository site was suspended in the UK in 1981, research on the generic properties of saturated crystalline rock continued with funding from the Department of the Environment at the Atomic Energy Research Establishment (AERE) at Harwell for several years. Studies on the thermomechanical response of Cornish granite have been conducted using a 20 kW electric heater at a depth of 50 m. Data from a circular array of sensors (20-30 m in diameter) indicate that the bulk thermal conductivity of this fractured medium can be portrayed by a single constant parameter. Multiple borehole pumping tests have helped to define fracture flow systems in a granite formation 100 m to 200 m below the surface. Measurements of interhole pressure drop and the migration of tracers have shown that most ground water flows through fractures. At UKAEA (Atomic Energy Authority) laboratories, modeling efforts have been carried out to describe thermally induced convective flow in fracture networks. The possibility that differential expansion by rock crystals may initiate local cracking and alterations in flow patterns has been assessed.

The UK has not specified a site selection process for high-level waste. As discussed in section II.C.1.e., the British intend to work through the siting process for low level wastes first, as it is viewed as a more pressing problem (and, of course, because of the 1981 decision to defer high level waste disposal).

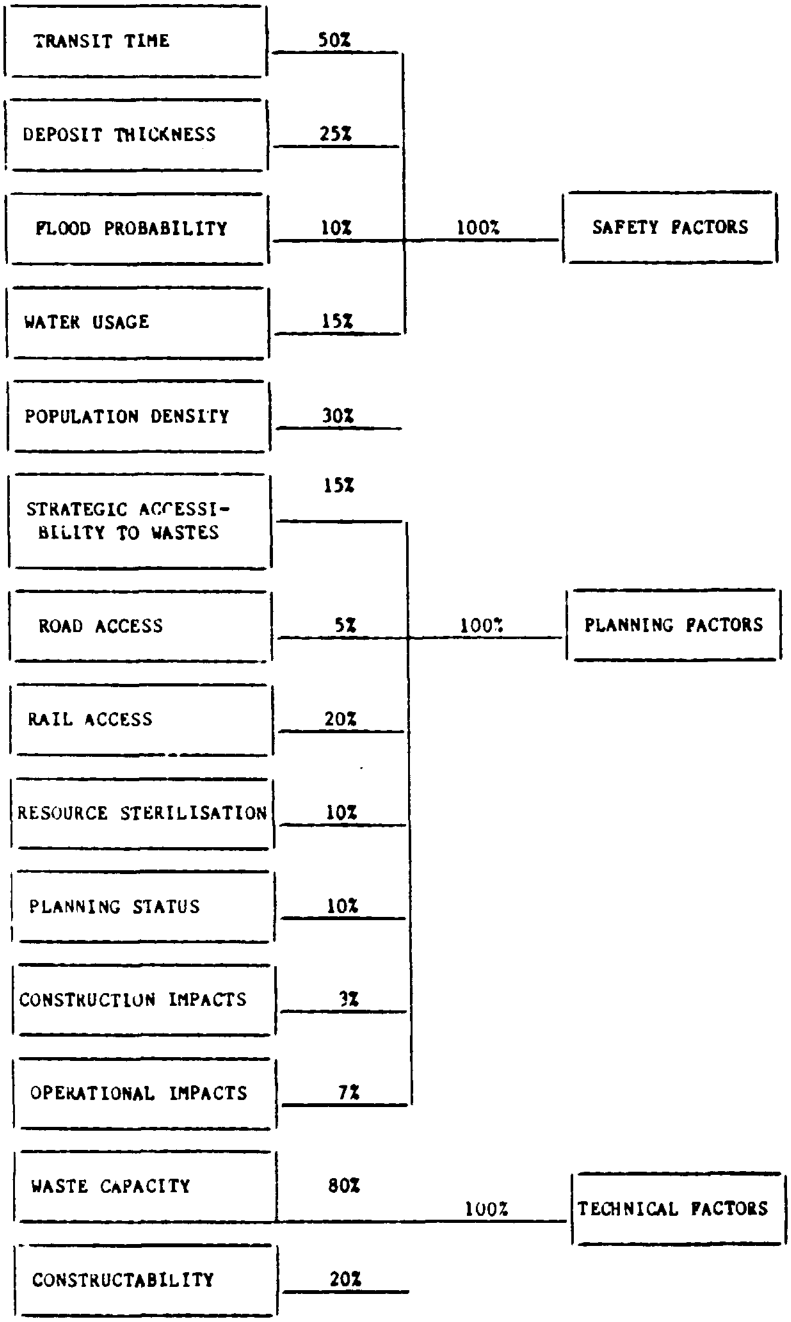
The methodology employed by NIREX (Nuclear Industry Radioactive Waste Executive) to site a new low level waste facility is discussed in detail below.

Four sites (Bradwell, Elstow, Fulbeck, and Killingholme) were nominated for preliminary site characterization for a combined low and intermediate level waste disposal facility. These were selected based on desk studies after an initial five step national survey. Geology, population density, conservation areas, and accessibility were screened to identify areas likely to have good potential sites. About 1000 sites were considered over 18 months, concentrating on large landholdings, as NIREX does not possess eminent domain powers. As of May 2, 1986, the Government decided that only low level waste would be disposed of in the shallow engineered trenches to be constructed at the chosen site.

Sites were then ranked on the basis of safety, planning, and technical factors (Figure 3-2). The best sites were considered to be insensitive to the weighting factors (McInerney, 1986). Since full containment is preferred to dilution and dispersal, all four proposed sites are located in saturated clay formations. In investigations of the sites for confirmation, NIREX has elected to develop site-specific repository designs as an element of the 8-part investigation scheme, set out below:

FIGURE 3-2

HIERARCHICAL NETWORK OF SITE SELECTION FACTORS USED IN UNITED KINGDOM FOR LLW SITING



Activity		Responsible Agency
1. Ground Investigation		Central Electricity
2. Planning and Scheduling		Generating Board (CEGB)
3. Geological Assessment		British Geological Survey (BGS)
4. Repository Design		Contractors
5. Non-Nuclear Environmental Assessment		
6. Radiological Assessment:	Geosphere	UK. Atomic Energy Agency (Harwell)
	Biosphere	National Radiological Protection Board (NRPB)
7. Waste Packaging and Transportation		Contractors
8. Research and Development		Contractors

Following Parliamentary passage of a Special Development Order, NIREX appointed contractors to commence drilling and on-site investigations. But access to all four sites was blocked by local groups who maintained a 24-hour vigil at the sites. Eventually NIREX obtained a court injunction to require all the groups to cease interfering with free access to the sites. During September the contractors gained access to all four sites.

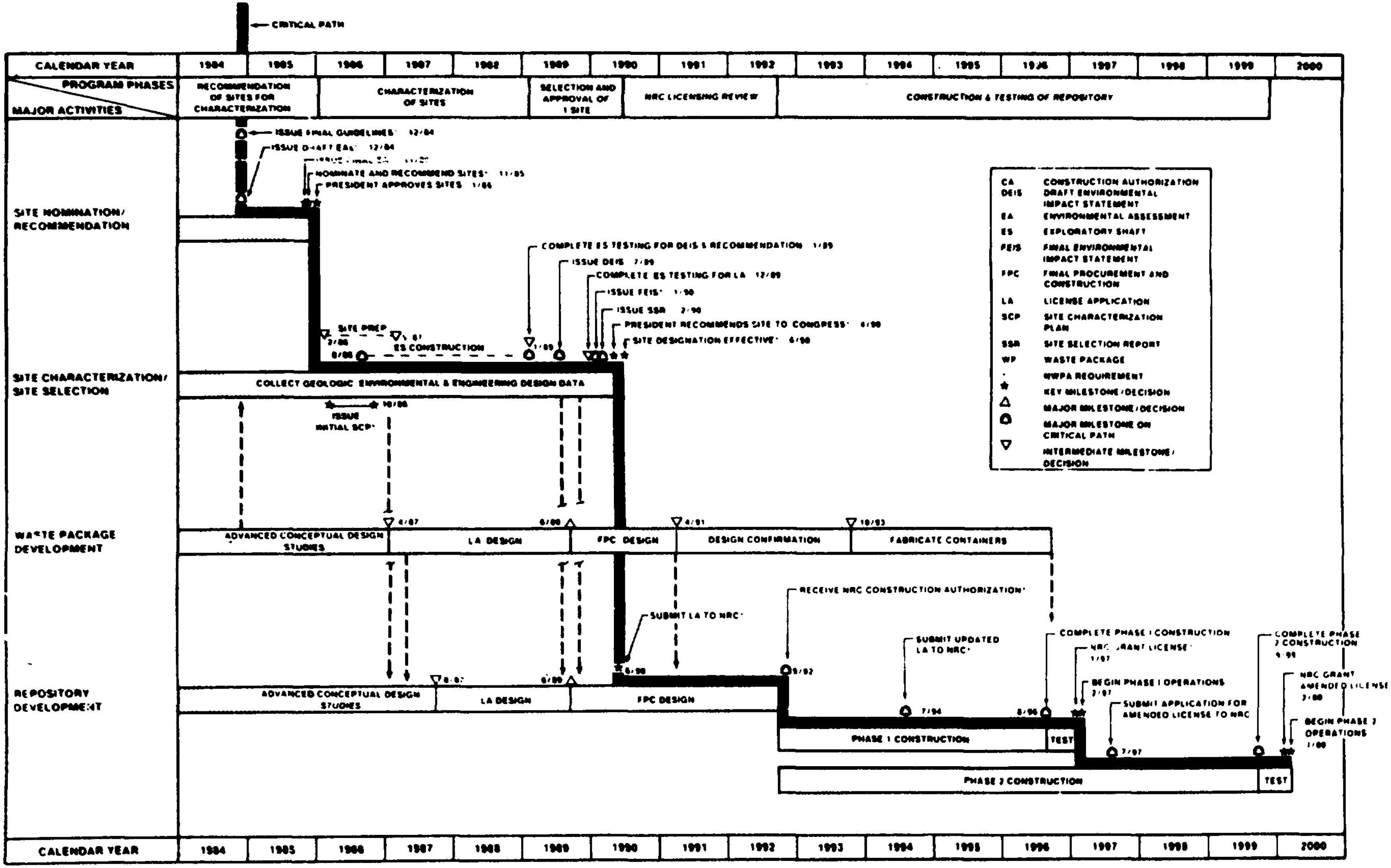
III.B.2.f. United States

A preliminary site selection process was already underway when the U.S. Congress passed an extraordinarily complicated piece of legislation setting out a step-by-step process and a timetable to site two civilian high level waste and spent fuel repositories and have one operating by 1998. The Nuclear Waste Policy Act of 1982 placed primary responsibility for the siting process in the Department of Energy (DOE). First DOE, with the concurrence of the Nuclear Regulatory Commission (NRC), was required to develop general guidelines to be used by the Secretary of the DOE in considering candidate sites for recommendation. After public review and comment these guidelines (see 10 CFR 960) were issued on November 30, 1984. (DOE, 1984)

Next, the Secretary of the DOE was required to nominate at least five sites deemed suitable for site characterization (Figure 3.3). Nominations were required to include environmental assessments, part of which consisted of suitability evaluations of the sites under the guidelines. Three of the nominated sites were then required to be recommended to the President for approval for characterization.

Following detailed characterization emphasizing underground, in-situ testing, a single site will be recommended to the President in 1987 (Figure 3-3). Final approval of site selection requires presidential consent and acceptance by the affected state, although objections by the latter can be overridden by a majority vote of both houses of the U.S. Congress. The Nuclear Regulatory Commission (NRC) is allowed up to four years to decide whether the Department of Energy (DOE) should receive a license for repository construction. Following construction during the mid 1990s, DOE must apply for another license to possess radioactive wastes for actual emplacement. The capacity of the first repository is limited to 70,000 MtU, which was the expected accumulation by the year 2000. Due to lower load growth and extended burnup, the first repository will be sufficient for a longer period of time. A site for a second repository, once

Figure 3-3. Reference schedule for first geologic repository.



scheduled for selection by 1990, has recently been deemed unnecessary at the present time.

Section 116(a) of the Nuclear Waste Policy Act (NWPA) required that States containing "potentially acceptable sites" be notified within 90 days of passage of the Act, but allowed 180 days for issuance of the siting guidelines. Thus the formal guidelines applied to the screening for a second repository, but did not require starting anew the screening for the first repository. At the time the Act was passed, nine sites were already being studied for the first repository, and the second repository was at the regional stage of investigation.

Of the nine potential sites for the first repository, two had been chosen on the basis of previous land use. The DOE screened federal lands where radioactive materials were already present, and found the basalt and tuff sites potentially suitable. Four bedded salt sites were found using the described screening process, and three salt domes were identified from 200 considered (offshore, younger salt domes were not included in the U.S. search).

Section 112(b) of the NWPA requires that the Secretary of the Department of Energy consult with the governors of the affected states before nominating at least five sites. The DOE, after holding public hearings at each of the nine potentially acceptable sites to obtain recommendations on the issues to be covered in the Environmental Assessment (EA) for each site, prepared Draft EAs for each of the nine sites to allow interested parties to review and comment on the evaluations. The Draft EAs, issued in December

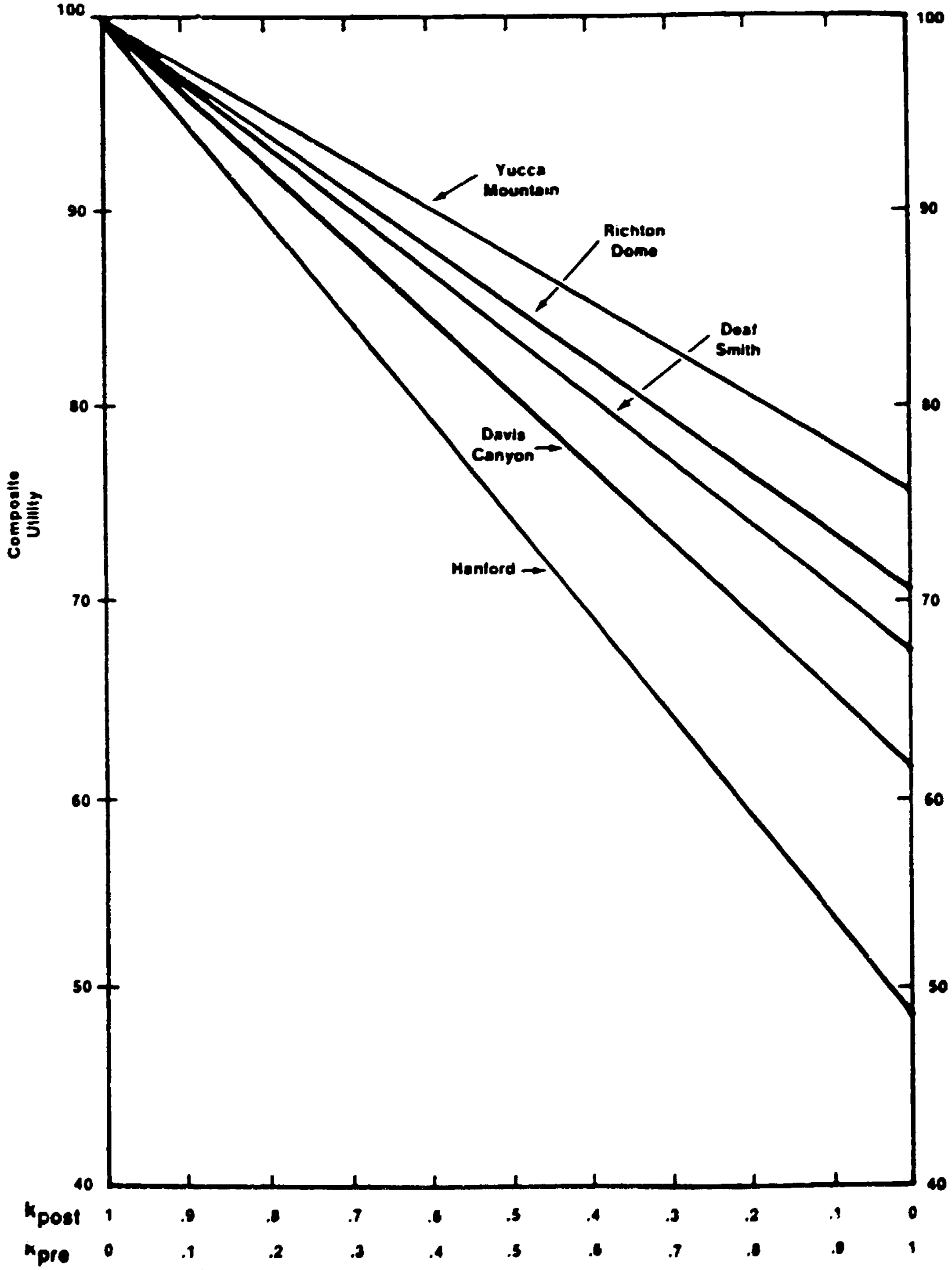
1984, included a common chapter containing the general guidelines, with the five sites proposed for nomination ranked against those guidelines. Final EAs of the five sites were published that incorporated comments received from the states, affected Indian tribes, other federal agencies, and the public.

The process for recommending three of those sites for characterization, described in the DOE Siting Guidelines (10 CFR Part 960,3-2-3), calls for evaluation based on available geophysical, geologic, geochemical and hydrologic data, other information and the evaluations and findings in the EAs that accompany the nominations. First, they are ordered based on that information. Then the siting provisions specify that at least two rock types and diverse geohydrologic settings be included in the final recommendation.

In the draft EAs, three simple quantitative methods were used to aggregate the rankings of each site under the technical guidelines. One of those methods was further developed and applied in a formal, multiattribute, utility-estimation, decision-aiding methodology which attempts to clarify which sites are preferable and why. (Department of Energy, 1986a) The technical siting guidelines are reviewed, together with the uncertainties and value judgements involved. The suitability and application of the decision-aiding methodology were the subject of an independent review by the Board on Radioactive Waste Management of the National Academy of Sciences, whose comments were included as an appendix to the report.

The three sites considered most preferable individually under the multiattribute analysis do not necessarily compose the best trio as a portfolio; thus... "the principal usefulness of the multiattribute utility method is to illuminate the factors involved in a decision, rather than to make the decision itself (U.S. National Research Council, 1986)." All five sites scored well and closely on the more-heavily-weighted post-closure guidelines. Under the pre-closure guidelines, the performance measures considered least important of all guideline subgroups in the siting guidelines--repository and transportation costs--were shown in the sensitivity analysis to dominate the aggregate scores. Though cost is a factor in choosing a site for development of a repository, at the recommendation for characterization stage cost estimates are still considered preliminary. Dropping repository and transportation cost scores from the preclosure aggregate scores in the Recommendation of Sites by the Secretary of the DOE (1984b) reorders the ranking from the multiattribute analysis. The tuff site at Yucca Mountain scored well under nearly all combinations of preclosure scores, best in the preclosure aggregate score and best in composite utilities (worth) (see Fig 3-4). The basalt site at Hanford, fifth among the five under the aggregate pre-closure scores, jumps to first when costs are dropped from the aggregate. The overriding stated rationale, excluding implicit political considerations, for choosing the Hanford site is that it maximizes the number of rock types under consideration. Choice of the third site, from among the three

Figure 3-4. Composite utilities of sites for all possible preclosure-postclosure weightings and base-case assumptions.



