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Nuclear Waste Management Issues: A Multidisciplinary Evaluation Framework

**M. Hoffman
TEKNEKRON, Inc.**

February 1980

**Prepared for
Pacific Northwest Laboratory
Under Special Agreement B-52865-A-L
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TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
1. SUMMARY.	1-1
2. INTRODUCTION	2-1
3. THE ANALYTIC METHODOLOGY AND ITS APPLICATION	3-1
3.1 The Nominal Group Technique	3-2
3.2 Generation and Ranking of Issues.	3-7
3.3 Discussion of the Issues.	3-18
3.3.1 The Need for Risk Levels and Design Standards--A Chicken-and-Egg Question.	3-18
3.3.2 Public Perception of Risk.	3-20
3.3.3 Setting an Acceptable Risk Level--Whose Responsibility?.	3-21
3.3.4 When Do We Stop Worrying?.	3-25
3.3.5 Technical Credibility and Society--The Need for a Legitimate Decision Process.	3-28
3.3.6 The Forcing Function--Who Establishes the Timetable and on What Is It Based?	3-34
3.3.7 Retrievalability and Contingency Planning--The Desire for Incremental Decision Making	3-38
3.3.8 Scaling Up--The Need for Cumulative Analysis	3-42
3.3.9 Post-Entombment Monitoring	3-45
3.3.10 Engineered Barriers.	3-48
3.4 Reranking of Issue Areas.	3-49
3.5 Systems Analysis for Issue Resolution	3-51
3.6 Issue of Political and Institutional Factors.	3-55
3.7 Summary Results of the Test Analysis.	3-56
4. CONCLUSIONS.	4-1
4.1 Bounding the Problem.	4-1
4.2 Client Representation	4-2
4.3 Generating Ideas, Not Solving Problems.	4-3
4.4 Technical and Non-Technical Components of a Methodology	4-4

TABLE OF CONTENTS (Continued)

<u>Section</u>	<u>Page</u>
4.5 Nature of the Product.	4-5
APPENDIX: ISSUE CHARACTERIZATION.	A-1
Radioactive Waste Forms	A-1
Risks From Radioactive Wastes	A-2
Deep Geologic Disposal.	A-4

1. SUMMARY

A study was undertaken to develop and test a methodology for the analysis of issues related to the management of radioactive wastes. The need for such a methodology stems from the complex nature of waste management issues, particularly those relating to permanent disposal in geologic formations. Because of the significant societal implications of applying permanent disposal technology, a host of non-technical issues must be considered in the deliberations that lead to program decisions (some of which are irreversible). Integrating these non-technical considerations with the technical factors requires a multi-disciplinary perspective and provides a significant challenge to a decision maker.

A review of historical attempts to integrate technical and non-technical factors in the analysis of radioactive waste management issues revealed little in the way of systematic methodology. Accordingly, we explored a technique that was originally derived to facilitate a group's creativity in program planning. This "Nominal Group Technique (NGT)" has been widely applied in health, social service education, industry, and government organizations.

The NGT is a systematic approach to generating ideas or solving problems where several disciplines are represented and there is a need to integrate individual perspectives. It is particularly useful for those situations in which a single discipline would not provide sufficient insight or knowledge to arrive at a successful solution to a complex problem. In the NGT, individual judgments are pooled so that the multi-disciplinary group can invent or

discover satisfactory courses of action. Hence, the process involves a strong iterative orientation to arrive at creative judgments or decisions.

In testing the methodology, we adopted the following principles:

- Group size should be kept small (six people) so neither the focus on the objectives of the analysis, nor insights derived from the disciplines involved will be lost;
- The group should be composed of both physical and social scientists due to the technical and non-technical dimensions of the issue to be analyzed; each member should have had extensive exposure to nuclear waste management programs and issues.
- Definitive groundrules and guidelines should be developed before the meeting to govern the structured panel dialogue; constraints on the participants should be minimized, consistent with the need to keep the panel's efforts focused on and aiming towards the objectives while simultaneously stimulating the innovative and creative inputs desired;
- The participants should be exposed at the outset to the assigned (waste management) issue, its relevance to the (waste management) program, and the purpose and objectives of the analysis. The assigned issue (the nominal question) was presented in the following form: *Please list the issues a program manager should resolve to deal with the potential human intrusion of an aquifer potentially contaminated by radioactive waste that has migrated from a deep geologic repository.*

The program manager was described as an individual with any one of the following three roles:

- employed by a government agency, such as the Department of Energy or the Nuclear Regulatory Commission, to develop guidelines and standards for the long-term disposal of nuclear wastes;
- employed by a firm with the responsibility to manage a number of deep geologic disposal sites; or

- employed by the Department of Energy, Nuclear Regulatory Commission, or a private firm responsible for allocating research and development resources regarding the disposal of nuclear wastes.

The two-day panel discussion identified a broad range of sub-issues related to the nominal question, consolidated these into a tractable number of major issues, ranked the major issues, and analyzed the factors potentially leading to issue resolution. The exercise resulted in the following general conclusions:

1. The considerations that should receive greatest attention in formulating acceptable solutions to the nominal question are:
 - a. the determination of acceptable levels of risk associated with establishing and operating the deep geologic waste disposal system over the relevant time periods;
 - b. the establishment of design standards for the performance of the deep geologic waste disposal system;
 - c. the adequacy of the techniques and data for the physical modeling and analysis of the system for postulated waste release scenarios; and
 - d. the adequacy of the repository site characterization.
2. Provisions for engineered barriers and contingency planning (to deal with unexpected events in the disposal system) were viewed as moderately important considerations; their relative importance could vary depending upon how the priorities were established for the items in 1 above.
3. Post-entombment monitoring and long-term institutional control of the depository and its environs were assigned low priority.

There was unanimous agreement among the experts that resolution of considerations 1 a) and b) must evolve through an iterative process between the derivation of design standards and the predicted risks associated with the application of those standards. Moreover, it was recognized that the credibility

of the predicted risks is a function of appropriately satisfying considerations 1 c) and d). The figure depicts how these considerations might interact in an iterative process to produce the desired results.

The results from testing the applicability of the NGT for effectively evaluating waste management issues led to the following conclusions about the analytical process:

- Physical and social scientists can effectively and productively engage in a structured dialogue within the NGT framework that results in a systematic identification of considerations that bear on an acceptable solution of the issue and in consensus courses of action designed to resolve complex technical issues having both technical and non-technical components.
- The size of the group selected for testing the NGT--six panelists plus moderator--appears to be reasonable in terms of maintaining control and focus of the group on the established objectives, sustaining the interest and participation of all panelists, and being sufficiently representative of critical disciplines to provide a meaningful iterative process for identifying and evaluating both potential options for resolving issues and the factors on which these options depend.
- An effective and continuous dialogue between social and physical scientists is desirable in deliberating the factors that influence the alternatives for resolving the waste management issues due to the extensive interdependence of these technical and non-technical factors.
- The extent that the product of the analysis is defined in quantitative terms will be principally influenced by a) the degree to which the panel participants are able to arrive at consensus positions on options for resolving the issue, and b) the extent of the program manager's ("client" for the product) interaction with or participation in the NGT process.

The value of this exercise, it would seem, lies not in altering the values and beliefs of a set of multi-disciplinary elites but, instead, in the ability of such a group to agree on issues where they can and to educate the less-informed observer or reader about their differing views where they can't.

FIGURE 1

Framework for Systematic Inter-Disciplinary Analysis of Nuclear Waste Management Issues

2. INTRODUCTION

Industrialized societies increasingly have had to deal with the impact of technology on society's overall development. The advancements that have led to harnessing nuclear energy also have confronted society with some of its most complex problems, ones that span virtually every discipline. The disposal of radioactive wastes requiring long-term isolation from human environment, for example, confronts policy makers with issues raised by engineers, economists, political scientists, environmentalists, geologists, ethicists, lawyers, and others.

Due to the circumstances associated with the implementation of nuclear waste management systems, these widely diverse disciplines find themselves grappling with the issues from their particular perspectives, with the result that the inputs from the various disciplines are not always consistent or compatible when viewed in their totality by the policy makers. One such unique circumstance is the public's concern for the risk that nuclear materials can pose to society's health and safety. Another is the extremely long period of time over which these risks are a matter of concern. A third is the increasingly vocal and effective stand being taken by intervenors in the policy process that has, in part, tied the future of nuclear energy to a solution to the nuclear waste disposal problem. And a fourth involves the numerous uncertainties associated with estimating future risks, uncertainties that arise from the difficulty of simulating the behavior of radioactive wastes in various environments over tens of thousands of years.

Until recently, the research and development in nuclear waste management has been the domain principally of "technicians" or physical scientists.

Yet the wide range of issues embodied in nuclear waste management involves concerns that are truly interdisciplinary in nature. It is therefore important to develop one or more techniques whereby a variety of experts with a background in nuclear waste management issues can contribute collectively to the development of options for resolving these issues. These techniques should become benchmarks to which policy makers can refer in gathering information, setting priorities, and checking the comprehensiveness and completeness of their analyses. In spite of the current emphasis on multi- or interdisciplinary analysis, such analysis occurs rarely in any meaningful sense in either academia, government, or industry. In the past interdisciplinary analysis of nuclear waste management issues has generally been pursued independently by relatively large groups of physical scientists and small groups of social scientists whose efforts were not sufficiently structured or focused to result in findings useful to program managers and policy makers.

After reviewing a variety of techniques used for problem solving or to facilitate decision making, Teknekron, Inc., under contract with Battelle Pacific Northwest Laboratories, explored one process for directly involving a range of experts on factors (or sub-issues) relevant to the resolution of specific nuclear waste management issues. The results of this process are intended to identify for a program manager the priority considerations he should address in resolving these issues. Teknekron believes that the direct and continuous interaction of a small group of individuals familiar with nuclear waste management issues, but representing different experiences and professional orientations, may be a promising analytic

framework that a program manager will find useful in organizing and analyzing the myriad issues he faces.

A meeting format--the Nominal Group Technique (NGT)--was chosen to provide a structure for the discussion and consideration of options for resolving waste management issues. The technique enabled us to disaggregate the issues into their technical and non-technical components and then to rank these sub-issues according to individual and group priorities. In order to focus the discussion and ensure a systematic and task-oriented approach, we framed a specific question and a client for whom an answer to the question or main issue would be useful. We bounded the discussion by focusing on the issue of groundwater contamination occurring at a deep geologic repository housing radioactive wastes, having noted the prevalent view that the most likely mechanism for migration of the radioactive materials to the biosphere is via groundwater transport. Moreover, the most probable scenario for groundwater containing significant levels of radioactive contamination to enter the biosphere is by means of human intrusion in the form of drilled wells. The probability of a well's being drilled directly into a contaminated aquifer is considered to be significant over the period in which the long-lived constituents of the radioactive wastes remain hazardous. This scenario represents a primary consideration that will have to be addressed and resolved in the formulation of disposal technologies, the selection of disposal sites, and related considerations.

We further bounded the group discussion by stating that the analytic framework should be useful to a generic-program manager (federal or private)

concerned with nuclear wastes from the perspectives mentioned in the summary.

Initially, this paper characterizes the nuclear waste problem that requires analysis to establish the rationale for an interdisciplinary approach to resolve it. The problem characterization also explains why the specific concern with contaminated groundwater and intrusion through drilling has been selected for the focus of the panel meeting. The Nominal Group Technique (NGT), the group process format chosen for the experts' deliberations, is explained in some detail and its value in facilitating the desired dialogue is described.

The Nominal Group Technique was employed first with a panel of technical and non-technical participants selected from Teknekron's staff of professionals with considerable experience in the nuclear waste management area. The experience with this two-day panel discussion provided an opportunity to refine the groundrules so that a more focused and effective analysis of the assigned issue would result. This effort was then followed by a similar meeting of experts from several disciplines selected from outside Teknekron. It was also conducted over a two-day period and involved six expert participants, a moderator from Teknekron, and a staff analyst. The proceedings were recorded and transcribed.

A substantial portion of this paper refers directly to the dialogue of the second meeting because, in most instances, only the actual discussion captures the dynamics and effectiveness of the interactions of the technical

and non-technical participants. The intent in using portions of the dialogue is to display the effectiveness of this methodology for analyzing complex waste management issues. These direct references to the panel dialogue are in no way intended to highlight individual preferences or conclusions about waste management policy decisions or to convey DOE or contractor endorsement of such preferences or conclusions. The dialogue is organized around the various issue areas that would be of concern to a program manager dealing with the potential problem of radioactivity escaping to the biosphere through human intrusion into contaminated groundwater. The participants are identified by professional discipline so that the dialogue can be presented in a realistic fashion.

Both the content of the dialogue and its format are evaluated. Particular attention is given to their usefulness in generating a cross-section of subissues and factors that should be addressed when analyzing the waste disposal system's adequacy to prevent contaminated groundwater escaping to the biosphere. We identify the major themes and disciplinary preferences that emerged during the course of the dialogue. We also discuss whether this format is applicable and useful for developing alternative courses of action that might be available to a program manager whose responsibilities include developing guidelines for nuclear waste disposal or allocating related R&D funds.

3. THE ANALYTIC METHODOLOGY AND ITS APPLICATION

Whether responsible for developing guidelines, managing sites, or conducting research and development, a program manager needs a strategy for resolving conflicting priorities and handling problems. Problems whose existence impedes achieving objectives must be systematically identified and strategies for their solution must be mapped out. More often than not, developing these strategies requires that there be a framework for organizing information requirements. This is particularly true when the problem area entails complex subject matter and the inventory of information requirements is incomplete. Even if the full range of information requirements is known, it is often not clear to the manager what the most effective sequence might be for obtaining and deploying the information to arrive at programmatic decisions.

