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EXPERT JUDGMENT ON INADVERTENT HUMAN INTRUSION INTO THE WASTE ISOLATION PILOT PLANT

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ABSTRACT

Four expert-judgment teams have developed analyses delineating possible future societies in the next 10,000 years in the vicinity of the Waste Isolation Pilot Plant (WIPP). Expert-judgment analysis was used to address the question of future societies because neither experimentation, observation, nor modeling can resolve such uncertainties. Each of the four, four-member teams, comprised of individuals with expertise in the physical, social, or political sciences, developed detailed qualitative assessments of possible future societies. These assessments include detailed discussions of the underlying physical and societal factors that would influence society and the likely modes of human-intrusion at the WIPP, as well as the probabilities of intrusion. Technological development, population growth, economic development, conservation of information, persistence of government control, and mitigation of danger from nuclear waste were the factors the teams believed to be most important. Likely modes of human-intrusion were categorized as excavation, disposal/storage, tunneling, drilling, and offsite activities. Each team also developed quantitative assessments by providing probabilities of various alternative futures, of inadvertent human intrusion, and in some cases, of particular modes of intrusion. The information created throughout this study will be used in conjunction with other types of information, including experimental data, calculations from physical principles and computer models, and perhaps other judgments, as input to a "performance assessment." The more qualitative results of this study will be used as input to another expert panel considering markers to deter inadvertent human intrusion at the WIPP.

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PREFACE

This SAND report was prepared from information presented by a panel of experts expressing judgments about future societies and the possibility that those future societies will inadvertently intrude upon the Waste Isolation Pilot Plant. Appendices C, D, E, and F were written by the panelists and do not necessarily reflect the opinions of the authors of this SAND report or of Sandia National Laboratories. The authors consolidated and utilized these appendices in preparing the body of the report. The members of the expert panel reviewed a draft copy of the report for misstatements of fact.

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EXECUTIVE SUMMARY

The information obtained through this study (modes and likelihoods of inadvertent human-intrusion activities) has two purposes. The first purpose is to provide background information for the design of mechanisms to deter future inadvertent human intrusion at the Waste Isolation Pilot Plant (WIPP). These mechanisms include systems of markers to inform and warn future generations, barriers to impede human intrusion, and information systems external to the WIPP repository that provide for the maintenance and communication of knowledge of nuclear waste repositories. The expert panel on future societies can advise on disposal-site markers. The need for the most practical permanent markers to designate disposal sites is specifically mentioned in section 191.14(c) (the Assurance Requirements) of the U.S. Environmental Protection Agency (EPA) regulation 40 CFR 191, referred to as the Standard (U.S. EPA, 1985). As discussed in the preamble to the Standard, the Assurance Requirements were included to counteract the uncertainty inherent in the analyses for the Containment Requirements. Thus, in order "to reduce the potential harm from some aspect of our uncertainty about the future," a set of actions was outlined for implementation. Section 191.14(c) of the Standard states that "[d]isposal sites shall be designated by the most permanent markers, records, and other passive institutional controls practicable to indicate the dangers of the wastes and their location."

A plan for implementation of a marker strategy, including design characteristics, will be necessary for compliance evaluation to show that such markers can be constructed. Part of marker design would be based on the findings from studying past monuments that have stood the test of time, current materials technology, and present understanding of communication methods. A second important input to marker design would be from the expert panel on future societies (called the Futures Panel). This input is about the possible future states of society (including the expected activities and resource needs, and the ability to interpret and heed warning markers) and how future societies might intrude upon a repository. While it was not specifically a part of their statement of work, two of the four teams comprising the Futures Panel recommended that a "no marker" strategy be considered for the WIPP because markers might draw attention to the WIPP.

The second purpose of this study is to provide quantitative estimates of the likelihoods of various types of intrusions. The information created through this study will be used in conjunction with other types of information, including experimental data, calculations from physical principles and computer models, and perhaps other judgments, as input to a "performance assessment." At the time of this study, the Standard is the regulation governing performance assessment for the WIPP. The EPA has defined performance assessment as a probabilistic evaluation of the potential releases of radioactive material to the accessible environment over the period of concern (10,000 years). The performance assessment is conducted using guidelines provided by the Standard, which suggests that "inadvertent and intermittent intrusion by exploratory drilling for resources (other than any provided by the disposal system itself) can be the most severe intrusion scenario assumed..." (Appendix B of the Standard, p. 38089).

The methodology employed in this study is referred to as expert-judgment analysis. For some aspects of performance assessment (human-intrusion in particular), conducting experiments that will provide data to resolve uncertainties is not possible. When such unresolvable uncertainties do exist, the judgments of experts are often used to quantify the uncertainties and express both what is known and what is not known. Expert judgment is pervasive in complex analysis. Judgments about the selection of models, experimental conditions, and data sources must be made. The choice is not whether expert judgment will be used; instead, the choice is whether it will be collected and used in a disciplined, explicit manner or utilized implicitly where its role in the analysis is not as obvious.

The Futures Panel was selected through a formal nomination process. Initial nominations for members of the Futures Panel were made by individuals from professional societies, government agencies, and public interest groups. The initial nominees could nominate themselves and/or others. The nominees came from the disciplines of futures research, law, physics, social science, agriculture, political science, and climatology, among many others. The actual selection of the panel was made by a committee external to Sandia National Laboratories (SNL) according to the following criteria: (1) tangible evidence of expertise; (2) professional reputation; (3) availability and willingness to participate; (4) understanding of the general problem area; (5) impartiality; (6) lack of economic or personal stake in the potential findings; (7) balance among team members so that each team has the needed breadth of expertise; (8) physical proximity to other participants so that teams can work effectively; and (9) balance among all participants so that various constituent groups are represented.

Sixteen experts arranged in four teams of four members each were used in this study. Geographic neighbors were placed on the same team while, at the same time, preserving balance among disciplines on each team. The teams were given the following designations: Boston Team, Southwest Team, Washington A Team, and Washington B Team. The team format was selected because the subject matter, the futures of society, is inherently multidisciplinary. Each team was given the same assignment, as described in the Issue Statement and Task Statement (Appendix G), that was presented and discussed during the first meeting in Albuquerque, New Mexico.

Methodologies

Consideration of the possible types of future human societies is an essential task in studying the potential for inadvertent human intrusion. The methodologies employed by the teams to delineate future societies, along with lists of the factors used in determining the possible futures, and alternative modes of intrusion into the WIPP are described in Chapter III. These methodologies were developed after the panel of four teams visited the WIPP and the surrounding area, and listened to presentations delivered by SNL staff regarding the WIPP, the Standard, performance assessment, the physical and cultural setting of the WIPP, and scenario development. Training in the expert-judgment process was also provided.

BOSTON TEAM

The Boston Team analyzed alternative futures describing future civilizations in two distinct ways. The first way began with the examination of intrusive activities and worked backward to determine the attributes of society that might lead to such intrusions. This "top down" approach led the team to define "generic" alternative futures--alternatives that are broad in scope and lack detail, but are representative of many possible futures. The second way of developing alternative futures that was employed by the Boston Team resulted in the creation of inventive, highly detailed pictures of the future. These futures were termed "point" futures by the team. Both the terms "generic" and "point" futures will be retained to describe the findings of the four teams.

When creating generic alternative futures, the Boston Team followed a consistent approach for each potential intrusion mode. This approach involved first identifying the vulnerability of the WIPP. The specific event or events that would be required to exploit the vulnerability were then analyzed. Next, the activities that could potentially require such events to take place were discussed, and an analysis of the societal and physical conditions necessary for these activities was presented. The team also identified criteria for each specific mode of intrusion that could be used to characterize the intrusion as inadvertent. Finally, initial probability assessments, in qualitative terms, were provided for each of the precursor events and activities defining the path to intrusion.

The point futures developed by the Boston Team provide a thought-provoking view of what future societies could be like. These future societies range from the WIPP becoming the nation's primary nuclear waste site to a society dominated by individuals who do not believe in science as currently practiced. The creation of alternative futures is the product of a highly imaginative process and expands the range of possible futures to consider when designing passive markers and barriers for the WIPP. These futures are not in conflict with the generic futures, but instead provide an alternative, detailed view of the future that, although of low probability because of the level of specificity, is instructive about the variety of futures that should be anticipated.

SOUTHWEST TEAM

The Southwest Team created views of the future through a forward process. This process also produced generic alternative futures. The process began with the establishment of key assumptions about the operations of the WIPP and the scope of the analysis to be provided. The team then identified environmental changes and socioeconomic factors that potentially would impact human intrusion. For each of the socioeconomic factors, a qualitative assessment of its impact on human intrusion was provided.

Five narrative futures were created by the Southwest Team. These futures were identified as

technological knowledge increases,
decline and rebuilding of technological knowledge: seesaw,
technological knowledge decreases,
altered political control of the WIPP area,
stasis (not included in probability elicitation).

These narrative futures are generic in that many possibilities are included within a single future. The probabilities of inadvertent intrusion arise from these futures by considering the probabilities of the persistence of the present political control over the WIPP, the pattern of technological development given the state of political control, and intrusion given both the state of political control and the pattern of technological development.

WASHINGTON A TEAM

The Washington A Team focused its views of the future on the relationship between earth resources and society. These futures were

continuity--continued population growth and current levels of resource consumption, radical increase--massive increases in the consumption of world resources,

radical discontinuity--erosion of conditions in the WIPP area by major war or political change,

steady-state resources--world consumption of resources dramatically reduced through zero population growth and extensive recycling.

The first three of these alternative futures involved population growth and substantial extractive activity. In these futures, the natural environment was thought of as a source of materials and energy rather than as a human habitat. In the fourth future, humans reached an equilibrium with nature. The state of the world became constant, and there was little need for extractive activity.

The Washington A Team allowed that the future may shift among several of these alternatives at various points in time. Thus, these futures should be viewed as snapshots of what the future might be like rather than complete, mutually exclusive paths that society's development might follow. This team also provided an extensive analysis concerning loss of memory about the WIPP and the inability to use existing information.

WASHINGTON B TEAM

The second team from Washington, the B Team, constructed a four-component model of paths leading to human intrusion. The first component of the model was the state of society, both local and worldwide. These views of the future states of society were based upon the climate at the WIPP area (both natural and human-induced changes are allowed), energy and mineral costs, food supply and demand, and governance of the WIPP area. The ensuing components of the model included the level of awareness about nuclear waste, the presence of potentially intrusive activities, and the modes of inadvertent intrusion into WIPP.

The factors that underlie the Washington B Team analysis are levels of resource prices, with higher levels bringing about greater exploration and extraction, modification of the existing climate or water importation, and the ability of the government to retain sufficient control to preclude inadvertent human intrusion. The analysis was based on forming all combinations of the levels of these factors. In this way the team created a potentially exhaustive set of alternative futures.

Catastrophes, which are unfortunate events that occur over a short time and have the potential to change the course of civilization, were also considered by the Washington B Team. These events, both natural and manmade, can cause such a disruption of society that memory of nuclear waste becomes lost, and the potential for inadvertent human intrusion increases.

Underlying Factors

Each of the four teams identified factors thought to be determinants of the activities of coming societies. In some instances these factors are given in tables found in the team reports, while in other cases the factors are identified in the narrative.

The facets of society that most directly impinge upon inadvertent human intrusion include the rate of technological development; population growth; economic developments, including the prices of minerals and energy resources; water availability and production in the WIPP region; and the level of governmental continuity and cognizance of nuclear waste. These factors are related and cannot be treated independently. For example, the level of technological progress may have a profound effect on the world economy's need for resources. Similarly, the world population size will also impact the level of resource exploration and extraction. The relationships among factors can be even more complex. Technology may directly impact both population size and resource utilization, for instance, and population may directly impact resource utilization. Thus, technology will have both direct and indirect (through population) impacts on resource utilization.

TECHNOLOGICAL DEVELOPMENT

Critical to future human activities is the progress that will be made in technological development. Many of the specific human activities that could result in inadvertent intrusion are in some way dependent upon the advance of technology. One type of intrusive activity is excavation for the purposes of construction. The most likely type of construction is a dam to hold water for industrial, energy, agricultural, or residential uses. Resource extraction may also be influenced by technology. New methods of resource exploration, similar to medical CAT scanners, may allow exploration in more nonintrusive manners than currently available. In addition, there may be new and efficient means of drilling, new fluids for solution mining, and new, rapid means of excavating.

It was proposed that both technological innovation and technological stagnation can increase the potential for intrusion. Under technological stagnation, intrusive means would be used for resource exploration. Impacts due to technological innovation include advanced drilling techniques, methods for high-volume water desalting that may make water extraction worthwhile, deep strip-mining techniques that would reduce the cost of resource extraction, the identification of new resources, and the use of autonomous mechanical extraction techniques for minerals.

Technological development that leads to the increased utilization of solar energy resources could lead to the extraction of mineral resources at the WIPP. Solar energy would be used in the processing of the ores. In a future with radically increasing resource exploitation, machines presumably not subject to the same hazards from contact with radiation as human beings would increase the willingness of drillers to take risks. Further, the existence of such technology may lead to overconfidence in the ability of their human directors to employ them without accident.

POPULATION GROWTH

Increases in population will impact the WIPP through a variety of paths. First, increases in world population will translate into increased resource demands. There is also the possibility of increased population density in the WIPP area and increased industrialization. The concept of local population growth was refined to include redistribution of the population by governmental policy and voluntary motivation. Voluntary redistribution might occur because of resource exploitation opportunities, grazing or crop production, or recreation purposes.

ECONOMIC DEVELOPMENT

The role of economic development in alternative futures containing human intrusion into the WIPP is not as sharply defined as that of technological development. One team used a single underlying factor to represent both technological and economic progress. Other teams implicitly included economic development in the alternative futures. For one team, the economic demand for resources and the political control that moderates the use of resources are fundamental in defining alternative futures.

CONSERVATION OF INFORMATION

The persistence of information about the WIPP and the continuity of government control are intertwined. The likelihood of loss of information is apt to increase when there is a discontinuity in governmental control. Despite the close relationship between these two aspects of inadvertent intrusion, they are separated in this discussion.

One team identified inadequate records, inaccessibility of records, inability to understand records, ignoring of information that is understood, and lack of information regarding the effects of nearby activities as contributors to inadvertent-intrusion possibilities. A second team identified the possibility that nuclear energy will be a short-lived phase of our economic development. In this event, some loss of memory is likely. Memory loss was identified as taking several forms. Memory about the facility may be lost, memory may be lost about the danger but not the facility, and local but not institutional memory may be lost. A third team identified four states of memory about WIPP. Memory of the WIPP could be relatively complete, memory of the location but not of the hazards may persist, memory of the WIPP may become a legend or a myth, or all memory may be lost. While complete memory of the WIPP and its attendant dangers will deter intrusion, partial memory can serve to attract potential intruders. Knowing that something is there, but not knowing what it is or what its value may be, may serve to attract investigations such as archaeological digs or salvage operations.

The survival of information may depend upon the survival of our information systems. Changes in the basic forms of communication are likely in the next 10,000 years. Both written and oral forms of communication may be quite different than they are today. Moreover, the means for storing information may be significantly different than the means used today. If this is so, future generations may find it difficult to access the information that we have intended for them.

PERSISTENCE OF GOVERNMENT CONTROL

A recurring perception among the teams is the small likelihood of continued U.S. political control over the WIPP. Governments are seldom stable for long periods of time, certainly not for the periods of time covered by this study. In one alternative future, a separate nation is formed from northern Mexico and the southwestern U.S. at some time in the future. In the chaos of the transition, information about the WIPP may be lost--except, perhaps, for local folklore about buried treasure. Alternatively, the discontinuity of government control could include the erosion of conditions so that New Mexico resembles a less developed nation in the future. The cultural differentiation of the region adds credibility to the hypothesis of a change in government control. A conclusion that may be drawn from the experts' views of political stability is that continued U.S. control of the WIPP for 10,000 years is unlikely. The transition from one government to another may be disruptive and preclude the transferal of information about the WIPP. Even if U.S. control is perpetuated, the application of effective measures to warn potential intruders may not follow.

MITIGATION OF DANGER FROM NUCLEAR WASTE

If nuclear waste is intruded upon at some point in the future, the exposed waste will not necessarily cause harm. Medical technology may have developed to a point where cancer is curable or the consequences of radiation exposure can be greatly reduced. Scientists may determine that low-level radiation is not hazardous, or a technology for safe redisposal may become available.

Modes of Intrusion

The underlying factors that determine the nature of future societies provide the basis for the consideration of alternative modes of intrusion into the WIPP. A summary of the modes of intrusion provided by the teams follows.

<u>Excavation</u>
- archaeological
- mineral
- construction

<u>Disposal/Storage</u>
- underground injection
- petroleum storage
- additional radioactive waste storage

<u>Tunneling</u>
- transportation
- pipeline
- mole mining

<u>Drilling</u>
- hydrocarbons
- water
- research

<u>Offsite Activities</u>
- water impoundment
- explosions
- water well field

Elicitation

Once the teams had developed systems for delineating possible future societies, they returned to Albuquerque to organize them further. These qualitative assessments of underlying societal and physical factors were developed into a framework from which the teams could be elicited as to the probabilities of various alternative futures, of inadvertent human intrusion, and in some cases, the probabilities of particular modes of intrusion. The different methodologies and frameworks developed by the teams resulted in elicited probabilities that took different forms. Two of the teams developed probabilities of a first intrusion for each alternative future, essentially ignoring additional intrusions as unlikely or irrelevant. These probabilities of intrusion over the entire 10,000 years ranged from 0.0095 to 0.07. Probabilities were not assigned to particular modes of intrusion.

The other two teams provided expected numbers of various intrusions over the entire 10,000 years. Both of these teams stated that boreholes drilled for resource extraction would not continue after about 300 to 500 years, with

0.86 and 0.93 boreholes per square mile expected in that initial period. The impact of some of the other modes of intrusion such as storage expansions and scientific investigations should be rather straightforward to assess because material would be brought to the surface. Other modes of intrusion, particularly indirect modes of intrusions, such as weather modification, dams, injection wells, explosions, and water wells, would require further study to determine just how these activities might impact the performance of the WIPP.

Conclusions

Clearly, the future may follow many paths--some more desirable than others. Several themes are so pervasive in the views of the future that they should be singled out for attention. First, in the time scale of nuclear waste decay, the continuity and stability of governments are insufficient to provide any assurance that humans will maintain active control of the repositories or be aware of the existence of buried nuclear waste. A second factor that occurs throughout the alternative futures is the rate of technological development and its persistence or lapse. While the work of any group of experts cannot define all the possible futures, let alone know which future will come to be, the futures envisioned by the experts involved in this project are sufficiently varied to alert us to the need to consider a very wide range of possibilities when designing markers and barriers to prevent human intrusion into radioactive waste repositories.