Source: U.S. Department of Energy, 1986

salt sites, quickly boils down to one of the bedded salt sites and the domal salt formation, as the other bedded formation is shown to be least-preferred of the salt sites under the aggregate preclosure guidelines.

The multiattribute analysis is most directly consulted for distinguishing among the salt sites; it shows the bedded Deaf Smith County site to rank consistently from first to third among all sites, whereas the dome site ranks from first to fourth for the same criteria. The Deaf Smith County Site is therefore chosen to be one of the recommended three.

Strictly under the multiattribute analysis the Yucca Mountain site was ranked first, Deaf Smith County third, and Hanford fifth. All five sites were shown to perform extremely well in the postclosure period, and each was located in a different geohydrologic setting. The Secretary of the DOE, taking into account the Nuclear Waste Policy Act (NWPA) requirement that sites be recommended in different geologic media, determined that the Yucca Mountain, Deaf Smith County, and Hanford sites are the three sites which constitute the final order of preference. Furthermore, "... it has been determined that the Yucca Mountain, Nevada, Deaf Smith County, Texas and Hanford, Washington sites offer, on balance, the most advantageous combination of characteristics and conditions for successful development of repositories at such sites (U.S. Department of Energy 1986b)." This choice has been contested by a Congressional Staff investigation, highly critical of DOE's application of the methodology and its subsequent decision. What is left unsaid in the recommendation, but made clear in the EAs, is that the DOE has ownership and control of all land and all surface and subsurface mineral and water rights at the Hanford site and that a portion of the Yucca Mountain site is currently controlled by the DOE, the remainder of the site is owned by the federal Bureau of Land Management and the Air Force (which uses its portion as a bombing test range). The Deaf Smith County land, presently entirely privately owned, can, like other privately owned land, be acquired through title transfers, voluntary purchase-sell agreements, or if opposition to acquisition arises, through the exercise of eminent domain. The other two salt sites also have major limitations: the Davis Canyon site is close to a national park and presents formidable transportation difficulties, while domal sites present unique intruder possibilities.

Characterization of the three sites is dependent upon the outcome of lawsuits filed by the affected states soon after the sites were announced.

III.C. Socio political Issues

Siting nuclear waste repositories has emerged as one of the most difficult and politicized tasks in managing the nuclear fuel cycle. In a number of countries attempts even to search for sites, be they for high level or low level nuclear waste facilities, have met with volatile and determined public opposition. Underlying this opposition has been the fear over the hazards of a nuclear waste repository, concern over the adequacy of safety measures, disagreements over national energy programmes, the so-called "not-in-my-backyard" (NIMBY) syndrome, and issues of equity and institutional trust. In the face of these problems, the six countries reviewed have formulated the different siting programmes outlined above, tied to the particular institutional structure and political culture of the country. Building upon the technical methodologies of siting, we turn to siting as a political process, first overviewing siting politics in the six countries, the contexts in which they operate, and the major sociopolitical issues which have emerged.

III.C.1. <u>An Overview of Siting Politics.</u>

III.C.1.a. <u>Federal Republic of Germany</u>

In the Federal Republic of Germany, nuclear waste siting has been highly controversial, a situation exacerbated by the Chernobyl accident. In 1974, the Federal Ministry for the Interior adopted the "Integrierte Entsorgungskonzept" (Integrated Waste Management Concept), which would integrate reprocessing, fuel fabrication, interim storage, and waste disposal in one system and, if possible, at one site. In 1977, the selection of Gorleben, by the Government of Lower Saxony, and the public controversy which resulted, led to the Gorleben International Review, involving lengthy public hearings and expert testimony. The eventual decision was to exclude reprocessing at the site but to continue with the exploration of the salt dome. Meanwhile local opposition has decreased. An associated cask storage facility has been constructed, is licensed for operation, but is also currently mired in court proceedings.

A second away-from-reactor storage facility at Ahaus (near the Dutch border) has had its construction halted due to a court challenge. However, a low level waste repository at Konrad, a former iron-ore mine, is in the licensing procedure and scheduled to go into operation in the early 1990s. Finally, a proposed reprocessing facility site at Wackersdorf (in Bavaria) attracted one of the largest anti-nuclear demonstrations ever to occur in West Germany in 1986 following the Chernobyl disaster. Although federal legislation in West Germany mandates reprocessing, direct disposal (Alternative Entsorgung) continues to be examined as a second option.

III.C.1.b. France

In France, siting efforts have proceeded with much less controversy in recent yeasrs although earlier there was substantial local opposition. (Syndicat. 1980) The first shallow land burial site for low level waste was opened in the late sixties close to the La Hague Reprocessing Plant, without much sociopolitical concern. The incentive for opening the site was the proximity to the reprocessing plant, and geological studies declared that the site was "adequate". In reality the geology is rather complex, with a succession of sandstones and schists, and a large number of fractures, so that even today the prediction of the movement of leached radionuclides in the ground is difficult, and conservative assumptions have to be used in safety studies.

In the late 1970's, the CEA (Atomic Energy Commission) decided that a second shallow land burial site was needed, as the first one was rapidly filling up, and its extension was not deemed feasible. In the officials' view its remaining capacity would be best utilized if primarily kept for the La Hague Plant. After some research (partly done by the French Geological Survey) a number of candidate sites were proposed. The CEA selected one and declared it optimal, pending more detailed in-situ reconnaissance. This site was in the mountains of Central France, on the site of an existing uranium mine which was being abandoned and backfilled, known as Les Bois Noirs at St. Priest-la-Prugne. It was a granitic site with fractured rock, and some alluvial deposits. The CEA considered that geology acceptable, as the burial of waste would take place on a thick concrete slab, assumed completely tight, and therefore not dependent upon the tightness of the underlying rocks. The incentive for selecting this site was again not geological, but based on the facts that the uranium mine workers and local people were familiar with radiation hazards, that the land was already owned by COGEMA (subsidiary of CEA), and that the opening of the site would bring needed jobs because of the earlier closing of the uranium mine.

In spite of this, local opposition to the project soon occurred and received additional support from anti-nuclear movements. The problem soon became a national one and the political parties took their sides, with the left clearly against the project. Hearings were held in the main town of the area, as well as local debates and protests. Two issues hurt the project very much: (i) Although meant for storage of low level waste only, the project stipulated that the site could also receive, for interim storage, some more radioactive waste (intermediate level waste or perhaps high level waste, without much precision). People suspected that, in fact, officials secretly planned to later open a deep mined repository for high level waste; (ii) CEA officials had publicly said that the site had been selected as one of the best among the list established by the French Geological Survey. But a document detailing the geological survey was soon leaked to the press showing that the site was at the bottom of the priority list!

Despite that, the reconnaissance of the site went forward and the site would probably have been opened if, in 1981, the Socialists had not taken over: President Mitterand visited the area, as a candidate, and promised to abandon it if he was elected. And he later did abandon the site. He also appointed as Minister for Energy Mr. Jean Auroux, who was the socialist representative of the area, and who had been the political leader of the opposition to the project!

Following the recommendations of the Castaing Commission in 1984, the government announced that two new shallow land burial sites had to be created before the end of the 1980s and that they would be selected after a detailed study of several candidate sites. This time, geological criteria were set first: the site should be built on a thin sand layer lying over a thick clay formation. The latter would serve as a tight protection for waters below the site, and the former would permit easy engineering of the site, as well as a natural drainage of any leaks, that could come from the concrete engineered structures on which the waste would lie. In an homogeneous sand formation, this drainage could easily be monitored, and would also be diluted at the streams surrounding the site.

Three sites corresponding to this prescribed geology were found, and studies started immediately. None of the sites were at reactor stations. A few communities volunteered to host the repository on the r land, attracted by the job opportunities and economic incenti . . None of these volunteered sites were found to meet the abo.e g ologic criteria, and were thus abandoned. Among the three r'ected sites, local opposition was moderate in one, and strong in the second. The third had to be discarded because of the eto of its local representative, who was also a member of the g vernment.

Therefore etailed reconnaissance were only made at one site, du Pli near Soulaines-Dhuys, in Aube, and the geology was found favorable. The project is now well underway, and the official permit is likely to be given within a year or so. If all goes well, disposal of waste could start in 1990. Meanwhile, the government has abandoned the project of opening simultaneously two new sites (the incentive for doing so was sociopolitical, not technical), and this one site is now considered adequate to meet French needs.

III.C.1.c. Sweden

In Sweden, site selection for nuclear waste facilities is moving forward, with several notable accomplishments already achieved, but with public opposition also apparent. The CLAB, a central interim storage facility, was successfully sited at an existing reactor site, even though this occurred during the intense discussions of the Swedish referendum of 1980, and it was commissioned in 1985. Similarly, the Swedish Final Repository (SFR), a final repository for low and intermediate level waste, has been sited at another existing reactor site, Forsmark, north of Stockholm, is currently under construction, and is scheduled to begin operations in 1988. Both facilities have experienced only low levels of public opposition.

The search for a high level repository has been more contentious. The initial examination of four sites in 1977 under KBS I, (SKBF, 1977) all at or near utility properties, generated only minor public concern. But since then, site exploration has encountered substantial local opposition. The Kynnefjäll site on the west coast has had a six year public occupation of the site, and organized opposition has been apparent at other locations.

III.C.1.d. Switzerland

Siting programmes in Switzerland have had their share of difficulties. The current siting effort involves a research drilling programme at 12 sites in northern Switzerland, which is scheduled to be completed in 1988, and the choice of a potential site in 1995.

The process for low level waste sitings has been described in detail above. Opposition in several cantons is apparent, however, and a lengthy political process prior to eventual site selection will be required. Meanwhile, there is considerable need for a centralized interim storage facility and a site has been proposed in the former reactor-site cavern at Lucens. However, strong public opposition has emerged.

III.C.1.e. United Kingdom

In the United Kingdom, radioactive waste facility siting has proceeded in the face of intense public opposition and evident political constraints. In 1980 the Government, as noted above, had identified 15 prospective sites to search for a high-level waste repository. The vociferous opposition manifested at two public inquiries led the Government to reassess the urgency of disposal. A decision to store high level waste for at least 50 years led to a decision to postpone exploratory drilling in favor of desk studies. The decision to postpone high level waste disposal means that such wastes will be kept in lengthy interim storage (50 years or more). This is deemed by NIREX (Nuclear Industry Radioactive Waste Executive) as appropriate for high level waste, as the volumes are small and cooled storage will allow the thermal heat to decay. This left intermediate level and low-level wastes to be addressed. In 1983, NIREX announced that it was preparing an application to examine two sites--low-level and short-lived intermediate-level waste near the surface at Elstow and intermediate-level waste in a deep mine at Billingham (an anhydrite mine site). Opposition was again intense--sufficiently so that Government officials required a police presence to attend the public meeting. A refusal by the mine owner to cooperate with NIREX exacerbated this situation. The Government decided in early 1985 that it would not proceed with Billingham and would ask NIREX to nominate three alternative sites to Elstow for a near-surface facility. NIREX announced four sites, and this generated a new round of controversy and related Parliamentary activity. In the face of the public concern about near-surface disposal, the Government in June 1986 indicated that all intermediate level waste would be disposed deep underground, and that site investigations would be restricted to low level wastes (to supplement the existing Drigg facility). A decision on which of the four sites to propose for development will be made by NIREX in 1988-89.

III.C.1.f. United States

In the United States, progress in waste facility siting is apparent but with evident opposition and uncertainty in the eventual outcome. After a series of abortive siting initiatives during the 1970s, the Congress in 1982 passed the Nuclear Waste

Policy Act (NWPA) which, quite extraordinarily, mandated a complicated high level waste repository siting process. But state or local opposition is apparent at each of the three candidate high level waste sites, and a variety of court challenges have already occurred. Meanwhile three sites in the state of Tennessee have been proposed by the U.S. Department of Energy for the monitored retrievable storage (MRS) facility, a centralized interim storage facility. Again, state opposition, albeit measured, and a court challenge have occurred. Meanwhile, low level waste facility siting in the U.S. is proceeding painfully, and slowly, through a tortured system of regional state compacts, with the first round of deadlines missed by all compacts, with no successful siting of new facilities yet achieved, and with nearly all in an early stage of development.

III.C.2. The Nature of the Siting Problem

Why, one might ask, have there been so few siting successes? What is it that makes radioactive waste facility siting so difficult and volatile?

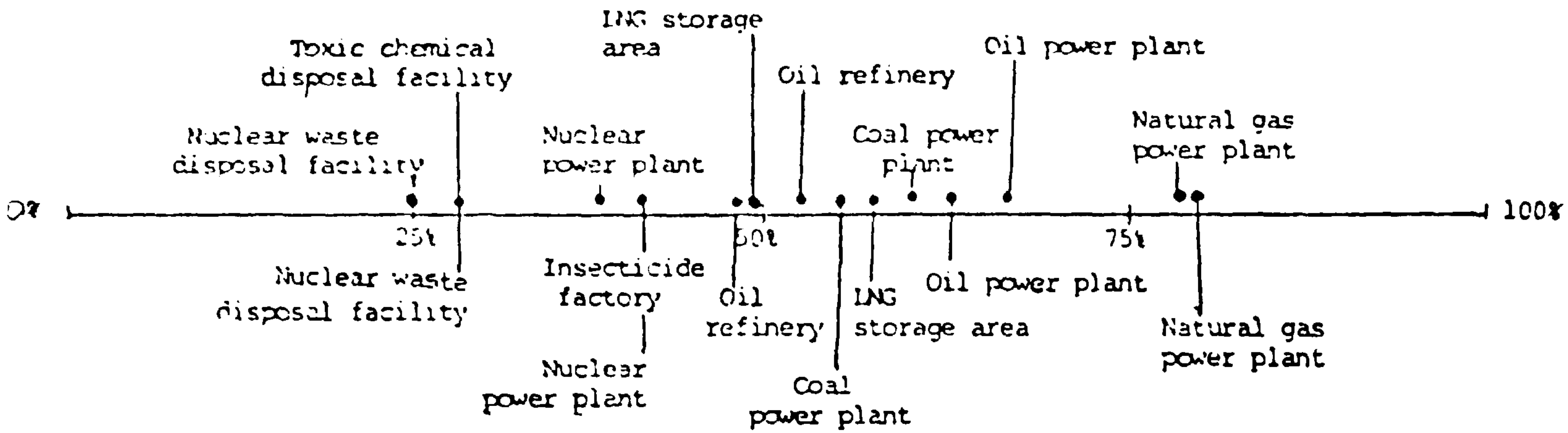
The answer does not lie, of course, in the technical realm although there are clear technical requirements for sound siting of geologic repositories. It is not geological issues which drive debate and public concern. Rather, a series of sociopolitical issues lies at the heart of local opposition.

Prominent among these is the public perception of high risk associated with a geologic repository, whether for high or low level radioactive wastes. Public opinion surveys in a number of countries provide convincing documentation of this public response. Public concern over radioactive waste stands at or near the top of concerns about the nuclear fuel cycle. A 1980 national poll in the U.S., conducted by Resources for the Future, found that only 10-12% of the public would voluntarily live a mile or less from a nuclear power plant or a hazardous waste disposal site, and majority acceptance did not occur until 100 miles from the site (U.S. Council on Environmental Quality 1980). A similar approach (Lindell and Earle 1984) assessing attitudes toward eight different industrial facilities indicated that nuclear waste disposal facilities were judged the least acceptable (Figure 3-5). Similar research in England has found that 79% of the population indicate that they would move away from their homes if a radioactive waste facility was proposed within 2 or 3 miles (as opposed to 51% for airport and 30% for a motorway). Psychometric research has indicated that radioactive waste shares many of the attributes associated with particularly feared technologies--they are "dread" hazards which are relatively "new," seen as likely to be fatal, and viewed as having catastrophic potential (Slovic et al, 1982). In regard to the last, since experts generally do not find credible catastrophic risks among accident scenarios for radioactive wastes, it may well be that the public does not always discriminate between nuclear power plant and waste repository risks. Also, it is possible that the public fears that accidental releases from a repository, or on associated transportation systems, may contaminate groundwater sources.

Exacerbating high risk perception is the distrust that some members of the public have for the institutions responsible for siting and managing waste facilities. While the level of distrust obviously varies from country to country, it is a generic problem. There is a perception among some members of the public that responsible officials are not committed to safeguarding public health and safety, that there is not candor and honesty about the risk involved, and that the views of those who will bear the risks will not be considered in siting decisions and facility design. The U.S. Office of Technology Assessment (OTA, 1985) has judged lack of credibility as "the greatest single obstacle that a successful waste management program must overcome ...". The Chernobyl experience in Europe, with the various problems experienced in risk communication, has understandably added difficulty to the siting challenge.

Finally, questions of risk and institutional credibility intermingle with value and policy issues. There is, in a number of countries, still much debate over the role that nuclear power should play in the national energy mix and the role that reprocessing should have in radioactive waste management and fuel supply. In the U.K. and the F.R.G., it is clear that concern over reprocessing contributes to local opposition to waste disposal more generally. Then, too, radioactive waste disposal poses two

Figure 3-5. Acceptance Scale for Eight Different Facilities



(Upper data: Lindell & Earle, 1981) (Lower data: Lindell, Earle, Hebert & Perry, 1978)

Source: Michael K. Lindell and Timothy C. Earle, "How close is close enough: public perceptions of the risks of industrial facilities," Risk Analysis 3 (December, 1984), 249.

equity problems (1) the distribution of risks and benefits over present and future generations and (2) over places of waste generation, places where repositories or other waste facilities are located, and connecting transport corridors. Why people should bear risks on behalf of others, what responsibility beneficiaries have to risk bearers, how we should value the future, whether compensation should occur and if so how--these are all value questions which intermingle with safety and more traditional facility impact issues. It is for these reasons (among others) that von Winterfeld and Edwards (1984), in their taxonomy of 162 technological controversies, assign hazardous waste facilities to the class of "technological mysteries and value threats" in which issues oscillate between factual disagreements and value disputes.

Taken together, these problems pose a potentially serious challenge to traditional siting mechanisms in each country.

III.C.3. The Context: Political Culture and Institutional Arrangements

The siting problem is not experienced the same way in each country. The particular issues posed by siting tend to interact with characteristics of political culture and institutional structure to determine the magnitude of the obstacles and the particular type of siting mechanisms which may be appropriate. While a searching review of these issues is beyond the scope of this report, several contextual features particularly pertinent to the siting experience in each country are noted.

III.C.3.a. Federal Republic of Germany

The Federal Republic of Germany, with a substantial nuclear investment and important (if arduous) progress on radioactive waste management, appears to face increasing difficulty in 1986. In the aftermath of Chernobyl and the pronounced public reaction its handling produced, polls showed a majority sentiment against nuclear power, and the Social Democratic Party moved to a position calling for a phaseout (Ausstieg) of this energy source. The party is also strongly opposed to breeder reactors, reprocessing, and the "plutonium economy." Meanwhile, 1986 has brought one of the largest anti-nuclear demonstration ever to occur in West Germany, accompanied by acts of violence.