The analytical process employed in this study has the following objectives:

1. To identify a broad range of issues that a nuclear waste manager should address to deal with potential human intrusion of an aquifer potentially contaminated with radioactive wastes.
2. To structure a meeting of interdisciplinary experts so that the first objective can be met.
3. To have the group rank the resulting issues, individually and collectively, and analyze the rankings.
4. To document the most interesting and salient portions of the meeting aimed at addressing these issues and the options identified by the group for resolving the most compelling issues.
5. To assess the analytic framework that results from the meeting in terms of its usefulness for a program manager.

As the methodology was applied in our group, the emphasis was not on solving the issues associated with human intrusion of contaminated ground-water per se. Rather, stress was placed on identifying what the participants felt needed to be resolved and, where possible, candidate options for resolution. The chief concern was to ensure that through the resolution of various issues the probabilities of social damage and financial costs associated with it would be reduced.

3.1 THE NOMINAL GROUP TECHNIQUE

The Nominal Group process, pioneered a decade ago by André Delbecq and Andrew Van de Ven,* is a technique to facilitate groups' creativity in program planning. It was derived from social-psychological studies of decision conferences, management-science studies of aggregating group judgments, and social-work studies of problems surrounding citizen participation in program planning. The process is well respected and has been widely applied in health, social service education, industry, and government organizations.

As is true with all group techniques, NGT should not be seen as a panacea for all difficulties that arise in group meetings. It is a special-purpose technique useful for situations where individual judgments must be tapped and combined to arrive at decisions that cannot be calculated by one person. It is a problem-solving or idea-generating strategy and is not appropriate for routine meetings, coordinating, bargaining, or negotiating. It is primarily concerned with judgmental and creative decision

*André Delbecq, Andrew Van de Ven, and David Gustafson. Group Techniques for Program Planning. Scott, Foresman and Company, 1975.

making. The central element of a situation in which NGT is useful is a lack of agreement or an incomplete state of knowledge concerning either the nature of the problem or the components that must comprise a successful solution.

We selected a group of six individuals--two political scientists and one geologist from academia, and three engineers from the private sector. All six have been involved with problems of nuclear waste disposal. A group this size (plus a moderator) is considered ideal for using the Nominal Group Technique.

To begin NGT, the moderator provides enough background material that the group is clear about the goals the conveners hope to achieve. Our initial presentation included the identification of the waste management issue to be addressed (subsequently referred to as the "nominal question"). This issue was presented to the group in the following form:

Please list the issues a program manager should resolve to deal with the potential human intrusion of an aquifer potentially contaminated by radioactive waste that has migrated from a deep geologic repository.

The presentation also included a brief discussion of a generic deep geologic repository and considerations related to disposal of nuclear wastes requiring long-term isolation from the biosphere. This material, which facilitates an understanding of the relevance of the issue or nominal question, is provided in the Appendix; it was intended to minimize undue background discussions at the beginning of the panel deliberations.

The program manager was described as an individual with any one of the following three roles:

1. employed by a government agency, such as the Department of Energy or the Nuclear Regulatory Commission, to develop guidelines and standards for the long-term disposal of nuclear wastes;
2. employed by a firm with the responsibility to manage a number of deep geologic disposal sites; or
3. employed by the Department of Energy, Nuclear Regulatory Commission, or a private firm responsible for allocating research and development resources regarding the disposal of nuclear wastes.

The wording of the nominal question is important to eliciting voluntary responses from the group that are helpful in achieving the overall objectives. In this instance we wished to constrain the discussion so that the pros and cons of nuclear development per se were not at issue, while at the same time leaving sufficient latitude that the participants felt that the substance was important and interesting.

As a next step, each member (individually) wrote a list of issues that occurred in response to the nominal question; 10 minutes was allocated for this activity. The issues were listed on a flip chart, and each was discussed so that the group shared a common understanding of the item.

While the participants were at lunch, the moderator and two assistants assembled the 30 to 35 issues into 10 issue-areas. The participants were given the list and asked to clarify, criticize, and, ultimately, validate the 10 issue-areas.

The participants then rank ordered the issues from one to five (five being most important); each number could be used no more than twice. A discussion then ensued that had as its goal the identification of the relative importance of each major issue-area and the factors that bear on their resolution vis-à-vis the constraints imposed by the nominal question and by the needs of the client/program manager. The discussion continued for the early part of the second day's session. The themes that surfaced in this discussion are identified in Section 3.3; some of the more insightful and relevant comments from various group members are included.

Finally, towards the end of the second day, each participant was asked to rerank each issue-area to determine whether the previous day-and-a-half of discussion had altered any individual's ratings and whether overall priorities changed appreciably between issue-areas.

Before proceeding with an analysis of the conference, a few observations about the process in general and the Nominal Group Technique in particular are in order. The use of a group at all merits examination. Research has shown that "brainstorming," i.e., group interaction, yields more ideas than group members are likely to generate alone.* Groups tend to become dominated by their more vocal and/or persuasive members with the contributions of less dominant or less articulate members being discounted or preempted. According to Delbecq and Van de Ven, "Three measures have generally been used to compare the relative effectiveness of nominal versus interacting group processes: 1) the average number of unique ideas; 2) the average total number of ideas; and 3) the quality of ideas produced."**

* Delbecq et al., p. 16.

**ibid. 17.

In terms of these three measures of performance, nominal groups have been found to be significantly superior to interacting groups in generating information relevant to a problem. Researchers have concluded that when the group task is to generate information on a problem, interacting groups inhibit creative thinking. (This is not a generic statement of superiority. For other purposes, such as attitude change, team building, and consensus generation, interacting groups are superior. The emphasis here is on idea generation.) Individual inhibitions and premature evaluation in interacting groups result in a decrease in quality of group ideas in terms of creativity, originality, and practicality.*

The Nominal Group Technique utilizes a proactive process to generate ideas rather than a reactive process to respond to them. The former facilitates the development of individual ideas from all members; these are then subjected to group review; in contrast, the latter process tends to encourage members to react to the opinions and ideas of others. The reactive process is characterized by short periods of focus on the problem, frequent interruptions, drifting comments by various participants, tangential discussions, and the need to expend energy to maintain social relationships.

The size of the group and the nature of the problem involved here lent itself to a Nominal Group process. The process facilitated the completion of specific tasks by encouraging the generation of ideas and the ranking of those ideas according to the question and client at issue. It provided for extensive interaction among a small group of experts on various aspects

*ibid, p. 17.

of nuclear waste management issues; personal perspectives were given credibility within the group. Towards the end of the second day, the constraints of the nominal question were relaxed so that issues surfaced that were tangential to and even separate from the human intrusion of contaminated groundwater.

Through this process we intended to address the following questions:

1. Given the nominal question, what range of issues is initially generated by an interdisciplinary group?
2. What is the extent of group consensus or disagreement regarding the issues and the options for their resolution at the outset and after substantial clarification and discussion?
3. How do technical experts respond to direct questions from non-technical experts, and vice-versa?
4. Are certain issues given primacy by the group?
5. What roles are set for the non-technician by the technicians in resolving the problem, and vice-versa?
6. What problems do the participants encounter with respect to the nominal question itself, the manner in which the "client" was specified, the group process, and the overall purpose of the exercise?

3.2 GENERATION AND RANKING OF ISSUES

Following an introduction by the moderator to explain the purpose of the meeting and what we hoped to accomplish, time was allowed for participants to seek clarification of (1) the nominal question, (2) the client's responsibilities and potential use of the analytical technique under development, and (3) his own role in the application and critique of the analytic framework.

Several felt that the nominal question would be overly constraining if it assumed that a site had already been selected. It was agreed that both technological and non-technological issues involving site selection would be considered fair game in addressing the problem of groundwater contamination and subsequent human intrusion.

In response to the question, "What do you mean when you use the word 'issue'?", we indicated that "issue" can be thought of as something needing attention, something that poses an obstacle at the present time to the future accomplishment of an objective. If it is generally believed that a technical or non-technical concern does not represent a problem either because its solution is common knowledge or because it is considered trivial to the accomplishment of a program objective or in the making of a decision, then the item would not be considered to be "at issue" for purposes of the discussion.

The original nominal question was changed at the group's request to indicate that both groundwater contamination and human intrusion were potential events, not assumed to occur, as the original wording of the question implied.

Several participants wanted clarification of what we meant by an "analytic methodology." It was indicated that the word "methodology" should not be interpreted rigorously. It might take the form of a list of issues that each of our client "types" should address if he were to adequately respond to the potential problem of human intrusion of contaminated water resulting from the deep geologic disposal of high-level radioactive waste. What would the program

manager need to know, how could he find it out, who has the information or is responsible for obtaining it, and what strategy might he follow in light of these factors? A more extensive application of the process could result in a list of action options intended to facilitate decision making for resolving the issues. We indicated that we would attempt to address as many of these components of a methodology as possible, beginning with the development of a list of issues.

At this point, the moderator asked everyone to take 10 minutes to write a list of issues that responded to the nominal question. The following issues or needs were identified as being among those a program manager should consider in dealing with the potential human intrusion of an aquifer potentially contaminated by radioactive waste:

1. Demonstration of high quality modeling of waste/media interactions.
2. Assurance of accurate data and measurements at the disposal site.
3. Design of a retrieval system if disposal strategy fails.
4. Assurance that wastes get to the repository safely without contaminating the environment in route.
5. Need to define what the "scientific" community considers acceptable risk.
6. Does the contamination level exceed design standards over the design time frame?
7. What needs to be done to set design standards?
8. What criteria does the program manager use to identify an issue?
9. Determine the feasibility of preventing consequences at some time in the future.
10. Develop a monitoring protocol.

11. Determine the feasibility of actually taking actions to mitigate future consequences.
12. How will it be determined in the future that consequences have in fact occurred?
13. Is this important to know from the program manager's point of view?
14. Develop a discount rate for the future.
15. Do we really have a socially legitimate process to arrive at these decisions?
16. Will future consequences be reversible?
17. Do mechanisms exist today to make them more reversible if they occur?
18. What should be done today if they are not reversible?
19. Can we assure the non-existence of an underground aquifer in a specific site over long time periods?
20. Need to estimate probable isotope concentrations over time.
21. What is the likelihood of a well's being drilled over a contaminated aquifer over time?
22. What is the likelihood that such an event will result in social injury?
23. What are the leach rates associated with various geologic conditions and various waste forms?
24. Should ALARA be applied?
25. Should NEPA be applied?
26. During time of active repository use, how do we ensure institutional monitoring of the restricted area?
27. Can engineered markings be used to designate the burial site for long periods of time and, if so, should they be?
28. Can routine radiological monitoring of groundwater be institutionalized and assured to be a part of future societies?
29. How can we establish an "acceptable" risk?
30. How can this level be accepted by society?

31. Are risk indices appropriate indicators for geologic stability?
32. Is it possible to establish a design time frame?
33. What is the likelihood of a large-scale (commercial drilling) versus a small-scale (residential well) aquifer intrusion?

The issues represent a cross section of technical and non-technical concerns in no particular priority. Some are general concerns and others quite specific, some substantive and others procedural. In order to reduce the number of issues to a manageable size and to eliminate redundancy, we collapsed the 33 issues to 10 issue-areas. Some of the 33 issues appear in more than one of the issue-areas because of inherent overlap. The 10 issue-areas, followed by the numbers of the issues to which they relate, are listed below.

Issues concerned with:

1. Current Political and Institutional Factors (5, 6, 7, 8, 11, 13, 14, 15, 24, 25, 27, 29, 30): Involves a range of issues represented by attitudes towards nuclear power, institutional control for nuclear waste management, the politics of site selection, the need for a socially legitimate policy process, etc.
2. Physical Modeling (1, 7, 20, 21, 22, 23, 24): Involves all efforts to model the geohydrological characteristics of a site (generically or specifically) over time, the simulation of all aspects of nuclear waste management over time to determine feasible and desirable parameters, etc.
3. Establishment of Design Standards (1, 5, 6, 7, 11, 12, 13): Concerns the development of design standards that specify the engineering and site characteristics that would yield performances above some minimally acceptable level.
4. Determination of Acceptable Levels of Risk (5, 7, 14, 29, 30, 31, 32): Primarily the establishment of acceptable health risks associated with exposure to entombed radioactive waste, over time.

5. Site Characterization (2, 19, 21, 33): The need to fully characterize candidate sites and collect as much site data before and after selection, right up until entombment and capping of the site.
6. Post-entombment Monitoring (10, 12, 26, 28): The monitoring of a disposal site, once capped, by means of sensors and other devices to provide short and/or long-term indicators of the state of the disposed waste.
7. Contingency Planning and Hazard Mitigation (3, 11, 16, 17): The investigation of strategies to abandon or alter a disposal site if data gathered before capping suggest future problems. Includes strategies for retrievability of waste if desirable and feasible.
8. Engineering Feasibility (3, 9, 10, 11, 17): Includes information on engineered barriers, alteration of waste forms, waste packaging, and similar strategies that rely solely on technological processes.
9. Long-term Institutional Awareness (11, 16, 26, 27, 28): Involves strategies for making future societies aware of waste disposal sites and of mitigation measures available to them.
10. Pre-disposal Handling (4): Involves the entire waste management process before ultimate capping of a disposal site; waste generation, treatment, storage, transport to the disposal site, and management of the disposal site before capping.