The intrusions identified through this process are more varied than those previously considered. The planning for this panel involved a conscious decision to solicit opinion on the future states of society and on a variety of modes of intrusion that go beyond what the Standard requires for performance assessment. While the increased variety of threats to the WIPP system will make designing markers and barriers more difficult, it will also make the task more meaningful. The probabilities of various modes of intrusion were elicited from the teams. In some instances, the probability of one or more intrusions is provided, while in other instances a rate per unit of time or time and area is provided. No attempt has been made to combine the intrusion probabilities across teams, nor has an attempt been made to add together the rates of various types of intrusion to obtain a single number. In the first case, combining across teams is unwise because the definitions of the types of intrusions differ--some are more aggregated than others. Aggregating probabilities or rates of intrusion across modes of intrusion is likewise unjustifiable. The severity of the various types of intrusion will vary greatly. It is arguable, for instance, that water impoundments such as dams will not result in the same magnitude or timing of releases of radionuclides to the accessible environment as a borehole would.

Combining an intrusion rate for dams with an intrusion rate for drilling would be meaningless.

The value of the report is that a reasoned approach has been taken in examining the possibility of inadvertent human intrusion. The qualitative findings, including the discussions of government control and the identification of possible modes of intrusion, are perhaps the most valuable contributions of the experts. The quantitative assessments of intrusions, both probabilities and rates, can be used for the performance and safety analyses of the WIPP system. These probabilities and rates reflect the best judgment of sixteen experts drawn from diverse backgrounds and reflect a very uncertain state of knowledge about the future.

I. INTRODUCTION

This study has been conducted to achieve several goals related to the potential for inadvertent human intrusion by future generations into the Waste Isolation Pilot Plant (WIPP). The specific goals are to (1) assemble an expert panel of individuals from a variety of disciplines that are believed to be important in the consideration of future societies; (2) convene the expert panel and provide them with both sufficient background information to perform their assigned task and a clear definition of their task; (3) elicit from the experts their opinions regarding the modes and probabilities of intrusion; (4) organize the elicited opinions for clear presentation to the expert panel studying markers for the WIPP; and (5) document both the process and the elicitation results in a report along with the more qualitative individual team reports.

Inadvertent human intrusion occurs when the integrity of a repository is unintentionally compromised by the activities of humans in the immediate vicinity of the disposal system. The intrusion may or may not result in the release of radioactivity to the environment. Hazards from nuclear waste can be long lived--lasting for many millennia. Over such long time periods, information about the location of nuclear waste and the inherent dangers from releasing the waste may become unclear and even forgotten. Uninformed individuals, corporations, or governments may inadvertently intrude upon radioactive material buried in underground repositories created during our lifetimes. Depending on the type of intrusion and the time in the future when intrusion occurs, there may be releases of radioactivity to the biosphere. The objective of this study is to envision the types of inadvertent intrusions that may take place in the future, to understand the motivations for these intrusions, and to appraise the likelihood these intrusions will occur. The specific repository under study is the WIPP near Carlsbad, New Mexico, which is a facility proposed for the disposal of radioactive waste generated by defense-related activities of the United States government.

Background

An October 23, 1989 memorandum from the Department of Energy, Albuquerque Operations Office (DOE/AL), to both Westinghouse (the DOE contractor responsible for construction of the WIPP repository) and Sandia National Laboratories (SNL) (Appendix A) initiated the process of outlining passive-marker design characteristics for the WIPP. The memorandum stated it was necessary to "define the criteria which will be used to decide what kind of passive markers can be used at the WIPP to significantly mitigate the effects of the human intrusion scenarios on performance assessment." SNL was given the responsibility to lead the effort to develop the criteria. Westinghouse was named as "the lead for the proof of concept and implementation of the passive markers selected."

SNL responded in a February 15, 1990 memorandum to A. E. Hunt at the WIPP Project Office (WPO) in Carlsbad, New Mexico (Appendix B). As part of the research outlined in the memorandum, SNL would conduct a literature review of previous studies regarding (1) repository marker and barrier "longevity," (2) the technological activities and requirements of future societies, and (3) communication to future societies of the location and danger of a repository over time. With the basis provided by the literature search, expert panels could be "organized and utilized" to develop opinions on the above topics, as well as the time to first intrusion, the longevity of passive institutional controls, and the rate of intrusions over the period of regulatory concern. The expected use of the opinions is both in future performance-assessment calculations of probabilistic cumulative radionuclide releases and in defining the criteria for passive-marker and barrier systems. Once the criteria have been established, SNL can work with Westinghouse to develop a plan to construct the marker and barrier systems, and to improve these systems over the operational life of the facility.

The expert group studying future societies has been asked to address a number of issues. These issues are all directed at establishing modes and likelihoods of inadvertent intrusive activities into the WIPP, which provides the foundation for the development of characteristics for markers and obstacles designed to prevent human intrusion. Human intrusion has been identified as the means by which the Standard could be exceeded (undisturbed conditions are expected to provide isolation for beyond that required by the Standard) and, therefore, is central to the performance of the WIPP (Marietta et al., 1989; Guzowski, 1990).

Because the regulatory period for the WIPP spans 10,000 years (based on one part of the applicable regulation), societies different from our own may encounter the buried radioactive waste left by us. Even though the potential risk associated with radioactive waste decreases with time (Klett, 1991), it is still necessary to consider possible future societies when designing markers and obstacles to prevent human intrusion. One approach is to create alternative futures for the development of society. These alternative futures can be constructed by considering alternative projections of basic trends in society. These trends may include population growth, technological development, and the utilization and scarcity of resources, among other factors. Overwhelming these factors in the possible impact on human intrusion are events that interrupt, modify, or reinforce the development of society. Such events may include nuclear war, disease, pestilence, fortuitous discovery of new technologies, climatic changes, and so forth. The creation of a reasonable set of alternative futures provides the first step in evaluating the types and likelihoods of intrusive activities. It is not possible, however, to ensure that all possible futures are considered. It is not even reasonable to assume that humans can conceive of all possible future societies. The farther into the future we delve, the less complete these alternative futures are likely to be.

Each alternative future provides a picture of certain possible characteristics of society at various points in the future. These characteristics, in turn, provide information about those activities that may take place and pose threats to the integrity of the WIPP. Such activities may include extractive industry, such as mining for potash or drilling for oil and gas, and drilling for water for use in agriculture, industry, or for other purposes.

The states of society and the types of potentially intrusive activities suggest modes of intrusion and motivations for these intrusions. The alternative futures and the states of society also provide information about the existence of knowledge concerning underground disposal of nuclear waste, the continued existence of the waste itself, and the availability of means to detect waste prior to, during, or after intrusion.

The products of the expert-judgment group to assess future societies and inadvertent intrusions include alternative futures for the development of society and descriptions of possible futures, along with the rationales supporting the possibilities of these futures. These rationales are conveyed as appendices to this report and serve as documentation of the experts' findings. Quantitative assessments of the likelihoods of various alternative futures have also been obtained. These probabilistic assessments are used to develop probabilities of intrusive activities over time.

The work required to develop the assessments for human intrusion was accomplished through two meetings of the experts and a study period between the two meetings. At the first meeting, the issues to be addressed by the experts, background information on the WIPP, and previous research findings were presented. Other research materials were distributed, training in probability assessment took place, and a tour of the WIPP was provided. All of these activities were carried out by SNL staff.

During the two-month period following the first meeting, the experts studied the issues and background material, and developed methods of creating possible future societies and their activities, with special attention to those activities that may impact the WIPP. It was requested that approximately two weeks of effort be spent by each expert in preparing these analyses.

The second meeting provided a forum for the discussion of possible future societies and the methods used to create them. Following the discussion, the experts participated in a formal probability assessment conducted by specialists in expert-judgment elicitation. The experts were asked to provide assessments of the likelihoods of various alternative futures, and of the frequencies of various types of intrusions given each alternative future. The experts were free to consider all modes of intrusion they deemed appropriate and were not limited to drilling, which was identified by the vacated standard as the worst case that needs to be considered.

Following the second meeting, the elicitation findings of the group were organized and returned to the experts for review, correction, and revision. The reports prepared by the teams discussing human intrusion are reproduced as submitted as Appendices C, D, E, and F.

Purposes of the Study

The information obtained through this study (modes and likelihoods of inadvertent intrusion activities) has two purposes. The first purpose is to provide background information for the design of mechanisms to deter future inadvertent human intrusion. These mechanisms include systems of markers to inform and warn future generations, barriers to impede human intrusion, and information systems external to the WIPP repository that provide for the maintenance and communication of knowledge of nuclear waste repositories.

The second purpose of the study is to provide quantitative estimates of the likelihoods of various types of intrusions. The information created through this study will be used in conjunction with other types of information, including experimental data, calculations from physical principles and computer models, and perhaps other judgments, as input to a "performance assessment." At the time of this study, the regulation governing performance assessment for the WIPP is the U.S. Environmental Protection Agency (EPA) regulation 40 CFR 191, referred to as the Standard (U.S. EPA, 1985). The EPA has defined performance assessment as a probabilistic evaluation of the potential releases of radioactive material to the accessible environment over the period of concern (10,000 years). The performance assessment is conducted using guidelines provided in the Standard.

The Futures Panel (whose work is described in this report) was established as the first part of a planned, multipart, expert-elicitation effort. The following section discusses this panel in the context of the overall expert-judgment effort to comply with the Standard.

The Regulatory Requirement for Evaluating Risks from Inadvertent Human Intrusion

Public Law 96-164 (1979) mandated the construction of the WIPP "for the express purpose of providing a research and development facility to demonstrate the safe disposal of radioactive wastes resulting from the defense activities and programs of the U.S. exempted from regulation by the Nuclear Regulatory Commission...." The WIPP is a deep geologic repository located in southeastern New Mexico, approximately 26 miles east of the city of Carlsbad. The actual disposal area is 2,150 ft (655 m) below the surface in a bedded salt formation. The WIPP has been designed for the disposal of transuranic (TRU) nuclear wastes. TRU wastes are those wastes with an atomic number greater than 92, a half-life greater than 20 years, and a concentration greater than 100 nCi/g, excluding high-level waste and/other specific waste types.

Disposal of TRU wastes is regulated by the EPA Standard. Subpart A of the Standard prescribes the operation of a disposal facility while wastes are being received. Subpart B prescribes how the repository must perform after it is decommissioned. Performance is regulated by four separate sections. Section 191.13, Containment Requirements, outlines the cumulative releases allowed for 10,000 years after disposal, based on the probability of such releases. Section 191.14, Assurance Requirements, describes the activities that must be undertaken in an attempt to improve the ability of the repository to isolate wastes from the accessible environment. Section 191.15, Individual Protection Requirements, limits radiation exposure to members of the public in the accessible environment from the undisturbed performance of the repository for 1,000 years after disposal. Section 191.16, Ground Water Protection Requirements, limits radiation concentrations in special sources of ground water from the undisturbed performance of the repository for 1,000 years after disposal.

Appendix A of Subpart B of the Standard provides the method for determining the allowable release rates of particular radionuclides and in total. Appendix B, Guidance for Implementation of Subpart B, is nonbinding guidance on the assumptions that were used in developing the Standard and on a recommended method of approaching compliance.

The United States Court of Appeals for the First Circuit vacated Subpart B of the Standard in 1987 and remanded it to the EPA for reconsideration. Until the Standard is repromulgated, the DOE and the State of New Mexico have agreed, through the Consultation and Cooperation Agreement (as modified), to undertake investigations based on the vacated Standard (U.S. DOE and State of New Mexico, 1981).

Efforts are under way, based on section 191.13 and the Guidance in Appendix B, to assess whether the WIPP has a "reasonable expectation" of complying with the Standard. Section 191.13(a) is excerpted below:

> Disposal systems for...transuranic radioactive wastes shall be designed to provide a reasonable expectation, based on performance assessments, that cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system.... (p. 38086)

Performance assessment, as defined in the Standard, involves identifying the processes and events that could impact the disposal system; determining the possible impacts of processes and events on the disposal system; and performing calculations to estimate cumulative releases considering "uncertainties" and the significant processes and events.

Significant events and processes for inclusion in the analysis are defined in the Guidance in Appendix B as having at least a 1 in 10,000 chance of occurring over 10,000 years, or as having a significant impact on the cumulative releases. Thus, events and processes with a smaller probability of occurrence can be removed from consideration (regardless of the impact). Other events and processes can be removed from consideration if the removal is not expected to significantly impact cumulative releases (regardless of the probability).

The Guidance also addresses the topic of possible disruptive events, including intrusion:

> Determining compliance with 191.13 will also involve predicting the likelihood of events and processes that may disturb the disposal system. In making these various predictions, it will be appropriate for the implementing agencies to make use of rather complex computational models, analytical theories, and prevalent expert judgment relevant to the numerical predictions. (p. 38088)

The two previous quotes make clear that attention must be paid to identifying those events that could impact the disposal system and estimating their probabilities, with the expectation that expert judgment might be used. The Futures Panel was convened to address these two needs. For performance-assessment calculations, significant events and processes are combined as appropriate to develop scenarios for the condition of the repository throughout the period of regulatory concern. For the purpose of WIPP performance assessment, a scenario is specifically defined as a combination of naturally occurring or human-induced events and processes that represents realistic future changes to the repository, geologic, and geohydrologic systems that could effect the escape of radionuclides from the repository and release to the accessible environment (Guzowski, 1990). Numerous computer codes are used to calculate cumulative releases of radionuclides to the accessible environment. These cumulative releases, when combined with the probabilities of the scenarios, are used to develop a complementary cumulative distribution function (CCDF). A CCDF, which plots cumulative releases of radionuclides to the accessible environment over 10,000 years versus the probability that a particular release will be exceeded, is compared to the limits established in Appendix A of the Standard to assess compliance with the Standard. Thus, expert judgment, through the Futures Panel, can be used to estimate probabilities of scenarios and to ensure that the simulated scenarios encompass a wide variety of alternative futures.

The undisturbed performance of the repository, as mentioned in the Individual Protection Requirements and the Ground Water Protection Requirements, is defined as "predicted behavior of a disposal system, including the consideration of the uncertainties in predicted behavior, if the disposal system is not disrupted by human intrusion or the occurrence of unlikely natural events." Previous calculations for the WIPP have shown that radionuclides will not migrate out of the undisturbed repository/shaft system for 50,000 years, much longer than the 1,000 years called for in these sections of the Standard (Marietta et al., 1989). After naturally occurring events and processes have been screened out, human-intrusion activities appear to be the events with the potential to be the failure mode of major concern. The impact of human intrusion on repository performance must be examined and included in performance-assessment calculations. The severity of such human intrusion, which must be considered for comparison with the Standard, is limited by the Standard itself.

> However, the Agency assumes that the likelihood of such inadvertent and intermittent drilling need not be taken to be greater than 30 boreholes per square kilometer of repository area per 10,000 years for geologic repositories in proximity to sedimentary rock formations.... Furthermore, the Agency assumes that the consequences of such inadvertent drilling need to be assumed to be more severe than: (1) Direct release to the land surface of all the ground water in the repository horizon that would promptly flow through the newly created borehole to the surface due to natural lithostatic pressure--or (if pumping would be required to raise water to the surface) release of 200 cubic meters of ground water pumped to the surface if that much water is readily available to be pumped.... (p. 38089)

Current performance-assessment calculations are guided by the vacated Standard. The wide-ranging view of possible modes of intrusion by the experts may prove especially useful if the repromulgated Standard requires the consideration of modes other than drilling.

Estimates of human activities far into the future must be based on judgments rather than experimental procedures. This inherent uncertainty, along with the importance of human intrusion in performance-assessment calculations, makes this process subject to close public scrutiny. Expert judgments must be collected in a manner that addresses the need for traceable actions and believable results.

In addition to providing input to performance-assessment activities, an expert panel on future societies can advise on disposal-site markers. The most practical permanent markers to designate disposal sites are specifically mentioned in section 191.14(c) of the Assurance Requirements. As discussed in the preamble to the Standard, the Assurance Requirements were included to counteract the uncertainty inherent in the analyses for the Containment Requirements. Thus, in order "to reduce the potential harm from some aspect of our uncertainty about the future," a set of actions was outlined for implementation. Section 191.14(c) of the Standard states that "[d]isposal sites shall be designated by the most permanent markers, records, and other passive institutional controls practicable to indicate the dangers of the wastes and their location."

A plan for implementation of a marker strategy, including design characteristics, will be necessary for compliance evaluation to show that such markers can be constructed. Part of marker design would be based on the findings from studying past monuments that have stood the test of time, current materials technology, and present understanding of communication methods. A second important input to marker design would be from the Futures Panel about the possible future states of society (including the expected activities and resource needs, and the ability to interpret and heed warning markers) and how future societies might intrude upon a repository.

In addition to being necessary for simple compliance with the Assurance Requirements, the existence of markers may impact inadvertent human intrusion and should therefore be considered in the analysis of cumulative releases. This idea is stated in the following text from the Guidance in Appendix B:

> The Agency assumes that, as long as such passive institutional controls endure and are understood, they: (1) can be effective in deterring systematic or persistent exploitation of these disposal sites; and (2) can reduce the likelihood of inadvertent, intermittent human intrusion to a degree to be determined by the implementing agency.

Thus, the consideration of markers in the analysis for the Containment Requirements can provide evidence supporting a decrease in the total number of intrusions or an increase in the time to the first intrusion. The Guidance states that the implementing agency must determine the extent to which the markers are able to deter inadvertent human intrusion. To accomplish this, marker design characteristics must be developed (given current knowledge of materials, construction techniques, and communication means) and then evaluated to estimate the extent to which markers might deter human intrusion. Again, these activities start from the point of the possible future states of society.

The work of the Futures Panel is thus supported by the Standard and supporting documentation as providing both input to performance assessment in terms of expected events and probabilities and to the marker design effort in terms of the possible future states of society and modes of intrusion.

II. ORGANIZATION OF THE PANEL

The methodology employed in this study is referred to as expert-judgment analysis (Bonano et al., 1990). For some aspects of performance assessment (human-intrusion analyses in particular), conducting experiments that will provide data to resolve uncertainties is not possible. The same problem occurs in many studies involving the assessment of technological risks. When such unresolvable uncertainties do exist, the judgments of experts are often used to quantify the uncertainties and express both what is known and what is not known.

Using Expert Judgment

The formalization of expert-judgment elicitation for nuclear waste repositories is described in Bonano et al. (1990). Expert judgment is pervasive in complex analysis. Judgments about the selection of models, experimental conditions, and data sources must be made. The choice is not whether expert judgment will be used; instead, the choice is whether it will be collected and used in a disciplined, explicit manner or utilized implicitly where its role in the analysis is not as obvious.