Facility siting is intrinsically difficult because of decentralization and in fact the Federal Government has limited power to carry through a national programme. Site selection and licensing (and generally land control) are the responsibilities of state government, so the Federal Government must forge a stable partnership with the states. Licensing is a public proceeding with extensive opportunity for opponents to register objections (which must be answered). The local community must grant a civil engineering license and thus is responsible for one domain of siting. Meanwhile, the courts have played an increasingly important role in technical (as well as procedural) matters, as indicated by the fact that use of major waste facilities (Gorleben, Ahaus) is presently held up by court challenges. Although court decisions are pending, underground exploration (shaft sinking) at

Gorleben as well as the licensing procedure for Konrad go on. The uncertain political future of nuclear power and reprocessing in West Germany, the complexity of institutional processes, and (perhaps) Chernobyl point to difficulties in existing and future siting efforts.

III.C.3.b. France

France is in the 1980s the atypical nuclear society. Critical to this, certainly, is the energy situation, which provides few resource options. But several aspects of political context also contribute. Since 1981, with the assumption of power by the socialists, the anti-nuclear movement has been in decline in France. The loss of a base of support for this movement when the Socialists reached an accommodation with nuclear power certainly has contributed to this development. Then, too, the highly centralized policy-making and administrative structure of France also makes facility siting more tractable. Local communes and departments possess only informal powers in siting, lacking local licensing or permit procedures. Such decisions are made in the central ministries, where a high degree of integration through personal contacts among senior officials prevails. Consultation with local publics or opponents is minimal and generally confined to procedural matters. Also, the French central administration enjoys a reputation for high technical competence and respect in the public and operates with a high degree of latitude and discretion. It is a situation, generally, conducive to siting even potentially controversial facilities. Nonetheless, the project of establishing a low and medium level waste storage facility in the ancient uranium mine of Saint Priest-la-Prugne provoked significant opposition and had to be cancelled.

III.C.3.c. Sweden

Compared to the United Kingdom, Switzerland, and the Federal Republic of Germany, the siting context in Sweden appears considerably more favourable. Key to this may be the accommodation reached in 1980 on the phaseout of nuclear power, which had at least prior to Chernobyl, de-escalated this issue considerably in Sweden. The political parties are not a major axis of conflict on nuclear power and the anti-nuclear movement, at least prior to Chernobyl, had waned substantially. Swedish political culture emphasizes negotiation, compromise, and accommodation. The broad international review of the KBS reports has won considerable international regard for the waste programme. Meanwhile, domestically the radioactive waste programme has gone forward with a strong emphasis upon the long-term safety of facilities. While local communities possess a veto authority on facility siting (now under review by the parliament) and local opposition has occurred during the high level waste repository search programme, the national political context and the siting successes of the CLAB interim storage facility and the Swedish Final Repository (SFR) for low and intermediate level wastes suggest that future siting efforts may have a reasonably favourable prospect of success.

III.C.3.d. Switzerland

Switzerland, is a federal state with high degrees of cantonal and local autonomy. Since 1974 there has been active local opposition to nuclear power and NAGRA (National Cooperative for the Storage of Radioactive Wastes) has confronted conflict with each siting initiative. Two national referenda on nuclear power have been conducted. In 1979 a proposal that no new nuclear plants be constructed lost in a very close vote (49 to 51%). In 1984, a similar referendum also lost narrowly.

In several cantons, anti-atomic laws requiring the canton to resist nuclear facilities and explorations for sites have been passed. While cantons are restricted to administering planning law and cannot decide policy matters on radioactive waste disposal, they do possess the power to tie up siting efforts in lengthy political and judicial procedures. The local community, meanwhile, can oppose a facility for any technical reason within its competence (usually dealing with construction) and can also introduce substantial delay or court challenges.

The judicial appeal process involves access to three tiers of review--local, cantonal, and federal courts. In addition, public proceedings require that all citizen concerns be explicitly answered at each stage. In general, facility siting in Switzerland requires the forging of partnerships among units of government and developmental efforts for siting to go forward--all this in the face of strong opposition.

III.C.3.e. United Kingdom

In the United Kingdom, a long tradition of local control over land use planning and decisions makes local opposition difficult to overcome. Local authorities, for example, can place a "Stop" notice which halts development for 48 hours to allow more discussion. Planning permission is required even for the government to conduct geological exploration, and this may involve a public inquiry. While a public inquiry is only advisory, in fact it carries substantial weight in governmental decisions and the ability to move ahead with proposed developments, as well as enhancing the power of local planners and land owners.

The introduction of the Special Development Order procedure is a marked change in the political handling of waste disposal in the U.K. Until 1986, it was held that every industrial application to conduct site investigations would be subject to normal planning law and would become the subject of a public inquiry. Faced with the requirement to conduct parallel investigations on several sites, the industry argued that substantial delay and duplication would occur unless the content of the inquiries were limited. The Government's response was to invoke the Special Development Order procedure, by which an order authorizing a strictly limited activity is laid before Parliament and, if passed, allows the activity (site investigation) to proceed without further planning permission. While the S.D.O. procedure is not new, it has not been used previusly in waste management.

It passed Parliament by a comfortable margin but was opposed by all four site constituency MPs.

In fact, there is currently no real institutional mechanism for involving the public at the waste facility siting consideration stage. Meanwhile, environmental groups, it is widely acknowledged, have easy access to the mass media, where they can effectively raise technical and social issues over radioactive waste. When these characteristics are joined with the apparent increasing prominence of reprocessing and the radioactive waste issue in national politics and a critical upcoming national election, it is a context in which facility siting is highly visible, politically costly, and straining existing institutions.

III.C.3.f. United States of America

The United States shows both important similarities and differences with the five European countries. As with the Federal Republic of Germany and Switzerland, there is a tradition of strong state authority with which the Federal Government must divide power. And, as with the Federal Republic of Germany, courts play an increasingly major role in regulatory decisions. Extensive local controversy has characterized hazardous waste facility siting, and organized national opponents exist to contest new sites and waste transportation.

Unlike Sweden, the United States has an adversarial political culture in which conflict is expected, regulations are highly quantified, governmental agency personnel are often held in generally low regard and are distrusted, and public participation is expected at all stages. With such dispersion of authority and multiple axes of conflict, assembling sufficient authority to carry through the complex siting legislation passed by the Congress is very difficult. The decision to defer the second repository mandated by the Nuclear Waste Policy Act suggests that radioactive waste facility siting in the United States is, as in the United Kingdom and the Federal Republic of Germany, not well insulated from the political process in the face of an upcoming election.

III.C.4. Informal Siting Criteria

Two types of criteria--formal and informal--have come into play in waste repository siting. The formal technical criteria and methodology has been documented above. They show considerable uniformity among the six countries. But there are also informal criteria, often sociopolitical in nature, which come into play.

Such criteria, while acknowledged by all, are not formally stated; thus, they must be inferred from practice and from the insights provided by interviewees in each country. Prominent among these are the perceived political acceptability of the site. A variety of considerations are involved ranging from questions of regional equity to the location of residences of key government ministries and members of Parliament, potential swing districts in upcoming elections, and likely local opposition.

One pattern of siting apparent in a number of countries is the nomination of radioactive waste facility sites at existing nuclear facility sites or sites of other projected but unsuccessful nuclear sites. Consider, for example,

(1) the successful Swedish siting of CLAB at the Oskarshamn nuclear power plant and the SFR at the Forsmark nuclear plant site

(2) the selection in Switzerland of the former Lucens research reactor as a potential site for a centralized interim storage facility

(3) the inclusion of the Hanford and Yucca Mountain (adjacent to the Nevada Test Site) sites in the top three nominated high level waste repository sites in the U.S.

(4) the designation of three sites in Tennessee in the U.S. for a monitored retrievable storage facility included the cancelled Clinch River Breeder Reactor Project site, the Oak Ridge Reservation site, and the site of a cancelled nuclear power plant at Hartsville.

Various arguments can be made why such sites are likely to be good candidates for a radioactive waste facility. But among them is certainly a perception that such sites, having passed the political test once, are likely to be politically more receptive than new sites lacking such experience. Since public acceptance is the key obstacle in facility siting, it may well take on greater importance than technical consideration.

Even formal methodologies are not immune to such considerations. When the multiattribute utility analysis by the U.S. Department of Energy (DOE) left the Hanford site in fifth place, DOE then utilized a technical consideration (diversity of geologic media) to move Hanford to second and drop the Richton site to fourth. Certainly purely technical considerations did not generate three nuclear-only sites in Tennessee for the Monitored Retreivable Storage facility, nor two existing reactor sites in Sweden for the CLAB interim storage facility and the Swedish Final Repository for Low and Intermediate Level Wastes (SFR). In the United Kingdom, political considerations were incorporated in the "planning" factor and led to the exclusion of one potential highly ranked site.

But co-location with an existing or projected nuclear facility is only one consideration in perceived political acceptability. A second is a depressed local economy and high rates of local unemployment. It is well known that the economic benefits and compensations (if any) of a nuclear waste facility are likely to be of greater attraction to communities with depressed local economies. Therefore, it is apparent that the calculus of likely political acceptability of a site includes this factor in some siting programmes. Gorleben, which was not one of the original candidate sites in the Federal Republic of Germany, is a prominent example (as is the proposed reprocessing facility at Wackersdorf). Richton, Mississippi and the Waste Isolation Pilot Plant in New Mexico are American cases.

Formal analysis, as through surveys of public opinion, of the potential public response does not appear to be a normal part of gauging the public acceptability of a site. Although studies of the geographical pattern of public opinion on nuclear power and radioactive waste facilities have been conducted by the Nuclear Industry Radioactive Waste Executive (NIREX) in the United Kingdom, they apparently have not been used centrally in site selection.

Finally, to counter the inevitable institutional distrust likely to surround site selection, it is possible that extraordinary means will be used to add legitimacy to the procedures adopted and eventual decisions taken. In the United States, the Department of Energy sought, and received, review of its use of a multi-attribute utility analysis in site selection from the National Academy of Sciences. In the Federal Republic of Germany, a prestigious international review committee was assembled to deal with the desirability and feasibility of waste management plans at the Gorleben site. The extensive International Reviews of the Swedish KBS studies are perhaps the most striking example. Such institutional mechanisms may emerge in other siting ventures, particularly where credibility is a major problem.

III.C.5. Compensation and Negotiation.

There are several rationales as to why compensation might be provided to local populations at a radioactive waste facility site: (1) to redress harm which may occur, thereby restoring the original condition, (2) to redress the broader inequities involved in the geographical separation of benefits and costs, and (3) to provide financial incentives to encourage public acceptance at the site. Such compensation can come in a variety of forms--direct monetary payments, taxes, payments in lieu of taxes, non-monetary concessions (jobs, schools, highways, economic development programmes). When compensation has the goal of increasing local acceptance, it is frequently combined with negotiation between the siting party and the host community, in part to define the terms and magnitude of compensation arrangements.

Practice in the various countries differs markedly in regard to compensation in the siting process. The most elaborate use, linked with negotiation, occurs in France. Under French law, developers of any large industrial facilities are required to manage impacts occurring in the host area, during both construction and operation phases. Until 1985, nuclear power plants also carried an economic incentive in the form of a host community reduction in electricity rates. The French ministries disallowed this practice because it was seen as violating equality provisions (because of discrimination against other host region communities) and, perhaps, because of the political conflict which had been engendered.

ANDRA (National Agency for the Management of Radioactive Wastes), responsible for siting both high and low level repositories, has broad discretion in negotiating with, and compensating, prospective host sites. In regard to low level waste repository siting, the Ministry of Industry, after discussions with ANDRA and the waste generators, set a compensation level of 30 million francs <u>prior</u> to the selection of any site for a high level waste repository. In this arrangement, Electricité de France will pay 70-75%, CEA (Atomic Energy Commission) will pay 10%, and ANDRA 15-20%. Since as many as 15-20 communities may be involved in the host region, ANDRA must decide on a pattern of allocation. This will be articulated in an overall developmental programme for the region, with components of the programme decided in negotiations between ANDRA and individual communities after an appraisal of local needs. ANDRA also guarantees a minimum facility (and equipment) tax payment of 1.5 million francs per year to communities in the host region. Beyond this, ANDRA will write a contract with the local communities which may include stipulations for the employment of local people, the hiring of regional industrial firms, and the involvement of local expertise in monitoring facility performance and environmental impacts. When combined with the centralization of decision making in site selection, these arrangements provide ANDRA with extraordinary leverage and flexibility in securing site acceptance.

Other European countries show much less use of compensation and negotiation. In most countries, the local community receives some traditional benefits--local taxes, some employment gains, and local expenditures by workers. In the Federal Republic of Germany, a state can request compensation for impact mitigation from the federal government. Lower Saxony did so in the case of Gorleben and received compensation, although the local area reportedly ended up with few of these funds. In Sweden and Switzerland, economic incentives beyond taxes and direct economic incentives are not offered. In the United Kingdom, compensation in radioactive waste facility siting is emerging as a significant public issue. Generally, there is not a tradition of such payments, except for direct impact mitigation, in industrial facility siting. But local arguments for compensation beyond impact mitigation are rising and, farther down the line (and probably after the chosen site public inquiry), a policy decision will have to be made.

Behind France, the United States is the country to make greatest use of compensation. A variety of federal programmes currently provide impact mitigation to local communities experiencing adverse siting effects. In large energy projects, monetary and non-monetary compensation has been provided, along with occasional use of economic incentives. The Nuclear Waste Policy Act of 1982, mandating funds to support host-state-sponsored socioeconomic impact studies and a negotiated impact mitigation fund, was extraordinary in that they were federally legislated requirements and have generally not been so mandated for other hazardous facility siting programmes. Even in these provisions, however, the U.S. Department of Energy has much less flexibility in the use of such funds. The U.S. Congress intended that the impact mitigation fund be used to redress inequity and specifically *not* as a means of securing site acceptance (although some Congressional members favoured such a use). The Department of Energy is constrained to act in a conservative way in state claims on that fund whereas the Congress retains the latitude to provide whatever additional further concessions, including appropriation of public funds, needed "to grease the wheels" of siting implementation.

The Monitored Retrievable Storage (MRS) facility, proposed for location at one of three sites in Tennessee, including two at Oak Ridge, provides an interesting insight on the issue of compensation. Possessing highly developed local expertise on such matters, Oak Ridge mounted a task force to consider the MRS issue, funded by $100,000 out of a 1.4 million dollar grant from the U.S. Department of Energy to Tennessee for a state review. In suggesting that the MRS facility be given only qualified acceptance, the task force called for a broad programme of local involvement and safety assurance. Included were a set of key recommended compensation arrangements that:

> *such "in lieu of tax" grants should begin when Congress authorizes the MRS and should continue after the MRS ceases operations and is completely decommissioned (emphasis added)
>
> *to the fullest extent possible, all related research, development, goods, and services should be acquired from within the impacted communities, regions, or state
>
> *all MRS major contractors should commit their firms to the diversification of the communities' economic base
>
> *to assist the communities' industrial development, DOE should make available for purchase an industrial site equal in size to the Clinch River MRS site.
> (King, 1986).

It is apparent that the role of compensation and negotiation is closely related to political culture. In France, the broad discretion possessed by the central government and the wise use of compensation is a means to overcome local resistance to a highly centralized administrative system. The "let's strike a deal" approach to adversarial relations is endemic to American politics. But in Sweden where cooperative and consensual approaches to problem resolution predominate, and in the United Kingdom, where the civil service has a long tradition of defining the public interest, such approaches are out of place. Indeed, it is instructive that radioactive waste disposal appears to be driving significant institutional changes in countries such as the United Kingdom and the Federal Republic of Germany, and requiring extraordinary institutional arrangements in the others.

III.C.6. Public participation

Where strong public concern exists over the siting of a waste facility, it is not surprising that demands for extensive consultation with and involvement of local publics arise. Such demands are likely to be more intense where perceived risk is high, where political cultures encourage participatory processes, and where distrust of siting institutions prevail. Generally, countries have approached public participation using traditional institutional mechanisms for facility siting. But it is apparent that high levels of local concern at sites are forcing procedural innovations, extraordinary measures, and, in some cases, broader institutional changes.

One approach is to treat radioactive waste facilities as one example of a broader class of industrial plant sitings. The public is typically not involved until a final list of sites has been selected, and then primarily in a procedural way. Exempting negotiations with local officials, public inquiries have proceeded this way in France. Other countries have also begun their radioactive waste siting programmes using traditional mechanisms, only to find local opposition forcing ad hoc supplements to these institutional means. So the Federal Republic of Germany called for a broad international review, as noted above, for Gorleben. In other cases, such as the interim storage facility at Ahaus where a public inquiry would not ordinarily be required, a special public inquiry has been mandated. In the first period of project Andere Entsorgungstechniken (1981-1983) the Ministry for Research and Technology (BMFT) formed an Advisory Committee to which critics as well as nuclear proponents were appointed. In the United Kingdom, radioactive waste siting has produced much debate about the scope and role of public inquiries, particularly in the aftermath of the far-reaching Sizewell B inquiry. In Switzerland, local opposition at sites has necessitated extensive consultation and negotiation, with both cantonal and local community representatives. In the United States, the Department of Energy has supplemented formal public hearings with extensive use of informal public meetings, at sites and outside the site regions, and expanded dissemination of information.

The second approach is to treat radioactive waste siting as a unique challenge and to seek earlier and broader consultation, with innovation in the traditional consultation mechanisms. Sweden has long made use of the study circles within the political parties or labor unions as a way of shaping national consensus in advance of programme implementation. In the United States, siting of the Waste Isolation Pilot Plant included funds from the Federal Government to create a technical advisory committee to the Governor of New Mexico, which would review technical plans and provide independent assurance that safety goals would be achieved and local and regional adverse impacts minimized or mitigated. In other cases, such as at the Grimsel site in Switzerland, host area demands have wrought guarantees that an investigation area could never become a permanent repository as a condition for agreeing to further research, or, to take another Swiss case, that wastes would be kept in a retrievable mode if the site were to be retained as a candidate location for a low level waste repository. Such participation and negotiation innovations, it should be noted, are regarded as dangerous and ill-conceived by some of the technical experts involved in siting programmes in a number of countries.

The Oak Ridge Task Force recommendations, related to the proposed Monitored Retrievable Storage (MRS) in the U.S., provide an indication of types of public participation, in a given political culture, that may be advocated as the price for local acceptance of a radioactive waste facility:

* a citizen MRS Environment, Safety, and Health Review Board should be established to represent the communities' interests during construction, operation, and decommissioning of the facility. It would participate in the development of safety and environmental standards, have access to all relevant information, and the right to suspend operations if releases exceeded standards.

* a community Environmental Monitoring Program would be established

* local governments would be granted formal opportunity to address transportation issues

* "consultation and cooperation" agreements should be signed between DOE and the local governments as well as between DOE and the states

* local governments should be granted preferred status in continued discussions with the state, DOE, and NRC regarding the MRS

* upon MRS authorization, DOE should finance a significant public education programme under the direction of the county and city (King, 1986) (DOE is the U.S. Department of Energy; NRC is the U.S. Nuclear Regulatory Commission).

Also instructive was an indication by the local citizens opposing the facility that they might well support it if these and other recommendations were adopted (King 1986).