With the exception of the last issue-area involving pre-disposal handling (which is outside the bounds of the nominal question), each issue-area consisted of four or more sub-issues. The assignment of sub-issues to each issue-area is a subjective process with arguments to be made for the inclusion of some and the deletion of others. Our primary concern, however, was whether the 10 issue-areas do justice to the range of sub-issues initially generated. We will focus on these 10 issue-areas from this point forward.

After some discussion and minimal reclusterings, the group did acknowledge the list of 10 issue-areas as being a fair cross section of the range of concerns raised in the initial round-robin exercise.

If we were to array these 10 issue-areas on a scale from concerns exclusively in the physical science or technical areas to those that are exclusively social science or non-technical in nature, the following might result.

On the non-technical extreme are the political and institutional factors associated with nuclear waste management that undoubtedly affect the strategies for dealing with human intrusion of contaminated groundwater as characterized in our nominal question. Components of this issue include the politics of institutional responsibility for nuclear waste management, the politics of site selection, the tradeoff between nuclear energy and other forms of energy, the public's perception of recommendations from the scientific community, the development of a socially acceptable waste management policy process, and

similar concerns. At the other extreme are the more specific and more technical issues associated with the design, construction and operation of a geologic repository system to isolate effectively the nuclear wastes. Near the middle of the scale would be located the contingency planning to minimize future costs/risks should new knowledge or circumstances emerge.

Again, the exact position of each of the issue-areas on the technical/non-technical spectrum is not as significant as the relative position of each to the other. The important point is that the issue-areas represent a range of issue types from the largely non-technical to the largely technical. This may help explain the priorities later assigned to the issues by the interdisciplinary group. It would be of little value to associate an issue-area with the participant who first identified it because: 1) the issue-areas are aggregations of sub-issues and, as such, the issue-areas are not directly generated by the participants, and 2) as soon as a sub-issue was volunteered by a participant, the other participants who might have listed it deleted it to avoid redundancy. Hence, we don't know how many people might have initially listed each sub-issue.

However, the ranking of the 10 issues did give us a sense of group consensus and priorities. Participants expressed concern that issue-area #1, current political and institutional factors, was not comparable to the rest, and hence, could not be rated with them. The other nine were viewed as somewhat technical, while the first was exclusively non-technical in nature. It was agreed that #1 would be deleted for the ranking exercise and would be handled later.

Table 1 shows the ratings given to each issue by each participant with a total score for each issue then converted to a ranking. The issues appear in descending order with respect to their rank. The respondents are identified by their professional discipline; the political scientists and engineers are distinguished by number.

The highest priority is given to "the determination of acceptable levels of risk," "the establishment of design standards," "physical modeling efforts," and "site characterization." None of these issues received a score of less than three, with the average score exceeding four in each case. A score of three appears six times, but the six "threes" are spread over five of the participants.

"Contingency planning" and "engineered barriers" were ranked as moderately important issues that would have to be addressed by the program manager, while "post-entombment monitoring," "issues involving long-term institutional controls," and problems involved with "pre-disposal handling" all ranked relatively low.

There were only three issues within which the high and low ratings differed by more than three. These are "contingency planning," "engineered barriers," and "pre-disposal handling," and in each case the deviant rating belongs to a different participant. The three scores referred to here are circled on the table.

It should be remembered in the discussion that follows that "site characterization" includes data collection at the site once it has been selected, as well as characterization of candidate sites. The issue of "engineered

barriers" includes waste packaging, waste treatment and form, and engineered barriers at the disposal site to contain the radioactive wastes during disposal management and following depository decommissioning and closure.

There is little disagreement among the participants that four issue-areas represent the issues of top priority in addressing groundwater contamination and its release to the biosphere via human intrusion. The priority issues are 1) the need for modeling, 2) the establishment of design standards, 3) the determination of acceptable levels of risk, and 4) the collection of data for site characterization.

TABLE 1
RANKING OF ISSUE-AREAS - FIRST ROUND

ISSUE-AREA	POLITICAL SCIENTIST 1	POLITICAL SCIENTIST 2	GEOLOGIST	ENGINEER 1	ENGINEER 2	ENGINEER 3	TOTAL	RANK
Current political/institutional factors	N o t R a n k e d							
Determination of acceptable levels of risk	3	5	5	5	5	4	27	High
Physical modeling	5	5	3	4	3	5	25	High
Establishment of design standards	3	4	5	5	5	3	25	High
Site characterization	5	3	4	4	4	5	25	High
Contingency planning	4	4	2	3	3	①	17	Med
Engineered barriers	3	3	④	1	1	2	14	Med
Post-entombment monitoring	2	2	2	2	1	2	11	Low
Long-term institutional awareness and control	1	1	3	1	2	3	11	Low
Pre-disposal handling (pre-capping)	④	2	1	1	2	1	11	Low

3.3 DISCUSSION OF THE ISSUES

Following the initial ranking, the participants conducted an extensive discussion of each issue. The purpose of this discussion was to reach a consensus on the formulation of the issues and the definition of terms, identify factors requiring further discussion or analysis in order to come to grips with the nominal question, and to bring to light significant differences in perspective between the various disciplines represented by the participants. As the transcripts of the discussion indicate, considerable time was spent in wrestling with the nature of the data available, the responsibility for setting risk levels, the need to establish design standards, and the assumptions about future events. The roles, the assumptions, and the priorities are clearly open to debate, but the process, in its most elemental form, will have to be traversed. And, as the discussion indicates, the manner in which it is done will have a lot to say about the legitimacy of the ultimate decisions in the eyes of the public.

3.3.1 The Need for Risk Levels and Design Standards--A Chicken-and-Egg Question

The engineers and the geologist generally feel that the biggest need is the establishment of design standards based on some acceptable level of risk. Once established, this would provide policy makers with the cost of meeting the standard and break the log jam of indecision currently keeping waste management engineers from proceeding with a chosen design. The physical scientists feel that establishing acceptable levels of risk is

the domain of the social scientists who are responsible for interpreting social values and preferences as expressed in the political, social, and economic arenas. The engineers would then design to satisfy those preferences.

The social scientists see the problem somewhat differently. First, they feel that the community of scientists must share in the tough process of setting acceptable risk levels. But they question whether we really have the data to sufficiently describe the relationship between radioactivity and human health. There was fundamental disagreement on this point.

Secondly, there was general concern that the risks associated with isolated events in nuclear waste management are so small as to be meaningless individually. It is only when you aggregate the risks associated with numerous individual mishaps and spread these sums over thousands of years that you arrive at significant probabilities. And it is misleading to discuss probabilities without attaching some level of confidence to them. The following dialogue is intended to highlight the group's concerns regarding the four top priority concerns facing the program manager in dealing with the nominal question. The discussion brings to light some of the fundamental issues and concerns facing the entire area of nuclear development, concerns that transcend the particulars of the nominal question. Abbreviations in the dialogue refer to the following: POLSCI = political scientist; GEO = geologist; ENG = engineer; and MOD = moderator. There are two political scientists and three engineers.

3.3.2 Public Perception of Risk

MOD: Earlier we mentioned the need to put nuclear risks and probabilities in perspective with other risks more familiar to society.

POLSCI 1: I don't know *why* you have to do this; it implies that because other things are risky you should accept this risk.

ENG 2: You need a frame of reference and that's all comparative risks are for. You may have to give many dimensions to it but you have to communicate it in some way.

ENG 3: You can for yourself. But you can't then assume other people attribute similar meaning...particularly in areas where you have different understandings of the value of life. You can't say that because there are risks over here they are somehow equivalent....

GEO: Let me give you an example. I want to put a repository somewhere in the Colorado plateau. The Colorado plateau apparently has not been cut up by faulting; it's been a stable block for a hundred million years. Who has any idea what's going to happen to that block in the next hundred to two hundred million years? Furthermore, I live in California. I'm about four miles from the San Andreas fault; the place is full of faults, but there's no fault under my house. If the Colorado plateau turns into another California, who could predict where the fault might occur when we're looking at an area of 500 miles. Yet, they put numbers on it. The numbers are things like ten to the minus eight, which is a small number, but as long as it's greater than zero, it can raise a concern in the mind of the average individual.

MOD: I think the scientific community has overestimated the public's ability to perceive risk, to understand very very large or very very small numbers. I think what we've been touching on is how you communicate to the public what the risk is and I think that so far the scientific community hasn't really attacked that communication-of-the-risk problem.

POLSCI 1: It may just be the reverse--that the public knows what the risks are.

MOD: And they're fearful?

POLSCI 1: Yes, and they're responding in ways that they'd respond no matter what you told them. As far as the information we have from agencies that have tried to involve the public in the real activities that they're undergoing, that seems the most likely outcome.

ENG 3: I don't believe that at all. I recently interacted with a reporter, a person who's in charge of relaying nuclear things, and she said, "Simply tell me if it's safe. I don't want to hear any of these-ten-to-the-minus numbers. I need to tell these people is it safe or isn't it safe." This person personifies the problem.

POLSCI 1: But she doesn't personify to me who it's being communicated to. She doesn't have a problem of hearing the information but of telling it and she needs to know from you to simplify her job.

ENG 3: My perception is that we are just beginning to communicate risks in our society and that very few people have the ability to handle this issue and it's going to be many years before the public can deal with the problem.

3.3.3 Setting an Acceptable Risk Level--Whose Responsibility?

MOD: I think that the feeling is that as far as social modeling goes we can't really say much and if we try to dignify that modeling with sophistication beyond what it warrants it probably discredits the people who have modeled it. As far as physical modeling goes, we're talking about it as a means to establish probabilities....

ENG 2: As I understand it, physical modeling is a means to establish risk potential, which involves probability and physical modeling to determine the system. If you go through the site characterization well enough, then you almost eliminate the problem of modeling the physical system. How do you have faith in that probability number?

ENG 3: Let's get back to the nominal question again. Let's zero in on this question of groundwater intrusion. How well can we estimate the probability of groundwater intruding into the repository or potentially leaching the waste given a detailed characterization of the site?

GEO: We've got a physical system and we've got the technology. The problem is getting the parameters and at the very least you can assume certain conservative parameters and you can grind through your model and it may turn out that if you put conservative parameters on you're way out of the ballpark. Or it may turn out that if you put reasonable parameters on you're in the danger zone. Or it may turn out that it's intermediate and you really have to pin down the parameters. But there we're not talking about probabilities. There you're talking about a deterministic physical system for which we have some technology if we could get the numbers.

ENG 3: You can put it in terms of probability but I'm not going to belabor that point. One way is a deterministic estimate of the length of time before you're going to get flooding of that repository.

GEO: If you give me the parameters, I could compute that.

MOD: Can you be given the parameters?

GEO: I can give you the parameters for a wide range of materials. I can give you parameters within certain limits, but it's going to fall within certain limits. But, the hooker is that someone says what if a fault goes through the site, then what happens? Okay, that's going to change everything.

ENG 3: With respect to the climate changes, that's a ten thousand or twenty thousand year time frame.

GEO: Okay, if you're talking about a small time frame, we can compute it under the present climate. If you're talking about a longer time frame, then we have to compute it under other climates.

ENG 2: We build nuclear power plants and the question can always come up, can a new fault all of a sudden rear its head at this particular site? It can, but I think that the general consensus of the technical community is that the probability of that is so low that it's not a concern.

ENG 3: Well, what happens when they get you on the witness stand and you are asked whether a new fault can appear at this site? You're going to have to say yes. And when you do, a new scenario has been born.

ENG 2: But the question is much more significant for power reactors than it is for a repository.

ENG 3: Is it? For a power reactor a geologist might attempt to say that it's impossible within thirty to forty years.

GEO: But it can happen. The earth can be destroyed by being hit by a big enough meteor.

ENG 2: It's been testified time and time again that there is no reason to believe that a new fault is going to appear at this location.

ENG 3: But it can. And perhaps society will judge that within the lifetime of a nuclear power plant, which is forty years, that it is not going to happen. But here we're dealing with a time frame that's 5000 times as long.

MOD: Let's go on to the next area, which came from points raised this morning, and that is the issue of establishing design standards. In part, that's going to be influenced by modeling results. But also it seems from your comments this morning that it is almost imperative for pursuing any sort of site construction that those standards be clarified, be accepted, and be acted upon.

GEO: We'll give alternatives if you suggest it.

ENG 1: Look at that ranking of issues. What the engineers here are saying is, give me something to work with, a framework.

ENG 2: This program manager who has to implement a strategy to do something about this aquifer is saying, give me the framework within which I'm to work. Can you get that framework before you determine acceptable levels of risk?

MOD: No, my feeling is that you've got to determine acceptable levels of risk first and establish design standards to perform to those levels.

POLSCI 1: I really disagree with that sequencing. There's a sort of uncertainty principle going on here that says give me design parameters before you know what the consequences of actually carrying the design out will be. The social science crowd and representatives of the public who are interested in this are saying, how do you expect us to give you a design from one single point, either risk levels or design standards? We don't know what the consequences of carrying these out will be.

POLSCI 2: It's the chicken and egg problem. What you're really saying makes it deterministic.

POLSCI 1: All along here the engineers are saying, give us these nice clean parameters, we'll design to it without any information about cost and without any information about a lot of other things that go along.

POLSCI 2: Again, the process must emphasize feedback, otherwise it becomes deterministic.

POLSCI 1: But, you see, you're asking the non-technical person to do something he simply cannot do. And that is to get inside your heads to know what alternatives are possible.

ENG 2: Give us an acceptable risk level first. I think you have to. There's some way to define acceptable risk. If you can't define acceptable risk, what do people do with the consequences? How do they judge whether that consequence is acceptable or not?