Precursor studies have provided a structure for the collection of expert judgment. These studies include, among others, the Electric Power Research Institute (EPRI, 1986) study of seismicity in the eastern United States and the NUREG-1150 study (U.S. NRC, 1990). These studies provide models for the collection of expert judgments--models that are designed to avoid pitfalls that interfere with the collection process.

A formal expert-judgment process should consist of several well-defined activities. Such activities include creating issue statements for the experts to respond to, selecting experts and training them in probability assessment, eliciting probabilities, and processing and presenting findings.

While the NUREG-1150 study was most central in the design of this current effort, there are substantial differences between these two studies that are important to note. The goal of the expert-judgment process in NUREG-1150 was to provide uncertainty distributions for parameters and to judge the likelihood of certain phenomena. The uncertain quantities were relatively well defined and well known. In the present study of future societies, the issues are less well defined, and the experts are required to employ substantial creative effort in structuring their analyses.

Several forms of organization for experts in an elicitation process have been described (Bonano et al., 1990). One of these forms is the organization of experts into teams. A team structure is useful when disparate disciplines need to be brought to bear on a given problem. An added benefit of using teams is that communication among experts is enhanced. In contrast, when experts from different disciplines work on separate, but connected, parts of the same problem, coordination and communication among the experts must be explicitly provided for.

Sixteen experts arranged in four teams of four members each were used in this study. Each team was given the same assignment, as described in the Issue Statement and Task Statement (Appendix G). The team format was selected because the subject matter, the futures of society, is inherently multidisciplinary.

Expert-Judgment Panel

The selection of experts began with the construction of a Task Statement for the expert teams. This statement is included in Appendix G. The tasks outlined in this statement required judgments about a wide variety of possible futures, based on a wide variety of underlying societal and physical factors. The study of these underlying factors indicates that a multidisciplinary approach is needed. Because the teams were to be composed of scientists and scholars from many disciplines, the pool of candidates needed to be sufficiently broad. To achieve this end, a nomination process was employed.

NOMINATIONS

The first stage in the nomination process was the identification of persons believed sufficiently knowledgeable in the disciplines identified by SNL staff as being pertinent to the project to nominate persons to serve on the teams. The disciplines included futures research, law, physics, social science, political science, agriculture, and climatology. The nominators were identified through contacts with professional organizations such as the Society for Mining, Metallurgy, and Exploration and the American Anthropological Association. Governmental organizations such as the National Science Foundation were also contacted, as were public interest organizations such as the Natural Resources Defense Council and Resources for the Future. Simultaneously, literature searches were performed in various areas such as futures research. From these literature searches, prominent authors were identified and contacted. The editors of journals were also contacted concerning nominations.

An initial contact was almost always made by telephone to explain the project to the potential nominator. This contact was done both to determine whether the potential nominator would be able to provide nominations, and to interest the potential nominator in the project so that the likelihood of cooperation was enhanced.

The identification of nominators and the initial contacts took place during the period from April 23 through May 23, 1990. On May 23, a formal request for nominations (Appendix H) was sent to all nominators who had agreed to contribute. This letter outlined the tasks to be accomplished by the experts, provided a tentative schedule, and included a description of the criteria to be used for selection of experts. The letter invited self-nomination if the nominator deemed this to be appropriate.

During the following week, additional letters were sent to those nominators who had not responded. Several potential nominators, who were thought to be sufficiently knowledgeable that their responses were highly desirable but could not be contacted verbally, were also sent letters. In all, 71 letters requesting nominations were sent. The parties to whom these letters were addressed are shown in Appendix I.

From this effort, a total of 126 nominations were obtained. On June 6, 1990, a letter was sent to each of the nominees (Appendix J). This letter outlined the tasks to be accomplished and firm dates for the two meetings to be held in Albuquerque. The nominees, if interested and able to participate in the project, were asked to send a letter describing their interests and any special qualifications relevant to the WIPP human-intrusion study. A curriculum vita was also requested from each nominee. Letters of interest were received from 70 nominees by noon of June 25, 1990. At that time, the selection committee began deliberations, and no further responses were considered.

SELECTION OF EXPERTS

Criteria for the selection of experts were drafted for use by the selection committee. These criteria were similar to the criteria that were distributed to the nominators and nominees but also included criteria related to the balance and geographic location of the teams. The criteria are included as Appendix K.

The selection committee was composed of three university professors: Dr. G. Ross Heath of the University of Washington (oceanography), Dr. Douglas Brookins of the University of New Mexico (geology), and Dr. Stephen Hora of the University of Hawaii (decision analysis). The members of the selection committee were provided with copies of the letters of interest and the curricula vitae several days prior to the selection meeting.

III. POTENTIAL FUTURE SOCIETIES

An essential task in studying the potential for inadvertent human intrusion into the WIPP is the consideration of the possible types of future human societies. The planning for this panel involved a conscious decision to solicit opinion on the future states of society and on a variety of modes of intrusion that go beyond what the Standard requires for performance assessment. This chapter explains the methodologies employed by the teams to delineate future societies, lists the factors used in determining the possible futures, and considers alternative modes of intrusion into the WIPP.

Methodologies

The activities of future societies and their awareness of the hazards from nuclear waste are important determinants of the likelihoods of intrusion. In studying these futures, the four teams adopted individual methodologies. These methodologies represent what each team believed to be the important underlying factors impacting societal activities and intrusion, the relationships between the factors, and the extent of the impact.

BOSTON TEAM

The Boston Team analyzed alternative futures by describing future civilizations in two distinct ways. The first way began with the examination of intrusive activities and worked backward to determine the attributes of society that might lead to such intrusions. This "top down" approach led the team to define "generic" alternative futures--alternatives that are broad in scope and lack detail, but are representative of many possible futures. The second way of developing alternative futures that was employed by the Boston Team resulted in the creation of inventive, highly detailed pictures of the future. These futures were termed "point" futures by the team. Both the terms "generic" and "point" futures will be retained to describe the findings of the four teams.

When creating generic alternative futures, the Boston Team followed a consistent approach for each potential intrusion mode. This approach involved first identifying the vulnerability of the WIPP. The specific event or events that would be required to exploit the vulnerability were then analyzed. Next, the activities that could potentially require such events to take place were discussed, and an analysis of the societal and physical conditions necessary for these activities was presented. The team also identified criteria for each specific mode of intrusion that could be used to characterize the intrusion as inadvertent. Finally, initial probability assessments, in qualitative terms, were provided for each of the precursor events and activities defining the path to intrusion.

The point futures developed by the Boston Team provide a thought-provoking view of what future societies could be like. These future societies range from the WIPP becoming the nation's primary nuclear waste site to a society dominated by individuals who do not believe in science as currently practiced. The creation of alternative futures is the product of a highly imaginative process and expands the range of possible futures to consider when designing passive markers and barriers for the WIPP. These futures are not in conflict with the generic futures, but instead provide an alternative, detailed view of the future that, although of low probability because of the level of specificity, is instructive about the variety of futures that should be anticipated.

SOUTHWEST TEAM

The Southwest Team created views of the future through a forward process. This process also produced generic alternative futures. The process began with the establishment of key assumptions about the operations of the WIPP and the scope of the analysis to be provided. The team then identified environmental changes and socioeconomic factors that potentially would impact human intrusion. For each of the socioeconomic factors, a qualitative assessment of its impact on human intrusion was provided.

Five narrative futures were created by the Southwest Team. These futures were identified as

technological knowledge increases,
decline and rebuilding of technological knowledge: seesaw,
technological knowledge decreases,
altered political control of the WIPP area,
stasis (not included in probability elicitation).

These narrative futures are generic in that many possibilities are included within a single future. The probabilities of inadvertent intrusion arise from these futures by considering the probabilities of the persistence of the present political control over the WIPP, the pattern of technological development given the state of political control, and intrusion given both the state of political control and the pattern of technological development.

WASHINGTON A TEAM

The Washington A Team focused its views of the future on the relationship between earth resources and society. These futures were

continuity--continued population growth and current levels of resource consumption,

radical increase--massive increases in the consumption of world resources,

radical discontinuity--erosion of conditions in the WIPP area by major war or political change,

steady-state resources--world consumption of resources dramatically reduced through zero population growth and extensive recycling.

The first three of these alternative futures involved population growth and substantial extractive activity. In these futures, the natural environment was thought of as a source of materials and energy rather than as a human habitat. In the fourth future, humans reached an equilibrium with nature. The state of the world became constant, and there was little need for extractive activity.

The Washington A Team allowed that the future may shift among several of these alternatives at various points in time. Thus, these futures should be viewed as snapshots of what the future might be like rather than complete, mutually exclusive paths that society's development might follow. This team also provided an extensive analysis concerning loss of memory about the WIPP and the inability to use existing information.

WASHINGTON B TEAM

The second team from Washington, the B Team, constructed a four-component model of paths leading to human intrusion. The first component of the model was the state of society, both local and worldwide. These views of the future states of society were based upon the climate at the WIPP area (both natural and human-induced changes are allowed), energy and mineral costs, food supply and demand, and governance of the WIPP area. The ensuing components of the model included the level of awareness about nuclear waste, the presence of potentially intrusive activities, and the modes of inadvertent intrusion into WIPP.

The factors that underlie the Washington B Team analysis are levels of resource prices, with higher levels bringing about greater exploration and extraction, modification of the existing climate or water importation, and the ability of the government to retain sufficient control to preclude inadvertent human intrusion. The analysis was based on forming all combinations of the levels of these factors. In this way the team created a potentially exhaustive set of alternative futures.

Catastrophes, which are unfortunate events that occur over a short time and have the potential to change the course of civilization, were also considered by the Washington B Team. These events, both natural and manmade, can cause such a disruption of society that memory of nuclear waste becomes lost, and the potential for inadvertent human intrusion increases.

Underlying Factors

Each of the four teams identified factors thought to be determinants of the activities of coming societies. In some instances these factors are given in tables found in the team reports, while in other cases the factors are identified in the narrative.

Figure 2 of the Boston Team report (Appendix C, p. C-9) and Table 4 of the Southwest Team report (Appendix D, p. D-21) present such information. Neither of the Washington teams provided a table of such determinants. A review of the reports identifies some common themes about the future that seem to be most critical in judging what the future will be like.

The facets of society that most directly impinge upon inadvertent human intrusion include the rate of technological development; population growth; economic developments, including the prices of minerals and energy resources; water availability and production in the WIPP region; and the level of governmental continuity and cognizance of nuclear waste. These factors are related and cannot be treated independently. For example, the level of technological progress may have a profound effect on the world economy's need for resources. Similarly, the world population size will also impact the level of resource exploration and extraction. The relationships among factors can be even more complex. Technology may directly impact both population size and resource utilization, for instance, and population may directly impact resource utilization. Thus, technology will have both direct and indirect (through population) impacts on resource utilization.

TECHNOLOGY

Critical to future human activities is the progress that will be made in technological development. The Boston Team identified a number of specific human activities that could result in inadvertent intrusion. Many of these activities are in some way dependent upon the advancement of technology. One type of intrusive activity is excavation for the purposes of construction.

The most likely type of construction is a dam to hold water for industrial, energy, agricultural, or residential uses. Such a dam would only be constructed if a major water impoundment and supply system were to be developed. The technology to modify weather, then, may play a key role in bringing about dam development.

Resource extraction may be influenced by technology. New methods of resource exploration, similar to medical CAT scanners, may allow exploration in more nonintrusive manners than currently available. In addition, there may be new and efficient means of drilling, new fluids for solution mining, and new, rapid means of excavating.

The Southwest Team proposed that both technological innovation and technological stagnation can increase the potential for intrusion. Under technological stagnation, intrusive means would be used for resource exploration. Impacts due to technological innovation include advanced drilling techniques, methods for high-volume water desalting that may make water extraction worthwhile, deep strip-mining techniques that would reduce the cost of resource extraction, the identification of new resources, and the use of autonomous mechanical extraction techniques for minerals. Biotechnology was also identified as having the potential to develop new means for the extraction of minerals.

The Washington A Team found that the development of solar energy resources could lead to the extraction of mineral resources (both metal and nonmetals) at the WIPP. Solar energy would be used in the processing of the ores. For example, magnesium could be obtained by electrolytic separation of metallic magnesium from the ground waters at the WIPP. This team also envisioned that, in a future with radically increasing resource exploitation, machines presumably not subject to the same hazards from contact with radiation as human beings would increase the willingness of drillers to take risks. Further, the existence of such technology may lead to overconfidence in the ability of their human directors to employ them without accident. Alternatively, the Washington A Team found that technologies useful in recycling resources are necessary to reach a stable-state world. In such a world there would be little motivation for resource development, which may decrease the probability of inadvertent human intrusion.

Economic and technological developments were tied together as a single factor by the Washington B Team. Wealth is both a result of technology and a precursor to technology. Weather modification and desalination of water on a large scale were identified as technological developments having the potential for impact on the WIPP system.

POPULATION GROWTH

Increases in population will impact the WIPP through a variety of paths. First, increases in world population will translate into increased resource demands (Washington A Team). There is also the possibility of increased population density in the WIPP area and increased industrialization (Boston Team).

The Southwest Team refined the concept of local population growth to include redistribution of the population by governmental policy and voluntary motivation. Voluntary redistribution might occur because of resource exploitation opportunities, grazing or crop production, or recreation purposes.

ECONOMIC DEVELOPMENT

The role of economic development in alternative futures containing human intrusion into the repository is not as sharply defined as that of technological development. Economic development was closely tied to technological development by the Washington B Team. In fact, that team used a single underlying factor to represent both technological and economic progress. The Southwest Team appears to have implicitly taken economic development into account in their five alternative futures.

Economic development also appears implicitly in the alternative futures constructed by the Washington A Team. Here, the economic demand for resources and the political control that moderates the use of resources are fundamental in defining alternative futures. Economic development in the WIPP region appears in the assessment structures given by the Boston Team. In the analysis of injection (disposal) wells, the level of industrialization of the WIPP region plays the major role.

CONSERVATION OF INFORMATION

The persistence of information about the WIPP and the continuity of government control are intertwined. The likelihood of loss of information is apt to increase when there is a discontinuity in governmental control. Despite the close relationships between these two aspects of inadvertent intrusion, we will attempt to separate them in this discussion.

The most complete discussion of the preservation and availability of information was provided by the Washington A Team. This team identified inadequate records, inaccessibility of records, inability to understand records, ignoring of information that is understood, and lack of information regarding the effects of nearby activities as contributors to inadvertent-intrusion possibilities. The reader is referred to the Washington A Team report (Appendix E, pp. E-7 - E-10) for elaboration.

The Southwest Team identified the possibility that nuclear energy will be a short-lived phase of our economic development. In this event, some loss of memory is likely. Memory loss was identified as taking several forms. Memory about the facility may be lost, memory may be lost about the danger but not the facility, and local but not institutional memory may be lost.

During the probability elicitation sessions, the Boston Team identified four states of memory about the WIPP. Memory of the WIPP could be relatively complete, memory of the location but not of the hazards may persist, memory of the WIPP may become a legend or a myth, or all memory may be lost. While complete memory of the WIPP and its attendant dangers will deter intrusion, partial memory can serve to attract potential intruders. Knowing that something is there, but not knowing what it is or what its value may be, may serve to attract investigations such as archaeological digs or salvage operations.

The survival of information may depend upon the survival of our information systems. The Southwest Team has noted that changes in basic forms of communication are likely in the next 10,000 years. Both written and oral forms of communication may be quite different than they are today. Moreover, the means for storing information may be significantly different than the means used today. If this is so, future generations may find it difficult to access the information that we have intended for them. In a point future related to communication, the Boston and Southwest Teams identify a world in which reading is performed by machines for humans.

Alternatively, the Washington A Team believed that the probability of hazard awareness (knowledge of the location of the WIPP, the wastes contained therein, how the WIPP could be intruded upon, and the risks of an intrusion) will be high throughout the study period. This probability could be reduced to a low level due to a catastrophe eliminating both markers and barrier systems.

PERSISTENCE OF GOVERNMENT CONTROL

A recurring perception among the teams is the small likelihood of continued U.S. political control over the WIPP. Governments are seldom stable for long periods of time, certainly not for the periods of time covered by this study. In an alternative future provided by the Southwest Team, a separate nation is formed from northern Mexico and the southwestern United States at some time in the future. In a similar future provided by the Boston Team, New Mexico secedes from the United States and joins Mexico. In the chaos of the transition, information about the WIPP may be lost--except, perhaps, for local folklore about buried treasure.

The "radical discontinuity" future provided by the Washington A Team also deals with the discontinuity of governmental control. Two possibilities include erosion of conditions so that New Mexico resembles a third world nation in the future. The Washington B Team also stated that at some points during the period of interest the area around the WIPP may be inhabited "by societies that are not part of the U.S." (Appendix F, p. F-5).

Presentations made by the teams indicated that the cultural differentiation of the region adds credibility to the hypothesis of a change in government control.

A conclusion that may be drawn from the experts' views of political stability is that continued U.S. control of the WIPP for 10,000 years is unlikely. The transformation from one government to another may be disruptive and preclude the transferal of information about the WIPP. Even if U.S. control is perpetuated, the application of effective measures to warn potential intruders may not follow.

MITIGATION OF DANGER FROM NUCLEAR WASTE

If nuclear waste is intruded upon at some point in the future, the exposed waste will not neccessarily cause harm. Medical technology may have developed to a point where cancer is curable. The avoidance of the consequences of radiation could be accomplished once it is recognized that a hazard has been encountered. These points were made by both the Washington A and Washington B Teams.

The Southwest Team specifically allows for this possibility in the analysis of technologically advanced futures. In such a future, the likelihood of the waste being dangerous is very low, and thus the consequences of inadvertent intrusion are greatly mitigated. In an appendix (Appendix C, p. C-77) to the Boston Team report, Dr. Bernard Cohen presents situations where inadvertent intrusion into the WIPP will not be an issue. These situations include the determination that low-level radiation is not hazardous, that medical progress can greatly reduce the consequences of radiation, and that technology for safe redisposal has become available.

Modes of Intrusion

The underlying factors that determine the nature of future societies provide the basis for the consideration of alternative modes of intrusion into the WIPP. A summary of the modes of intrusion provided by the teams is given in Table III-1.