A final issue of great importance in public participation is the role of judicial review. In France, Sweden, and the United Kingdom, local citizens and opponents generally do not have access to the courts to contest the siting of a facility. In the Federal Republic of Germany, Switzerland and the United States, there is substantial access. In each of these latter countries, the courts have been flooded with legal challenges to radioactive waste facility siting programmes. In the Federal Republic of Germany this had led to a larger intrusion by the courts into substantive technical areas than has prevailed previously. Such participation also has clearly posed threats to the viability of established institutional processes, as in the Federal Républic of Germany where all siting efforts are mired in court-induced delays, and in the United States where there are state and local judicial challenges to DOE's implementation of the Nuclear Waste Policy Act. It is clear that judicial ensnarlment is forcing consideration of new public participation means (e.g., environmental mediation) for resolving public controversy.

III.D. Conclusion.

Substantial efforts and programmes for siting radioactive waste facilities are under way in the six countries. Results of research in the various countries on appropriate geological environments for high level waste sites are encouraging that suitable sites can be found. In addition, there appears to be considerable consensus on the properties of sites and appropriate methodologies which contribute to long-term safety.

At the same time, it is apparent that siting radioactive waste facilities is, and is likely to remain for at least the short term, highly controversial. The roots of local opposition and objections by critics are relatively well understood. But national responses are quite variable as are the outcomes of siting efforts. It is apparent that solutions will vary from country to country, according to characteristics of political culture. But siting difficulties are likely to challenge established institutional processes and test the will of central governments to sustain political costs to register progress on effective facility siting efforts.

The experience with siting radioactive waste facilities, when viewed across countries, has been uneven, with some successes apparent but with many failures. It is apparent that siting such facilities typically elicits a high degree of public concern and, not infrequently, intense local opposition. Overcoming determined local opposition is everywhere a serious problem, but, because of constitutional structures and local planning traditions, a greater problem exists in some societies than in others. Siting difficulties are, without question, one of the primary sociopolitical obstacles to mounting effective radioactive waste management programmes across the six countries.

Previous experience with siting large industrial facilities provides only limited guidance for responding to the siting problem. It is not the traditional social and economic impacts at the site which drive conflict, but the nature of the material in the repository and the fear and distrust it invo[illegible]. These reactions are compounded by equity questions and value issues. These are sometimes referred to as the "special impacts" of a repository and are expected to overwhelm the more traditional impacts. Existing institutional mechanisms for siting facilities are often inadequate for dealing with the conflicts engendered.

While the generic nature of the problem is apparent, generic solutions are not. Rather they seem to be guided by attributes of the particular political culture which prevails in that country. Thus, whereas compensation and bargaining will be central to acceptable solutions in France, Switzerland, and the United States, they are likely to play much less of a role in Sweden, West Germany, and (perhaps) the United Kingdom. What is apparent is that the institutional processes will require means to address the underlying conflicts, and that institutional adaptation and extraordinary measures may be necessary, since the problem often becomes extraordinary.

References

Ahlstrom, P.-E. 1986. Current Status of the Swedish Waste Disposal Program. Paper presented at the IAEA International Symposium on the Siting, Design and Construction of Underground Repositiories for Radioactive Wastes. Hanover, Germany, March 3-7.

Alder, H. 1986. Personal Communication. Federal Institute for Reactor Research, Switzerland.

Buser, M. and Wildi, W. 1984. Das Gewahr Fiasco -- Materiellen zam gescheiterten Projekt "Gewahr" der Nagra. SES, Zurich.

Castaing Commission 1983. The Second Report. MRI/CSSN. Rapport du groupe de travail sur les recherches et developpement en matiere de gestion des dechets radioactifs propose par le CEA, 18 Mars. Paris.

Commission of the European Communities, 1979. European Catalogue of Geological Formations Having Favourable Characteristics for the Diisposal of Solidified High-Level and/or Long Lived Radioactive Wastes, Vol. 1. Introduction and Summary.

Faussat, A. 1986. Personal Communication ANDRA. Paris.

Feates, F.S. 1984. Personal Communication. U.K. Department of Environment.

Gray, D.A. et al. 1976. Disposal of Highly-Active, Solid Radioactive Waste into Geologic Formation -- Relevant Geological Criteria for the U.K.. NERC-IGS Report No. 76/12. London.

Hirsch, H. 1983. Nuclear Waste Management in West Germany -- The Battle Continues. The Ecologist 13:4-15.

International Atomic Energy Agency, 1977, "Site Selection Factors for Repositories of Solid High Level and Alpha-Bearing Wastes in Geological Formations," Vienna, Austria.

Keen, N.J. 1984. Personal Communication. NRPB, Chilton. May 22.

King, J.C. 1986. MRS and the Local Community. Forum for Applied Research and Public Policy 1 (Spring): 42-49.

Lindell, M.K. and Earle, T.C. 1984. How Close is Close Enough: Public Perceptions of the Risks of Industrial Facilites: Risk Analysis 3 (December): 245-253.

McInerney, T. 1986. Personal Communication NIREX. Harwell. 6 May.

Merz, E., Kuhn, K., Bloser, M., Matting, A. 1986. Implementation of the Federal Republic of Germany's Policy and Strategy of Radioactive Waste Disposal. International Symposium on the Siting, Design, and Construction of Underground Repositories. IREA, Vienna, Austria.

NAGRA, 1981. Die Endlagerung Schwach-Und Mittelradioaktiver Abfalle in der Schweiz: Potentielle Standortgebiete Fur ein Endlager Typ. B. NAGRA Technischer Bericht NTB 81-04.

NAGRA, 1983. Die Endlagerung Schwach-Und Mittelradioaktiver Abfalle in der Schweiz: Evaluation der Potentiellen Standortgebeite. NAGRA Technischer Bericht NTB 83-15.

SKB 1985. Final repository for reactor waste -- SFR. Stockholm: SKB.

SKBF, 1977. Hardling of Spent Nuclear Fuel and Final Storage of Vitrified High Level Reprocessing Waste-KBS-1.

SKBF, 1983. Final Storage of Spent Nuclesar Fuel-KBS-3.

Slovic, P., Fischoff, B., Lichtenstein, S. 1982. Rating the Risks: The Structure of Expert and Lay Perceptiosn in Hohenemser, C., Kasperson, J.K. (Eds) Risk in the Technological Society. Westview Press.

Syndicat CFDT. de l'Energie Atomique, 1980. Le Dossier Electronucleaire. Editions du Sevil, Paris.

U.S. Council on Environmental Quality 1980. Public Opinion Issues. Washington: USGPO.

U.S. Department of Energy 1984. "Nuclear Waste Policy Act of 1982; General Guidelines for the Recommendation of Sites for Nuclear Waste Repositories; Final Siting Guidelines. 10 CFR 460." Federal Register 49, No. 236 (December).

U.S. Department of Energy 1986a. A Multiattributed Utility Multiattributes Utility Analysis of Sites Nominated for the First Radioactive Waste Repository -- A Decision-Aiding Methodology. Washington: The Department.

U.S. Department of Energy 1986b. Recommendation by the Secretary of Energy of Candidate Sites for Site Characterization for the First Radioactive-Waste Repository. Washington: The Department.

U.S. National Research Council 1986. Letter of October 10, 1985 and April 10, 1986 to Ben C. Rusche, Director, DOE Office of Civilian Radioactive Waste Management from Frank Parker, Chairman, Board on Radioactive Waste Management, National Research Council.

U.S. Office of Technology Assessment 1985. Managing the Nation's Commercial High-Level Radioactive Waste. Washington: USGPO.

Von Winterfeldt, D., and Edwards, N. 1984. Patterns of Conflict about Risky Technologies. Risk Analysis 4 (March): 55-68.

CHAPTER IV

INTERIM STORAGE OF SPENT FUEL

By 1980 approximately 8000 metric tonnes of uranium (MTU) had been discharged and stored in facilities at reactor sites in the United States and some 3,700 MTU were being stored in similar facilities across Western Europe (U.S. Office of Technology Assessment,1985; Geck and Taormina, 1983: 107). By the end of the decade, these figures are expected to increase to 21,000 MTU and 23,335 MTU, respectively. Worldwide heavy metal in spent fuel is expected to increase to 172,000 metric tons by the year 2000 (Barkenbus, et al. 1985). It is expected that not more than one fourth of that fuel will be reprocessed (Nechaev et al. 1986). Whether reprocessed or not, long term storage will be an important part of the backend of the fuel cycle as shown in Table 4-1. Since most countries will store high level wastes for 30 to 50 years to allow the wastes to cool substantially prior to final disposal, the expansion of interim storage capacity has become an important priority for waste management policies on both sides of the Atlantic.

Most Western European countries have expanded the storage capacity of their reactor pools. Moreover, the construction of large centralized storage facilities away from reactor pools, and in particular those connected with the reprocessing plants

TABLE 4-1

OVERVIEW OF INTERIM STORAGE

COUNTRY	PROJECTED LENGTH OF STORAGE	INSTITUTIONAL RESPONSIBILITY	FACILITIES/ SITING	PUBLIC RESPONSE	KEY SOCIO-POLITICAL ISSUES
France	40-50 years for vitrified waste	Producers of waste responsible for management (COGEMA and EDF)	Existing facility at Marcoule; another planned at La Hague. Third facility planned at a new site.	Little apparent public opposition	Little apparent controversy
FRG	20-30 years for vitrified waste	Utilities responsible to develop and operate facilities (DWK)	Licensed facility at Gorleben; facility at Ahaus under construction. Storage also planned at Wackersdorf	Intense political opposition to siting	Strong debate over reprocessing and future of nuclear power
Sweden	40 years	Utilities responsible to develop and operate facilities (SKB)	CLAB successfully sited at reactor site (Oskarshamn)	Little apparent local opposition	Little apparent controversy
Switzerland	Uncertain; at least 20-30 yrs. likely	Utilities responsible to develop and operate facilities (NAGRA)	Decision pending over centralized vs. decentralized facilities	Strong local opposition to siting	Lengthy interim storage and retrievability key political issues
U.K.	50 years for vitrified waste	Development and operations of facility by utilities (NIREX)	Co-located at Sellafield	Strong support for lengthy interim storage	Strong demand that all wastes be kept retrievable. Reprocessing also volatile issue
U.S.	5-10 yrs for spent fuel	U.S. Department of Energy to assume waste and build and operate interim storage facilities (including MRS)	MRS is key planned facility, proposed for State of Tennessee	State-level opposition to process of locating MRS in Tennessee	Retrievability a legal requirement, apparent public issue. Public participation & compensation potential issues.

at LaHague (France) and Sellafield (U.K), has considerably alleviated the short term and long term at-reactor storage requirements. In the United States, by contrast, the Congress while affirming the primary responsibility of nuclear power plant owners to provide interim storage has authorized a minimum of 1900 metric tons (U.S. Congress, 1982) to be provided by the Federal Government of away-from-reactor storage facilities. In addition, the Congress has found that "long term storage of high-level radioactive waste or spent nuclear fuel in monitored retrievable storage facilities is an option for providing safe and reliable management of such waste or spent fuel." While the Department of Energy has proposed such storage in a Monitored Retrievable Storage Facility (MRS) Congress has yet to authorize such a facility. Therefore large increases in the capacity of at-reactor storage facilities will be required in the U.S.A. before the end of the century if reactor shutdowns are to be prevented (unless authorization is received for the proposed monitored retrievable storage facility in Tennessee). Even with reracking and transshipment to underutilized reactor sites approximately 2600 tons of additional storage capacity will be needed by 1998. (Anderson, 1985)

In Sweden the construction and operation of the CLAB facility and in the Federal Republic of Germany the construction of three away from reactor storage facilities at Ahaus, Gorleben and Wackersdorf will also alleviate any near term storage problems at reactors. Switzerland with its reprocessing contracts abroad and the reracking at all its reactors does not face immediate storage problems though it intends to construct an interim storage facility.

This chapter describes and compares the major technologies that are available for storing spent fuel, overviews the initiatives undertaken in the six countries to provide both short and long term storage of high level radioactive wastes and spent fuel, and identifies the major sociopolitical issues which have arisen in connection with such storage.

IV.A. Interim Storage Technology

Practically all existing commercial spent fuel at reactors is being stored in water filled basins, which is a proven technology for providing the high level of radiation shielding and cooling that is needed during initial storage periods. The basic technical aspects of wet storage systems are described in the International Nuclear Fuel Cycle Evaluation (INFCE) (1980) and IAEA Technical Publication 218, among others (1986b). One of the earliest critiques of interim storage technologies was carried out by the Committee on Radioactive Waste Management of the U.S. National Academy of Sciences (NAS, 1975). In that critique the committee found that the technology for interim storage was available, that it preferred a stand alone naturally air cooled cask, and that the "multiple barriers against dispersal of radionuclides" would ensure public safety.

This discussion focuses upon (1) the opportunities that exist for expanding the storage capacity of already built wet storage facilities, (2) the wet and dry storage systems that are now being considered for expanding storage capacity, and (3) considerations of relative safety and costs of implementing wet and dry storage systems.

It should be noted that, in general, a system that can satisfactorily store spent fuel can also be designed to store solidified high level wastes from reprocessing (U.S. Office of Technology Assessment, 1985). Therefore, while the discussion of storage in this section focuses upon spent fuel storage, because this is predominately what will be stored, it is also pertinent to the interim storage of solidified high level wastes.

IV.A.1. Wet Storage

At the time the reactors that are currently in operation or under construction were originally designed, it was assumed that spent fuel would be stored in water pools at reactor sites for a short period of time (to permit radioactive decay of short-lived radioisotopes contained within the fuel and thermal decay) and periodically shipped off-site for reprocessing. Wet storage has been routinely used for over 20 years. At-reactor storage facilities were typically designed with only sufficient capacity for about 1 1/3 full nuclear reactor cores. Assuming a three to four year reactor fuel reload cycle, the at-reactor storage pools could store an average of one year's discharge with enough remaining capacity to store a full core discharge in case of a complete reactor or fuel element inspection. Under normal operating conditions, about five years' spent fuel discharge could be accommodated before the pools were filled. At-reactor storage facilities were, therefore, not originally designed to store an accumulated inventory of spent fuel and, as a result, their potential capacity was not maximized. The capacity of at-reactor and away-from-reactor water basins may, however, be increased in two ways:

(a) Reracking allows for closer spacing of stored spent fuel elements by replacing the original, inefficient, but relatively inexpensive aluminum storage racks with more expensive racks made of stainless steel and, to prevent criticality problems, borated, stainless steel. Through reracking, utilities have increased the capacity for stored fuel in each square foot of pool from less than 0.25 tU to as much as 0.58 tU (Lawrence and Johnson 1983). As discussed below, most utilities in the United States and Western Europe have replaced their storage racks, and some have reracked several times.

(b) Rod consolidation involves disassembling fuel elements and packing the individual fuel rods more closely together in steel storage canisters. This technology allows the capacity of existing storage basins to be nearly doubled in some instances (subject to structural limitations on the ability of the basin to withstand the additional loads) at a cost comparable to reracking. Large-scale rod consolidation has yet to be demonstrated, although demonstrations of the concept have been carried out. (U.S. Office of Technology Assessment 1985).

More recent experience in rod consolidation technology is available in the Proceedings of the Third International Spent Fuel Storage Technology Symposium/Workshop (U.S. DOE 1986) and for wet storage in Minutes of the IAEA Committee Meeting (IAEA, 1986).

The most recent away from reactor interim storage facility placed in operation, the CLAB facility in Sweden, is a wet storage facility.

IV.A.2. Dry Storage

Though dry storage has been studied for sometime, it has not been developed or used to the extent that wet storage has (Anderson & Meyer, 1980, NEA, 1982, Johnson, 1982). Two canisters of CANDU fuel have been stored under dry conditions since 1975. However, some concepts of dry storage appear to be particularly well suited for storage over long time periods (U.S. Office of Technology Assessment 1985). Most of the following dry storage concepts require sealing spent fuel elements in steel canisters before emplacement. INFCE (1980) presents a detailed discussion of some dry storage technologies.

* Air cooled vault -- a large concrete structure using natural air convection for cooling.
* Concrete surface silo -- a concrete cylinder resting vertically on the ground.
* Casks -- large metal casks (which may be designed to be used for transportation as well) resting in warehouse-like sheds.
* Surface drywell (dry caisson) -- a steel and concrete

lined hole in the ground that will hold one or several spent fuel elements.

* Tunnel drywell storage -- drywells sunk in the floor of subterranean tunnels.
* Tunnel rack storage -- movable racks placed in tunnels inside a mountain.

The recent away from reactor interim storage facilities constructed in the Federal Republic of Germany are dry storage in CASTOR casks in a storage building.

IV.A.3. Comparison of Interim Storage Technologies

The IAEA (1984) has compared the relative safety and costs of implementing wet and dry storage systems as means for increasing the capacity of at-reactor and away-from-reactor storage facilities. (The findings of the IAEA report generally [illegible] with those reached earlier in the INFCE (1980) studies.) The findings of the later OTA (1985) studies are also similar.

IV.A.3.(a). Safety Considerations

The IAEA Guidebook (1984) points out that the main nuclear safety issues to be considered are "(1) protection of fuel cladding integrity, (2) radiological shielding and environmental protection, (3) accidental criticality, and (4) management of nuclear waste."

To protect the fuel cladding both the temperature and the purity of the cooling media must be controlled. In wet storage systems approximately 3 m of water are required for radiation protection while in dry systems the construction material provides the shielding. Steel-concrete construction is relatively inexpensive but relatively heavy while lead-steel would be relatively expensive but relatively light. Criticality must be avoided and this is accomplished by fixed spacing and the use of boron steel in wet storage systems. Because air and inert atmospheres have lower moderation than water, spacing between fuel assemblies can be reduced. In addition boron or other neutron absorbers can be used to further reduce the spacing. To purify the water in wet storage produces radioactive waste in the form of ion exchange resins and particulate filters. Both wet and dry storage systems may require air filtration and produce air filters as waste.

IV.A.1.b. Costs

Table 4-2 presents a comparison of the capital and operational costs of implementing alternative spent fuel storage technologies. Unfortunately, simple comparisons of the costs per tonne using these different technologies is precluded by the wide range of technical and financial assumptions relied upon by available studies (U.S. Office of Technology Assessment 1985: 60). Preliminary assessments do suggest however, that for both at-reactor and away-from-reactor storage facili-

TABLE 4-2. COMPARISON OF CAPITAL AND ANNUAL OPERATING COSTS OF AT-REACTOR STORAGE OPTIONS ($/kilogram of uranium--operating costs in parentheses below capital costs)

	Facility capacity (tonnes)		
Storage option	500	1,000	2,000
Cask (5-tonne capacity)	118	109	103
	(1.3)	(0.7)	(0.4)
Vault (fuel canned)	100	87	81
	(1.9)	(1.6)	(1.5)
Cask (10-tonne capacity)	80	75	73
	(0.3)	(0.2)	(0.2)
BWR reracking (stainless steel to borated stainless steel)	63	61	60
	(1.1)	(1.1)	(1.1)
Pool	97	59	42
	(4.9)	(3.0)	(2.0)
Silo	70	59	42
	(4.9)	(3.0)	(2.0)
Vault (fuel not canned)	67	48	39
	(2.1)	(1.5)	(1.2)
Drywell	53	41	35
	(0.9)	(0.7)	(0.6)
PWR reracking (stainless steel to borated stainless steel)	39	38	38
	(0.5)	(0.5)	(0.5)
Rod consolidation within existing pool[a]	40	—	—
PWR reracking (low density to stainless steel)	25	25	25
	(0.4)	(0.4)	(0.4)
BWR reracking (low density to borated stainless steel)	22	22	22
	(1.0)	(1.0)	(1.0)
BWR reracking (low density to borate stainless steel)	20	20	20
	(1.0)	(1.0)	(1.0)
PWR reracking (low density to borated stainless steel)	18	18	18
	(0.4)	(0.4)	(0.4)
Double tiering[b]	—	—	—

[a]No operating cost data available.
[b]No cost data, but reracking costs represent lower limits.