POLSCI 1: I'd like to have bands of consequences so that you go from some normally agreed upon level of risk that you could attain and double it and triple it and then go back and show me four different design configurations, cost requirements, accident rates, etc., and let me see what the implications are for these alternatives if they were implemented, particularly on a large scale.

ENG 3: I'm having trouble seeing this. I don't see that the development of design standards (#3) is anything more than a bridge between the need for modeling (#2) and the determination of an acceptable level of risk (#4). The design contamination level is the output, if you will, of one or more of the scenarios that may exceed allowable design standards and that is based upon the acceptable level of risk.

GEO: Number 3 and number 4 go together, there's no question.

POLSCI 2: But I can see a distinction between the modeling and acceptable levels of risk. These are different processes. But I don't see number 3 as a distinct issue area.

GEO: Wait a minute. Everybody's not talking at odds here. We're really in the same ballpark. Here's a guy who is faced with the job of designing a repository. Now, what should be built into it? He's got the feeling that he could put some front-end packaging that'll be good for 500 years and nothing

will move for 500 years, and then he's got the feeling that this shale is going to hold it for another 1000 years and after that it's going to leak a certain amount. Is that good enough? That's his question. Or should he put something else in? Or should he go to another site? That's the kind of thing he needs to know to begin to select sites. So, he goes to a social scientist and he says, tell me if that's acceptable, right? And you say, well I can't tell you if it's acceptable until I see the cost and some alternatives. As was said earlier, the only way to do this is with some iterations. Someone's got to say, here are some reasonable possibilities: now go find a site and design something for that and tell us the cost. But no one is even doing that.

The social scientists resist accepting the responsibility for recommending an acceptable risk level over time; they claim they need additional information regarding the likely costs associated with alternative levels. They reject a deterministic solution, though such an approach simplifies the task for the engineer by providing a single point around which a system can be designed. Underlying the discussion of determinism versus iteration is the general concern of the public's perception of risk. The participants generally feel that probabilities, around which risks are based, may be misinterpreted by people not familiar with their meaning and ultimately create a much higher degree of public concern than may be warranted. This is compounded by the tendency for policy makers to adopt extremely conservative future scenarios where the likelihood of error is often assumed to be unity beyond some point in time. As a result, waste management policy makers face a compound problem regarding the public perception of probabilities. Small, unlikely events create anxiety in spite

of their unlikeliness, and the practice of assuming the worst tends to reinforce society's latent suspicions.

The debate underscores the need for feedback or an iterative process between risk analysis and setting design standards. Only in this way can the social scientist be made aware of the alternatives available and the range of costs and risks, as well as the uncertainties inherent in the analytical methods. This process also allows for the incorporation of public participation in arriving at the acceptable levels of risk.

The engineer is accustomed to aiming toward a "point design," based on a fixed standard. He forgets, however, that the establishment of many of the standards given in his design manuals are based on trials and errors cloaked in a history of mishaps. Whereas we could live with minor mishaps in the design of toasters and engines, or even bridges and highways, we simply do not have the luxury to empirically revise design standards for a deep geologic radioactive waste repository.

3.3.4 When Do We Stop Worrying?

Bound up with the information needed to establish acceptable levels of risk is the value or moral judgment involved. The following discussion regarding the establishment of a time frame beyond which we will no longer be concerned with emission reflects one example of value judgments and the information required to make them.

MOD: Without putting numbers or values in, we keep talking about the standard. How would you phrase the standards;...what pieces of information do you need?

GEO: First of all, the time frame. You can't begin without consideration of the time frame.

MOD: Emissions per time period.

GEO: Right. And over what period you're concerned. You know, it's really a moral question whether we're concerned over a million years, a thousand years, or what. By answering that question the thing could be simplified tenfold. Let me give you a couple of numbers. If your time frame, for example, is a thousand years at Hanford, they could leave it on the surface and it's going to cost us less than a billion dollars. If the time frame is a hundred thousand or a million years, they've got to put it down deep and it's going to cost ten billion or fifty billion dollars. No one is giving them that piece of information. So they're doing both.

POLSCI 1: Let's think about this for a minute. What information would you need to have to resolve that uncertainty? What else would you want to know that's not now known that would allow you to say with some confidence that you were doing a sensible thing?

ENG 2: I want to be able to build the facility and put waste in it.

POLSCI 1: No, just answer that time question. What you're saying is somebody else make a moral decision for me and I'll go ahead.

POLSCI 2: But do you know anybody in this country who's going to say we are going to stop worrying about future generations in X years?

POLSCI 1: Is there some knowledge that, if you had it, you wouldn't have to worry for more than a thousand years. What kind of information would that be?

ENG 2: Release rates to the biosphere as a function of time.

POLSCI 1: What would that tell you? How would that help you choose between a thousand and a hundred thousand?

ENG 2: As a function of time how much can leak in the first thousand years, how much can leak in the next ten thousand, how much can leak in the next...

POLSCI 1: When does he stop worrying about that?

ENG 2: They may say you have to carry this on forever.

POLSCI 1: I'm asking you all, what information would you need to have to stop at a thousand years---we'd quit worrying about the future after a thousand years knowing what we do about the toxicity of this material.

ENG 2: You have to have answers well beyond a thousand years and you have to know its impact on future generations.

GEO: No, that's not the question. If someone could say, the hell with everything past a thousand years, I don't care what happens, then they leave it there and engineer it and it's 500 million dollars. But if someone says, no, we've got to worry for ten thousand years and we have an obligation, then it's very simple if they put it deep. I can make that decision right now.

ENG 2: I think we have to worry beyond a thousand years.

POLSCI 1: I'm asking you a different question. I'm asking you to step outside your skins as technologists for a second and put yourselves in the position of the person you're asking to make that decision. Then say, since you're all scientists here and you care about knowledge and you need some more information than you have now that will allow you to say we can quit worrying about it after a thousand years. Given what you know about the characteristics of this stuff, what would you want to know that would allow you to say a thousand years?

ENG 2: I would want to know what is the potential impact on the population beyond a thousand years.

POLSCI 1: What kind of impact? Any impact? On friendships?

ENG 2: No, on their health and safety.

POLSCI 1: What kind of health and safety?

ENG 2: The exposure that they are likely to receive, the radiation exposure.

POLSCI 1: And what if it just gave them more cancer? What difference does that make? We do that now.

ENG 2: I would want to look at the risk that they would be subjected to in comparison with something. I'd have to look at some other risk form out there. Maybe it's natural background. Maybe I'm going to limit this to a small percentage of natural background.

POLSCI 2: I don't think that's going to be the thing that will make that determination. You may have a better sense of the consequences at various points in time but it's not going to tell you whether you should worry about those consequences at any greater or lesser level.

ENG 2: You have to make a decision.

It became apparent that the arbitrary establishment of a time frame beyond which we will no longer be concerned is a fruitless discussion providing little assistance to the program manager. If such a decision were to be made, it would have to be based on a careful assessment of the risks over time and the comparison of these risks against some standards or acceptable levels. This was the point of entry into the discussion of time frames.

3.3.5 Technical Credibility and Society--The Need for a Legitimate Decision Process

The concern over who should take the responsibility for making the decisions, which inherently involve moral, technical, and political considerations, eventually focused on the increasing distrust of technologists by the public. How can the scientific community recover some of its lost credibility, and how will this facilitate greater collaboration between the physical scientist, social scientist, and the public?

POLSCI 1: What can the technical agencies do to help recover the credibility they used to have? How do you assure that the technical agencies answer the kinds of questions, however stupid they may appear to be, from people outside the federal community who are concerned and who make it their business to ask questions? What conditions must the technical community meet to recover that legitimacy?

ENG 2: Or is the lack of credibility inherent in a technical community or in a bureaucracy?

POLSCI 1: Oh no. Of course not. This is a very new phenomenon.

GEO: I think we've identified the problem here. We've spent a lot of time arguing that the technologist can't answer the question without the decision makers giving them certain standards. You folks said you can't give those standards without information from us. Let's not argue that. How do we break into that cycle?

MOD: As social scientists we want the security of choice and as an engineer you want the security of specificity.

ENG 1: Is it possible that we have an iterative process that has to take place that maybe hasn't been done before?

POLSCI 1: What might we suggest be done to help recover some credibility? That's really what it means to have a legitimate system.

POLSCI 2: I guess I'm not persuaded by the line of reasoning that you laid out that if only the technologist had the standards, however derived, they could do a better job.

GEO: And plan the go ahead on the right questions.

POLSCI 2: Well, that's only part of doing a better job, I think. I guess I don't see in my experience that the fundamental problem of doing the job has been the lack of standards because, again in my experience, I've seen people proceeding as if they could set the standards themselves and act upon that basis without the standards being given to them. I really don't see that as a critical problem in terms of the effectiveness of the operation. I just don't see that as the critical problem.

ENG 2: The critical problem for you is the nuclear power plant.

POLSCI 2: Well, the kinds of things I think you're talking about are not the sorts of things that I think the geologist is trying to argue. It seems to me the problem of the difficulties in getting on with the job, doing a competent job, stems less from the lack of standards than from other factors.

GEO: Could you tell us quickly what the other factors are?

POLSCI 2: Well, I think part of it has been a faith that has been very much a part of the American system that technology can solve things automatically, that once the technologists are given a free hand they can solve virtually any problem; a sense of technological virtuosity. That's had something to do with it. I think the fact that nuclear waste is at the end of the fuel cycle has something to do with it: When you develop the nuclear power system you deal for very rational reasons with the front end and the reactor as a more pressing problem than waste management. We all know the kind of low priority waste management has received until very recently. I don't think any of these factors, which I see as major problems in getting the job done properly, have anything to do with the fact that there has been lack of design standards.

ENG 1: Who usually takes the initiative in technological development?

ENG 3: The technologist.

POLSCI 1: Where's the guy who has the basic information with regard to design possibilities? The one who, in the past, has chosen to look at those design alternatives in shop, provide the one answer the outside world in the past had been comfortable with, but in the recent past has questioned? This change has occurred in part because in the earlier days the engineering community simply presumed that they were representative and their social criteria, implicit though they were, were adequate for everybody else and that's no longer true. Or it can't be held to be that way automatically. The technical community is essentially being pushed to provide the range of their thinking well in advance of what it used to be. That is to say, earlier on in the consideration of their alternatives. They're also being asked to include additional criteria in the characteristics of the design.

MOD: How do those additional demands change their method of operation ...are we talking about a significant departure from the way they had been doing business?

POLSCI 1: No. It doesn't change their process. Except to add criteria that they usually don't take into consideration when they design things. I think it's a tougher design job because it's hard to take technical criteria and then economic criteria and other sorts of criteria when you aren't sure how to act them out in a design process. That's what's happening. You now have to add health criteria, economic criteria, and the like to purely technical criteria. Increasingly you have a set of criteria that have to do with the long-term consequences of things and that's much more difficult from the design point of view--to know enough to meet design criteria. There are several other criteria we would think of in terms of the pre-disposal state that I would think will make a difference in the operation of the system and its design. These are social and political criteria. Insofar as that changes the basic processes of engineering or engineering design, then I guess I would have to change my answer. I don't know that it does. It just makes it more difficult because we have multiple criteria.

MOD: I think it's compounded somewhat by the fact that to some extent the additional criteria are not the domain per se of the engineer and technician. The scientist may now realize the need to incorporate them but can't generate them. In other words, they really have to come from outside. How do the outside contributors of those additional criteria get brought into the process? I think a very important point was raised yesterday. There may indeed be a lot of activities that would be unnecessary, a lot of data that might not have to be collected if there were a basis by which some target or range of targets could be developed. In other words, you don't have to make this pyramid effort of comprehensiveness at the bottom level and then moving up into something that's going to take the scientific community, with whatever assistance they get, a hundred years to get the answer. There are shortcuts that could be made but someone has to take the responsibilities for putting forth those strawmen.

GEO: Right. And you know there are a lot of people who really think it's going to be pretty easy to find the right formation and engineer it to meet any set of reasonable standards. Maybe they're right.

The group agreed that the credibility of the technical community vis-à-vis the public has suffered and that continued erosion will invariably complicate the task of adopting and implementing a waste disposal strategy with legitimacy and broad-based support. The political scientists are suggesting that the boundary around the "technical arena" has been greatly enlarged in recent years. This has been witnessed in many areas, from decisions not to pursue the space race to a pull-back of federal support to develop the supersonic transport. The commitment of massive resources to many technological pursuits, by government at least, is being more thoroughly evaluated in terms of alternative uses for those resources.

The area of nuclear waste management introduces even more compelling reasons why the program manager must involve a broad base of interests and perspectives before he is able to resolve an issue. If the design standards must ultimately reflect multiple criteria, then the varied sources of information needed to develop these criteria must be incorporated in the overall process that leads to the development of alternative design standards and the eventual adoption of the best one. In many respects, the interdisciplinary effort to incorporate a far wider range of issues and attendant criteria will necessitate more and varied information; conversion of this information into a feasible and justifiable design standard for a given disposal site will prove difficult, if for no other reason than it is difficult to translate multi-dimensional criteria into uni-dimensional design standards.

In some respects the social scientists are suggesting that, before the technical community's credibility is reestablished, enlarged technical input and multiple criteria must become part of the process. Otherwise, the intervenors in the process will continue to be successful in convincing large numbers of the public that they should be suspicious of the present process. The need to create an environment of acceptance was viewed as important by all the participants. Why it is lacking was not as clear. The following dialogue focuses on the need to develop credibility through the NEPA process.

ENG 2: So you've got to create an environment for acceptance. I think that doesn't exist now.

POLSCI 1: Where? I mean how do you decide where you're going to go to create the environment for acceptance?