TABLE III-1. INTRUSION MODES

EXCAVATION	DRILLING
Archaeological	Hydrocarbons
Mineral	Water
Construction	Research
DISPOSAL/STORAGE	OFFSITE ACTIVITIES
Underground Injection	Water Impoundment
Petroleum Storage	Explosions
Additional Radioactive Waste Disposal	Water Well Field
TUNNELING	
Transportation	
Pipeline	
Mole Mining	

IV. SUMMARIES OF PROBABILITY ELICITATIONS

A probability elicitation is a formal session during which one or more experts are assisted in representing their beliefs as probability distributions. For this study, each team of four members worked with a normative specialist, an individual familiar with decision analysis and experienced in conducting this type of session. Dr. Stephen C. Hora (University of Hawaii) and Dr. Detlof von Winterfeldt (University of Southern California) were the normative specialists for this study. The sessions were tape recorded for future reference in documenting the results of the sessions. In some cases, it was necessary for the normative specialist to contact the team members for clarification of some aspect of the elicitation results.

It is important to note that the conditional probabilities found in the following tables are used in the calculation of the probabilities of intrusion by various modes. As intermediate values, it is inappropriate to round them off at this stage.

Knowledge of the WIPP was often a factor in estimating intrusion probabilities. If there is knowledge of the WIPP, the intrusion is not strictly inadvertent. The analyses, as presented by the teams, are described below and document the individual treatment of knowledge of the WIPP.

Boston Team

APPROACH AND DECOMPOSITION

The methodology employed by the Boston Team is based upon five underlying factors: the level of technology, the world population, the cost of materials, the persistence of knowledge regarding the WIPP, and the level of industrialization in the WIPP area. These factors were treated in a dependent fashion, with the level of population density and the persistence of knowledge about the WIPP depending upon the level of technology. Six modes of intrusion were considered by the Boston Team--drilling for resources, underground storage of nuclear waste, disposal of wastes through injection wells, archaeological explorations, explosive testing, and the construction of dams for water impoundment.

The frequencies of the various modes of intrusion are related to the four underlying factors through relatively complex structures. These structures are presented and analyzed in the section on the evaluation of intrusion probabilities. Table IV-1 provides a summary of those factors that are related to each mode of intrusion. In the cases of the level of technology

TABLE IV-1. BOSTON TEAM - MODES OF INTRUSION AND UNDERLYING FACTORS

Intrusion Mode	Underlying Factors
Resource Exploration and Extraction (drilling boreholes)	State of Technology Knowledge of the WIPP Value of Materials
Reopening for Storage	State of Technology State of Knowledge
Disposal by Injection Wells	State of Technology Industrial Activities
Archaeological Exploration	State of Technology Knowledge of the WIPP
Explosive Testing	State of Technology Knowledge of the WIPP
Water Impoundment	State of Technology Knowledge of the WIPP Population Density

and the level of population density, the factors appear as conditions in conditional probabilities. In the case of knowledge of the WIPP, the factor appears as a multiplier applied to the intrusion rate. For example, archaeological intrusion is fifty times more likely if knowledge of the WIPP persists as a myth than if all knowledge of the WIPP is lost.

The logical structure for resource exploration and extraction was developed assuming that gas and oil are the primary resources. Drilling activity depends upon the value of materials, which in turn depends upon the state of technology. Moderating the rate of drilling is knowledge of the WIPP, which is, in turn, dependent on the state of technology.

The Boston Team also considered the possibility that the WIPP system would, at some time in the future, be reopened for the storage of additional wastes. During such a reopening, materials may be accidentally released to the biosphere. The likelihood of such an intrusion depends directly upon knowledge of the WIPP. Once again, however, knowledge of the WIPP is dependent on the state of technology.

The frequency with which injection wells will be built depends upon the level of industrial activity and the time period. Industrial activity, in turn, depends on the level of technology.

The rate of archaeological exploration is also dependent upon knowledge of the WIPP and, therefore, indirectly dependent on the state of technology.

The structure for intrusions because of underground weapons explosions is similar to that of reopening the WIPP for additional storage.

The rate of water impoundment is influenced by the population density in the WIPP area. Population density, in turn, is dependent upon the state of technology. The moderating multiplier for the rate of intrusion is dependent on the knowledge of the past.

SUMMARY OF PROBABILITY ELICITATIONS

The assessments from the Boston Team were obtained interactively from the group. Each probability represents a combination of opinions from the individual team members. Each combination of probabilities was obtained using (1) negotiation, (2) arithmetic averaging, (3) geometric averaging, or (4) a combination of these techniques.

Underlying the analysis are the following features of potential future societies:

technology: low, moderate, or high relative to today's technology (today considered to be moderate);

world population: below 10 billion (low) or above 20 billion (high);

cost of materials: low or high relative to today's cost (today considered to be low);

knowledge of the WIPP: precise knowledge, location known but consequences unknown, a myth, or completely unknown;

level of industrial activity at the WIPP: low or high (today considered to be low).

The probabilities of the various states of society depend upon the time period in the future being considered. While the Boston Team provided the information necessary to compute rates of intrusion at several points in time (100, 1,000, and 10,000 years after closure), the performance-assessment calculations require rates of intrusion during the entire continuum from 100 to 10,000 years after closure. In order to accomplish the interpolation needed to satisfy the performance-assessment requirements, a logarithmic scale has been used. The midpoint of the logarithms of the 100-year and 1,000-year points is approximately 300 years. The midpoint of the logarithms of the 1,000-year and 10,000-year points is approximately 3,000 years.

This scale provides the motivation for using the rates calculated from the assessment at 1,000 years to represent the 2,700-year period from 300 to 3,000 years. Similarly, the 100-year rates are used for the 100- to 300-year period, and the 10,000-year rates are used for the 3,000- to 10,000-year period.

Assessments were made for each of three time periods: 0 to 300 years after the closure of the WIPP, 300 to 3,000 years after the closure of the WIPP, and 3,000 to 10,000 years after the closure of the WIPP. Dependencies also exist between the state of technology and the world population density, and the state of technology and knowledge of the WIPP.

Beginning with the state of technology, the following team probabilities were obtained (Table IV-2).

TABLE IV-2. BOSTON TEAM - STATE OF TECHNOLOGY

State of Technology	Probability of Occurrence		
	100-300 Years	300-3,000 Years	3,000-10,000 Years
High	0.80	0.70	0.80
Moderate	0.15	0.20	0.10
Low	0.05	0.10	0.10

The assessments of probabilities of future population densities were conditional on the state of technology. Probabilities of population densities as a function of the state of technology are presented in Table IV-3.

TABLE IV-3. BOSTON TEAM - PROBABILITIES OF POPULATION DENSITIES AS A FUNCTION OF THE STATE OF TECHNOLOGY

Population Density	Probability of Occurrence		
	100-300 Years	300-3,000 Years	3,000-10,000 Years
	HIGH TECHNOLOGY		
High	0.45	0.40	0.40
Low	0.55	0.60	0.60

TABLE IV-3. BOSTON TEAM - PROBABILITIES OF POPULATION DENSITIES AS A FUNCTION OF THE STATE OF TECHNOLOGY (Continued)

Population Density	Probability of Occurrence 100-300 Years	300-3,000 Years	3,000-10,000 Years
		MODERATE TECHNOLOGY	
High	0.65	0.65	0.50
Low	0.35	0.35	0.50
		LOW TECHNOLOGY	
High	0.40	0.30	0.30
Low	0.60	0.70	0.70

The probabilities provided by the individual team members were fairly consistent for both the state of technology and future population size. This was not the case, however, for the value of materials. Shown in Table IV-4 are the individual and averaged probabilities for high and low materials costs at the three future times.

TABLE IV-4. BOSTON TEAM - PROBABILITY OF VALUE OF MATERIALS

Value of Materials	Probability of Occurrence 100-300 Years	300-3,000 Years	3,000-10,000 Years
HIGH			
Average Probability	0.5125	0.325	0.325
(Individual Probabilities)	(0.7, 0.3, 0.75, 0.3)	(0.6, 0.1, 0.5, 0.1)	(0.6, 0.1, 0.5, 0.1)
LOW			
Average Probability	0.4875	0.675	0.675
(Individual Probabilities)	(0.3, 0.7, 0.25, 0.7)	(0.4, 0.9, 0.5, 0.9)	(0.4, 0.9, 0.5, 0.9)

The persistence of knowledge of the WIPP was assessed as conditional on the time period and the state of technology. The individual judgments about the four potential states of knowledge and the exact averages are shown in Tables IV-5, IV-6, IV-7, and IV-8.

TABLE IV-5. BOSTON TEAM - PROBABILITY OF PRECISE KNOWLEDGE ABOUT THE WIPP AS A FUNCTION OF LEVEL OF TECHNOLOGY

		Probability of Occurrence		
Team Member	Level of Technology	100-300 Years	300-3,000 Years	3,000-10,000 Years
1	High	1.0	0.9	0.85
	Low	0.7	0.5	0.1
2	High	0.9	0.2	0.0
	Low	0.9	0.2	0.0
3	High	0.6	0.4	0.2
	Low	0.6	0.3	0.1
4	High	0.5	0.3	0.2
	Low	0.2	0.1	0.0
Average				
	High	0.75	0.45	0.3125
	Moderate*	0.675	0.3675	0.1812
	Low	0.6	0.275	0.05

* Moderate level of technology is an arithmetic average of the values of the high and low levels.

TABLE IV-6. BOSTON TEAM - PROBABILITY OF LOCATION OF THE WIPP KNOWN BUT CONSEQUENCES UNKNOWN AS A FUNCTION OF LEVEL OF TECHNOLOGY

Team Member	Level of Technology	Probability of Occurrence		
		100-300 Years	300-3,000 Years	3,000-10,000 Years
1	High	0.0	0.0	0.05
	Low	0.2	0.1	0.2
2	High	0.0	0.2	0.0
	Low	0.0	0.2	0.0
3	High	0.2	0.3	0.2
	Low	0.2	0.3	0.1
4	High	0.1	0.3	0.3
	Low	0.2	0.2	0.1
Average				
	High	0.075	0.2	0.1375
	Moderate*	0.1125	0.2	0.1188
	Low	0.150	0.2	0.1

* Moderate level of technology is an arithmetic average of the values of the high and low levels.

TABLE IV-7. BOSTON TEAM - PROBABILITY OF THE WIPP'S EXISTENCE AS A MYTH AS A FUNCTION OF LEVEL OF TECHNOLOGY

Team Member	Level of Technology	Probability of Occurrence		
		100-300 Years	300-3,000 Years	3,000-10,000 Years
1	High	0.0	0.1	0.05
	Low	0.1	0.2	0.5
2	High	0.1	0.2	0.2
	Low	0.1	0.1	0.2
3	High	0.1	0.1	0.2
	Low	0.1	0.1	0.2

TABLE IV-7. BOSTON TEAM - PROBABILITY OF THE WIPP'S EXISTENCE AS A MYTH AS A FUNCTION OF LEVEL OF TECHNOLOGY (Continued)

Team Member	Level of Technology	Probability of Occurrence		
		100-300 Years	300-3,000 Years	3,000-10,000 Years
4	High	0.0	0.2	0.3
	Low	0.1	0.3	0.3
Average				
	High	0.05	0.15	0.1875
	Moderate*	0.075	0.1625	0.2438
	Low	0.1	0.175	0.3

* Moderate level of technology is an arithmetic average of the values of the high and low levels.

TABLE IV-8. BOSTON TEAM - PROBABILITY OF NO KNOWLEDGE OF THE WIPP AS A FUNCTION OF LEVEL OF TECHNOLOGY

Team Member	Level of Technology	Probability of Occurrence		
		100-300 Years	300-3,000 Years	3,000-10,000 Years
1	High	0.0	0.0	0.05
	Low	0.0	0.2	0.2
2	High	0.0	0.4	0.8
	Low	0.0	0.5	0.8
3	High	0.1	0.2	0.4
	Low	0.1	0.3	0.6
4	High	0.4	0.2	0.2
	Low	0.5	0.4	0.6
Average				
	High	0.125	0.2	0.3625
	Moderate*	0.1375	0.275	0.4562
	Low	0.15	0.35	0.55

* Moderate level of technology is an arithmetic average of the values of the high and low levels.

ACTIVITIES AND MODES OF INTRUSION

The states of society and the states of knowledge given in the preceding tables provide the conditions for probability assessments about potentially intrusive activities. These activities and their respective conditioning variables are listed below.

Drilling

The frequency of drilling boreholes for the exploration and extraction of resources depends on the value of materials in the ground. The value of the materials depends upon the amount of time that has passed. If material values are high, then in the near future (100 years), the number of boreholes drilled in the WIPP area will be in the range of from 0.25 to 4 times the current rate. If material prices are low, however, the rate will be only 0.1 of the rate for the high material cost case. Beyond the near future, it is unlikely that boreholes will be drilled for materials extraction in the WIPP area. Knowledge of the WIPP will moderate the drilling frequency at the WIPP, as shown in Table IV-9. As before, the multiplier is applied to the rate of intrusion.

TABLE IV-9. BOSTON TEAM - RATE OF ACTIVITY MULTIPLIERS FOR INTRUSIONS INTO THE WIPP[a]

Activities	State of Knowledge			
	Precise Location-Impacts Understood	Precise Location-Impacts Not Understood	Myth	Loss of Memory
Excavation[b]	0.50	0.90	0.70	1.00
Storage (Expand WIPP)	1.00	1.70	0.40	0.00
Boreholes	0.60	0.60	0.60	1.00
Subsurface (Archaeology)	0.25	1.00	1.00	0.02
Explosive Testing	1.00	0.00	0.00	0.00
Construction/ Impoundment	0.40	0.25	0.80	1.00

[a] The analysis of disposal by injection wells does not include the use of multipliers.
[b] The multipliers for excavation were not used because this activity was not analyzed in detail.

Storage

Additional storage of hazardous wastes may continue at the WIPP even after the original facility is closed. In the future, if knowledge of the WIPP becomes fuzzy, additional storage facilities may be created there. During the construction of such facilities, inadvertent intrusion in the form of tunneling or boring may occur. The frequency of such intrusions depends, first, upon the WIPP being reopened for expansion. This reopening is only feasible in a moderate or high technology society. Given moderate or high technology, the probability that the WIPP will be reopened in the near future (represented by 0 to 300 years) is 0.5; during the intermediate period (represented by 300 to 3,000 years) the probability is 0.6; and in the far future (represented by 3,000 to 10,000 years) the probability is 0.7. Given that the WIPP is reopened during the near or intermediate future, there will be between 1 and 10 expansions during these periods. Similarly, if the WIPP is opened for expansion in the far future, there will be between 1 and 10 expansions. These rates of intrusion are moderated by the appropriate multipliers shown in Table IV-9.

Disposal by Injection Wells

Disposal refers to the injection of industrial wastes into the ground. While this mode of intrusion involves drilling and boring, it is different from extractive drilling in that materials are injected rather than withdrawn. This difference will require that the consequences of such intrusions be modeled differently than those for drilling for extraction. Disposal activity depends upon the level of industrial activity near the WIPP. If the level of industrial activity is high, injection disposal may occur. On the other hand, if the level of industrial activity is low, it is doubtful that such activity will occur.

The rate of creation of injection wells in the WIPP area is dependent on the level of industrial activity. The level of industrial activity was assigned two levels by the Boston Team--high and low. The present level of industrial activity in the WIPP area is low. Table IV-10 contains the averaged probabilities of high and low industrial activity given the level of technology and the time period.

After the initial elicitation sessions, it was determined that insufficient information had been obtained from the Boston Team to provide a rate of disposal intrusion. The team members were requested by mail to supply rates of disposal well construction per square mile per 1,000 years for each of the three time periods under both high and low industrialization. Three of the experts responded to the request. The fourth expert was out of the country and unable to respond. The results are shown in Table IV-11.

TABLE IV-10. BOSTON TEAM - AVERAGED PROBABILITIES OF INDUSTRIAL ACTIVITY AS A FUNCTION OF THE LEVEL OF TECHNOLOGY

Level of Industrial Activity	Probability of Occurrence: 100-300 Years	300-3,000 Years	3,000-10,000 Years
	HIGH TECHNOLOGY		
High	0.6	0.65	0.65
Low	0.4	0.35	0.35
	MEDIUM TECHNOLOGY		
High	0.2	0.25	0.25
Low	0.8	0.75	0.75
	LOW TECHNOLOGY		
High	0.15	0.15	0.15
Low	0.85	0.85	0.85

TABLE IV-11. BOSTON TEAM - FREQUENCY OF INJECTION WELLS PER SQUARE MILE PER 1,000 YEARS

Level of Industrialization	Frequency of Occurrence: 100-300 Years	300-3,000 Years	3,000-10,000 Years
HIGH			
Average Probability	0.4	$1.0\overline{33}$	$4.00\overline{3}$
(Individual Probabilities)	(1, 0.1, 0.1)	(2, 0.1, 1)	(2, 0.01, 10)
LOW			
Average Probability	0.017	0.167	1.667
(Individual Probabilities)	(0, 0.001, 0.05)	(0, 0.001, 0.5)	(0, 0.001, 5)

Archaeological Investigation

In a state of partial knowledge about the WIPP, the facility may become a prime target for archaeological exploration. The rate of such investigation would be in the range of 0.01 to 4 times per 1,000-year period. The frequency would be moderated by the multipliers shown in Table IV-9.

Explosions

The testing of nuclear weapons at the WIPP may take place at some time in the future. Such testing would only take place with precise knowledge of the WIPP's location and purpose. Given that knowledge of the WIPP is precise, the rate of testing could be anywhere between 0.01 tests and 10 tests per 10,000 years. The geometric mean of the assessments provided a value of 0.3 tests near the WIPP per 10,000 years given precise knowledge.

Construction and Impoundment

Construction of dams near the WIPP may result in seepage into the repository. The likelihood of such construction depends directly on the population density, which, in turn, depends upon the state of technology and the time period. The state of knowledge about the WIPP may also moderate the frequency with which dams are built near the WIPP area.

Given a high population density, the team reported that somewhere between 1 and 20 dams might be built in the Nash Draw area adjacent to the WIPP if knowledge of the WIPP is lost. For the low population scenario, the number of dams would be between 0 and 10. Multipliers of 0.4, 0.25, 0.8, and 1.0 were provided for the four states of knowledge of the WIPP, as shown in Table IV-9.

ASSEMBLING THE JUDGMENTS

Drilling

The complexity of the decomposition provided by the Boston Team has required that the recomposition of judgments be done with the assistance of computer software. To aid in this recomposition, the computer program InDia (Influence Diagram Analysis) was employed. InDia supports generalized decision trees as described by Shachter (1986). In order to demonstrate how the calculations are performed, a single type of intrusion mode, drilling, has been selected. The manual calculations will be presented for this mode of intrusion in the near future (0-300 years after closure).