SOURCE: Electric Power Research Institute, *Cost Comparisons for On-site Spent-Fuel Options*, EPRI NP-3380, May 1984, tables 12-1, 12-2.

ties, technologies that provide relatively large, fixed capacities (water basins or dry vaults) appear to be more expensive per tonne of storage than do the dry storage technologies that allow expansion in annual modules (drywells, silos, and casks). The principal reasons for this are the lower initial capital costs of installing modular dry storage technologies, and the opportunities for spreading out the remaining costs over time by deferring the installation of additional containers. Preliminary assessments also suggest that once spent fuel elements have been stored at an interim storage facility, it may be less expensive to leave them there indefinitely than to remove and transport them elsewhere. The U.S. Department of Energy has, for example, estimated that the annual costs of retrieval and transportation are nearly three hundred times greater than the annual maintenance costs at a 48,000 tonne dry storage facility. In developing full scale reprocessing and disposal operations, therefore, it will be important to consider the most cost effective methods for drawing down the backlogs of spent fuel that will already have been placed in storage.

IV.A.3.c. Susceptibility to Nuclear Weapons Proliferation

As the IAEA Guidebook (1984) points out interim storage of spent fuel with significant quantities of fissile material should come under the Agency's safeguard programme. Though the safeguards have been applied to reactor storage pools, this would become more important in the future as more states produce sufficient irradiated fuel elements to require safeguards. At the minimum there would be a proliferation of sites where safeguards would need to be maintained. The details of such techniques are given in the Guidebook.

Though safeguards would also need to be applied to a repository with spent fuel, once the repository is sealed, the burden would be considerably eased. The fear about interim storage sites is that once the decision is made to abrogate the safeguards the time of conversion from spent fuel to weapons material is only 1 to 3 months (IAEA, 1984).

Barkenbus et al. (1985) argue that precisely for that reason U.S. and other major nuclear powers should offer centralized interim storage facilities. In addition they argue that it is attractive commercially to do so and environmentally sound because the best sites can be used. They do acknowledge the political difficulties in such actions.

IV.B. Overview of National Programs

Utilizing a number of comparative studies (INFCE, 1980; NEA, 1982; Geck and Taormina 1983; Parker et al. 1984; IAEA, 1984; Orlowski, 1985 and DOE, 1986), documents relating to spent fuel storage in individual countries (referenced at the end of this chapter), and interviews conducted with responsible officials, major approaches to interim storage in the six countries can be distinguished. Table 4-1 provides a summary for the discussion which follows.

IV.B.1. Federal Republic of Germany

The Entsorgungskonzept, as established in 1979, stipulates that each utility must demonstrate that the spent fuel (to be discharged over a future rolling period of six years) can be managed (either by on-site storage, storage in a centralized facility, or by reprocessing contracts).

The storage capacity of at-reactor facilities ranges from 1.5 years to over 11 years of fuel discharges. This wide range of capacities results from the expansion of storage facilities being limited by structural considerations at some units, and by the regional success of groups opposing the development of nuclear power in mobilizing against licensing of planned expansions or by court prohibitions of expansions that had already been licensed.

The total capacity of at-reactor storage facilities in the Federal Republic of Germany is approximately 5000 MTU. In addition, three away-from-reactor storage facilities, each with a capacity to store 1500 MTU, are either operational or are planned: an away-from-reactor storage facility at Gorleben in Lower Saxony was ready for operation in 1985; a similar facility is under construction at Ahaus in Nordrhein-Westphalia; and an away-from-reactor storage facility with a 1500 tonne capacity is being planned as part of a radioactive waste reprocessing facility at Wackersdorf in Bavaria.

Together with the contracts for reprocessing abroad there should be sufficient interim storage in the Federal Republic of Germany until the final repository is operational.

Recently the Federal Republic of Germany conducted discussions with China concerning the possibility of exporting 150 tonnes of waste as part of a package arrangement involving the sale of several reactors. Most spent fuel, however, is committed to reprocessing contracts with France and the U.K. as well as to the projected Federal Republic of Germany reprocessing facilities. Discussions with China have now apparently been dropped (Bloser, 1986).

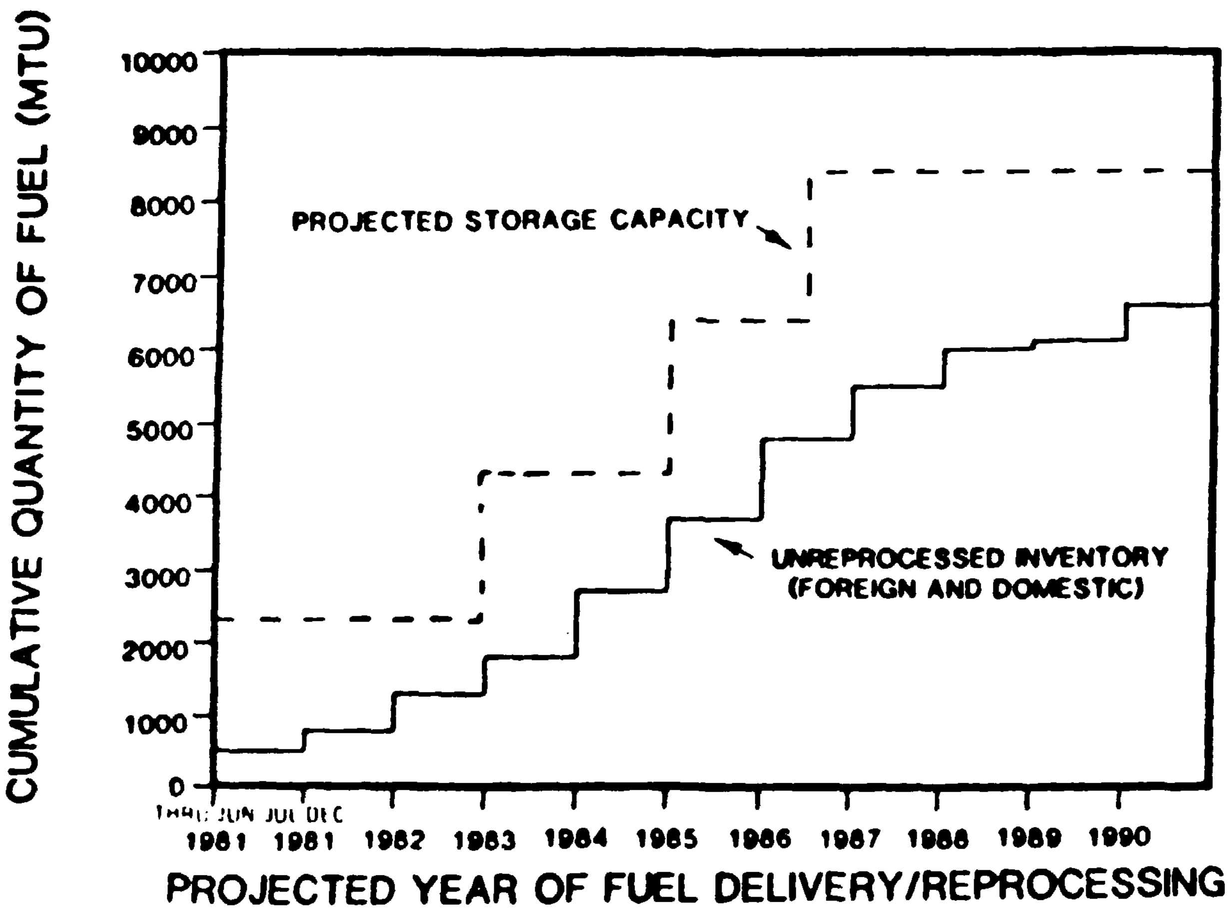
The current technical concept of the repository is to have high level radioactive wastes aged for 20-30 years prior to final disposition.

IV.B.2. <u>France</u>

Since all the reprocessing needs for French reactors will be met by COGEMA, and because of the large storage capacity (consisting of four water basins, each with a potential capacity to store 2000 MTU) built at La Hague, no spent fuel storage problems are anticipated in France.

As suggested by Figure 4-1 (Geck and Taormina 1983: 135), substantially greater storage capacity (8000 MTU) is being

FIGURE 4-1.



Projected spent LWR fuel storage situation at COGEMA, La Hague.

Source: M.J. Geck and A.M. Taormina, 1983, Spent Fuel Storage in Europe in the 1980s, p. 135.

planned at La Hague than will be required to store the 6485 MTU of spent fuel which is expected to accumulate by 1990, assuming that spent fuel is reprocessed according to the projected annual quantities as a result of already contracted shipments from French and foreign reactors (see Table 4-3). The storage capacity of water basins at French reactor sites has also been expanded (to between two and four years), mainly to provide a greater buffer between refueling and transportation operations. The general objectives in France are not to leave waste as a burden for the future and to optimize the role of interim storage in the overall waste management system.

IV.B.3. Sweden

A centralized away-from-reactor storage facility, known as CLAB (Central Storage for Spent Fuel) and consisting of a rock cavity 180 m x 21 m x 25 m housing four stainless-steel-lined concrete storage pools, was commissioned in 1985 with a total capacity of 3000 MTU, with the potential to expand this capacity to 9000 MTU. This amount is substantially greater than the 7,500 MTU that are expected to be discharged from the twelve existing Swedish reactors by 2010. The total receiving capacity is about 300 tonnes per year, or about 100 spent fuel shipping casks (Ahlstrom 1985). According to present policy, the great bulk of Sweden's spent fuel will be shipped to CLAB after about six months of cooling in pools at reactor sites and will remain there for 40 years. Transport to a deep

TABLE 4-3.

PROJECTED SPENT LWR FUEL SHIPMENTS TO COGEMA – LA HAGUE UNDER EXISTING CONTRACTS FOR THE UP2 AND UP3A FACILITIES (MTU)

Country	Through June 1981	July-Dec. 1981	1982	1983	1984	1985	1986	1987	1988	1989	1990 [a]
Belgium											
UP2	73	32	19	20	0	0	0	0	0	0	0
UP3A	0	7	21	24	40	23	47	48	50	54	56
FRG											
UP2	418	57	51	30	0	0	0	0	0	0	0
UP3A	25	53	131	195	287	265	333	257	250	195	110
Netherlands											
UP2	76	3	0	0	0	0	0	0	0	0	0
UP3A	0	12	12	12	12	12	12	12	12	12	12
Sweden											
UP2	0	0	20	32	0	0	0	0	0	0	0
UP3A	0	0	0	84	84	84	84	84	84	84	84
Switzerland											
UP2	80	0	25	25	0	0	0	0	0	0	0
UP3A	1	9	34	54	54	54	54	54	56	50	49
Japan											
UP2	101	25	25	0	0	0	0	0	0	0	0
UP3A	25	40	100	150	245	255	235	180	250	280	440
Europe Totals UP2	647	92	115	107	0	0	0	0	0	0	0
UP3A	26	81	198	369	477	440	530	455	452	395	311
Domestic Fuel [b]	85	12	125	155	370	545	671	778	912	1 103	1 198
Worldwide Totals (With France)	884	250	582	781	1 092	1 240	1 436	1 413	1 614	1 778	1 949

[a] 66 MTU under contract for UP3A are scheduled to be shipped in 1991

[b] Including the Chooz reactor owned 50% by EdF.

Source: Geck & Taormina, p. 132.

geologic repository is not expected to begin until about 2020. Currently, Swedish officials estimate the costs of interim storage at approximately 18% of all waste management costs (Ahlstrom 1986).

The capacity of Swedish at-reactor storage facilities has been considerably increased following the installation of high density storage racks. (Installed storage capacity ranges from four to ten years; older facilities built greater capacity in anticipation that CLAB might not become operational until the mid-1980's). Sweden has also signed contracts to ship wastes to the La Hague and Sellafield reprocessing plants (although they have exchanged some rights with the Federal Republic of Germany for fuel elements that will not be reprocessed). Sweden would also like to sell or exchange the rest of their reprocessing contracts so that they will only have spent fuel for disposal. Together, these measures should preclude any interim storage problems for spent fuel discharged by Swedish reactors, and simplify the disposal task.

IV.B.4. Switzerland

Switzerland intends to have all of its spent fuel reprocessed. The utilities are responsible for the waste until it is placed in a repository. Contracts to ship spent fuel produced by Swiss reactors have already been signed with the reprocessing plants for 1200 tonnes at LaHague and 400 tonnes at Sellafield.

All at-reactor storage facilities were reracked (requiring a license change) by the end of 1982, and have capacities for seven to fourteen years of spent fuel discharge. Together with reprocessing contracts, the large storage capacities at reactor sites should preclude any storage problems in Switzerland during the next decade. The Swiss government has undertaken studies for a centralized interim storage facility; several alternatives ranging from wet storage to dry storage in casks or a vault have been considered. The current priority is for dry storage at a central facility, using Gorleben as a reference facility (de Haller, 1986). Such a facility is projected to cost $85 million to construct, not including cask costs. The facility would have double walled cask storage, with cooling by natural convection. Current Swiss policy requires that high-level radioactive wastes be stored 40 years prior to final disposal. The project also includes a series of additional facilities for interim storage of ILW and LLW standard containers.

IV.B.5. United Kingdom

The policy in the United Kingdom is to store spent fuel at the reactor sites for the required cooling time, and then to transport the fuel to the Sellafield reprocessing plant.

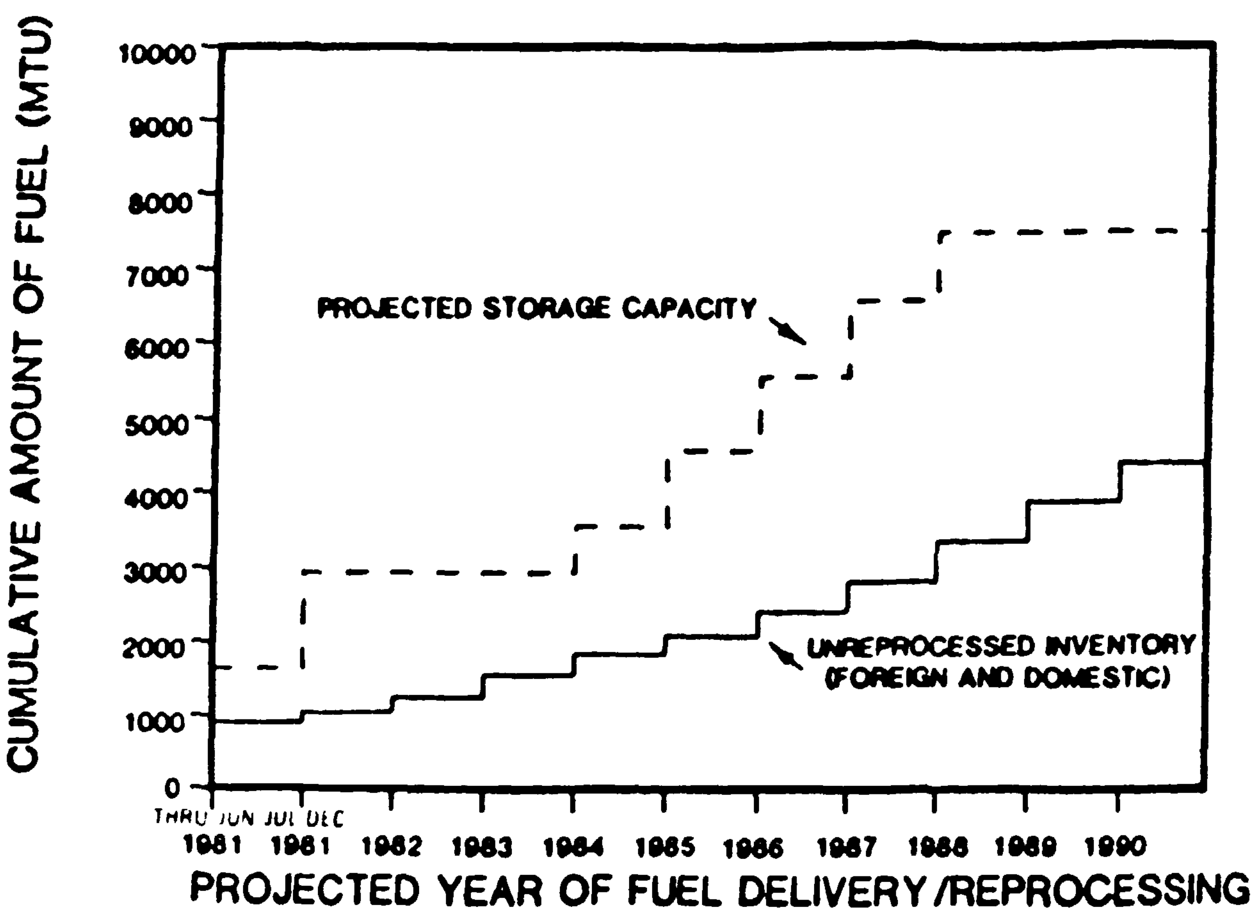
There are no plans currently to increase at-reactor storage capacity, and the storage facilities at Sellafield constitute the only existing or planned away-from-reactor storages. As indicated by Figure 4-2, the potential capacity (7500 MTU) of storage facilities at Sellafield is substantially greater than the amount of spent fuel (4381 MTU) which is under contract to be shipped from British and foreign reactors (Table 4-4).

IV.6. United States

Considerable delays are still expected before repository facilities become operational in the United States (U.S. Office of Technology Assessment, 1985). Since the existing at-reactor spent fuel basins are filling up, this presents utilities with a significant problem. The Department of Energy (1983) has determined that even if the capacity of existing basins were maximized by reracking and transshipments of spent fuel are allowed between reactors within the same utility system, as many as 60 reactor may be forced to shut down by 1998 unless additional storage pacity is made available on a timely basis.

The Carter administration raised the possibility of a direct Federal role in interim storage by proposing to construct an away-from-reactor facility to store commercial spent fuel until permanent disposal facilities became available. The 96t Congress, however, declined to authorize this

FIGURE 4-2.



Projected spent oxide fuel storage situation at BNFL, Windscale.

Source: Geck & Taormina, p. 139.