ENG 2: Oh, I think you do it in a number of different ways. You may be able to add some direct incentives to the state, but over and above that I think you have to develop credibility within the government. Secondly, I think you have to clearly define what constraints, i.e., consequence, of this repository that you're going to operate within. And that gets back to acceptable levels of risk and maybe some peripheral things. But I think you have to state at the onset that here are the things that we're going to stay within and we're not going to exceed these. So now the people have some idea of what type of thing they're being confronted with. Right now it's open ended. You hear all of these concerns expressed.

POLSCI 1: That's the way it has been done in the past--just like that with a number of what were essentially promises in a technical area that said, this is what the future will be like. The public or the region had said, right, that's the thing, go ahead--only to find ten years later that those promises hadn't been realized.

ENG 2: That's why I said credibility is a very important part of this.

POLSCI 1: First of all, when presented with a specification, local communities have not usually been drawn into the approval process. It's been a kind of plebiscite--this or nothing. Here's what it is, we're going to do it, it's sort of the one best way. They aren't so sure they know how to evaluate it. In the past they have said, we don't know how to evaluate that; we trust you; go ahead and do it and we believe what you say about the future. Recently that confidence has been shaken.

ENG 3: You're saying that EPA over the past eight years has not contributed anything to...

POLSCI 1: Oh, certainly it has. It's contributed two things. First it's contributed to the lack of confidence. Not because of EPA, but because of what EPA has uncovered--uncovered bad analysis, uncovered hasty analysis, uncovered some very biased analysis. So that it wasn't analysis but was support to a prior conclusion. In other cases it provided enough information for intervenors to pull back and become satisfied. But look at the enormous political energy that has been required from outsiders.

POLSCI 2: But, it seems to me that the technical community has a stake in doing a credible and good job on things like environmental impact statements. In the nuclear area both you and I could point to things as examples where the things that have been turned out have been, from a technical standpoint, really not very good. They have been clearly distorted to make a point that the agency wants. Perhaps the decision to write the EIS in that fashion came down from the agency and was imposed upon the technical people. It seems like technical people have as much of a stake in making sure that these kinds of documents are technically credible, technically legitimate as the intervenors do. A number of times when the intervenors have challenged these documents on the grounds that they were technically illegitimate, technically bad pieces of work, something the people should not be particularly happy with, all they got was flack. All they got was told they're trying to disrupt progress. So the issue gets translated from the issue of doing a good technical job to one of merely value conflict. You disagree with my priorities and I disagree with your priorities. In that kind of a situation the whole process becomes terribly distorted and it's simply a conflict over whose values are better. That's really not what the process is meant to be.

ENG 3: Without a question the nuclear EIS's that have turned out over the entire eight-year period have been one order of magnitude better, technically, than EIS's in almost any other area that I have seen.

POLSCI 2: I guess the point is that if you're talking about credibility, I think there's really a common ground where the technicians and environmentalists, as opposed to the agency bureaucrats who have a political stake in particular projects, can stand and that is trying to obtain the best kind of credible, technically competent pieces of analysis. I think that's something.

ENG 2: There is no feeling in the technical community of not trying to present factually complete and thorough information. Sometimes, because of the framework in which these things are prepared, a poor result comes out. There can be time constraints, there can be lack of understanding of what is really required. But, generally I think the technical community is really trying to do a very thorough, complete analysis.

POLSCI 1: I don't think we are challenging the sincerity of the effort.

POLSCI 2: But what I'm suggesting is I know personally of cases where orders have come down from agencies about the type of content that should be and should not be included in the analysis. Now, what is included and what is not included obviously has a profound impact on the quality of the analysis. If issues are simply defined out of existence by bureaucratic fiat, then the quality of the effort is going to suffer. So I think technicians and environmentalists or intervenors in general have a common stake to ensure that any agency seeking to advance its political objectives through analysis be rebuffed. I think there really is a common ground between the two of you in most cases.

POLSCI 1: At the outset we all felt that we needed a socially legitimate process to arrive at decisions. The answer is that it's variously legitimate at the present time and I guess what I'm hearing is the question, how might the technical community behave to increase that legitimacy?

The social scientists articulated the general frustration with the NEPA process over its short history in honestly portraying the decision-making process within federal agencies. This has been reflected by a recent CEQ-proposed rulemaking* in which considerable attention is given to the candid treatment of alternatives in the EIS. The waste management program manager, regardless of his specific mission, ultimately will be faced with the preparation of an Environmental Report or Statement that explains and supports his decisions. It would behoove him, therefore, in this particularly sensitive field, to lay out the decision-making process in an open and objective fashion, and to support his decisions with credible analysis.

3.3.6 The Forcing Function--Who Establishes the Timetable and on What Is It Based?

Credible scientific findings require full disclosure by the scientific community, a process that appears handicapped in nuclear waste disposal

*"Proposed Regulations for Implementing Procedural Provisions, Council on Environmental Quality," Federal Register, Vol. 43, No. 112, June 9, 1978.

for three reasons. First, as we noted, much of the probabilistic information is prone to misinterpretation by the public. This results in confusing feedback being given the technical community. Second, the engineering community does not generally see the need to substantiate and verify those aspects of nuclear waste disposal that they believe to be trivial or unknown, but non-technicians, on the other hand, treat these issues with doubt and even skepticism. Third, the technical community and those currently charged with the responsibility to develop a nuclear waste disposal strategy feel the need to forge ahead because of a fear that the nuclear industry will collapse if a solution to the high-level waste disposal problem is not resolved soon.

Referred to in our discussions as the "forcing function," this philosophy tends to discourage extensive exploration into areas that might be technically justifiable but viewed by some as efforts to sidetrack the mission and eventually derail our nuclear energy program. This forcing function affects the legitimacy of the decision-making process in the eyes of the nontechnical community by raising an issue whose urgency may not be justified and then using it to shortcut more careful, deliberate, and comprehensive research, development and demonstration efforts. And, in the eyes of the technical community, efforts to broaden the line of inquiry and question findings which have already been accepted are suspect.

A reference to the role this forcing function plays in influencing strategies and policies was reflected in a discussion on site characterization generally, and the WIPP site specifically. This is another dimension to the problem of establishing the credibility of the technical and, most importantly, the governmental sector.

ENG 1: You all gave one of the highest rankings to site characterization, which will result in throwing out some sites because they can't satisfy this nominal question.

POLSCI 2: Let me comment on site selection, though you probably will have strong feelings about what I am about to say. Let's look at the role that NEPA can play and I'll use, as an example, WIPP because it points out some of the problems with the way agencies have used WIPP. The law under NEPA requires that reasonable alternatives to the proposed project be assessed and, despite this very clear mandate in the law, the WIPP project has proceeded on the basis that the only real site was going to be the one at Carlsbad. Several other alternatives were examined in the WIPP EIS, including just leaving it in Idaho. But, clearly, the decision makers had decided before the EIS was written that, for all their public disavowal, WIPP is going to be sited in Carlsbad unless something really unforeseen comes up in terms of the technical suitability of the site. What they have done is to say, why waste money and effort to look at alternative sites for this initial project? That has now been recognized by the Department of Energy as a very ill-conceived approach, politically. And I would argue legally, as well.

ENG 2: But not technically.

POLSCI 2: That's right.

POLSCI 1: But we don't even know that.

ENG 2: I think we do. I think we do.

POLSCI 2: But to me that is a narrow focus. I mean NEPA imposes certain legal requirements on agency action that are important and it imposes certain analytical requirements on agency action that are also important. As long as the NEPA process is used in a very constrained and narrow fashion it's not going to be very satisfactory in providing credibility. I would argue that if the people in the WIPP project have in fact looked at a variety of sites, maybe all of New Mexico, maybe some in the Salina Basin and elsewhere, and then concluded that WIPP was a good site, that the Carlsbad location is a good site, then their ability to obtain a socially legitimate decision would have been enhanced.

MOD: So you're saying that there at least has been a double standard in the analytic rigor that was used.

POLSCI 2: Well, one could argue that there's been an attempt, if not to skirt the law, then to not live up to its spirit.

ENG 2: Yes, but I have a problem in always looking for the best site and that is what NEPA tends to try to do.

POLSCI 2: It doesn't say the best site.

ENG 2: Well, but that's implied--you look at the alternatives and select the best one.

POLSCI 2: No, you assess what the alternatives are and you may select one that is not environmentally the best, but it has other characteristics. But what NEPA really is is a full-disclosure act, the truth-in-advertising act.

ENG 2: I think a lot of the reasons for DOE's push to proceed with that repository in New Mexico are not the types of things that are going to come out in an environmental impact statement.

ENG 1: They think that they need a demonstration that will....

GEO: They want an event.

ENG 2: First of all, they want to proceed in the very near future. And to do that they need a site where there is a lot of information. Now, if we could go back several years I think it could have been done differently. But looking at it today and the dilemma facing DOE, the site looks extremely acceptable. It's a good site. As far as we can tell today, technically it's an extremely good site. Secondly, the information for the site is sufficiently developed that we could proceed rather quickly towards development of that site as a waste repository. I think the urgency of proceeding by the government in this regard is viewed as something very important because of the nuclear energy situation. Consequently, to spend time in evaluating a large number of sites when this site, from the technical standpoint, appears to be excellent, is not justifiable.

POLSCI 1: What you're saying, then, is let's get a demonstration site and if we get that demonstration site we can continue to build nuclear reactors.

ENG 2: That's true--I believe that's true.

POLSCI 1: I don't. I don't think a demonstration site is going to tell you very much about the 18 sites you'll eventually need if you commit yourself to a waste processing system that's required by 600 nuclear reactors in this country.

ENG 2: It's a matter of public perception.

POLSCI 1: No it's not. It's a matter of analytical parallel between what you can do on a small-scale level and what you do on a large-scale level.

ENG 2: WIPP is really not a demonstration that we know how to dispose of waste. I think we know how to dispose of waste.

POLSCI 1: I don't. I'm not convinced that that's true.

ENG 2: I'm convinced; you're not convinced. You see that's exactly the problem that we have, I believe. The technical community is convinced. Most of the people I've talked to are convinced that we can safely dispose of nuclear waste. The public and the non-technical community, on the other hand are not convinced. How do you convince those people?

POLSCI 1: You can convince me by answering a whole lot of questions that never even came up today that have to do with the total system involved and its performance when you're dealing with a fully deployed nuclear economy, because that's what we're buying into if we accept your logic and the public accepts your logic. To buy WIPP is to buy the whole package, and I don't think....

ENG 2: No, not necessarily. It's not an irreversible process.

POLSCI 1: Well, then, show me what the strategies for reversibility are and that they have been considered as carefully as the promotion of the project itself.

ENG 2: Well, WIPP will be reversible for the next 25 years.

POLSCI 1: Well, then, maybe we should wait for 25 years before we say it's okay.

ENG 2: I mean WIPP is reversible. In other words, if we changed our minds over the next 25 years, we could remove all of the waste from WIPP and go back to something else.

POLSCI 1: But look at what you just said. You don't really mean that we're likely to, but the public understands that you do. The public understands that you do when you say it like that.

ENG 2: Well, I'm fully convinced that we're correct and that there would be no reason that I could conceive of that we would remove that waste. It's a concession only to the people who are opposed to going ahead with the facility. And I think it's a poor concession. To me it shows lack of confidence in what we're doing and I see no technical justification for it. I think we've got to solve the waste problem. As I perceive WIPP, it's primarily a way to start moving in a direction where, if it's properly handled, we can add to our ability to solve the problem.

3.3.7 Retrievability and Contingency Planning--The Desire for Incremental Decision Making

Perhaps the most unique aspect of disposing of high-level radioactive waste is the finality associated with the decision to seal up a repository; the prospects are that the consequences of that decision will then be out of man's hands to influence in the short run as well as the long run. Even if

monitoring devices indicated a problem, the likelihood that the waste would be retrieved is small. And beyond several hundred years, the ability to maintain the awareness and vigilance of future societies is considered remote at best. Still, there are many questions currently being asked regarding such things as the retrievability of the waste in the event of a serious occurrence, methods of treating the site to reverse environmental degradation should contamination be detected, and strategies or contingency plans that should be considered at the front end to make the retrievability of the waste and/or the reversibility of the contamination easier than would be the case without such front-end contingency planning.

POLSCI 1: Most technological development in the past, up to this particular technology, has assumed that you could learn from trial and error. But the errors that were committed were not so severe that you couldn't accept them and then learn from them. You also had a very short feedback time. You could reverse the thing. All of those things apply not at all or very little in this and we really don't know how to deal with that.

POLSCI 2: That's a question I would like to raise. I've asked this in any number of forms and have gotten essentially no answer back. We presume that consequences of failure in a repository are essentially irreversible. It could be true axiomatically if the people who are living in the environment a hundred thousand years from now don't know what radioactivity is and if there's a problem, they can't deal with it. But, is it true in a technical sense? To what extent can there be reversibility if there should be a problem?

GEO: Well, it depends what your event is. First of all, there is no such thing as irreversibility. It's simply difficult and costly. Secondly, it depends on what the event is. Here we're talking about groundwater contamination. There are lots of things you can discuss. We have aquifers that get screwed up because their chlorides get high.

POLSCI 2: If you know you've got a problem you can do something about it. What sorts of things would be irreversible?

GEO: Say you get a fault that will increase the transport up to the biosphere. Well, there are things you could do about it. You could dilute the flow and, if it gets into your groundwater, you could manage it just the way they're managing those plumes. There's a plume in one of their cribs that they watch very carefully and I think it's a mile from the river now. Well, the thing has a short half life so I don't think there's anything they need to do about it. By the time it gets to the river it'll be okay, but if it weren't they could pump a certain way and reverse the flow. They could recharge the water elsewhere and send it back.