Figure IV-1 is the influence diagram for intrusion due to drilling for resources. Three different entities are represented by three symbols in the influence diagrams. The most prevalent symbol is the single oval. The single oval represents a concept that will potentially influence other concepts shown in the diagram and that possesses a probability distribution, perhaps a conditional probability distribution. Probabilities may be assigned to quantities (random variables) or qualitative categories such as myth or high. The distributions are conditional because they depend upon the predecessor concepts. An oval has also been used for the time period as a matter of

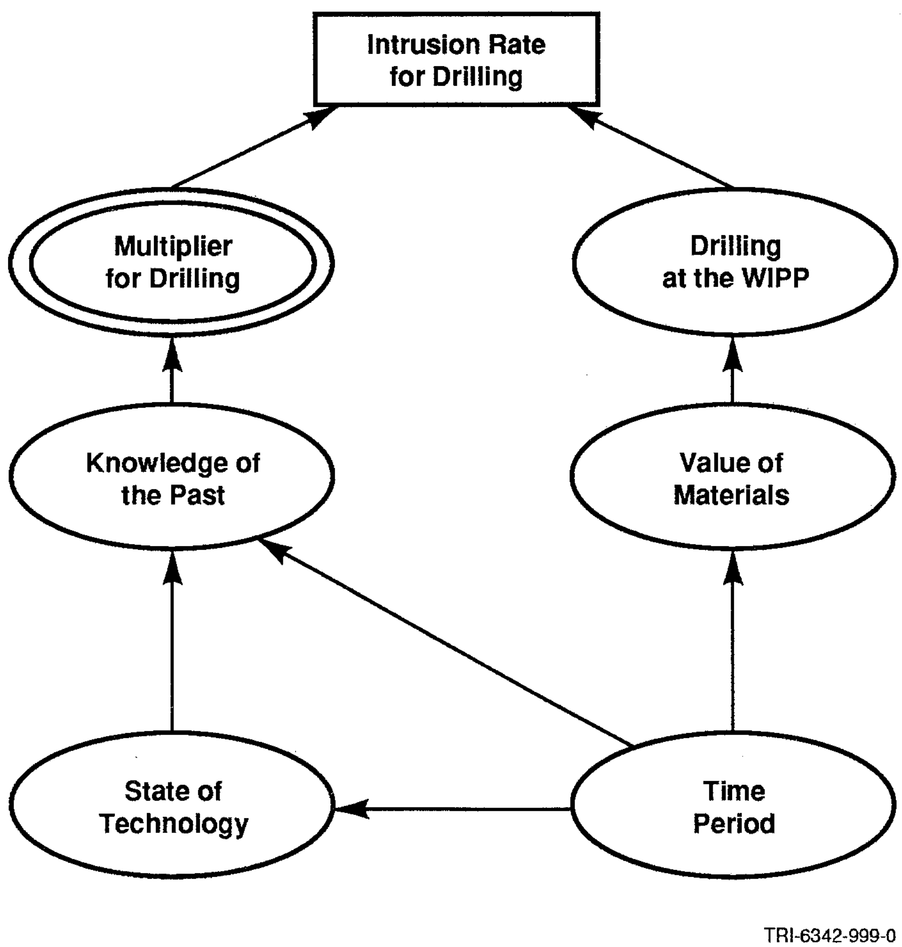

Figure IV-1. Boston Team - Influence Diagram for Resource Drilling Intrusions.

convenience. The double oval represents a deterministic quantity, usually a multiplier that is conditional on a state of knowledge. The arrows in the diagram show the directions of the influence. The third symbol is a rectangle that represents a mathematical function.

The following symbols will be used in the manual analysis of the decomposition shown in the diagram:

T_i	=	{the ith time period, i=1,2,3}
ST_j	=	{the jth state of technology, j=1,2,3}
KP_k	=	{the kth state of knowledge about WIPP, k=1,2,3,4}
VM_l	=	{the lth state of the value of materials, l=1,2}
$D_m(T_i, VM_l)$	=	{a random multiplier for drilling that depends on T_i and VM_l}
$m_d(KP_k)$	=	{a deterministic multiplier for drilling that depends on KP_k}
bhr	=	{the historic borehole rate in the region, a parameter}.

The random variable that is the drilling rate per 10,000 years can be expressed as the product:

$$\text{drilling rate} = bhr * D_m(T_i, VM_l) * m_d(KP_k). \qquad \text{(IV-1)}$$

Because D_m is a random variable and the conditions VM_l and KP_k have probability distributions that are, in turn, dependent on other conditions such as the state of technology, the distribution of D_m is not simple to develop.

As an example, suppose that the value of materials is high (l=1) and knowledge of the WIPP is mythical (k=3). Consider the determination of the drilling rate for given VM_1 and KP_3. The value of $m_d(KP_k)$ is then 0.60. In contrast, $D_m(T_i, VM_l)$ is a random variable that has the distribution shown in Table IV-12 when the value of materials is high. This distribution was created to span the range from 0.25 to 4 and have a mean of 1. The distribution is discrete rather than continuous, so that it can be accommodated by the InDia software.

TABLE IV-12. BOSTON TEAM - RANDOM MULTIPLIER FOR DRILLING

			High Value of Materials		
D_m	0.25	0.50	1.00	2.00	4.00
Prob	0.19	0.19	0.50	0.06	0.06
			Low Value of Materials		
D_m	0.01	0.1	0.25	0.5	
Prob	0.35	0.5	0.075	0.075	

Combining bhr, the historic borehole rate of 83 boreholes per square mile per 10,000 years, with $m_d(KP_k)$ = 0.6 and the above distribution for $D_m(T_i, VM_l)$, the conditional distribution for the average number of boreholes per square mile per 10,000 years is obtained, which is shown in Table IV-13.

TABLE IV-13. BOSTON TEAM - CONDITIONAL DISTRIBUTION FOR THE AVERAGE NUMBER OF BOREHOLES PER SQUARE MILE PER 10,000 YEARS (FOR GIVEN EXAMPLE)

$bhr{*}D_m{*}m_d$	12.45	24.9	49.8	99.6	199.2
Prob	0.19	0.19	0.5	0.06	0.06

The probability of the conditions of the above distribution is obtained in the following manner. Considering only the near future time period, the probability of both high material values and mythical knowledge of the WIPP is derived from the state of technology in the following manner:

$$P(KP_3, VM_1) = \sum_{j=1}^{3} P(KP_3 | ST_j)\ P(VM_1)\ P(ST_j) \qquad \text{(IV-2)}$$

$$= (0.05)(0.5125)(0.8) + (0.075)(0.5125)(0.15) + (0.1)(0.5125)(0.05) = 0.029$$

where KP_3 symbolizes the state of knowledge "myth," VM_1 symbolizes high value of materials, and the three values of ST_j are high, moderate, and low.

For each of the six sets of conditions, a different distribution for the borehole drilling rate is derived. These conditional distributions are then combined using the probabilities of the conditions. For the borehole drilling rate, the combined distribution is given in Table IV-14.

TABLE IV-14. BOSTON TEAM - DISTRIBUTION FOR EXPECTED NUMBER OF BOREHOLES PER SQUARE MILE PER 10,000 YEARS

	Probability		
Number of Boreholes	0-300 Years	300-3,000 Years	3,000-10,000 Years
0.498	0.153	0	0
0.83	0.022	0	0
4.98	0.218	0	0
8.3	0.032	0	0
12.45	0.116	0	0
20.75	0.017	0	0
24.9	0.116	0	0
41.5	0.017	0	0
49.8	0.218	0	0
83	0.032	0	0
99.6	0.026	0	0
166	0.004	0	0
199.2	0.026	0	0
332	0.003	0	0

In the intermediate and far futures, drilling is not apt to occur, and thus the drilling rate is set at zero.

The method of recombining the probability assessments for each of the other modes of intrusion is similar. The underlying factors may vary, however, and the exact form of the decomposition will vary. Influence diagrams for each of the other modes of intrusion are given in Figures IV-2 through IV-6. The recombined distributions for each mode of intrusion and time period are given in the following sections.

Reopening the WIPP for Additional Storage

The structure for intrusions from expansions of the WIPP to increase storage is shown in Figure IV-2. For each of the three time periods, standard conditional probability calculations yield probabilities of no expansion of 0.577, 0.930, and 0.946, respectively. If there are one or more expansions, then the distribution of the number of expansions is given as a uniform distribution on the integers 1 through 10, which is, in turn, modified by the multiplier that reflects the influence of knowledge of the past. Rather than applying the multiplier to each of the integers directly, we have chosen to apply the multiplier to the number 10 and create a uniform distribution on the numbers 1 through 10*multiplier. This relationship retains the integer nature

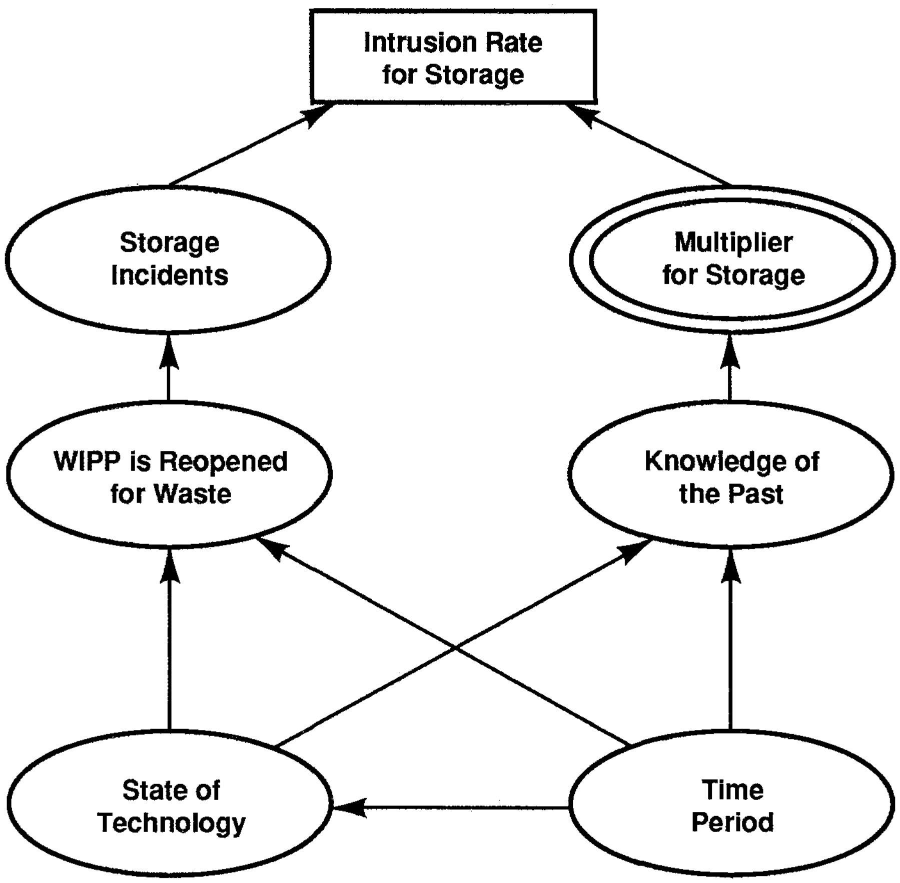

Figure IV-2. Boston Team - Influence Diagram for Expansion of the WIPP.

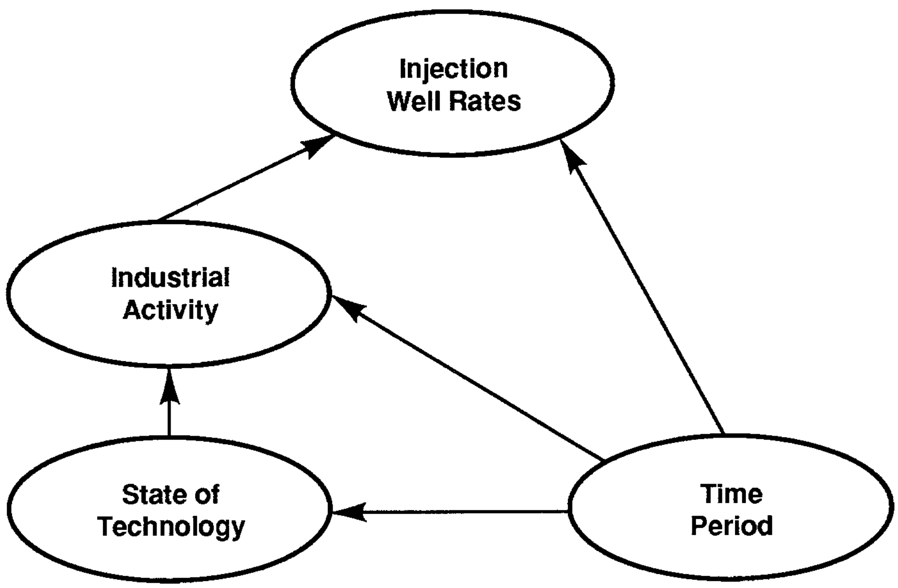

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Figure IV-3. Boston Team - Influence Diagram for Disposal by Injection Wells.

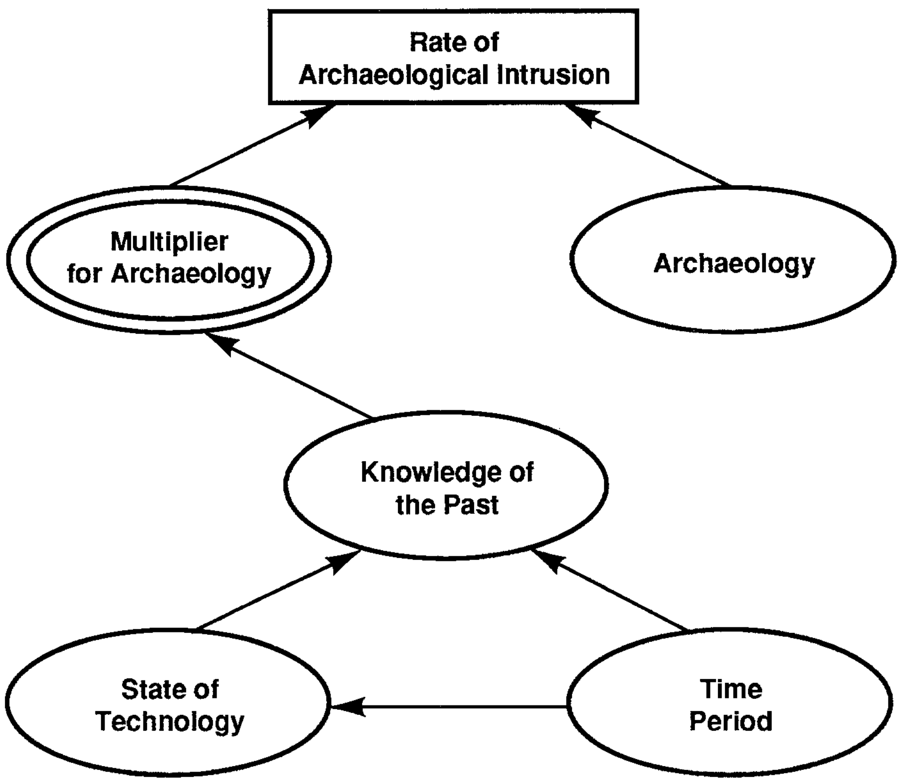

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Figure IV-4. Boston Team - Influence Diagram for the Rate of Archaeological Investigation.

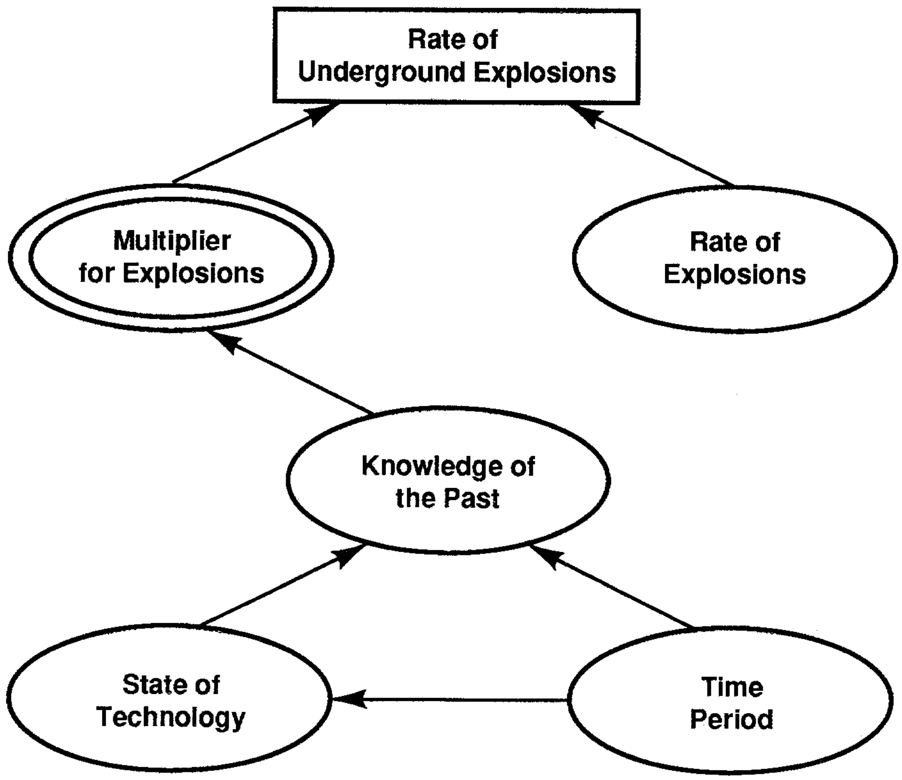

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Figure IV-5. Boston Team - Influence Diagram for the Rate of Underground Explosions.