TABLE 4-4

PROJECTED SPENT OXIDE FUEL SHIPMENTS TO BNFL – WINDSCALE UNDER EXISTING CONTRACTS (MTU)

Country	Through June 1981	July-Dec. 1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
FRG	73	17	17	0	0	11	11	11	40	40	40
Italy	75	12	0	0	0	0	0	0	0	0	0
Netherlands	7	3	3	3	3	3	3	3	3	1	0
Spain	132	13	7	0	0	0	0	0	0	0	0
Sweden	87	11	42	0	0	0	0	0	0	0	0
Switzerland	79	0	10	9	10	9	10	9	10	9	10
United Kingdom	206	20	25	86	85	125	173	198	205	218	244
EUROPE TOTALS	659	76	104	98	98	148	197	221	258	268	294
Japan	321	78	103	177	162	134	150	180	250	280	440
WORLDWIDE TOTALS	980	154	207	275	260	282	347	401	508	548	734

[a] Additional 30 MTU are scheduled for shipment in 1991.

Source: Geck & Taormina, p. 136.

facility. The issue was again raised by the 97th Congress as part of the deliberations leading to the Nuclear Waste Policy Act of 1982. The Act requires that the Department of Energy (DOE) provide a maximum of 1900 tonnes of away from reactor storage. The Act also requires that the DOE prepare a proposal for a "monitored, retrievable storage" (MRS) facility which could accommodate high level radioactive wastes for a period of time prior to final disposal. In April 1985, DOE chose three sites in Tennessee as preferred locations for the MRS. The site of the cancelled Clinch River Breeder Reactor project in Oak Ridge, Tennessee, was placed first on the list.

An important difference between the MRS proposal now under consideration and previous proposals for long term away-from-reactor storage facilities in the United States, is that instead of simply providing an alternative to the immediate development of a geologic repository, the MRS would perform operational functions previously assigned to the repository. The primary purpose of the MRS, according to the Department of Energy, would be to receive and prepare spent nuclear fuel from commercial reactors (possibly excepting western plants) for disposal in a geologic facility. In particular, spent fuel rods would be removed from their assemblies at the MRS and packed (or consolidated) before being sealed inside cylindrical steel canisters. This repackaging procedure it is claimed would reduce, by as much as half, the number of containers required for fuel rod storage and permanent disposal. By loading consolidated spent fuel into uniform canisters, it would facilitate storage, handling, and further processing at the repository. It would also reduce the number of shipments to the repository on dedicated trains (Cotton 1986; Colglazier 1986). In this way, the MRS would be developed as part of an integrated management system for handling nuclear wastes -- a system that would begin with initial storage in at-reactor water-filled basins and end with the emplacement of the waste at a permanent disposal facility. The Department of Energy estimates that the MRS facilities could cost from $1.6 to $2.6 billion to construct and operate and require 8-11 years to complete following congressional authorization (U.S. General Accounting Office 1986). Submission of a plan on the MRS to Congress did not occur in February 1986 as planned, and is awaiting the outcome of a court challenge filed by the state of Tennessee (see below).

IV.C. Socio Political Issues

Interim storage arrangements in the six countries are strongly related to the decision on reprocessing and to plans for repository development. But the six countries also reveal very different nuclear programmes and sociopolitical contexts, which affect the level of public controversy and management responses over progress in deploying interim storage facilities. The key issues are discussed below:

IV.C.1. Length of Storage

The general preference is for lengthy interim storage, ranging from 20 to 50 years (or more) in the five European countries. The United States is the prominent exception, with a projected interim storage of only 5-10 years (although initial spent fuel inventories will be much older) followed by direct disposal. Lengthy interim storage has many technical and programmatic advantages: the cooling of the waste makes final disposal easier, disposal options can be left open to a future time, flexibility is provided in the overall management programme, and the results of research and development efforts over the coming decades can be used to optimize waste disposal designs. This rationale finds favour throughout Europe and specifically underlies the Swedish approach to radioactive waste management and the arguments for the MRS in the United States.

Within this broad approach to interim storage there are, however, some significant differences. The Federal Republic of Germany, for example, mandates that the waste be disposed of "as soon as possible," thereby limiting the interim storage period to 20 years rather than 50. Similarly in France, objectives of the waste disposal program include a stipulation that constraints on future generations should be minimized (CEA, 1985). In the United Kingdom, by contrast, a more leisurely approach to high-level waste disposal is apparent, with a willingness to project actual disposal farther into the future (50 years or more).

Behind the technical rationale, political considerations are apparent. The 1970s and 1980s have been a volatile time for nuclear power and, in some countries, for other hazardous facility siting as well. Clearly there is the hope that the future may bring more tranquil environments for siting radioactive waste disposal facilities. Then, too, interim storage provides a means for leaving the siting burden to future political figures, so that the immediate adverse political consequences can be avoided by those currently in office. In the United Kingdom, various government and industry officials indicated that the 50-year period of interim storage was a direct result of the intense political protests over the geologic search programme for a repository and that the 50-year figure was not primarily based on technical considerations.

The monitored retrieval storage facility (MRS) of the United States has been controversial because of a fear that it could become a permanent repository if geologic disposal programmes failed. To deal with this concern, MRS construction and operation has been explicitly linked to progress on a permanent repository.

IV.C.2. <u>Institutional structures</u>

Institutional arrangements tend to be quite similar for the management of waste during interim storage. Generally the producers of the waste remain responsible for it during the period of interim storage, including the siting, development, and operation of facilities. Characteristically, new organizations have been established to accomplish this task as part of a broader responsibility for waste management. Examples are DWK in the Federal Republic of Germany, ANDRA in France, SKB in Sweden, NAGRA in Switzerland, and NIREX in the United Kingdom. Again, the United States is an exception to this general pattern, with a public agency (the Department of Energy) responsible for any interim storage once it acquires the spent fuel from the utilities. In all cases, the facilities will be licensed by the competent authorities of the respective country. Interim storage costs in all countries are financed as part of a general fee on electricity production.

IV.C.3. Siting

Two key considerations in the development of interim storage are (1) whether interim storage should be centralized or decentralized (at reactors), and (2) whether it should be co-located with other existing nuclear facilities. In all countries, save Switzerland and the United States where the decisions are yet to be made, central interim storage facilities exist or are planned. In the Federal Republic of Germany, the interim storage facility at Gorleben has been licensed and another facility is under construction (although temporarily halted by court action) at Ahaus. In France, the existing storage facility at Marcoule will be supplemented by another at La Hague and possibly by another later at a repository site. Sweden commissioned its CLAB facility in 1985 and has received its first shipments of spent fuel. In Switzerland the strong industry preference is for a centralized interim storage facility (partly to increase flexibility in reprocessing contracts), but political opposition has resulted in uncertainty as to whether a centralized or decentralized strategy will ultimately be adopted. Enlarged storage at existing reactor sites in Switzerland has become a political issue since Chernobyl and a license amendment is required (although involving only an administrative ruling). A central facility, by contrast, requires a favourable action by Parliament, involving a lengthy, complicated political process.

Siting strategies have varied among the countries, with differing political outcomes. Generally the approach has been to co-locate interim storage with other nuclear facilities. Thus, the La Hague and Sellafield sites will include ancillary interim storage facilities, and these proposed additions have not generated significant political controversy. The siting of interim storage facilities at the waste disposal complex at Gorleben and at Ahaus has met fierce public opposition, although conflicts over reprocessing may be at the bottom of these protests. Both facilities are presently held up by court rulings. German siting of interim storage facilities faces the particular legal paradox of demonstrating that interim storage is needed (in order to fund additional facilities) at the same time that utilities must demonstrate annually adequate at-reactor capacity. Sweden successfully sited its CLAB facility at an existing reactor site (Oskarshamn) without apparent significant local opposition even at the height of the nuclear debate during the referendum. Switzerland has identified a prospective interim storage facility at the site of the former Lucens research reactor (which suffered a serious accident), but strong local opposition is apparent. Finally, in the United States, three proposed sites in Tennessee, a state presumed to have a favourable political climate, have generated significant state and/or local opposition to the monitored retrievable storage facility.

As a general observation, interim storage facility siting does not always appear to be controversial. Where the facility has been co-located with an existing facility (as in France and Sweden), opposition has been fairly minimal. Where the sites are at new locations, however, or if co-located with facilities embroiled in other controversies (such as reprocessing, or beset by other waste problems), then interim storage appears to have the same potential for conflicts that nuclear power plants, reprocessing facilities, and waste repositories have.

IV.C.4. Retrievability and future generations

Retrievability has emerged in several countries as a primary political issue in both high level and low level radioactive waste management. In the United States, this was a sufficiently significant consideration that a 50-year regulatory requirement for spent fuel retrievability has been enacted, and lengthy (10-50 years) interim storage at the MRS is an option under the Nuclear Waste Policy Act of 1982. It could become an issue of contention if a repository is built in salt because of the tendency of salt to flow under heat, making the retrievability requirement more difficult to meet.

But it is in the United Kingdom, as detailed above, that this issue is most volatile. The position of the Nuclear Industry Radioactive Waste Executive (NIREX) in the U.K. is that it will do nothing for any waste disposal effort to increase retrievability that detracts from the long-term safety of disposal. But environmental critics and local publics at potential sites have strongly pressed the argument that all waste should be kept in a retrievable mode. Similar demands, it should be noted, have emerged in Switzerland as well. The rationale for this position is straightforward: knowledge of the long-term behavior of waste is still limited, there is no urgency to put waste in the ground in the near future, and surface or near surface storage of waste can be done safely.

Various societal groups find self-interest in such an approach. Industry can defer the highly contentious siting process which exacerbates existing public opposition to nuclear energy. Politicians who tend to operate on short-term time perspectives--the upcoming election--can defer a threatening issue to their successors. And environmentalists can keep alive the claim that "no permanent solution to the waste problem exists." The deferral of disposal of both high and intermediate level waste and the retention of both in a retrievable mode in the U.K. speaks to the political power of these convergent interests.

The importance of retrievability in public perceptions of waste management appears to stem from several sources. It is clear, first, from various polls and psychometric studies that substantial public fear exists over radioactive waste hazards. Second, inadequacies at a number of existing facilities (e.g., Sellafield, Maxey Flats, etc.) and the associated widely publicized leaks have cast doubts on future as well as past management systems. As the report of the Parliamentary Environment Committee in the U.K. concluded in 1986: "While we understand that Sellafield suffers from being first in the civil reprocessing business, it is hard to deny its record looks bad. From the Windscale fire of 1957 to the November 1983 incident, the impression it conveys is one of error and misjudgement. Against this background it must be difficult for the industry to expect its figure on dose rates, safety levels and minimal risk to be believed by the public" (U.K. House of Commons, Environment Committee 1986, I, xcix.). Third, in several countries there is a lack of trust that responsible authorities will do all that is required for safety. In a national survey in the United Kingdom, only 15 percent of the population thought it unlikely that something might seriously go wrong with a waste repository (U.K. House of Commons, Environment Committee 1986, I, xcvii). Finally, there is a common sense preference, as one environmentalist told us, "to have the waste in a structure where you can walk around it, look under it for leaks, sniff it, and see for yourself that it works and that it's not getting in the groundwater." (Boyle 1986). Arguments that such structures are more vulnerable to external hazards, including terrorist attacks, appear to be less persuasive.

In conflict with retrievability is the concern that the waste burden may be exported to future generations or that temporary storage facilities may become permanent repositories. The latter was a key consideration in adverse reaction in the United States to the concept of the "retrievable surface storage facility" in the mid-1970s, and as noted above, to the proposed MRS. It has also arisen as a concern at the proposed interim storage facility at Ahaus in Germany.

The reactions to these issues appear quite differently in the several countries studied. Retrievability, as noted, is a powerful public issue in Britain whereas potential export of risk or management burden to the future has not been pursued by critics because, as a representative of Friends of the Earth informed us, "it doesn't resonate with the public." (Boyle 1986). Retrievability also is clearly an important issue in Switzerland and may be emerging in the United States as well. But in France, Germany, and Sweden it generally has not been a public issue and has not entered into public debates.

IV.D. Conclusions

Developments in both the technical arena and in the politics of radioactive waste management point to an emerging policy issue likely to be faced in the various countries studied.

First, the evolving dry storage technologies for the intermediate storage of spent fuel make possible the low cost and safe storage of this fuel for far longer periods of time (100 years or more) than originally considered in at-surface facilities. The passive system of cooling the fuel through natural convection offers a significant advantage over storage pools, both in terms of design and safety. While current plans in most countries call for utilizing only a portion (20 - 50 years) of this potential, it is apparent that a technological option exists for considerably lengthier periods of monitored storage without serious deterioration of the fuel or major accident risks. These advantages have led Switzerland, for example, to revise its original design from water-based to dry storage.

Second, the formidable political costs involved in finding disposal sites have led a number of countries to delay or modify their siting programmes. There will be a continuing appeal for politicians to search for solutions, even if they are not the most technically preferred, which provide means for escaping high political prices now and for adequate storage of the wastes. This reality is augmented by a strong and apparently growing public demand in several countries for retaining all wastes in a retrievable mode. It is a situation in which various interests have something to be gained in avoiding geologic disposal: politicians can avoid siting controversies, industry can avoid further opposition to nuclear power, and environmentalists can maintain their claim that a permanent solution to radioactive wastes does not exist.

The coalescence of these developments is one which will offer a clear temptation to extend the projected time horizons of interim storage beyond those for which this phase of waste management was originally intended and to escape the immediate political costs of implementing geologic disposal plans. One country - the United Kingdom - appears to be very close, if not actually representing, such a path in radioactive waste management. Such a development can also be rationalized in terms originally stated for briefer storage, namely that

(a) there is adequate evidence that the technology exists for storing such wastes economically and without undue risks

(b) scientific evidence and experience will accumulate, improving prospects for geologic disposal designs and practice

(c) since the wastes are retrievable, errors are correctable.

It is also clear, however, that decisions to move to very lengthy intermediate storage and to postpone, or slow, geologic siting programmes threaten

(1) to defer the waste problem to future generations, in the face of broad international consensus that this is socially unacceptable

(2) To increase the risks of radioactive waste management, including those of terrorism and international conflicts and low probability environmental events.

Institutional mechanisms may be needed to ensure the politically expedient decisions do not result in environmentally unacceptable uses of interim storage options.

REFERENCES

Ahlström, F.E. 1986. Current Status of the Swedish Waste Disposal Program. Paper presented at the IAEA International Symposium on the Siting, Design and Construction of Underground Repositories for Radioactive Wastes, Hannover, Germany, March 3-7.

Anderson, Earl. 1985. Utilities Face Squeeze in Spent Nuclear Fuel Storage Space, Chemical and Engineering News, April.

Anderson, F.A., H. S. Meyer, 1980. Dry Storage of Spent Nuclear Fuel, NUREG/CR-1223, National Technical Information Service, Springfield, VA.

Barkenbus, Jack N., Alvin M. Weinberg, Marcelo Alonso, 1985. Storing the World's Spent Nucleasr Fuel, Bulletin of Atomic Scientists, November.

Boyle, S. 1986. Interview. 9 May.

Colglazier, E.W. 1986. The MRS: an assessment of the need and feasibility. Forum for Applied Research and Policy (Spring): 25/37.

Commisariat a L'Energie Atomique, Institut de Protection et de Surete Nucleair 1985. French Regulations and waste management (Revision 1). Rapport des No 70e. Paris.

Cotton, T.A. 1986 The MRS facility: Radioactive waste management at a cross roads. Forum for Applied Research and Policy (Spring): 10/24.

De Haller, Yves, 1986. Interview. 6 June.

Geck, M.J. and Taormina, A.M. 1983. Spent fuel in Europe in the 1980's. In Nuclear Power Experience, Proceedings of an international conference held by the IAEA, Vienna, September 13-17, 1982.

IAEA, 1984. Guidebook on Spent Fuel Storage, Technical Reports Series No. 240. International Atomic Energy Agency, Vienna, Austria.

IAEA, 1986(a). Minutes of Committee Meeting on Wet Storage, Leningrad, USSR, May 26-30.

IAEA, 1986(b). World Survey of Wet and Dry Storage Experience, Special Technical Publication 218.

International Nuclear Fuel Cycle Evaluation (INFCE). 1980. Spent Fuel Management Report of INFCE Working Group 6. Vienna: International Atomic Energy Agency.

Johnson, A. B., Jr., F. R. Gilbert, R. J. Guenther, 1982. Behavior of Spent Nuclear Fuel and Storage System Components in Dry Interim Storage, Pacific Northwest Laboratory PNL-4189, August. Pacific Northwest Laboratory, Richland, WA.

NEA, 1982. Dry Storage of Spent Fuel Elements, Nuclear Energy Agency, Organization for Economic Co-Operation and Development, Paris, France.

Nechaev, Alexander, Vladimir Onufriev, K. T. Thomas, 1986. Long Term Storage and Disposal of Spent Fuel. IAEA Bulletin. Spring.

Orlowski, S. 1985. Status of the Commission of the European Communities Radioactive Waste Disposal Programme. Paper presented at the International Topical Meeting on High Level Waste Disposal, Pasco, Washington, USA, September 24-26.

Parker, F.L., et al. 1984. The Disposal of High-Level Radioactive Waste. Stockholm, Sweden: The Beijer Institute.

Salmon, A. 1983. Experience in spent thermal fuel storage, transport and reprocessing. In Nuclear Power Experience. Proceedings of an international conference held by the IAEA, Vienna, September 13-17, 1982.

United Kingdom, House of Commons, Environment Committee 1986. Radioactive waste. 3 Vols. London: HMSO.

United States Congress. 1982. Nuclear Waste Policy Act.

United States, Department of Energy (DOE). 1983. Spent Fuel Storage Requirements. Washington, D.C.: DOE.

United States, Department of Energy (DOE). 1986. "Third International Spent Fuel Storage Technology Symposium/Workshop". CONF.860417 National Technical Information Service, USA.

United States, Department of Energy (DOE). 1986. Third International Spent Fuel Storage Technology Symposium/Workshop, CONF-860417, April 8-10.

United States National Academy of Sciences. 1975. "Interim Storage of Solidified High Level Radioactive Wastes". National Academy of Sciences, Washington, D.C.

United States General Accounting Office 1986. Nuclear waste: Monitored retrievable storage of spent nuclear fuel. Washington: USGPO.

United States, Office of Technology Assessment. 1985. Managing the Nation's Commercial High-Level Radioactive Waste. Washington, D.C.: OTA.

CHAPTER V

CONCLUSIONS

This study involving a number of different countries and an array of both technical and socio-political issues resulted in numerous findings. The major conclusions of this comparative analysis follow.

V.A. Conflicting Technical and Political Rationales

A generic source of tension in the emerging national radioactive waste programmes is the divergence between the technical rationale and the political calculus for waste management. That such differences should exist are not surprising given that (a) experts are solving a specific technical problem whereas politicians are dealing with a broad array of policy concerns, (b) public response is a primary consideration in political responses but not in technical planning, (c) the rationality which underlies determination of risk acceptability differs in the two communities, and (d) the time horizons of the political calculus and technical planning depart markedly.