POLSCI 2: Are there any states currently requiring radiological monitoring of groundwater?

GEO: I don't know. If I were to guess, I would guess it depends on the local situation. I would guess that areas where there are uranium ore deposits, I would guess that but I don't know.

ENG 2: But, it seems to me that the probability of contamination is going to have to be so low that one is not going to be worried about that particular event because it is so inconsequential. Society does not do a lot of things to protect itself from very low probability events and it seems to me we would have to convince ourselves, society would have to convince itself, that the likelihood of that occurrence is so small we're just not going to worry about it.

ENG 3: The premise under which we're working here is...this is not a low probability event and yesterday we all said it's fair game to talk about a thousand to a hundred thousand years, that in that period of time someone is going to drill into that aquifer and that aquifer is going to be contaminated. To me that is not a low probability. Nobody has been able to convince me that that is a low probability.

ENG 2: No. The nominal question says the aquifer is potentially contaminated. It is not contaminated. And I don't know how many people we're talking about and I think that's very important. I think we're talking over a period of tens of thousands of years and we're talking about potentially endangering a few people....

ENG 3: From the analyses I've seen I think it's prudent and maybe realistic to assume that it's going to happen.

ENG 2: Okay. Let's examine that then. Let's assume that we have some criterion. I don't care. You just proposed a criterion. Given that criterion of acceptability, recognizing that we can't have zero risk for future generations, what would we do? Is there something that could be done? Would there be something that we could do differently? Or do we just have to accept whatever the outcome is? Now, if we're going to say a certain number of people could be subjected to some kind of hazard in X number of years and that's acceptable, then we'd have to look at it from that standpoint. But not knowing what kind of bound we have on this problem, I agree with you, there is some degree of risk in the future.

POLSCI 2: We've already gone through this. We know we need acceptable levels of risks in this process. We're trying to focus down the stream what else do we need to know?

ENG 2: We've agreed that the probability of somebody drilling into this aquifer and making use of the water is extremely high. And we also agree that we can't with certainty today, or in the foreseeable future, convince ourselves that we are not going to get some of this waste into the aquifer. If the potential exposure exceeds our criterion then we have to look for a site that will meet the criteria that we have set.

ENG 3: But I'm doing a systems' analysis on this thing and I'm looking at the probability curve of every one of these things and there's some point on that combination of probability distributions that represents contamination of the aquifer that exceeds the standard. I'm trying to go down the path of the entire systems analysis and we come to the contingency planning part. Now, I realize that from a design point of view that that's alien to your thinking but I'm saying that I think we've come to the point where we realize that this kind of thinking about this problem is necessary.

ENG 2: You're saying that we exceed the criteria, now what are we going to do about it?

POLSCI 2: There is some probability that we exceed the criteria.

POLSCI 1: As I understand the issue of contingency planning, there are two time scales of contingency. One of them is before you plug the site and the other one is thinking about that problem of after a thousand years. Once you plug it up you can ask a question like this: In the range of things that would have to occur for us to have a problem in the year 10,001, what are the known possibilities of reversing the consequences? As I heard it, your response to him was that there's a whole series of things that might happen, some of which are consequences that can be mitigated through known technology if you knew they were happening. And some of them can't be. And some we don't know about.

GEO: Let me back up. To begin with, you would not put the repository under an aquifer of any significant yield. That's the first thing. So you're not going to have supplies there that will contaminate a city or something like that.

MOD: What's your time frame on standing behind that probability?

GEO: Say a thousand years. We've already extended ourselves well beyond a thousand years.

POLSCI 1: I think it makes a difference because of the character of the waste forms after a thousand years.

GEO: Okay. Let's look at two possibilities. Most of the sites will have places where the overlying materials are so fine that you're never going to develop anything other than an individual well. Some places, like Hanford, there's not enough water to develop a significant supply, but if the climate changes, yes, you could develop. But let's look first at the place where the stuff is so fine it's overlayed with a clay material, you're not going to develop a big supply. So that's out for that kind of site. However, the chances are if we go from the past, that an individual will put wells in there, even if it's in the sand, trying to hit a pocket to try and get himself a hundred gallons a day. If it turns out it's contaminated, probably in that situation, it doesn't pay to do any remedial work. It pays for him to move out of there or get an alternate water supply.

POLSCI 2: So then it's a question of knowing.

GEO: It's a question of knowing in that kind of case.

POLSCI 2: Or not worrying about it.

GEO: Now, the second type. Let's say we take Hanford, which is contaminated today, and you put the repository there and in 2000 years it breaks and people don't know it was contaminated. And let's say the climate changes and there is enough water in there and people are developing supplies there. Let's say they do know that something has happened. Then there are management ways you can reverse things by pumping, by recharging you can change the direction of the flow, you could treat it, you could dilute it.

POLSCI 2: Let me follow that line of thinking. What you're saying is that technology exists today in this current description of society of reversibility. There is a little more question as to whether the technology of monitoring exists. Whether it be routinely monitored today, in a few years, or a century, it may be routinely monitored. That's the society we're characterizing today. In almost every other aspect of this waste management issue everyone seems to say that the best we can do is to look at society as it exists today and what our standards are today.

This discussion implies a degree of reversibility generally considered outside the realm of possibility. In terms of the nominal question, the program manager is urged to consider sites that possess, at least currently, aquifers of relatively low yield. Moreover, he may be well advised to consider the possibility, at least, of routine radiological monitoring of groundwater by future generations. If this is assumed, it is not unreasonable to further assume the capability for contingency actions in the event of contamination, either through condemnation of very low-yield aquifers or diversion of more significant aquifers.

3.3.8 Scaling Up--The Need for Cumulative Analysis

The social scientist or policy analyst expresses a greater need to know the cumulative problem posed by radioactive waste disposal sites in the aggregate because some number over some time period will contaminate the environment. Once you assume this to be the case, you want to know the distribution of the

contamination and the increment contributed by the waste emissions to the degradation of man's environment. Is this figure significant or insignificant in the aggregate sense?

POLSCI 1: Well, you see, the way you argue it is that you've only got one well and one repository in the whole world that this is happening to. What if you have the total sum of repositories needed to carry the total burden of radioactive waste produced in the next 200 years and every single one of them has had the same thing happen to it? Most of the underlying tone of the discussions about a single repository assumes that if it's safe for one it's safe for every one cumulatively. To the public it looks as though if you take care of the waste in the year 2000, then the problem isn't qualitatively changed after that. I don't believe that's necessarily true.

ENG 3: All I can say is that you need to look at each individual repository in its own site, do a risk analysis, and determine the magnitude of the risks, and then your cumulative risk is the summation of all those repositories over all the populations.

MOD: Are you suggesting that cumulative risk is greater than just an additive factor?

POLSCI 1: I'm saying that it's possible that the scaling up of the consequences might have qualitatively different types of effects at some point.

ENG 3: I don't understand the methodological basis under which that is the case. You talk about repository and the population exposure and its effect and then you add the effects from the next one, etc.

POLSCI 1: I'll give you an example. Let us suppose that you look at the tax rates for one community and you figure it's a certain amount and that community will hang in there. You can then do that to every community in your system and when you do you discover the whole thing collapses because the total amount of resources withdrawn is a function of the tax increases, and at some level it has a scale effect that destroys the capacity of the system to exist.

ENG 3: That example involves a mathematical equation that is nonlinear. Here we are dealing with a linear non-threshold model that most radiation biologists feel is additive.

POLSCI 1: One would suppose that as the population grows water resources will become more attractive and people will drill. All right, if they drill and if we can assure ourselves that there's going to be leaching and groundwater con-

tamination, then you're back to your assumption. Given the time frame, you are eventually going to have these events in some number regardless of your design criteria. If that's realistic, then one must be concerned with the cumulative question.

ENG 2: I think what you'd like to know is, for example, if you took all the waste, all the radioactivity that will exist, say, past a thousand years from today, maybe a thousand years after we quit using nuclear fuel, and look at that quantity and just say okay, I'm going to take that and I don't know quite how it's going to be distributed to the population but I'm going to distribute it. I'm going to take 10% of it and assume that that 10% is going to be taken up by the population somehow over 50,000 years. What would be the consequences, and this could be a very simple calculation, of that uptake in terms of the people and the type of radiation that they receive naturally, or is it something significant to the societies of the future?

GEO: You mean to say no one has made these calculations?

ENG 2: I'm not aware of one. I think that's a rather interesting thought. If that turned out to be negligible from a societal standpoint, that might give you a little bit warmer feeling about the whole thing. If it turned out to be very significant, you might say....

POLSCI 1: You see up until five years ago, or something like that, it was assumed by the people who are deploying this thing that they could design a fail-safe system so that never was in question. The minute you say it's likely to fail, a whole range of consequences comes up. Only if you believe that you can make a fail-safe system can you avoid them. Until these questions have been raised, that prior assumption held. Is that true?

ENG 3: I'm not sure they thought it was going to be fail-safe but I think they thought that the consequences of the failure would be essentially trivial. Is that your sense?

ENG 1: Yes.

ENG 3: And, therefore, not worth the time worrying about.

ENG 2: I would be very curious and very interested in knowing what the answer is to that question. I don't have any idea what the answer is.

POLSCI 1: Do you understand what I'm saying? I don't mean technically. But while this turns out to be a question that may not be technically interesting, it's interesting from a policy point of view.

ENG 2: I think this is very significant because I think it's the fear of the unknown. People are concerned about future generations and they lack understanding of the total impact of what's being done. If they could get some bounding of value for what that impact is, they'd have some idea of what the implications are of the decisions they are trying to make today.

GEO: It isn't just the fear of the unknown. For example, I'm less concerned about a nuclear reactor accident than I am about what the day-by-day releases are and what it is doing to the total level and the genetic consequences. I get so perturbed at the discussions of what if an explosion occurs here, because I'm more concerned about that is it going to do to the whole level.

POLSCI 1: What is the burden to the biosphere, cumulatively, when we are in fact doing the same thing with coal, we're doing the same thing in other areas, we're increasing the amount of radiation in the biosphere at some rate. And I don't even know whether it makes a difference or not except....

There was general agreement that an analysis needs to be performed that assesses the cumulative environmental effects of several repositories for various scenarios of future growth. Although the linear non-threshold dose-response model implies that the effects should be additive, it was suggested that beyond a certain point, the cumulative effects may be qualitatively as well as quantitatively more significant. At a minimum, the public needs to be informed about the relative magnitude of the future impacts related to decisions being made today.

3.3.9 Post-Entombment Monitoring

Even though post-entombment monitoring was given low priority, participants had fundamental differences as to whether it had any significance whatever, as the following discussion demonstrates:

POLSCI 1: Do any of us feel that post-entombment monitoring is much of an issue? That is to say that it's something that ought to be thought about because every body agrees that it's important.

GEO: I would say everybody feels it should be done but you're not going to be able to do it very effectively far in the future. Yet, there's no reason not to do it.

POLSCI 1: But you may be able to do it for a few tens of years or a few hundred years. Most people involved in this process say that as long as we have the resources to do it, let's do it as long as possible.

ENG 2: I don't necessarily agree with that at all.

POLSCI 1: Okay. Obviously we have an issue.

ENG 3: Now what are you going to gain by post-entombment monitoring? The only thing I can think of is that you can still dig the stuff up while we're still able to.

ENG 2: I heard those words, but I can't conceive of that situation occurring. I just can't conceive of a disaster that would cause you to dig up the stuff and create the type of additional risks that would be imposed as a result of that.

MOD: But you may decide that whatever buffer zones have been established for the disposal site should be enlarged because things aren't working out, that it's worse than your worst case.

POLSCI 1: The environmental panel that I mentioned before considered this problem. The key now is the fact that you don't entomb until you're very sure. Now that may mean that you watch the stuff for 50 years.

POLSCI 2: But it's precisely the performance of those seals, the boreholes and the shafts, that you start worrying about at that point. It's the failure of those that would seem to me to be the primary consideration.

ENG 2: On the WIPP facility, for example, one criterion is that the waste be retrievable. Now, I don't view that as important because of a technical concern about endangering the health and safety of the public. I think that is there to appease the public and grease the skids for acceptance of that facility. I don't think there's any technical justification for it. Now, that's my view, right, wrong, or indifferent. I think it's only there to make the job easier.

ENG 3: The way the problem was presented to us by EPA was if you monitor and discover you are wrong, then it's too late. The idea of monitoring is silly because once you've discovered you've made an error it's really a serious error.

MOD: I don't understand the EPA position that you don't monitor because if you did and found out that it was bad news then it would be too late. You could take actions that perhaps you didn't take initially to safeguard the area that you would now consider because of new information.

ENG 3: Their point of view is that what you've done is to commit the future for a very long time to doing that. They wonder about the institutional mechanisms that would support such a thing. They're saying that the character of the error in this case...and they may be wrong about this...negates the utility of monitoring.

GEO: That's gross oversimplification. For example, your fission products are your more soluble and mobile. Suppose you find that your fission products are showing up in the groundwater. You might take steps to reverse gradients, which will give you a hundred years of time by a heavy pumping program, and maybe in that time your fission products problem will be stabilized.

MOD: If there's a way of getting additional information we should. I guess I'm surprised we attribute a cost to knowing more.

ENG 2: Yes, it's a cost-benefit factor in evaluation.

MOD: But the monitoring is not a particularly costly thing.

POLSCI 1: It's not the cost of knowing more. It's having found out, the cost of responding to the knowledge.