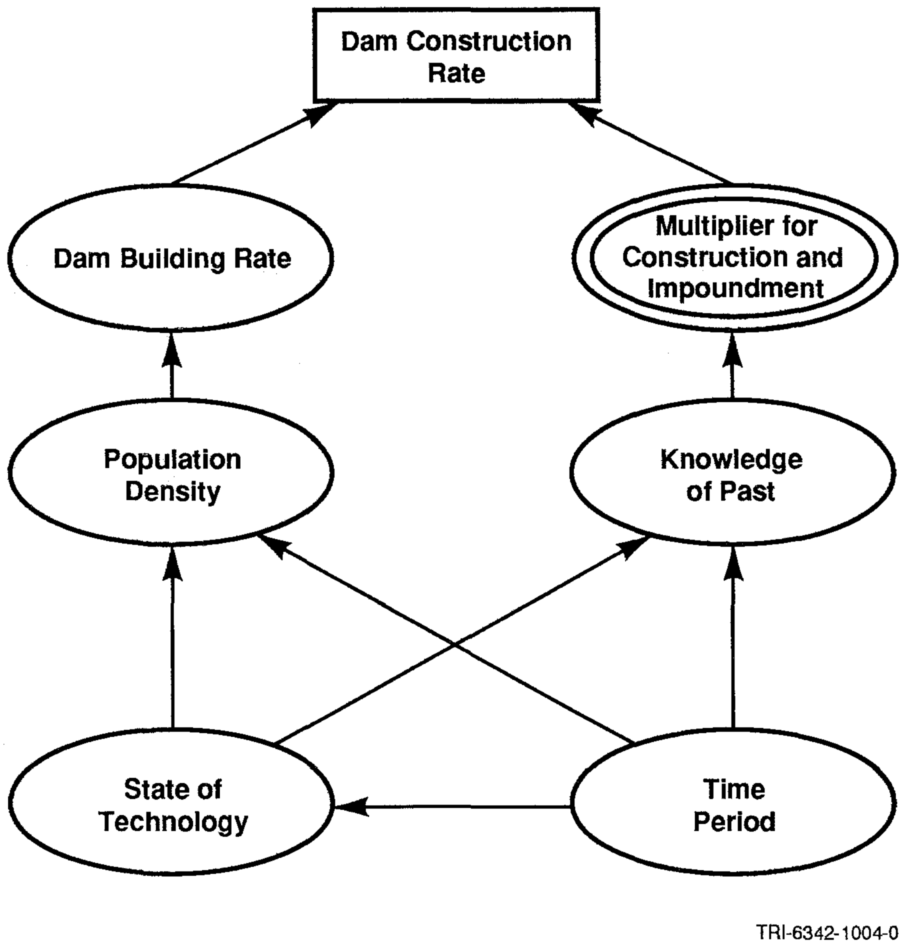

Figure IV-6. Boston Team - Influence Diagram for the Rate of Dam Construction.

of the number of intrusions. For example, if the multiplier is 0.4 (the WIPP is a myth), the distribution of the number of intrusions, given at least one intrusion, is uniform over the integers 1 through 4.

The resulting recompositions for the three time periods are shown in Table IV-15.

TABLE IV-15. BOSTON TEAM - PROBABILITY OF NUMBER OF EXPANSIONS OF THE WIPP WITH RELEASE OF MATERIAL

Number of Expansions	0-300 Years	300-3,000 Years	3,000-10,000 Years
0	0.577	0.930	0.946
1	0.044	0.008	0.008
2	0.044	0.008	0.008
3	0.044	0.008	0.008
4	0.044	0.008	0.008
5	0.037	0.005	0.003
6	0.037	0.005	0.003
7	0.037	0.005	0.003
8	0.037	0.005	0.003
9	0.037	0.005	0.003
10	0.037	0.005	0.003
11	0.002	0.001	0.001
12	0.002	0.001	0.001
13	0.002	0.001	0.001
14	0.002	0.001	0.001
15	0.002	0.001	0.001
16	0.002	0.001	0.001
17	0.002	0.001	0.001

Each expansion does not necessarily generate an intrusion. The assessed probability that any given expansion will generate an intrusion into the previously stored waste is 0.01. If this mode is to be studied further, it will be necessary to generate the number of expansions per time period and then generate binary random variables to determine if each expansion has resulted in an intrusion.

Waste Injection Wells

The rate of creation of waste injection wells is dependent on the time period and the level of industrial activity. In turn, the level of industrial activity is dependent upon both the time period and the state of technology. Three resulting distributions were obtained for the rate of injection well creation per square mile per 1,000 years. The distributions are shown in Table IV-16.

TABLE IV-16. BOSTON TEAM - DISTRIBUTION FOR EXPECTED NUMBER OF INJECTION WELLS PER SQUARE MILE PER 1,000 YEARS

	Probability		
Number of Injection Wells	100-300 Years	300-3,000 Years	3,000-10,000 Years
0	0.161	0.160	0.147
0.001	0.161	0.160	0.147
0.01	0	0	0.186
0.05	0.161	0	0
0.1	0.345	0.173	0
0.5	0	0.160	0
1.0	0.172	0.173	0
2.0	0	0.174	0.186
5.0	0	0	0.147
10.0	0	0	0.187

The means of the three distributions are 0.21, 0.62, and 2.9 wells per square mile per 1,000 years in the near, intermediate, and far periods, respectively.

Archaeological Investigation

The rate of archaeological investigation is tied to knowledge of the WIPP. Total memory and total loss of memory will decrease the rate of investigation, while partial memory or myth will enhance the rate of intrusion. The influence diagram in Figure IV-4 shows the relationship of knowledge of the past to the rate of archaeological investigation. The distribution of the expected number of archaeological intrusions was given to be between 0.1 and 4 with a mean of about 1.0 per 1,000 years. This rate, unmodified by knowledge of WIPP, was modeled as follows:

Expected Intrusions	0.10	0.50	1.00	2.00	4.00
Probability	0.25	0.40	0.20	0.10	0.05

Analysis of the structure yields the following probability distribution for the rate of archaeological investigation at the WIPP. The rate is given in terms of the expected number of investigations per 1,000 years (Table IV-17).

TABLE IV-17. BOSTON TEAM - DISTRIBUTION FOR EXPECTED NUMBER OF ARCHAEOLOGICAL INVESTIGATIONS PER 1,000 YEARS

	Probability		
Expected Number of Investigations	100 to 300 Years	300 to 3000 Years	3000 to 10,000 Years
0.002	0.032	0.058	0.098
0.010	0.051	0.092	0.156
0.020	0.026	0.046	0.078
0.025	0.183	0.104	0.068
0.040	0.013	0.023	0.039
0.080	0.006	0.012	0.020
0.100	0.035	0.089	0.084
0.125	0.293	0.166	0.109
0.250	0.146	0.083	0.055
0.500	0.129	0.183	0.162
1.00	0.065	0.092	0.081
2.00	0.014	0.035	0.034
4.00	0.007	0.018	0.017

The means of the distributions for the intrusion rate for the three periods are 0.27, 0.38, and 0.34 investigations per 1,000 years in the near, intermediate, and far periods, respectively.

Explosions

Weapons testing in the WIPP area might be undertaken in the future presumably because of pre-existing radioactive contamination. This possibility will only occur, however, if precise knowledge of the WIPP is maintained. During the near, intermediate, and far futures, the probabilities of no testing are 0.269, 0.585, and 0.728, respectively. If testing is undertaken, the number of tests per 10,000 years was assessed as being between 0.01 and 10. A log uniform distribution (uniform in the exponents) might be used to generate the testing rate. The rate can be low enough that no tests will occur during a 10,000-year period.

Water Impoundment (Dams)

The elicitation structure for water impoundment is shown in Figure IV-6. The underlying factors include population, knowledge of the past, and, indirectly, the level of technology. Table IV-18 displays the mean dam building rate (mean number of dams per 10,000 years) for each of the three time periods. While a single rate was assessed for the low and high population cases, the application of multipliers increases or decreases the rate, in most cases resulting in different rates for the three time periods. The distribution of the number of dams (per 10,000 years) should be constructed from the mean rate by doubling the mean rate and creating a uniform distribution from zero to twice the mean rate.

TABLE IV-18. BOSTON TEAM - DISTRIBUTION FOR EXPECTED NUMBER OF DAMS CONSTRUCTED PER 10,000 YEARS

	Probability		
Number of Dams	100-300 Years	300-3,000 Years	3,000-10,000 Years
1.25	0.043	0.112	0.079
2.00	0.383	0.234	0.163
2.50	0.041	0.088	0.053
4.00	0.377	0.268	0.234
5.00	0.067	0.128	0.236
8.00	0.027	0.068	0.081
10.00	0.061	0.102	0.155

The expected number of dams in each of the three time periods are 3.6, 4.1, and 4.9 dams per 10,000 years, respectively.

Southwest Team

APPROACH AND DECOMPOSITION

In their own paper, the members of the Southwest Team state: "Our team is varied: An astrophysicist who also writes science fiction, a decision analyst, a physical scientist turned social scientist, and a geographer" (Appendix D, p. D-6). In spite of this diversity, the team members agreed on the basic approach to the problem, the set of futures, and a decomposition that facilitated the assessment of the probabilities in response to the questions raised in the Issue Statement.

The team members examined a variety of environmental and socioeconomic factors that are relevant for distinguishing whether inadvertent intrusion may or may not occur. They considered environmental changes (seismic activity, increased moisture, increased vegetative density, and increased soil fertility) and concluded that these changes would merely be contributing factors either to facilitating intrusion (seismic activity--disrupting the existing geology/hydrology to allow greater transport of radionuclides) or to the consequences of intrusion (increased population due to increased moisture, vegetative density, and soil fertility). They examined in some detail the following socioeconomic factors:

economics,
water availability,
population change,
technological influences,
memory loss,
altered political control,
communication changes,
facility management.

Based on a qualitative assessment of the probabilities of inadvertent intrusion for different states in each of the environmental and socioeconomic factors, the team members concluded that the following alternative futures represent the key factors that would make a difference to the probability of intrusion:

steady increase: technology continues to increase,

steady decline: society stagnates and reverses,

seesaw pattern: technology cycles through declines and upward swings,

alteration of political control: the U.S. loses control over the WIPP,

stasis: a future in which everything goes right in terms of WIPP being inviolate--many activities must take place.

The authors describe each of these five alternative futures in rich detail (Appendix D), and thus we need not repeat these descriptions here. Noteworthy, however, is the qualitative description of the stasis future that leads to the conclusion that many things need to go "right" in this future, and that therefore the joint probability of the stasis future is small. This future was not evaluated mathematically. In addition, the authors seem to consider the probability of altered political control to be high, and it is discussed further in this section.

The Southwest Team arranged the five futures presented previously to represent mutually exclusive and exhaustive cases through the use of the event tree in Figure IV-7. The first three futures listed above are basically variants of social and technological development patterns. The fourth is an example of several possible variants (e.g., U.S. maintains control, control is passed back and forth between U.S. and other countries, and a superordinate government containing the U.S. assumes control). The stasis future is a special case of combining the steady-increase and the no-alteration-of-political-control patterns. In Figure IV-7, the first event node is political control, with two possible futures: alteration of political control or U.S. forever. Given the nature of political change and the historical evidence about the longevity of governments, the team members considered the U.S.-forever event to be very unlikely. The team assigned a probability of 0.001 to this alternative future. It is possible that societies could skip among the three technological development patterns and between the two types of political control throughout the study period.

The second event node refers to the state of technological development. The events at this node are the three futures described above: steady increase, steady decline, and seesaw pattern. The team members assigned preliminary conditional probabilities to these three futures as shown. The main difference in these assessments is that the team members considered it more likely that there would be a steady decline if the U.S. maintained political control than if there was altered political control.

By definition, the six resulting futures (paths through the event tree) are mutually exclusive. Also, by interpreting the boundaries of each event broadly, the six futures could be considered as exhaustive for most practical purposes. These conditions facilitated the elicitation of probabilities considerably.

At the end of each path through the event tree, the inadvertent-intrusion node characterizes whether or not there will be an intrusion. The team focused on a single intrusion because they considered more than one intrusion unlikely. The team also assigned probabilities to the events at this node. In general, they considered intrusion most likely in the seesaw pattern and least likely in the case of steady increase and steady decline. The reason for a higher probability in the seesaw pattern was that in this case memory would be lost, but the technology for intrusion is likely to be regained. The reason for the low probabilities in the steady-decline future was that the technology for intrusion would be lost. The reason for the low probability in the steady-increase future was that the ability to detect the wastes and understand their harmfulness would likely exist and prevent inadvertent intrusion.

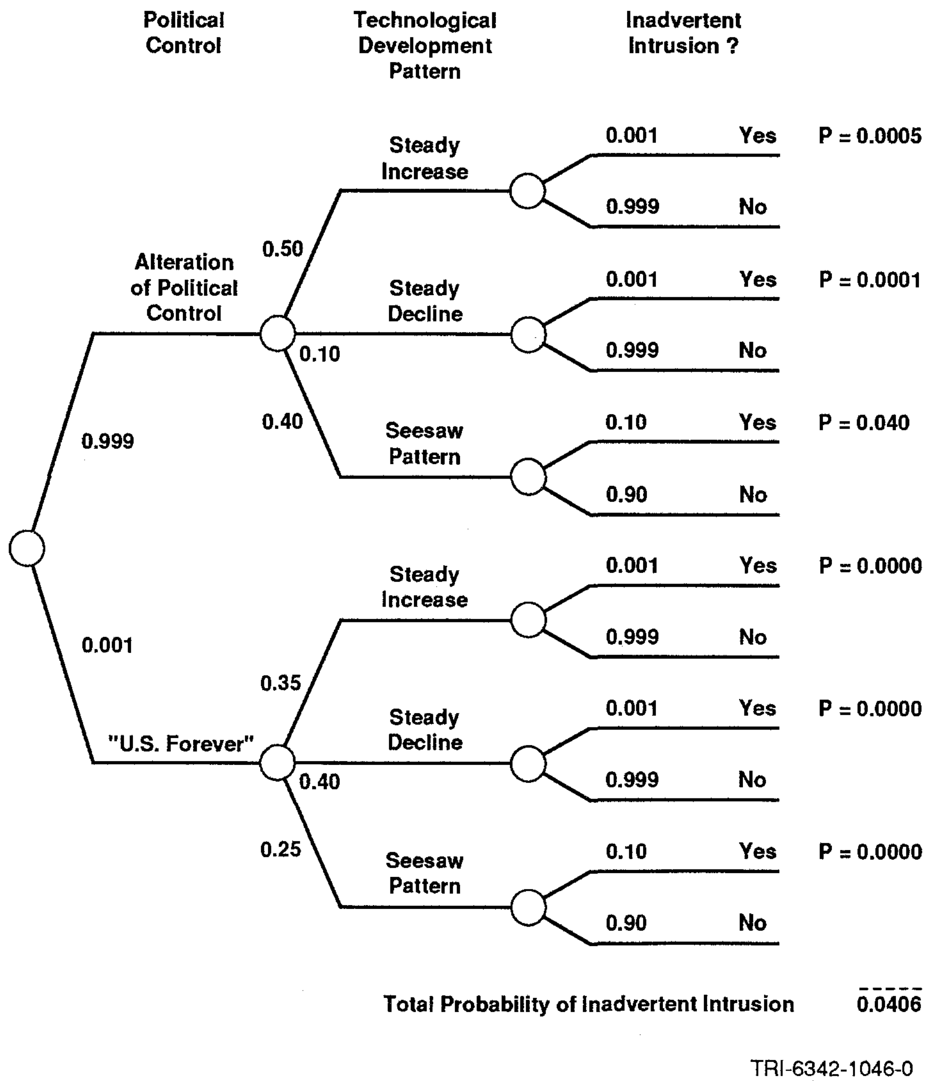

Figure IV-7. Southwest Team - Alternative Futures for Inadvertent Intrusion (Assessments Prior to Elicitation).

Given the structure in Figure IV-7 and their preliminary team assessments, the team arrived at a total probability of inadvertent intrusion of between 1 and 25 percent over the 10,000 years. The actual assessments differed by individual members. By far the largest contributor to this probability was the future that combined altered political control with a seesaw pattern of technological development.

ELICITATION AND RESULTS

The elicitation was fairly straightforward because the team had already defined the alternative futures in the form of an event tree and had assigned preliminary probabilities. The elicitor first discussed the structure of the futures and examined whether the team wanted to be elicited within this structure. After confirming this, he first asked the team members to separately state the 1st, 50th, and 99th fractiles of their subjective probability distribution over the probability of intrusion for the next 10,000 years. The idea was to work backwards from this very intuitive assessment to a more formal one.

Table IV-19 shows the 1st, 50th, and 99th fractiles of the subjective probability distributions over the probability of inadvertent intrusion over 10,000 years for the four team members separately. In addition, the respective group averages are shown. Team member D is the most pessimistic with respect to inadvertent intrusion, giving a median probability of 0.20 and a 99th fractile of 0.80. However, the size of the ranges of the distributions across team members are wide, covering 0.19, 0.27, 0.40, and 0.79, respectively, for the four teams' members.

TABLE IV-19. SOUTHWEST TEAM - INTUITIVE AND CALCULATED OVERALL PROBABILITY JUDGMENTS OF INADVERTENT INTRUSIONS

	Intuitive			Calculated Median
Team Member	1st Fractile	Median	99th Fractile	
A	0.01	0.05	0.20	0.03
B	0.03	0.085	0.30	0.046
C	0.001	0.041	0.40	0.041
D	0.01	0.20	0.80	0.222
Average	0.013	0.094	0.425	0.085

The average for each of the fractiles are shown in the last row of this table. In addition, the last column of the table shows the calculated medians, based on the decomposed judgments described below. The intuitive and calculated medians are compared to ensure that through the decomposition/recomposition process the opinions of the team members are correctly expressed. The first-cut intuitive medians and the calculated medians agree to a considerable extent, both among team members and in the average. This agreement may be due to the fact that team members had previously thought in terms of their decomposition and had made tentative probability judgments as well as calculations within it. Yet, even the team member who deviated from the trend of the others had these deviations clearly represented in the calculated results.

Overall, Table IV-19 indicates probabilities of inadvertent intrusion over the 10,000 years that are large enough that they must be considered in the performance assessment (both the intuitive and the calculated medians just below 0.10). While there is a wide band of uncertainty around this median, none of the team members seemed to think that the chances of intrusion are extremely low.

Next, the elicitor asked each team member separately for the probability of intrusion, given any one of the six possible futures. First, the team members considered the more likely case of altered political control and assigned conditional probabilities of intrusion to each of the three technological development patterns. Subsequently, the same judgments were made for the case of continued U.S. control over the WIPP repository.

Table IV-20 shows the individual results as well as averages. All probabilities should be interpreted as medians of the probability distributions over the probability of intrusion. This table also shows the relative probabilities assigned to the altered-political-control events (0.999) versus the U.S.-political-control event (0.001). These latter probabilities were based on a team consensus and thus were not elicited separately.

To a large extent, the pattern shown in Figure IV-7 (the seesaw technological development pattern contributes the most to the overall probability of intrusion) is repeated here with some interindividual variation. All team members agree that the seesaw future is accompanied by the highest probability of intrusion. There is some disagreement about how much the probability of intrusion decreases for the steady-decline and steady-increase futures, with team member C assuming a considerable reduction in probabilities and the other team members seeing relatively little change. The effect of moving from altered political control to U.S. political control is minor, except for team member D.