The evident public concern over radioactive wastes has necessitated a larger role for political judgements and political processes than that which ordinarily prevails for the technological problems faced by advanced industrial societies. Thus, the shaping of radioactive waste programmes has involved active legislation (the Stipulation Law in Sweden, the Nuclear Waste Policy Act in the United States), substantial parliamentary involvement in setting policy (the pending decision on Project Gewähr in Switzerland), political directives for setting programmes (agreement of heads of the federal and state governments on Entsorgung in Federal Republic of Germany, shifts in the timing of disposal and what is to be disposed of near surface in the United Kingdom, deferral of the second repository in the United States), and intrusion of the courts into technically substantive issues (as in the Federal Republic Germany).

On the one hand, the politicization of radioactive waste management is probably both inevitable and necessary. A management programme emerging from a solely technical rationale is unlikely to be well adapted to the political considerations which will enter into radioactive waste matters. Since governmental agencies are distrusted by parts of the public in several of the countries, a political process becomes necessary to win public acceptance and to accommodate social conflict. And, not infrequently, key political decisions have provided greater direction, resources, and political will to the management task (as in France or as with the Nuclear Waste Policy Act in the U.S.).

On the other hand, the politicization of programme development in a number of countries has introduced a high degree of instability into planning. The United Kingdom is a noteworthy case where the government has reacted in an ad hoc manner to intense political conflicts over the siting of facilities through programme shifts which while designed to reduce the potential conflict, have changed the technical structure of the waste management programme. The political response to Chernobyl in the Federal Republic of Germany has reverberated on the positions of the political parties (notably the Social Democrats and the Christian Democratic Party) in regard to key elements (e.g. reprocessing) of the waste management programme. In the United States, deferral of the second repository in the face of widespread political opposition to siting threatens the integrity and political viability of the Nuclear Waste Policy Act and perhaps orderly progress of the first repository.

Not only will this politicization continue, but it is quite likely to grow as the back end of the fuel cycle is progressively deployed. Accommodating the roles of technical experts and reluctant political decision-makers in traditional institutional structures will be a continuing problem.

V.B. Safety

V.B.1. Risk and Risk Acceptability

The long term nature of radioactive waste management makes risk assessment intrinsically difficult, since populations and human activities will certainly change markedly and even natural processes can be predicted with only modest confidence.

Nonetheless, over the past decade substantial progress has occurred in the identification and technical assessment of risks associated with radioactive waste management. As compared with other technological risks, radiation risks are relatively well understood. Accident scenarios have been defined for a large number of events which could occur during the operational, pre-closure phase of waste management and those which could threaten the long-term integrity of the repository. There appears to be emerging technical consensus over the types of risks involved, the relative magnitude of potential consequences and likelihood of occurrence, and appropriate management responses (e.g. mutliple-barrier containment) for reducing the risks.

The public evaluations of risk and social judgements on risk acceptability are another matter. Here substantial dissensus is often apparent. A broad array of risk considerations enters into societal responses to radioactive waste risks, including the qualitative attributes of the risks (newness, voluntariness, export to future generations), the ways that the benefits of nuclear power are judged, the equity problems in the locations of waste sources and repository sites, how we value future generations, and the institutional processes involved in waste management decisions. Indeed, it is apparent that the numerical calculus of risk provides little guidance as to the stringency required in regulatory standards to win public acceptance and the magnitude of effort which must be allocated to the management task. Though there is widespread similarity in environmental standards, national differences exist in the perceived urgency of the tasks and the amount of resources which should be devoted to the problem. Meanwhile, substantial uncertainty as to the eventual public acceptability of these programs continues to exist.

V.B.2. Human Actions as a Risk Problem

Among the intrinsic difficulties in risk assessment of long-term radioactive waste management, it is apparent that the limited ability to anticipate human actions even for the relatively near term (50-100 years) represents a continuing significant constraint. Our limited ability is shown by the often erroneous assumptions underlying five year economic plans or the loss of knowledge or institutional control at some radioactive waste sites over the past 25 years. In complex human technological systems, the potential contribution of human behavior to risk is essentially limited by the creativity of the human mind. Over the long periods of time involved, this limited ability to predict human actions constrains risk assessment in two chief ways: through the necessary incompleteness in scope of risk scenarios and in the inability to assign probabilities to inadvertent or intentional human intrusion into a repository. These problems are acknowledged in all of the national approaches to waste management.

That this issue will be of continuing uncertainty and an object of debate is illustrated by several recent or ongoing cases from the national programmes reviewed. In the first, a potential high level waste site identified in Sweden (but dropped for non-technical reasons) was independently also chosen by an entirely different search process for a storage site for natural gas, suggesting that assigning probabilities to inadvertant drilling into a repository is very difficult. A second case involves judgement about the likelihood of future solution mining in salt formations and whether future human beings would correctly assess the source of the potentially large consequences in time to prevent disaster. Finally, predicting which geologic or repository materials will be defined as a resource in the future and whether future people will respond to efforts to warn them (would they be attracted instead?) are issues of evident limited comprehension.

Human action is a significant element in the waste risk management system as well. Experience from nuclear plant operation and from major accidents (e.g. Chernobyl, Bhopal) indicates the large role played by human error. The design of the management system will need to take account of the various ways by which human behavior can compromise well designed technical systems and whether safety can be arranged in such a way to avoid the "normal accidents" which some (e.g. Perrow, 1984) believe are intrinsic to technologically complex systems.

V.B.3. <u>No proof in the traditional sense.</u>

The time frames of concern are really two, as shown by comparison of the waste classification schemes in the various countries. The first era is the time when the consequences of fission product releases and exposures dominate, 600-1000 years, and the second is greater than 1000 years up till the time we care to compute or until the expected lifetime of the sun (3.5×10^{10} years). Even for the fission product era, for most countries, national boundaries have little meaning because these have changed so extensively over the last 1000 years and are likely to do so over the next 1000 years and more. It is also clear that recorded history, only approximately 5000 years, is not much longer than the time of the fission product era. Consequently, proof in the traditional scientific sense of hypothesis and testing is not to be had because of the long time periods involved. Therefore, we are faced with a choice of options, none of which is completely satisfactory.

V.B.4. Demonstrating Safety

There appears to be an important emerging divergence over how the long-term safety of a waste repository will be demonstrated. The scientific and regulatory community has addressed at length the standards of safety which should prevail and how reasonably to assure, in the absence of the possibility of strict model validation for the long time periods involved, that the future performance of the repository will be consistent with these requirements. And despite some differences -- over individual vs. collective dose limits, the length of time that protection needs to be assured, or the degree of quantification and qualitative guides which should be used in safety assurance, -- considerable technical consensus among the six countries is emerging.

Foremost in this is the work of the Nuclear Energy Agency, which has tried to define means of demonstrating safety by short term tests and mathematical models. Consensus has been reached on what it is possible to do (NEA, 1983). The International Commission on Radiological Protection (1985) has also given considerable assistance in that it recommends that, although there is a risk to every bit of radiation absorbed, one should take into account the risks involved in reducing the radiation dose, and one should not decrease the radiation dose beyond the point where the risk in the remedial action is greater than the risk avoided. It is mystifying to scientists that as life expectancy continues to increase, as age-adjusted cancer rates continue at present levels or decline (except for lung cancer for women), and as cancer remission rates continue to rise, the fear of cancer from radioactive and hazardous chemical wastes continues at high levels or even grows.

It is widely recognized, however, that demonstrating safety to the expert community and to often skeptical or distrustful publics are quite different things. Our review and discussions with officials in the six countries indicate that they are very well aware of the differences in expert and public assessments and the importance of the public acceptance process. In addition to all the traditional institutional mechanisms--safety reports, regulatory reviews, licensing, public inquiries, etc.--many of the responsible authorities have started to issue information materials directed to laymen. The officials of the utility companies are also spending much time and interest on public information meetings, and in many cases have employed staff members who are specialized in risk communication.

Critics and local opponents, in contrast, appear to have relatively little interest in, and considerable suspicion of, the emerging technical standards and criteria for performance evaluation. Rather, they focus on the institutional process of demonstration--the scope of review, the participants and their roles, the locus of final decision, easy access to information, transparency of decisions, etc.--which will be used. In particular, there is, in a number of the countries, substantial distrust over the traditional institutional processes and the roles to be played by experts and publics, proponents and opponents. How this divergence in safety demonstration will be addressed and whether it will be confronted in advance or only when conflict occurs appears quite crucial.

V.B.5. Inherent Safety and Public Acceptability

Although there is considerable scientific consensus on the adequacy of the technical design of mined geological repositories, there is often an intense public debate over technical issues and the safety achieved. The controversy involves questions with regard to geology, encapsulation material, groundwater, etc.

If a solution could be found that offers an encapsulation system that is in thermodynamical equilibrium with its surroundings in the repository, an inherently safe system could be a reality. Such a solution--even if not a necessity for meeting repository performance standards--could be an important part of a technical and political initiative to narrow the debate over radioactive waste disposal and to win increased public support.

V.B.6. International Repositories and International Consensus

There are several possibilities for international initiatives in radioactive waste management. Numerous arguments favor the development of international repositories for high level waste and spent fuel. A technical one is that for some countries having nuclear energy programmes it may be difficult to find suitable geological formations within their own borders. In such cases it may--from local as well as global safety points of view--be a better solution to dispose of the material in a repository in another country, through a bilateral or a multilateral arrangement. An economic advantage is that countries with small and/or short nuclear energy programmes may find cost advantages in using repositories abroad rather than using large funds to find a suitable site of their own and develop it into a (comparatively small) repository. Public acceptance problems might also be minimized through the use of international repositories. The Not in My Back Yard (NIMBY) - response might be reduced particularly if the international repositories were at sites far away from densely populated areas and in those countries where support for nuclear programmes is higher.

A second initiative is the use of international review and the shaping of international consensus on technical and safety issues. International organisations such as the Commission of the European Communities, the Nuclear Energy Agency, and the International Atomic Energy Agency can play an important role. Some individual countries have used reviewers from the international scientific community for scrutiny of their documents on waste repositories. Positive reactions from highly respected scientists lead to increased confidence on the technical level, which in turn also may increase public acceptance in the country. While the latter effect has not been very apparent to date, it may become important over the longer term.

V.C. Interim Storage

V.C.1. The Role of Interim Storage

All countries have interim storage facilities at reactors. Most countries will require additional facilities either at the reactor, at the disposal site, or at some other location. The debate about the length of interim storage continues with questions unresolved on the wisdom of double handling of wastes, increased transportation, rod consolidation, vulnerability to terrorist attacks, rate of reduction of uncertainty of safety of final disposal with time, increased operational safety with increased throughput at a single site, trade-offs between occupational dose increase and public dose decrease, costs, etc.

The reliance upon interim storage varies from country to country (e.g. both the United States and the Federal Republic of Germany require early disposal of high level radioactive wastes, whereas the United Kingdom will utilize interim storage for at least several decades).

V.C.2. Interim Storage for Very Long Periods

There is need for interim storage capacity for different types of material, such as spent fuel, high level waste (HLW) from reprocessing, intermediate level waste (ILW) (particularly large quantities in countries with reprocessing) and low level waste (LLW). The interim storage of HLW and spent fuel in the countries covered by this study is aimed at storage periods ranging from 5-10 years up to several decades. From a technical point of view, long interim storage is advantageous since it makes final disposal easier (less heat production in the material), allows time for further research on the engineered features and the site itself and also leaves the choice of disposal options open.

Most existing commercial spent fuel is currently being stored in water-filled basins, based on well-known technology. Although there has been much less experience with dry interim storage, such systems may have potential safety advantages--mainly due to their passive cooling system and the physical protection obtained through the heavily shielded containers. There are also indications that dry interim storages may have cost advantages.

To obtain public acceptance for the handling of waste and spent fuel, it is necessary to have a well-defined waste strategy. The length of the time period for the interim storage should be well specified. It should also be very clear which type of waste will be placed in each particular interim storage facility. In the face of public opposition to the siting of repositories there is a clear temptation to lengthen the period of interim storage, as a result of many (quite different) interests:

- Once spent fuel elements have been placed in an interim storage facility, it may be cheaper to leave them there for an extended (even indefinite) time period than to remove them and to transport them to a final repository.

- Politicians may appreciate that the political costs of the final repository issue can be deferred to their successors.

- The importance of retrievability in public perceptions may lead to demands for prolonged interim storage.

- Nuclear critics may also appreciate the monitoring systems and the retrievability of interim storage. Furthermore they may find that a lengthy interim storage gives support for their claim that the question of final disposal of HLW has not been solved (or even cannot be solved). This in turn may be used as an argument against further use of nuclear power.

- Industry may also see the advantage in deferring the controversy over repository siting to a future period when public concerns about nuclear power and radioactive wastes may have abated.

These interests provide the temptation to utilize interim storage for periods of time well beyond those originally conceived, as a means of avoiding the political costs of siting. Such a redefinition of the role of interim storage could pass the waste burden to future generations and increase risks during the early period of waste management. Nations may require new institutional means to guard against such political expediency.

V.D. Siting

V.D.1. Low Level Versus High Level Wastes

Though this report started out to discuss high level waste facility siting, it became apparent that there was more relevant information about low level waste siting and licensing experience than there was about high level waste (including transuranics). The analogy is not perfect, however, because, depending upon each country's classification system, low level waste tends to be mostly beta-gamma emitters with little alpha emitting material, has half lives of 30 years or less, is similar in form and content to municipal waste, and usually does not present acute radiation hazards. High level waste, in contrast, while generally having high levels of beta gamma emitters, also has large quantities of alpha emitters, has half lives extending to millions of years, is unique in waste form (vitrified glass or spent fuel), and after the decay of the majority of the beta-gamma emitters in 600 to 1000 years is primarily a hazard only if ingested or inhaled. Prior to that decay, the unshielded waste presents an acute radiation hazard.

Consequently, low level waste will decay to innocuous levels within time frames of human comprehension, will stay at ambient temperatures that man is accustomed to dealing with, and is therefore subject to far less technical uncertainty about its behavior during its hazardous lifetime. The degree of safety in disposal, therefore, depends upon the resources that society wishes to spend, ranging from the near surface, shallow land burial at Drigg, the near surface engineered storage at Centre de la Manche, to the intermediate depth, greater confinement geologic disposal at Forsmark.

High level waste, by contrast, if disposed of immediately after discharge from the reactor, would reach temperatures substantially above those normally encountered in geologic formations. This introduces increased uncertainty about prediction of chemical interactions within the waste form and with the canister, backfill, and host rock. High level waste will have to be sequestered during the periods of acute radiation hazard and will have to be contained to a high degree for extraordinary periods of time (compared with man's experience) to prevent the ingestion or inhalation of the alpha emitters which could lead to cancer deaths. Consequently, high level wastes are in almost all situations allowed to cool prior to storage to reduce the rate of energy release, and consequent heat production, thereby significantly reducing the temperature rise in a repository. This cooling also reduces the degree of uncertainty about the waste interaction with the packaging and repository environment. After 50 years out of the reactor, the rate of decrease of energy emission slows considerably so that there is little temperature reduction to be gained by further storage. High level waste is treated to reduce its release rate and is placed deep underground to reduce, in the short term, exposure to acute radiation hazards, and to reduce in the long term, inadvertant contact with concentrations leading to cancer deaths.

Because of these dissimilar objectives, the technical requirements for disposal sites for high level wastes are quite different from those for disposal of low level wastes. Low level waste disposal facilities need to guard their integrity for a relatively short period and therefore are less demanding in their geological and hydrogeological requirements. Integrity can be maintained by engineering the waste form, by choosing carefully the waste environment or by both. The geologic requirements are much less severe than for high level wastes; consequently, a wider variety of locales is suitable for such sites. Because of the long time periods involved, high level waste must have both highly engineered waste forms and environments that will isolate the wastes. Consequently, the number of locales that can meet such geotechnical environments will be fewer than those for low level waste.

Permanent storage of high level waste, without intermittent intervention to upgrade the facility, will not provide the degree of protection from natural events for the time period during which such wastes remain hazardous.

Human intrusion, while possibly a hazard to low level waste sites, cannot produce the same degree of exposure to acute levels of radiation effects that intrusion at high level storage sites can induce.

V.D.2. A Technical Consensus on Criteria

There will be siting, whether interim or final, because the wastes already exist. Even if, as in the most radical scenario, nuclear energy were to be phased out immediately, the existing spent fuel, the core inventory, and the decommissioning wastes would still need to be disposed of. The question, then, is not whether to site but what is the most desirable or least disruptive approach to siting.

It is clear that no best solution can ever be found and that what is sought is a satisfactory solution. There is relatively remarkable scientific consensus on the desirable technical attributes of a repository site. It is relatively easier to be sure of absolute disqualifiers of a site (e.g. no suitable geological formations at depths less than 5000 meters) than to balance the various attributes of the different sites in order to choose the most suitable site for investigation. Clearly a site with simple geologic properties is easier to characterize than a more complicated site. Most countries which have made a choice use a single performance measure -- individual dose to a member of the critical group -- to determine whether a site is satisfactory. Only the United States uses both collective and individual dose limitation and individual barrier and geological parameter limits.

In most countries, the problem is not so much in finding a suitable site as it is in securing public support to explore and develop potential sites. There is as yet no licensed site for disposal of high level or transuranic wastes in any of these countries, though an unlicensed facility for military transuranic waste is nearing completion in the United States. Licensed sites for interim storage for spent fuel and low and intermediate level wastes already exist, of course, in the Federal Republic of Germany, Sweden and the United States, and licensed sites for low level waste disposal exist in France and the United Kingdom. Although all countries are searching or intend to search for a high level waste disposal site, the search is complicated in some countries by the debate over a series of fundamental policy and social issues: reprocessing versus direct disposal, the potential for proliferation in each method, cost differences between spent fuel and processed waste disposal, between large and small energy programmes, inequities in local versus national interests, inequities between present and future generations, appropriate means of public involvement, the difficulty in finding suitable geology at reasonable depths and away from densely populated regions, etc.

Because the need for low level waste disposal sites is more pressing (larger volume) and there is no technical reason for delay (no potential thermal decay exists for non-heat-generating wastes), the process for site selection and licensing is further advanced. Both positive and negative lessons can be learned from this experience.

V.D.3. The Socio-Political Experience with Siting

The experience with siting radioactive waste facilities, when viewed across countries, has been uneven, with some successes but with many failures. It is evident that siting such facilities typically elicits a high degree of public concern and, not infrequently, intense local opposition. Overcoming determined local opposition is everywhere a serious problem, but, because of constitutional structures and local planning traditions, a greater problem in some societies than in others. Siting difficulties are, without question, one of the primary sociopolitical obstacles to mounting effective radioactive waste management programmes across the six countries.

Previous experience with siting large industrial facilities provides only limited guidance for responding to the siting problem. It is not the traditional social and economic impacts at the site which drive the conflict, but the nature of the material in the repository and the fear and distrust it invokes. These reactions are compounded by equity questions and value issues. These are sometimes referred to as the "special impacts" of a repository, and are expected to overwhelm the more traditional impacts. Existing institutional mechanisms for siting facilities are often inadequate for dealing with the conflicts engendered.

While the generic nature of the problem is apparent, generic solutions are not. Rather they seem to be guided by attributes of the particular political culture which prevails in each country. Thus, whereas site compensation and bargaining will be central to acceptable solutions in France, the United States, and Switzerland, they are likely to play much less of a role in the Federal Republic of Germany, Sweden, and (perhaps) the United Kingdom. What is apparent is that the institutional processes will require means to address the underlying conflicts, and that institutional adaptation and extraordinary measures may be necessary since the problem often becomes extraordinary.