GEO: In monitoring this, someone isn't just going to go up to the aquifer. There would be sensors put a hundred feet above the repository, 200, 300 400...there would be a number of sensors. When you get the first indication there may be many things you could do. You might divert the river that's recharging the aquifer.

POLSCI 1: When would all this happen? How far in the future might this occur?

GEO: Maybe in ten years...let's say you really blew it. Maybe in ten to fifty years a sensor right in the vicinity of the repository would indicate a problem. Maybe you'd have a sensor right outside the canister.

ENG 2: Instrument malfunction is what I would say. The repository is going to be open for 25 years and it's only at the end of that period that you're going to close it down. Anything that would cause waste to leak out at a rapid rate in a short period of time after you've been monitoring the site for 25 years and collecting data and observing behavior within the site...it seems to me it's got to be of such a catastrophic nature that you're going to observe the potential for release through other mechanisms rather than detection by monitoring.

MOD: What if you had some sort of seismic activity or something unpredicted and you wanted to know what the effect of that activity was on that site?

ENG 3: I think the cost of the knowledge would be extraordinary.

MOD: It does boil down to what the cost of monitoring would be.

ENG 3: The cost of nuclear power plant monitoring is about \$200,000 to \$300,000 a year. I suspect that a repository monitoring program might be a good deal more.

ENG 2: Yes, but the potential for release and the consequences of release are so different.

GEO: Even if you were 100% sure that you couldn't do anything about it, and you were not going to have any releases, you're talking about a billion dollar installation and it's inconceivable to me why you wouldn't build in a few sensors.

POLSCI 1: Let me just construct a different scenario. Twenty-five years go by and you close it up and you say nothing is wrong. The public wonders why you supposed anything would have gone wrong in the first place. You'd have to be so sure because if you did find that something was wrong, you couldn't do much about it. Retrieval costs would be enormous.

3.3.10 Engineered Barriers

There was substantial discussion regarding engineered barriers and what they include. It was agreed that design of the repository, packaging of the waste, and the waste form can all be influenced by technological treatment so that the likelihood of radioactive releases can be minimized. In the long run it will still be the geologic properties of the site that will serve as the long-term barriers to radioactive leakage to the biosphere. Neither the social nor physical scientists in the group gave much credence to engineered barriers or warnings on top of the site to discourage tampering with the repository area. As one of the social scientists indicated, surface warnings or barriers would only be effective during the relatively near term, say a few hundred years, when the probability of leakage is extremely low and the risk is high. As that probability increases over time, however, the ability of surface markers and institutional controls to restrict the area diminishes,

as does the risk. As a result, all the participants agreed that long-term safety must rely on the abilities of the natural barriers to isolate the wastes until their eventual leakage to the biosphere presents little, if any, health risk.

3.4 RERANKING OF ISSUE AREAS

After the detailed discussion of the issues, we asked the participants to again rank the nine issue areas initially identified. We were interested in learning whether eight to ten hours of discussion, clarification, and exhortation would result in a change of priorities attributed to the issue areas individually or collectively. Our hypothesis was that significant shifts would be unlikely because of the familiarity each participant had with nuclear waste management going into the conference. While changes in interpretation might occur, basic beliefs and values would not be altered and, as a result, priorities would remain relatively constant. Moreover, there was very little disagreement among participants initially so that there was little reason for one or two people to try to convince the group of their ideas. If anything, the day-and-a-half of discussion tended to clarify the explicit meaning of the issues sufficiently that each issue had a more uniform meaning for each of the participants at the conference's conclusion.

Table 2 depicts each participant's rating for each issue with the top number in each box being the first rating and the bottom number being the second.

The issue involving political and institutional factors again was not ranked.

The top four issues remained where they were after the first ranking. No parti-

TABLE 2
RANKING OF ISSUES - SECOND ROUND

ISSUE-AREA	POLITICAL SCIENTIST 1	POLITICAL SCIENTIST 2	GEOLOGIST	ENGINEER 1	ENGINEER 2	ENGINEER 3	TOTAL	RANK
Current political/institutional factors	Not Ranked							
Determination of acceptable levels of risk	3/4	5/5	5/5	5/5	5/5	4/3	27/27	High
Physical modeling	5/5	5/5	3/4	4/4	3/4	5/5	25/27	High
Establishment of design standards	3/4	4/4	5/5	5/5	5/5	3/3	25/26	High
Site characterization	5/5	3/4	4/4	4/4	4/4	5/5	25/26	High
Contingency planning	4/3	4/②	2/3	3/3	3/①	1/2	17/14	Med
Engineered barriers	3/3	3/3	4/②	1/③	1/③	2/④	14/18	Med
Post-entombment monitoring	2/2	2/2	2/1	2/1	1/1	2/2	11/9	Low
Long-term institutional awareness	1/1	1/1	3/①	1/1	2/2	3/1	11/7	Low
Pre-disposal handling (pre-capping)	4/②	2/1	1/2	1/2	2/2	1/1	11/10	Low

Key:

Before
After

participant changed his rating of any of these four by more than one point from his previous ranking.

Contingency planning and engineered barriers remained moderately important issues, though they changed places in the overall rankings and six individual ratings were changed by two points from the initial rating. These have been circled. This was due, in part, to a clarification of the meaning of contingency planning and engineered barriers. One participant, for example, had been under the impression that engineered barriers included modeling activities, which was not true. When it was agreed that engineered barriers did include preparation of the waste form, several people increased their ratings. In the first ranking, three of the issue areas exhibited a three number range from high to low. In the second ranking, none of the issues has a spread of more than two numbers.

As one of the participants stated, it would be difficult to imagine that six people who have thought about most of these problems for approximately three years would alter their beliefs significantly as a result of a two-day discussion.

3.5 SYSTEMS ANALYSIS FOR ISSUE RESOLUTION

Toward the conclusion of the conference, an attempt was made to develop the issues identified into a systematic framework for analysis. It was recognized that the details of such a framework would depend significantly

on the specific mission of our generic program manager. Moreover, the political scientists represented on our panel expressed some strong reservations about moving in such a direction, stating that political and institutional factors (discussed below) do not allow such an orderly resolution of issues.

Notwithstanding the above, a first cut at such a framework was pieced together and is depicted in Figure 1. Data on the health effects of radioactivity and on the state of the art of radioactive waste disposal must be combined with societal and political priorities in establishing an acceptable level of risk over time. It may well be that the technical data are used to bound the risk levels, while the political, social, and economic constraints will serve to reduce the range to a discrete level but, regardless, the level of risk must be established. This, then, serves to establish the performance criteria to which the system must be designed. These standards must specify some combination of site characteristics, waste form, waste package, etc., that will then serve as constraints on site selection and engineering design once the design standards are shown to be technically, economically, and politically feasible. If the design standards prove to be infeasible, then they must be revised or consideration must be given to raising the acceptable level of risk so that the design standards can be made less demanding while still ensuring attainment of the repository performance over time.

Site-specific characteristics that satisfy the design standards must then be obtained for input into a validated physical model to predict the probabilities and releases from the repository over time. Both the requirement

FIGURE 1

Framework for Systematic Inter-Disciplinary Analysis of Nuclear Waste Management Issues

for site-specific (as opposed to generic) data and the need for model verification were emphasized several times during the discussions.

The site characteristics would be combined with the representation of the entire physical system (including any engineered barriers that satisfy the design standards) in modeling the releases. Additionally, a number of assumptions would have to be made about the behavior of the environment over time. These would include future scenarios regarding climate, hydrology, seismology, and many other factors.

The model will then simulate the future and project the likely releases of radionuclides from the depository over time. Given assumptions about the population density, behavior, and vulnerability of future societies, one can arrive at future exposure levels over time and convert these to levels of risk to which future societies are likely to be subjected. If these levels are at or below the acceptable risk levels over time established initially, then the repository could be developed as characterized. If these levels exceed the established levels, then the program manager must grapple with the potential efficacy of future contingency planning (assuming a state of intelligence and behavior of future societies), or consider the possibility of tightening design standards or increasing the acceptable level of risk.

This is, admittedly, a simplified representation of the linkage between the major issues raised by the panel. It is realized that such a systematic process will only be approximated in the real world. Nevertheless, if no

other contribution has been made in developing this framework, Figure 3 at least gives recognition to the need for iteration in the process, one of the principal outputs of the conference.

3.6 ISSUE OF POLITICAL AND INSTITUTIONAL FACTORS

We have chosen not to rank the issue involving political and institutional factors, though a significant portion of the dialogue centered on the role these factors play in the perception and treatment of the other nine issues that are, to varying degrees, more technical in nature. How might we organize the political and institutional factors that come into play here? First is the issue of credibility; indeed this may be the overriding "process" issue of which all others are a subset. Problems need to be explored, information gathered, and decisions made in a way that engenders public confidence in both the decisions and the process that leads to them. Visibility leads to heightened awareness and interest, which, in turn, places greater emphasis on the credibility of the decision process. Nuclear waste management has become a publicly visible issue.

Second is the need to establish a socially legitimate process whereby technical and non-technical information can be researched, developed, and brought to bear on the setting of acceptable risk levels and designing of waste disposal facilities. Determining an acceptable risk level may well rely upon technical inputs, but its ultimate acceptance must depend upon the sanction, or at least the acquiescence, of society, most of whose members are not technically trained. At issue is the extent to which technical information can drive the decision-making process. And here is the crux of the difference between the feelings

and perceptions of the social scientists and physical scientists at the meeting. The social scientists generally opt for gathering a broad range of economic, legal, health, and engineering data to bound the problem and let the political process choose a "point" from within the boundaries. They feel the need to move more slowly, to gather more varied data (especially where little has been gathered to date), and to qualify the data by attributing a level of confidence to it, especially if the data stem from modeling efforts that rely on controversial assumptions.

The physical scientists, though certainly not uniform in this regard, feel a greater need to expedite this process so that a level of acceptable risk can be set and agreement can be reached on design standards. Generally, the physical scientists differ from the social scientists in the following areas:

1. They tend to have a higher degree of confidence than do the social scientists in much of the data that have been generated.
2. The social scientists place greater emphasis on a broader range of data that would be needed for assessing alternative policies in a broader context involving cost-benefit analysis.
3. The physical scientists appear more willing to accept the constraints imposed by the forcing function, which ties the solution of the waste disposal problem to the future of nuclear energy. The social scientists feel there may be legitimate and prudent ways to buy time without jeopardizing the nuclear industry while gathering valuable data on which to base the development of risk levels.

3.7 SUMMARY RESULTS OF THE TEST ANALYSIS

The panel of experts was convened for a two-day meeting primarily to test the efficacy of the NGT. While the general methodology may have been proven in

other situations, its utility needed to be tested for serving as an analytical framework within which physical and social scientists could systematically review complex issues associated with technological systems having significant social implications. A secondary purpose was to determine the quality of the product resulting from the discussion of the nominal question posed for the test. Our primary attention, therefore, was on the analytical process and its application, the dynamics of the iterative process used by the participants to arrive at the objectives of the analysis, and other considerations important to assessing the methodology.

Nonetheless, the conclusions drawn from the analysis of the nominal question provide some insight about the effectiveness of the NGT in analyzing problems related to waste management. These conclusions, which would normally be an integral and significant part of the analysis results given to a program manager, may be summarized as follows:

1. The considerations that should receive greatest attention in formulating acceptable solutions to the nominal question are:
 - a) the determination of acceptable levels of risk associated with establishing and operating the deep geologic waste disposal system over the relevant time periods;
 - b) the establishment of design standards for the performance of the deep geologic waste disposal system;
 - c) The adequacy of the techniques and data for the physical modeling and analysis of the system for postulated waste release scenarios; and

d) the adequacy of the repository site characterization.

2. Provisions for engineered barriers and contingency planning (to deal with unexpected events in the disposal system) were viewed as moderately important considerations; their relative importance could vary depending upon how the priorities were established for items in 1 above.
3. Post-entombment monitoring and long-term institutional control of the depository and its environs were assigned low priority.

There was unanimous agreement among the experts that resolution of considerations 1 a) and b) must evolve through an iterative process between the derivation of design standards and the predicted risks associated with application of these standards. Moreover, it was recognized that the credibility of the predicated risks is a function of satisfying appropriately considerations 1 c) and d). Figure 1 depicts how these considerations might interact in an iterative process to produce the desired results.

The panel could not agree on an outside time limit beyond which there would no longer be concern about the levels of risk associated with the depository's performance in isolating the emplaced wastes (other than the very long time period -- hundreds of thousands of years -- required for the hazards associated with the wastes to be comparable to those of naturally occurring ore bodies). Therefore, recognizing the likelihood of having to characterize the levels of risk associated with this disposal strategy for a variety of audiences, including the public in the NEPA process, the program manager should consider

undertaking a careful assessment of the risks over time and their comparison against some established standards. Such analyses will probably be necessary to provide the desired credibility for program decisions and the process by which those decisions were derived.

4. CONCLUSIONS

Program managers involved in developing policy, technology, and regulations for managing nuclear wastes need a cross-sectional analysis of issues to which they must be sensitive in carrying out these responsibilities. Whether in the public or private sector, these managers' decisions will invariably have far-reaching effects: this country's disposal strategies, which could set world-wide precedents, will be significantly shaped by decisions made in the next decade. This paper has explored one process intended to help organize and address myriad issues explicitly and implicitly embodied in the disposal of nuclear wastes. What have we learned? What are the strengths and weaknesses of the analytical process developed and tested? How might this pilot effort contribute to a more extensive approach required to supply program managers with the information they need? The answers to these questions are important to establishing the overall utility of the methodology.