TABLE IV-20. SOUTHWEST TEAM - DECOMPOSED JUDGMENTS: PROBABILITY OF INTRUSION GIVEN THE STATE OF POLITICAL CONTROL AND PATTERNS OF TECHNOLOGY

Team Member	Increase	Decline	See-Saw
	Future: Altered Political Control - 0.999		
A	0.010	0.050	0.050
B	0.010	0.100	0.100
C	0.001	0.001	0.100
D	0.060	0.300	0.300
Average	0.020	0.113	0.138
	Future: U.S. Political Control - 0.001		
A	0.010	0.050	0.050
B	0.010	0.120	0.120
C	0.001	0.001	0.100
D	0.020	0.100	0.100
Average	0.010	0.068	0.093

The next task was to assess the probability of occurrence of each of the six mutually exclusive futures. First, the team members each stated the conditional probabilities of each of the three technological development patterns given altered political control. Next, they assigned probabilities to the three technological development patterns given U.S. control. Finally, they assigned probabilities to the two states of political control.

Table IV-21 shows the probabilities of the three technological development futures given the possible states of political control both for each individual and in terms of group averages. The overall pattern, agreed on by all team members, is that the steady-decline future has a relatively lower probability, with the other two futures dividing the major proportion of probability. There is a slight disagreement on which of the two remaining futures (seesaw or steady-increase) is the more likely one. The pattern of responses for the case of U.S. political control is quite similar.

Table IV-22 summarizes the responses to the three questions: When will there be a loss of active controls and markers, what modes of intrusion will occur at what time, and will wastes be rendered harmless? The team was fairly pessimistic with respect to society's ability to maintain active controls and effective markers. Two of the four team members stated that the loss would

TABLE IV-21. SOUTHWEST TEAM - DECOMPOSED JUDGMENTS: PROBABILITY OF PATTERNS OF TECHNOLOGY GIVEN THE STATE OF POLITICAL CONTROL

Team Member	Increase	Decline	See-Saw
Future: Altered Political Control - 0.999			
A	0.50	0.10	0.40
B	0.60	0.05	0.35
C	0.50	0.10	0.40
D	0.30	0.10	0.60
Average	0.475	0.0875	0.4375
Future: U.S. Political Control - 0.001			
A	0.67	0.13	0.20
B	0.35	0.40	0.25
C	0.35	0.40	0.25
D	0.30	0.10	0.60
Average	0.4175	0.2575	0.325

TABLE IV-22. SOUTHWEST TEAM - OTHER ASSUMPTIONS AND ESTIMATES

Loss of Active Controls and Markers (All Futures)

A	1,000 years
B	100s years
C	100s years
D	<100 years

Modes and Timing of Intrusion (Consensus)

Increase	Moles; Deep Strip Mining; Nanotech	1,000-2,000 Years
Decline	Conventional Drilling + Excavation	100-500 Years
See-Saw	Conventional Drilling + Excavation	Cycles of 1,000 Years

Wastes Rendered Harmless?

Increase	Yes (0.95-0.99)
Decline	No
See-Saw	No

likely occur within hundreds of years. One team member (A) stated that the controls and markers may last as long as 1,000 years, and one member (D) thought that the loss would occur in less than 100 years. It is probably fair to say that team member A based his judgment on an optimistic view of technology, while team member D based his judgment on a pessimistic assessment of society's cultural and social ability to maintain active control and effective markers at the WIPP. While there was no clear group consensus, it appears that any further analysis should consider the assumption that markers and active controls might be lost in about 100 years. A base case for this group might be 500 years.

ANALYSIS AND AGGREGATION

Figure IV-8 reproduces Figure IV-7 with probabilities that were calculated from the decomposed judgments described in Tables IV-20 and IV-21. In all cases, we have inserted the averaged group probabilities and conditional probabilities. As in Figure IV-7, the major contributor to the overall intrusion probability is the seesaw future assuming alteration of political control.

Group consensus was obtained on all other ancillary questions. For the steady-increase future, moles, deep strip-mining, and exotic technologies were considered the prevalent modes of intrusion, and these modes were assumed to lead to intrusion sometime between 500 and 2,000 years. For the steady-decline future, the intrusion modes were thought to be drilling and excavation, with a time frame of 100 to 500 years. For the seesaw future, the modes were again conventional drilling and excavation, occurring in cycles of about 1,000 years.

The team also agreed on the conditional probabilities that the wastes will be rendered harmless (through early detection, treatment, or other mechanisms). This possibility was considered high (0.95-0.99) for the steady-increase future and essentially zero for the other two futures.

CONCLUSIONS

From examining both the team members' intuitive probability judgments and their calculated ones, it is clear that all members consider it moderately likely (medians of 0.03-0.22) that inadvertent intrusion will occur at some time during the 10,000 period after closure of the WIPP repository. While

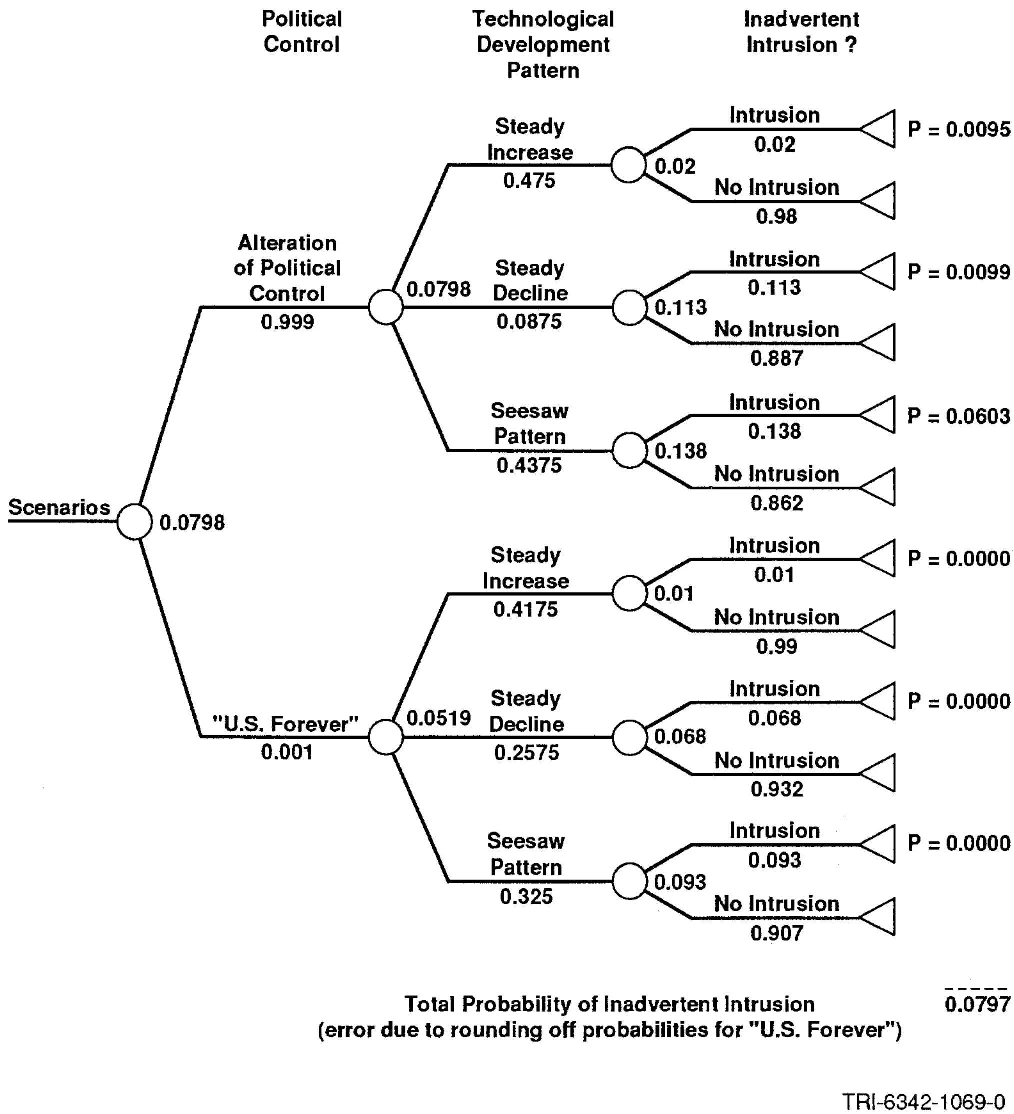

Figure IV-8. Southwest Team - Alternative Futures and Probabilities for Inadvertent Intrusion (Assessments from Decomposed Judgments). The probabilities are calculated by multiplying the numbers from left to right. The intermediate probabilities located at the circles are calculated by multiplying and summing from right to left.

team members disagreed to some extent (about a factor of 7 in their respective medians), this disagreement was not of orders of magnitude as is often found in this type of probability elicitation.

All team members considered the probability of the U.S. maintaining political control of the WIPP over the long term to be very small (0.001). The results are therefore strongly shaped by their (implicit and--in the decomposition--explicit) assumption that the U.S. loses political control as described, for example, in the alternative future of a "Free State of Chihuahua" (Appendix D, p. D-31). The following comments can therefore concentrate on the case where political control changes.

The main contributor to the overall probability of intrusion is the seesaw future. The reason for the dangers in this future is the belief that memory, markers, and control are lost, while the technology may be regained to intrude. The steady-increase future contributes a small probability, but the potential danger resulting from intrusion is negated by the team's assessment of a high probability that the waste will be rendered harmless by the time this intrusion will occur. The steady-decline future itself is the least probable and carries with it only a one-time possibility for intrusion, presumably after memory and control are lost but while the technology still exists for intrusion. This analysis indicates a total probability of intrusion of about 8 percent over 10,000 years.

As a conclusion, the team itself writes: "The probability of inadvertent intrusion into the WIPP repository over the next ten thousand years lies between one and twenty five percent" (Appendix D, p. D-43). They also observe that there is a high likelihood of altered political control over the next 200 years. Further, following their description of the possible exotic modes of intrusion, they warn of intrusions from all sides of the repository. They point out the possibility that members of future generations may not speak any presently known language.

The team recommends that markers be developed that address these issues, and that a "no-marker" strategy at least be considered as a possibility to deter curiosity seekers. They also recommend that a standing group devoted to further alternative futures analysis and marker development be established.

Washington A Team

APPROACH AND DECOMPOSITION

The Washington A Team began by listing factors that affect the likelihood of human intrusion and subsequently defined several alternative futures that are distinguished with respect to these factors (Appendix E). The list of factors that affect the likelihood of human intrusion includes

(in)-sufficiency of information:
- records that are inadequate,
- records that are inaccessible,
- records that are not understandable,
- records that are ignored,
- lack of understanding of the side effects of activities in spite of records;

ability to intrude;

interactions with the WIPP:
- search for resources,
- unrelated activities near the WIPP (e.g., tunnels, dams).

The team members developed a detailed argument regarding the insufficiency of information about the existence and danger of the WIPP wastes. Essentially they make the point that information inherent in markers or records needs to satisfy many criteria besides physical survivability to be an effective deterrent against intrusion. The information has to maintain its message value (e.g., not deteriorate), remain accessible (e.g., not shelved away in obscure libraries), and be understandable (e.g., readable by generations who may not speak any language known to current civilizations). But even if all these conditions are met, the team members felt that the records may be ignored or their implications for some activities may not be understood. Overall, the team argues that records are very unlikely to be an effective means of discouraging intrusion.

The ability to directly intrude the WIPP repository by technical means such as excavation or drilling is certainly an important factor for assessing the likelihood of intrusion. The team felt that, while there exists a possibility that a future society may lack the ability to intrude the repository, there is a history of society's ability to do so. Moreover, the team members felt that intrusion could also occur by indirect means (e.g., water withdrawal or explosions) that could occur in spite of effective information about the WIPP (Appendix E, p. E-10).

Exploration and development of resources is the most likely type of human interaction with the WIPP, according to this team. However, the team stresses, and the elicitation confirms, the importance of indirect interactions with the WIPP, based on inadequate understanding of how the indirect activity interacts with the wastes in the repository. The team lists several possible interactions: construction of a deep tunnel on route from Texas to California, building a dam, drilling a field of wells, and setting off large explosions (Appendix E, pp. E-11 - E-12).

Knowledge, ability, and type of interactions formed the backdrop against which the team created four alternative futures that, for practical purposes, are considered mutually exclusive and exhaustive. They are listed below and discussed in the following text:

continuity,
radical increase,
discontinuity,
steady-state resources.

The authors note that the future does not necessarily need to follow any of these alternatives exclusively, but may shift among them, perhaps even several times during the 10,000 years considered (Appendix E, p. E-18). For the purpose of the elicitation, the alternative futures were assumed to be mutually exclusive and exhaustive.

The continuity future is essentially an extrapolation of today's growth patterns. Population growth, technology development, and resource exploration and extraction are to grow roughly at a rate that continues past trends. The modes of intrusion would be conventional drilling and excavation. In this future, intrusion could happen at any time, with a greater chance of occurring in the next 200 years.

The radical-increase future assumes that society's willingness and ability to extract resources will grow at a much higher rate than what current extrapolations suggest. The modes of intrusion would include unintentional intrusion by machines that would take over the tasks of exploration and extraction of resources, accidentally drilling tunnels or pipeline ducts through the repository, and conventional drilling and excavation. Intrusion under this future is likely to occur within the next 200 years as the rate and effectiveness of resource extraction increases.

The discontinuity future consists of two sub-futures. One assumes a major war that leads to a demise of western civilization as we know it. The other involves radical political changes, leading to substantial reconfigurations of political power and socioeconomic development in the southwestern region of the United States. In both sub-futures, the main path to intrusion is the loss of knowledge about the WIPP coupled with eventual resource exploration and extraction. The time frame of intrusion would be about 200 years after the major changes (through war or political upheaval) occurred.

The fourth future assumes a reversal in the current trends of resource extraction and consumption. The emphasis of resource development is on steady state rather than growth. Population shows no growth or even negative growth, and energy is produced primarily by use of renewable resources. The authors state that "under such a scenario there would be little pressure to drill for gas or oil at or near the WIPP site, and almost certainly less interest in other possible resources. As long as such values prevailed, the likelihood of inadvertent intrusion at WIPP would be minimized" (Appendix E, pp. E-29 - E-30). However, intrusion by indirect means (a dam or well field for example) could still occur.

With the exception of the discontinuity future, these alternative futures are largely driven by the prevailing societal value system regarding growth and resource use and the political will to implement these values. The continuity future is characterized by a "value system which postulates that the resources of the earth exist to be developed by man as soon and as completely as possible with relatively little respect paid to environmental constraints" (Appendix E, p. E-19). The radical-increase future "postulates a massive increase in our current willingness to use all the earth's resources for human material needs..." (Appendix E, p. E-25). The steady-state future "involves a future in which current attitudes toward the control of nature through technology have been radically altered.... Growth for growth's sake, regardless of the ecological consequences, has been repudiated as a dominant societal ideal" (Appendix E, pp. E-28 - E-29). Thus, the assessment of alternative future probabilities becomes, to some extent, an assessment of future societal values and political will--an exceedingly difficult task.

The Washington A Team had not developed a particular decomposition prior to elicitation, but they had stated modes and timing of intrusion for each future. In the first three alternative futures, a crucial time period was the first 200 years. In the steady-state future, there would be a fairly low probability of intrusion, distributed over the whole time period of 10,000 years. Further, in the continuity and discontinuity futures, the main modes of intrusion would be conventional drilling and excavation for the purposes of resource exploration and extraction. In the radical-increase future, more exotic modes of intrusions like machine intrusion, tunnels, and deep pipelines would be added to conventional drilling and exploration. In the steady-state future, the intrusion would likely come from activities near the WIPP but unrelated to the repository (e.g., from building a dam or from irrigation).

Knowledge of the WIPP and existence of active controls are another important aspect of decomposition. The team members made an important point that knowledge, while perhaps existing somewhere, may not be effective in deterring intruders. Thus, existence of effective knowledge was a major conditioning factor that could radically change the assessed probabilities of intrusion. Three of the four team members were also quite pessimistic about the possibility of maintaining active controls for any period of time, even for 100 years. One member was much more optimistic in this regard, although he felt that this opportunity for long-term active control had to be bought at substantial human costs, possibly affecting human rights and other aspects of the culture and value system of society.

A decomposition that captures the conditioning variables above is shown in Figure IV-9. Clearly, the main variable that determines the probability of intrusion is the nature of society. The four alternative futures were described by the team as time independent, even though they acknowledge that futures can alter and several futures could occur in sequence during the 10,000 years. For simplification, this decomposition as well as the subsequent elicitation will ignore such sequential aspects and assume that these futures are mutually exclusive and exhaustive.

The probabilities of all other events are a function of time. The first event node is characterized by either existence or nonexistence of effective active controls. If active controls exist at a given time, there will be no intrusion. The second event node defines whether effective information about the WIPP exists. If there are no active controls, but if there is effective information, there still may be some chance of intrusion, though this chance would be lower than if there is no effective information. Finally, a chance node defines whether there is intrusion or not given no active controls and effective or no effective information. This decomposition suggests first to assess probabilities for the four futures and subsequently to assess probabilities of active controls, effective information, and intrusion as a function of time and conditional on each future.

The team chose not to address the issue of whether at any given time the wastes might be detected or rendered harmless (e.g., by medical cures of cancer or by processing them on contact). The team members considered this task not to be part of their charter and referred this assessment to the analysis addressing issues related to consequence assessment.