V.D.4. Anticipating Potential Siting Failures

Experiences with the early stages of implementation in national repository siting programmes for both low level and high level waste facilities point up several types of failure which may occur when viewed over the long term. These failures have their common root in the intense public reactions to the siting of radioactive was facilities, and the desire of many politicians and decis akers to escape the political costs. This situation could lead to policies and choices which will ultimately prove be environmentally and socially undesirable.

The first potential failure is that itical sensitivities will prevent the emergence of international approaches to waste management and force each nation, even very small countries, to develop its own full-fledged waste programme. This will result in disposal sites in suboptimal geologic environments and in management programmes with less depth of technical expertise.

The second potential failure would be the export of waste siting to developing countries. Already offers for sites have been extended by developing countries and such offers have been seriously considered by advanced industrial societies. Such solutions, while expedient, would locate sites in the societies least prepared to deal with the technical and regulatory complexities and most likely to encounter problems associated with institutional instabilities.

The third potential failure would involve the premature adoption of emerging technological options for which substantial technical and social uncertainties may remain. The example of very long interim storage has already been discussed. The development of subseabed disposal repositories prior to the accumulation of requisite scientific knowledge poses another possible case.

Finally, the sociopolitical problems in siting could threaten the erosion of the consensual technical criteria which have emerged over the past decade. As the political obstacles mount to site selection and development, the temptation to site facilities according to a political calculus, even if this involves compromise of technical criteria, will grow. Failures in technical integrity to siting could quickly lead to further losses in public acceptability for waste management and threaten national waste management programmes.

V.E. Summation

V.E.1. Uncertainty and Contentiousness

No societal consensus is possible on a number of the difficult issues in radioactive waste management because they involve deeply held beliefs, competing values, and diverse stakeholders. Although the growth of scientific understanding and the expenditure of greater resources on technical programmes may reduce uncertainties, significant issues of continuing debate and social conflict almost certainly will not disappear.

In some cases, further knowledge may even raise more scientific questions than it resolves. Because of this, as already noted, international agreement on what constitutes safe disposal will be helpful. One drill hole may leave considerable uncertainty about the geology but, as the number of drill holes increases, the microdifferences between cores become dominant. The effect of these differences upon repository performance may not be great, but the necessary global perspective may be lost under the weight of detailed evidence.

Although international agreement on the desirable features for a safe disposal site exist, the social inequities in siting (local versus national, beneficiaries versus impactees) will remain, as with other actions in society. Resolution will depend upon appropriate institutional responses, the sharing of other risky societal endeavors (e.g. hazardous chemical waste facilities), and an appreciation of the interdependence of various countries in our global environment.

V.E.2. <u>Perspectives</u>

Safety, interim storage and the siting of nuclear facilities are highly interrelated. The proper use of interim storage can reduce the technical uncertainty in safety evaluation and lead to less contentiousness about technical matters. The Swedish interim storage facility (CLAB) and the repository for transuranic waste at the Waste Isolation Pilot Plant in the United States have been developed. Exploration at the Gorleben site in the Federal Republic of Germany continues. France, with an existing underground methodology laboratory, will develop another underground laboratory for testing the geophysical and geohydrological properties of a potential repository site. Switzerland has an underground rock laboratory in operation. This is not to imply that there has not been controversy in each of the countries but to point out that whatever the problems, there has been important progress in siting nuclear waste facilities. Progress in reducing risk continues as increased understanding of the interactions of the wastes with the waste package and the host rock is obtained. Further reduction in risk will be obtained and could even be accelerated by the development of inherently safe waste forms such as those that are at thermodynamic as well as kinetic equilibrium with the host rock. It is doubtful, however, that this reduced technical risk will do as much to increase the probability of success in siting as obtaining an equivalent level of knowledge of the social and political forces that influence siting as we have of technical problems.

Despite increased knowledge in both of these spheres, an irreducible amount of uncertainty about the risks of such disposal will always remain. It must be emphasized that in this preoccupation with technical and social processes we have not found any information, nor do we believe, that there are catastrophic outcomes hidden over the horizon waiting to occur. Technical gaps will be filled by increased understanding of the processes, and not by the elimination of fatal flaws in the methodology. Increased understanding should help to reduce, but not eliminate, the scientific controversies and the areas of public concern about siting. Further understanding of the social and political processes is clearly essential to such reduction. Clear, consistent, scientifically and uncompromised valid performance will over the long term, do much to reduce controversies about government intentions and resolve that today continue to frustrate the implementation of radioactive waste disposal in Europe and North America.

REFERENCES

Perrow, Charles, 1984 Normal Accidents, Basic Books, New York.

ICRP, 1985 Radiation Protection Principles for the Disposal of Solid Radioactive Waste, ICRP-46.

NEA, 1983. Long-Term Management of High-Level Radioactive Waste--The Meaning of a Demonstration, OECD/NEA, Paris.

LIST OF ACRONYMS

AERE: Atomic Energy Research Establishment, **UKAEA**.

AFR: Away from reactor.

AGNEB: Arbeitsgruppe des Bundes fur die Nukleare Entsorgung (Federal Interagency Working Group on Nuclear Waste Management), Switzerland.

AIChE: American Institute of Chemical Engineers (USA).

ALARA: As low as reasonably achievable.

ALI: Annual limit on intake.

AMOS: Waste treatment and interim storage facility at Studsvik (Sweden).

ANDRA: Agence Nationale pour la Gestion des Dechtets Radioactifs (National Agency for the Management of Radioactive Wastes), France.

APC: U.S. built long coring device supplied to ESDPE cruise

AR: At reactor.

AVH: Atelier de Vitrification de La Hague (La Hague Vitrification Facility), France.

AVM: Atelier de Vitrification de Marcoule (Marcoule Vitrification Facility), France.

BAG: Bundesamt fur Gesundheitswesen (Federal Office for Health), Switzerland.

BBLM: Benthic boundary layer model, **SWG**.

BEW: Bundesamt fur Energiewirtschaft (Federal Office of Energy), Switzerland.

BGR: Bundesanstalt fur Geowissenschaften und Rohstoffe (Federal Agency for Geosciences and Resources), FRG.

BGS: British Geological Survey, UK.

BIOMOVS: Biosphere Model Validation Study.

BIOPATH: Computer code (Switzerland).

BMFT: Bundesministerium fur Forschung und Technologie (Federal Ministry of Research and Technology), FRG.

BMI: Bundesministerium des Inneren (Federal Ministry of Domestic Affairs), FRG.

BNFL: British Nuclear Fuels Ltd., UK.

Bq: Becquerels.

BRGM: Bureau des Recherches Geologiques et Minieres (Bureau for Geological and Mining Research) France.

BWIP: Basalt Waste Isolation Project, USA.

BWR: Boiling Water Reactor.

CEA: Commissariat a l'Energie Atomique (Atomic Energy Commission), France.

CEC: Commission of the European Communities.

CEDRA: Societe Cooperative Nationale pour l'Entreposage de Dechets Radioactifs (National Cooperative for the Storage of Radioactive Wastes), Switzerland.

CEGB: Central Electricity Generating Board, UK.

CFR: Code of Federal Regulations, USA.

COGEMA: Compagnie Generale des Matieres Nucleaires (General Company for Nuclear Materials), France.

Ci: Curies.

CIINB: La Commission Interministerielle des Installations Nucleares de Base (Interministerial Commission of Nuclear Power Plants), France.

CLAB: Central interim storage facility for spent nuclear fuel, Sweden.

CRPPH: Committee on Radiation Protection and Public Health, **NEA/OECD**.

CSDR: Commission Scientifique pour les Dechets Nucleaires (Scientific Commission for Nuclear Wastes), France.

CSSN: Conseil Superieure de la Surete Nucleaire (Supreme Council for Nuclear Safety), France.

DBE: Deutsche Geselschaft zum Bau und Betrieb von Endlagern fur Abfallstoffe mbH (German Company for the Construction and Operation of Waste Repositories, Ltd.), FRG.

DCW: Decommissioning wastes.

DED: Direction Chargee des Effluents et Dechets Radioactifs (Directorate for Radioactive Wastes and Effluents), France.

DM: Deutsche Mark (German Mark), FRG.

DOE: Department of Energy, USA.

DoE: Department of the Environment, UK.

DWK: Deutsche Gesellschaft fur die Wiederaufarbeitung von Kernbrennstoffen mbH (German Company for the Reprocessing of Nuclear Fuels, Ltd.), FRG.

EA: Environmental Assessment (report), USA.

EdF: Electricite de France (French Electricity Company).

EIR: Eidgenossische Institut fur Reaktorforschung (Federal Institute for Reactor Research), Switzerland.

EPA: Environmental Protection Agency, USA. Also as **US-EPA**.

ESOPE: Etudes des sediments oceaniques par penetration (study of oceanic sediments by penetration) NEA.

ESTG: Engineering Studies Task Group, of the SWG.

ETH: Eidgenossische Technische Hochschule (Federal Institute of Technology), Switzerland.

EVED: Federal Department of Transport, Communication and Energy, Switzerland.

FoE: Friends of the Earth, Ltd., UK.

FRG: Federal Republic of Germany.

gB: Giga-becquerel.

GOEK: Gruppe Okologie (Ecology Group). Also known as Institut fur Okologische Forschung und Bildung (Institute for Ecological Research and Education), FRG.

GSEK: 10^9 Swedish Krona (currency).

GSF: Gesellschaft fur Strahlen- und Umweltforschung mbH (Radiation and Environmental Research Company, Ltd.), FRG.

GWe: Giga Watts of electricity.

HAW: Highly Active Waste.

HLW: High-level waste.

HM: Heavy metal.

HMI: Hahn-Meitner-Institut fur Kernforschung Berlin mbH (Hahn-Meitner Institute for Nuclear Research, Ltd. Berlin).

HMSO: Her Majesty's Stationary Office, UK.

HSK: Hauptabteilung fur die Sicherheit der Kernanlagen (Federal Office of Energy, Nuclear Safety Department). Also known as ASK - Abteilung fur die Sicherheit der Kernanlagen (Division for Reactor Safety), Switzerland.

HYDROCOIN: Hydrological Code Intercomparison Study, NEA.

IAEA: International Atomic Energy Agency.

ICRP: International Commission on Radiological Protection.

IGS: Institute of Geological Sciences, UK. Now **BGS**.

ILW: Intermediate-level waste.

INE: Institut fur Nukleare Entsorgung (Institute for the Back-end of the Nuclear Fuel Cycle) **KFK**, FRG.

INFCE: International Nuclear Fuel Cycle Evaluation.

INTRACOIN: International Nuclide Transport Code Intercomparison Study, **NEA**.

IOS: Institute of Oceanographic Sciences, UK.

IRG: Inter Agency Review Group, USA.

IRDI: Institut de Recherches Technologiques et de Developpement Industriel (Institute for Technological Research and Industrial Development), France.

ISIRS: International Sorption Information Retrieval System, **NEA**.

IPSN: Institut de Protection et de Surete Nucleaire (Institute for Nuclear Protection and Safety), France.

JRC: Joint Research Centre, CEC.

KBS: Karnbranslesakerhet (spent fuel safety), Sweden.

KfK: Kernforschungszentrum Karlsruhe mbH (Karlsruhe Nuclear Research Center, Ltd.), FRG.

KRISTAL: 12-core-hole-drilling campaign for HLW repository investigation, Switzerland.

KSA: Eidgenossische Kommission fur die Sicherheit von Atomanlagen (Federal Commission for the Safety in Nuclear Installations), Switzerland.

LAW: Low Activity Waste, or Low Active Waste.

LLW: Low-level waste.

LWR: Light water reactor.

MAFF: Ministry of Agriculture, Fisheries and Food, UK.

MARIAH: Marine transport code.

MAUT: Multiatribute Utility Analysis, especially the one performed for the U.S. DOE.

MAW: Medium Activity Waste, or Medium Active Waste.

MGR: Mined geological repository.

MI: Ministry of Industry (France).

MINE QL: Computer code Migration of Radionuclides in the Geosphere.

MIRAGE Modeling Program (France).

MIT: Massachusetts Institute of Technology, USA.

MLW: Medium Level Waste.

MOX: Mixed-oxide fuel.

MRI: Ministere de l'Industrie et de la Recherche (Ministry of Industry and Research), France.

MRS: The proposed Monitored Retrievable Storage facility, USA.

MSEK: Millions of Swedish Krona (currency).

MTU: Metric Tonnes of Uranium.

NAGRA: Nationale Genossenschaft fur die Lagerung radioaktiver Abfalle (National Cooperative for the Storage of Radioactive Wastes), Switzerland. In French **CEDRA**.

NAK: Namnden for Hantering av Anvant Karnbransle (National Board for Spent Nuclear Fuel), Sweden. (Now SKN)

NAS: National Academy of Sciences, USA. Also as USNAS or **US-NAS**.

NEA: Nuclear Energy Agency, **OECD**.

NEPTUNE: Computer Code.

NERC: Natural Environment Research Council, UK.

NII: Nuclear Installations Inspectorate, UK.

NIMBY: Not in my back yard.

NIREX: Nuclear Industry Radioactive Waste Executive, UK.

NRC: Nuclear Regulatory Commission, USA. Also as USNRC or **US-NRC**.

NRPB: National Radiological Protection Board, UK.

NWPA: Nuclear Waste Policy Act, USA.

NWTS: Nuclear Waste Terminal Storage Program, USA.

OECD: Organisation for Economic Co-operation and Development.

OKG AB: Owner of Oskarshamn reactors, Sweden.

ONWI: Office of Nuclear Waste Isolation, USA.

ORNL: Oak Ridge National Laboratory, USA.

OTA: Office of Technology Assessment, USA.

PAE: Projektgruppe Andere Entsorgungstechniken (Other Entsorgungs Technology Project Group), FRG.

PAGIS: Joint European Performance Assessment of Geological Isolation Systems (CEC).

PAMELA: Pilotanlage Mol zur Erzeugung lagerfahiger Abfalle (Pilot Facility Mol for the Production of Disposable Wastes), FRG and Belgium.

POTG: Physical Oceanography Task Group, **SWG**.

PSAC: Probabalistic Systems Assessment Codes (**NEA**).

PSE: Projekt Sicherheitsstudien Entsorgung (Entsorgung Safety Studies Project), FRG.

PTB: Physikalisch-Technische Bundesanstalt (Federal Institute for Science and Technology), FRG.

PWR: Pressurized water reactor.

RANCH, RANCH MD, RANCH N: Swiss computer codes.

R+D: Research and Development.

REM: Regional eddy resolving model, **SWG**.

RSK: Reaktorsicherheitskommission (Commission for Reactor Safety), FRG.

RWE: German Utility Company.

RWMAC: Radioactive Waste Management Advisory Committee, UK.

RWMC: Radioactive Waste Managment Committee, **NEA**.

SCPRI: Service Central de Protection contre les Rayonnements Ionisants (Central Service for Protection Against Ionizing Radiation), France.

SCSIN: Service Centrale de Surete des Installations Nucleaires (Central Service for the Safety of Nuclear Installations), France.

SDP: Subseabed Disposal Programme, **US-DOE**.

SES: Schweizerische Energiestiftung (Swiss Energy Foundation).

SFR: Swedish Final Repository for Reactor Waste).

SKB: Swedish Nuclear Fuel and Waste Company.

SKBF: Svensk Karnbransleforsorjning AB (Swedish Nuclear Fuel Suply Company). Now **SKB**.

SKI: Statens Karnkraft Inspektion (Swedish Nuclear Power Inspectorate).

SKN: Statens Karnbranslenamd (Swedish National Board for Spent Nuclear Fuel).

SPD: Social Democrat Party, FRG.

SSI: Statens Stralskyddsinstitut (National Institute for Radiation Protection), Sweden.

SSK: Strahlenschutzkommission (Commission on Radiation Protection), FRG.

SSTG: Site Selection Task Group, **SWG**.

STACOR: Large-diameter long coring device used on ESOPE cruise.

SV: Sievert(s).

SWG: Seabed Working Group, **NEA**.

SYVAC: Systems Variability Analysis Code, Canada.

TROUGH: Swiss computer code.

TRU: Transuranic.

tU: Tonnes of Uranium (metric).

UEGO: Untergruppe Geologie (Geology Subgroup) of the **AGNEB**, Switzerland.

UK: United Kingdom.

UKAEA: United Kingdom Atomic Energy Authority.

UCLOS: **United Nations Conference on the Law of the Sea.**

UNSCEAR: United Nations Scientific Committee on the Effects of Atomic Radiation.

UP1: French reprocessing plants.

UP2: French reprocessing plants.

UP3: French reprocessing plants.

URL: Underground research laboratory.

US: United States (of America).

USA: United State of America.

US-DOE: United States Department of Energy. Also as **DOE** or USDOE.

US-GPO: United States Government Printing Office.

US-GS: United States Geological Survey. Also as **GS** or USGS.

US-NAS: United States National Academy of Sciences. Also as **NAS** or USNAS.

VLLW: Very Low Level Waste.

WAK: Wiederaufarbeitungsanlage Karlsruhe (Karlsruhe Reprocessing Facility) FRG.

WHO: World Health Organization.

WIPP: Waste Isolation Pilot Plant, USA.

WISP: Waste Isolation Systems Panel, USA.

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NAK Report 1

SAMMANSTÄLLNING AV NUKLEÄRA KÄLLDATA FÖR ANVÄNT KÄRNBRÄNSLE

(Compilation of Nuclear Source Data for Spent Nuclear Fuel)

Göran Olsson
Studsvik Energiteknik AB
April 1983

(19 pages of tables and diagrams, Swedish text)

NAK Report 2

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Caj Airola
Studsvik Energiteknik AB
November 1983

(119 pages mainly on engineering aspects of ceramic encapsulation, in Swedish)

NAK Report 3

ENCAPSULATION OF SPENT NUCLEAR FUEL IN CERAMIC MATERIALS AN INTRODUCTORY STUDY

S Forsberg
T Westermark
Department of Nuclear Chemistry
The Royal Institute of Technology
Stockholm, Sweden
March 1983

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Gunnar Karlsson
Department of Psychology,
University of Stockholm
September 1983

(43 pages in Swedish)

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Ragnar Gelin
Studsvik Energiteknik AB
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(40 pages in Swedish)

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(International Development of Intermediate Storage and Reprocessing of Spent Nuclear Fuel and on Recycling of Plutonium)

G Carleson
Å Hultgren
Studsvik Energiteknik AB
August 1984

(56 pages in Swedish)

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Frank L Parker
Robert E Broshears
Janos Pasztor
The Beijer Institute of the Royal Swedish Academy of Sciences
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(Vol I 116 pages, Vol II 209 pages, in English)

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Clas-Otto Wene et al
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Ragnar Gelin
Studsvik Energiteknik AB
April 1985

(37 pages in Swedish)

NAK Report 15

UPPFÖLJNING AV DEN INTERNATIONELLA
UTVECKLINGEN AV MELLANLAGRING OCH
UPPARBETNING AV ANVÄNT KÄRNBRÄNSLE

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Göran Carleson
Studsvik Energiteknik AB
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