4.1 BOUNDING THE PROBLEM

In testing the analytical process, we defined the nominal question and the objectives of the analysis to focus the discussion as best we could; nevertheless, it is clear that the issue areas generated by the question varied widely in their scope and nature. This is probably unavoidable with a multi-disciplinary group. Each participant has an interest in discussing what he or she knows best and in sharing this information with others in the group. But it is also a result of the "hidden agendas" we all bring to discussions, consciously or not. Thus, the bounds of the initial issue may be gradually expanded to encompass

more issues. To the extent that these issues can be tied to the primary question, and their influence on the resolution of the primary question can be explained, the broadening of the initial boundaries is a fundamental benefit in a multi-disciplinary discussion. It is the inability or unwillingness of a homogeneous group of specialists (as contrasted to the heterogeneous group used in the study) that, by its nature, misses the vital linkages between different issues, regardless of their respective levels of specificity or generality. Whether the linkages can be made in a constructive sense rests with the structure of the group process and the skills of the moderator. What should be avoided is the decision by the group that the primary issue cannot be addressed until more fundamental issues are resolved. That is an issue in and of itself and should be discussed as such, but it should not preclude a continued effort to view the primary issue from a full 360 degrees. On balance, the test of the methodology employed in the study successfully demonstrated its applicability for analyzing complex technical issues having potential societal impacts and for generating the desired products of the analysis.

4.2 CLIENT REPRESENTATION

In the radioactive waste disposal area, as in so many other complex areas, there is the active involvement of three groups: government, academia, and the private sector. Our exercise did not involve a government representative who could play the role of "client" and, as a result, what might be useful to such a client had to be assumed. The application of the methodology for analyzing waste management issues, in our judgment, can be undertaken

effectively with or without "client" participation in the analytic process. It is noted, however, that when a key actor is unrepresented, there is a tendency to gradually "gang up" on that actor and make him (in this case the governmental sector) a scapegoat for the system's problems. This occurred to some extent, but it could be avoided by having such individuals as part of the process, thus available to defend themselves and counter such attacks. It could also lend authenticity to the actual role of the assumed client.

4.3 GENERATING IDEAS, NOT SOLVING PROBLEMS

The Nominal Group Technique generated (from individuals) a variety of issues before any tone was set in the meeting. This approach perhaps, is not as effective as the Delphi Technique* in generating an exhaustive list of issues, but it is certainly better than having the group generate issues collectively; moreover, NGT is more effective in bounding the basic issue (nominal question) for purposes of analysis. In this connection, the effort by the staff to cluster the numerous and overlapping issues into a smaller number of issue areas resulted in a list of issues the group could rank and discuss in terms of priorities and factors influencing their resolution. Both the voluntary generation of issues and their clustering are important if one is to treat a relatively complex and rambling problem in a multi-disciplinary framework. This process appears to work well in generating ideas, and bringing into focus the compelling considerations, as perceived

*Runyan, Dean. "Tools for Community-Managed Impact Assessment." JAIP, V.43, N.2. April, 1977.

by the group of experts, that must be addressed to effect a resolution of the assigned problem. It is not a procedure for solving a problem directly but for defining the problem, and disaggregating it into its component sub-issues. It is also useful to identify and rank order alternative courses of action for resolving the sub-issues. These are key ingredients for facilitating the decision-making process that underpins finding solutions.

4.4 TECHNICAL AND NON-TECHNICAL COMPONENTS OF A METHODOLOGY

The ten issue areas ranged from the primarily technical to the primarily non-technical. While there is no formula for assessing the extent of technical versus non-technical qualities of an issue, we made an attempt to array the issue areas across a technical/non-technical spectrum in Chapter 3. Though the issue area identified as "current political/institutional factors" was not ranked, the dialogue suggests its role as being extremely important in resolving waste management issues. Subsumed within this issue area are the following:

1. The "forcing function," which pushes for an operating disposal site relatively soon so that the role of nuclear energy is not threatened.
2. The need for "technical credibility" in the eyes of the public.
3. The need for a "socially legitimate" decision-making process in nuclear waste disposal.

The four issues that ranked highest span the technical/non-technical spectrum from the "establishment of an acceptable risk level," which requires value judgments and political assessments, to "site characterization" which primarily involves technical activities. However, the results from

such technical activities can, and usually do, influence the value judgments and political assessments associated with the non-technical considerations. It is this inter-dependence of the technical and non-technical considerations that the iterative process of the NGT can effectively address.

4.5 NATURE OF THE PRODUCT

The output from this analytical process was envisioned as a qualitative product. But what is the product and to what use can it be put by a program manager? First, the product is a process, involving the selection of a group, the structuring of a meeting format, the specification of an issue or nominal question, identification of analytical objectives, the generation and discussion of sub-issues and related factors important to the resolution of the issue, etc., all of which serve as a candidate process for addressing complex problems of this type. Application of the technique does not inherently preclude the development of a quantitative product, i.e., discrete and definitive options for the resolution of the assigned issue; it could include, for example, specific R&D on advanced techniques for site characterization. It is recognized that a more direct participatory role in the process by the "client" to use the resulting product would be conducive to the production of a more quantitative output from the process.

Secondly, the product is a set of sub-issues, with priorities attached, that the program manager should consider in his efforts to deal with the nominal question. Finally, it is a structured dialogue among experienced

people with different perspectives that can reflect personal priorities, concerns, and alternative courses of action systematically derived for resolving those concerns, all of which can serve as a backdrop to aid the program manager in interpreting and deciding the issues.

The products from the application of this analytical methodology are exemplified by the results (Section 3.7) that derived from the test of the Nominal Group Technique.

APPENDIX: ISSUE CHARACTERIZATION

RADIOACTIVE WASTE FORMS

Radioactive wastes are produced in a wide variety of activities and consist of radioactive species of almost all chemical elements; they exist as a large number of chemical compounds; some contain naturally occurring radioactive materials and others contain man-made radioactive materials; the wastes exist as gases, liquids, and solids. Therefore, it is not possible to characterize the nature of radioactive wastes in a simple fashion.

Most of the radioactive wastes now in existence have resulted from either the generation of commercial nuclear power or from military programs, including the production of plutonium for use in nuclear weapons. In the latter case, the spent nuclear fuel, after irradiation, is removed from the reactor, dissolved in acid, and reprocessed to separate the plutonium and uranium from the remaining highly radioactive fission products, actinides, and other nuclides. As a result of reprocessing for military operations, approximately 265,000 m³ (U.S. Department of Energy, 1978) of radioactive wastes are now being stored in near-surface facilities at three major sites in the United States: the Hanford Reservation in the state of Washington, the Savannah River Plant in South Carolina, and the Idaho National Engineering Laboratory. Most of these wastes have been neutralized with sodium hydroxide and are in the form of insoluble sludges, soluble salt cake, and residual liquids.

Radioactive wastes are also generated by the commercial nuclear power industry. Although a small amount of commercial spent fuel was reprocessed at the Nuclear Fuel Services facility in West Valley, New York, the vast majority of commercial wastes are still contained in the spent fuel assemblies that

are stored in large water-filled pools at the reactor sites. Because of concern about proliferation of nuclear weapons, current United States policy is to defer indefinitely the reprocessing of commercial spent fuel and the recycling of recoverable uranium and plutonium.

A potential risk to public health is presented by the current practice of indefinitely storing radioactive wastes and spent fuel in surface and near-surface facilities. Therefore, final disposition of the wastes in appropriately designed repositories is a priority issue of our national waste management program.

RISKS FROM RADIOACTIVE WASTES

For all their variety, radioactive wastes have one thing in common: they will be potentially hazardous as long as they remain highly radioactive. This potential hazard results from the fact that exposure to and/or uptake of radioactive material can cause biological damage. In humans, it can lead to a variety of diseases, including cancer, that can be fatal. In addition, radioactive material can be mutagenic, thereby transmitting biological damage into the future.

To protect people against exposure to harmful amounts of radioactivity, federal standards have been instituted that require that the average population exposure from all man-made, non-medical radiation not exceed 170 mrem per year, and that no individual dose should exceed 500 mrem per year. Radioactive wastes from nuclear reactors, if not properly disposed of, could result in violation of these current standards at some future date.

The central scientific fact about radioactive material is that there is no way to alter the period of time over which a particular species remains radioactive, and consequently potentially hazardous: only with time will the material decay to a stable (non-radioactive) element. Thus, if current and future generations are to be protected from potential biological damage, a way must be provided to isolate radioactive wastes from the biosphere either permanently or for time periods sufficiently long to render them innocuous when they do enter the biosphere.

Strategies to achieve such waste isolation require a high degree of technical skill and creativity, but the problem is not entirely technical. At the core, the judgment that a satisfactory solution has been found is a social one. Thus, resolving the problem of radioactive wastes involves designing a system whose operation appears to be so technically sound that it can be widely accepted.

For the past three decades, the management of high-level and transuranic radioactive wastes can be characterized by inadequate perceptions of the additional technological and scientific skills needed to develop an acceptable disposal capability. Very few earth scientists have been involved in either program management or scientific R&D; this situation must change now that the problem is recognized as one whose resolution will clearly require an unprecedented extension of capabilities in rock mechanics, geochemistry, hydrogeology, and long-term predictions of seismicity, vulcanism, and climate. Important groups of scientists from disciplines such as materials research and risk assessment modeling have also come lately to the waste management program.

Similarly, social scientists with backgrounds in economics, political science, and sociology are new members of task forces and study groups investigating alternatives for waste management. Their probing to determine the "state of knowledge" has helped underscore the inadequacy of much of our current modeling efforts by exposing the uncertainty associated with much of the technical data when applied to extended future time periods.

DEEP GEOLOGIC DISPOSAL

The most advanced disposal strategy at the present time is to implant the waste in a mined repository (using conventional mining techniques) located deep underground in an environment judged geologically, hydrogeologically, geochemically, and tectonically suitable to provide assurance of long-term isolation of radionuclides from the biosphere. Conceptual designs to date depict a facility of the type displayed in Figure 2. The repository is intended to provide isolation of the emplaced radioactive materials from the human environment for the very long periods of time (hundreds of thousands of years) during which these materials constitute radiological hazards.

However, it is generally recognized that engineered safety features cannot be relied upon to provide post-emplacement waste containment for the very long periods required for some radionuclides. Therefore, it is generally felt that protection against migration of radionuclides from the repository to the biosphere should be based upon the naturally occurring "multiple barriers" created by the geologic formations that underlie the repository site. However, it is also recognized that even with a natural barrier system deemed suitable for containing the wastes, this containment cannot

Figure 2. Waste Isolation Facility

be guaranteed permanently. Furthermore, since the site exploration drilling likely will be minimized so as not to jeopardize the effectiveness of the natural barriers, the data base characterizing the geologic/hydrologic features of the site may be less than optimum.

Because of these inherent uncertainties, the absolute containment of the nuclear wastes during the very long period of potential hazard cannot be guaranteed. Therefore, any evaluation of potential post-emplacement radiological impacts undoubtedly will conservatively assume that the depository will become saturated with groundwater during its early life. (Conservatively, as used here, refers to making predictions based on the worst possible event or set of events.) For purposes of the evaluation, the groundwater would then be assumed to provide a pathway for the radionuclides to migrate to the biosphere.

The most reliable method for assessing the radiological impacts from deep geologic nuclear waste disposal would be to measure empirically the amount and concentrations of radionuclides released from the depository. However, considering the extended length of time over which the waste will remain hazardous, such an empirical effort is infeasible. Therefore, a theoretical approach using predictive models is considered to be the only feasible method for predicting and evaluating potential impacts.

The analytical approach consists of modeling the geologic and hydrologic parameters that define the transport properties and interactions of the geologic formation; from this model it is possible to predict the migration of groundwater containing radionuclides to surface water bodies, and the subsequent movement of radionuclides along all pathways to man. The radiological dose

calculations can then be made using the analytical methods established by NRC in connection with the safety analysis required for commercial nuclear power stations.

A typical physical model of this system is represented by Figure 3. It consists of six geologic layers. A surface layer (under the repository buildings) that may or may not be hydrologically confining is situated above a hypothetical upper aquifer layer. A barrier layer is situated below the upper aquifer and above a waste depository layer where the host rock properties satisfy the siting criteria for a deep geologic repository. This layer is assumed in the model to be separated by another barrier layer from a second aquifer below the depository layer. The upper aquifer is assumed to be in hydrologic connection with the biosphere via surface water bodies such as wells, lakes, or a river/estuary/ocean system.

In a conservative release scenario, it is projected that water flows from the lower aquifer upward into the depository under the driving force of artesian pressure; the depository under such a scenario eventually becomes saturated. For any given waste form, the geohydrologic and geochemical parameters are assumed to control the release of waste into the groundwater and the subsequent movement of the groundwater and radionuclides to the biosphere. The modeling approach permits simulation of different strata types, different geometric dimensions, path lengths, and the properties that influence the rates of groundwater flow and the radionuclide migration.

By varying the model parameters that represent the geologic and hydrologic properties, a variety of conditions of the geologic systems can be analyzed.

Figure 3. The Physical Model

Thus, the parameters can be selected to represent conditions ranging from geologic units that are free from any natural or man-made flaws to ones that are flawed by faults, breccia pipes, or failed borehole and shaft seals. Such analyses have been performed. The results indicate that any one of postulated geologic irregularities can potentially result in the groundwater's being contaminated with radioactive materials released from the depository. Therefore, the potential for contamination of the groundwater leads to a concern that humans might inadvertently drill wells into the contaminated aquifer and use the water for human consumption.

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