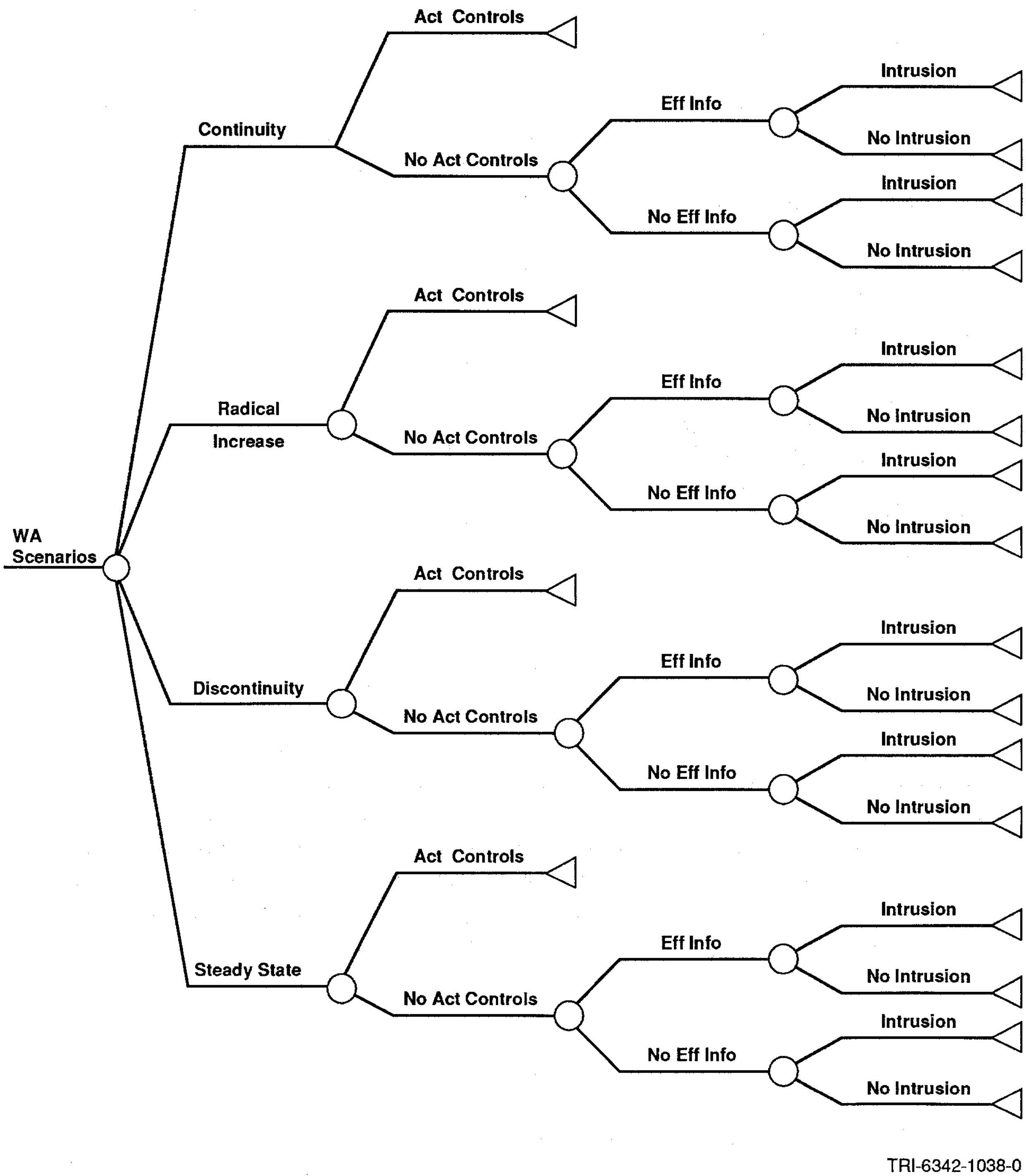

Figure IV-9. Decomposition of the Washington A Team.

ELICITATION AND RESULTS

The decomposition in Figure IV-9 was not available at the beginning of the elicitation session, and the structure represented in that figure only emerged during the elicitation. The main idea of the elicitation was first to obtain rough estimates of the probability of one or more intrusions during the 10,000 years and then to back up these rough estimates with successively detailed decomposed estimates.

The team members first presented their reasoning for the four alternative futures, and they stated individually and separately their rough guesses of the intrusion probability. One member (C) gave the 5th and 95th fractiles in addition to the median. Another member (D) specified the functional form (log-normal) in addition to these two fractiles. Analysis of the data showed that team member D apparently thought that intrusion was much less likely to occur than the other three team members did. Discussion revealed that this team member felt that there was a substantial chance of maintaining active control over the repository for a significant period of time and that his more optimistic view of the low probability of intrusion was based on that assumption.

Table IV-23 shows the team members' elicitation results for the first-cut intuitive judgments of the probability of intrusion over the 10,000-year period. The last column shows the calculated median intrusion probabilities based on the decomposed probability judgments p(future) and p(intrusion|future). The intuitive and calculated medians are compared to ensure that through the decomposition/recomposition process, the opinions of the team members are correctly expressed. This table shows a considerable amount of agreement among team members. Team member D, however, has a distinctly lower median. As he stated, this result was influenced by the fact that he gave significant credence to the effectiveness of active controls. In his decomposed judgments, he had explicitly assumed no active controls, and, therefore, his calculated intrusion probability is much higher.

The first layer of decomposition consisted of determining the probability of intrusion conditional on each future as a function of time, intuitively averaging out other contingencies such as the existence of active controls and effective information. In terms of Figure IV-9, this determination is equivalent to assessing p(intrusion at t|future). Because of the overall sense of the team that most of the intrusions would occur during the first 200 years, this probability was not assessed as a continuous function of time but rather for two time periods: the first 200 years and the following 9,800 years. Each team member gave his judgment separately.

TABLE IV-23. WASHINGTON A TEAM - INTUITIVE AND CALCULATED OVERALL PROBABILITY JUDGMENTS OF INADVERTENT INTRUSIONS

Team Member	Intuitive: 5th Fractile	Intuitive: Median	Intuitive: 95th Fractile	Calculated Median
A	n.a.	0.30-0.50	n.a.	0.37
B	n.a.	almost 0.50	n.a.	0.37
C	0.01	0.30	0.50	0.40
D	0.01	0.07	0.50	0.70

Table IV-24 shows the results of the probability judgments at this layer of decomposition. The probabilities of intrusion over the entire 10,000-year period are the sum of the probabilities of the near and far future and are not time averaged (i.e., there is not a probability per year). For a number of reasons, team member D felt uncomfortable answering the questions regarding the time dependency of futures 1-3, and this lack of response is indicated by a "n.a." Overall, the agreement among the other three members is very good. Clearly, the continuity and the discontinuity futures are responsible for the largest probabilities of intrusion averaged over the entire 10,000 years. These futures are the ones with a high probability of intrusion in the 200-10,000-year time period. The steady-state future has the lowest overall probability and only a 0.01 probability of intrusion within the first 200 years.

Next was the elicitation of the probability of futures, p(future). These probabilities were again assessed individually. First, the elicitor asked for a rank order of the alternative futures and for an estimate of the distribution of the probabilities among the various futures. Subsequently, he asked for point estimates of the probabilities. Table IV-25 shows the elicited probabilities of the four alternative futures, both separately for each team member and for the average. The trend, with the exception of team member D, was to assign higher probabilities to the continuity and steady-state futures and relatively lower probabilities to the other two futures. The main difference was in terms of the degree of optimism about the possibility of achieving a steady-state future. Team members A and B agreed that this possibility was as likely to happen as not (0.50), while the other two team members were increasingly pessimistic.

TABLE IV-24. WASHINGTON A TEAM - DECOMPOSED JUDGMENTS: PROBABILITY OF INTRUSION GIVEN THE ALTERNATIVE FUTURES

Team Member	Continuity	Radical Increase	Discontinuity	Steady State
		Over the Entire 10,000 Years*		
A	0.30	0.89	0.85	0.10
B	0.30	0.89	0.85	0.10
C	0.30	0.60	0.85	0.10
D**	0.50	1.00	0.85	0.10
Average	0.35	0.85	0.85	0.10
		Split up by Time Periods		
0-200 Years***				
A	0.09	0.80	0.43	0.01
B	0.09	0.80	0.43	0.01
C	0.09	0.54	0.43	0.01
D	n.a.	n.a.	n.a.	0.01
200-10,000 Years***				
A	0.21	0.09	0.42	0.09
B	0.21	0.09	0.42	0.09
C	0.21	0.06	0.42	0.09
D	n.a.	n.a.	n.a.	0.09

* The probabilities are the sum of the probabilities from the two time periods and are not time averaged (i.e., there is not a probability per year)

** With no active controls; otherwise much smaller

*** Uniform distribution over years

TABLE IV-25. WASHINGTON A TEAM - DECOMPOSED JUDGMENTS: PROBABILITY OF ALTERNATIVE FUTURES

Team Member	Continuity	Radical Increase	Discontinuity	Steady State
A	0.21	0.18	0.11	0.50
B	0.21	0.18	0.11	0.50
C	0.30	0.25	0.15	0.30
D	0.30	0.30	0.30	0.10
Average	0.255	0.2275	0.1675	0.35

The next task was to estimate the probability of the existence of active controls (AC) as a function of time and the particular alternative future. In other words, the team members individually estimated p(AC at time t|future). All four team members directly stated a functional form that related probability to time. Figure IV-10 shows the plots of probabilities of the existence of effective controls as a function of time and future. The plot labelled continuity indicates the consensus opinion of team members A, B, and C about the probability of the existence of active controls given the continuity future as a function of time. Specifically, the team members felt that this function should be exponentially decreasing, with a halving period of 25 years between 0 and 200 years. They also asked the elicitor to fit the curve to go through about 0.03 at year 200. Applying the rule of "halving" the function yielded a functional form of $y=(0.5)^{x/25}$, which has an ordinate of 0.004 at 200 years. Because this was close enough to the intended value (indicating that at 200 years the probability was extremely small), we used this function for analytical purposes.

These three team members also stated that the shape of the function would remain the same for the radical-increase future but with the effectiveness of the controls reduced by 0.3, as shown in Figure IV-10. Further, they indicated that the probability of active controls would be even less than that in the discontinuity future but did not specify how much less.

The three team members also reached a consensus regarding the steady-state future. They agreed that in this future in 200 years there would be a 0.10 chance of still having active controls. An exponentially decreasing curve was fitted to go through the 0.10 point and has a halving period of 50 years.

Team member D had a minority opinion, which is shown in Figure IV-11. He felt that the probability of maintaining effective active controls would decrease linearly (rather than exponentially), beginning for the continuity future with 1.00 and going to 0.90 in 200 years and to 0 in 2,000 years (Figure IV-11). He agreed that, in the radical-increase future, the effectiveness part of the active controls curve would be depressed by about 0.30 (Figure IV-11). He also indicated that, in the case of the discontinuity future, the probabilities of maintaining active controls would be even lower. He did not provide any statements regarding the steady-state future, but he obviously considered the chances of maintaining control to be fairly high for this future.

The final task was to estimate the probability of the availability of effective information about the WIPP as a function of future and time. This information was elicited for the first 200 years only because the team members considered it extremely unlikely that such information would exist and be effective in preventing intrusion after 200 years.

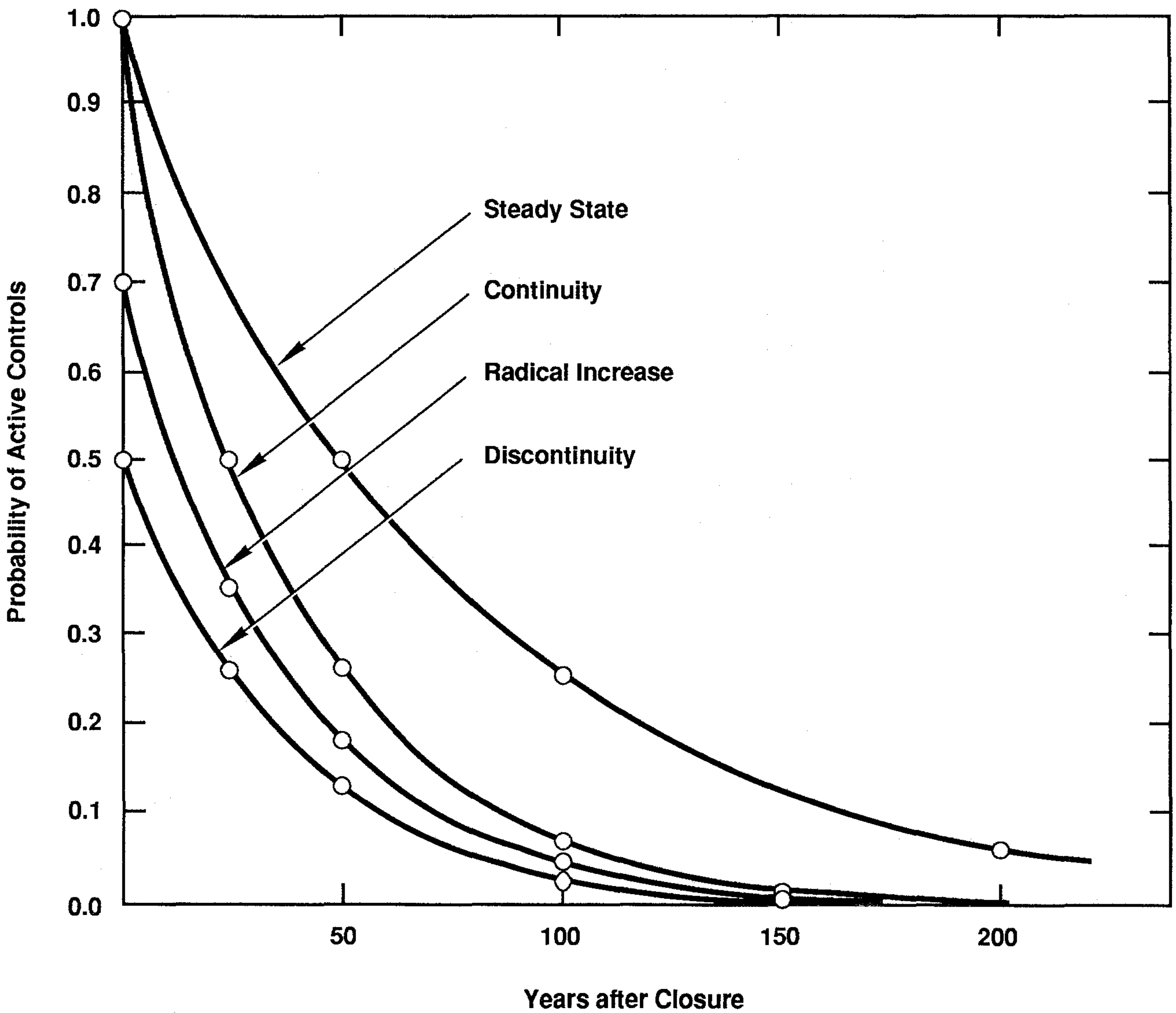

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Figure IV-10. Washington A Team - Probability of Existing Active Controls as a Function of Time and Future (Team Members A-C).

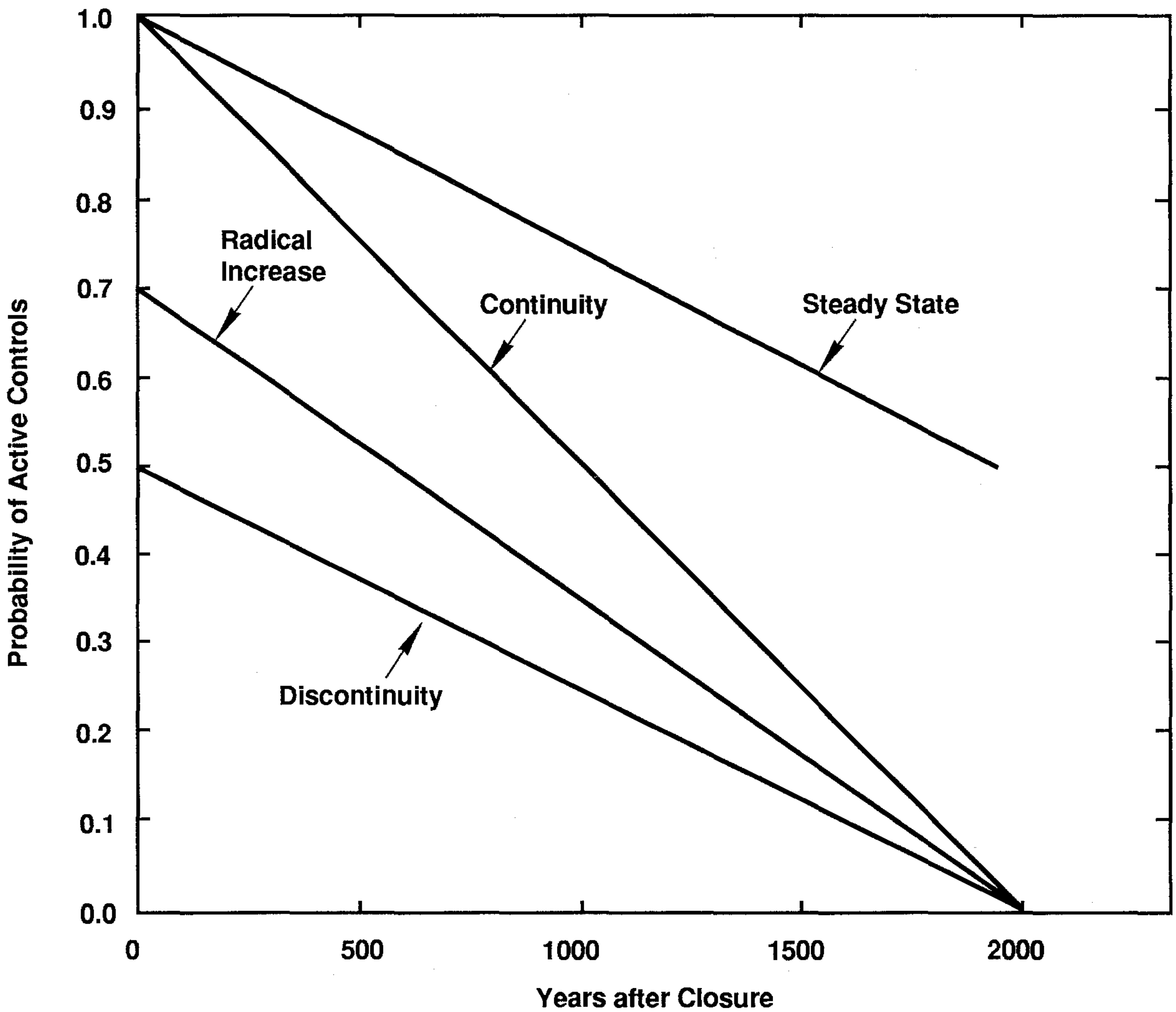

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Figure IV-11. Washington A Team - Probability of Existence of Active Controls as a Function of Time and Future (Team Member D).

The Washington A Team also discussed the existence of effective information about the WIPP as a function of time. The team members felt that, for the continuity and radical-increase futures, the probability is high that the information would exist somewhere during the first 200 years, but much lower that it would be effective in preventing accidental intrusion. For the discontinuity future, the team members indicated that the probability is high that effective information will not survive. For the steady-state future, the team felt that it would be very likely that effective information would remain available throughout the relevant time period. The team members also indicated that, if information exists and is effective, the probability of intrusion would be about half of that without information.

At the end of the session, the team members discussed modes of intrusion and means to prevent it. The team members were in consensus that the main modes of intrusion would be conventional drilling, excavation, and indirect effects. In the steady-state future, the main mode would be indirect effects because there would be much less need for drilling or excavation. For the other possible futures, the main modes would be drilling and excavation.

ANALYSIS AND AGGREGATION

Because the team members did not provide all the information needed for re-composing the tree in Figure IV-9, we made several assumptions for analysis purposes. These results were distributed to the team members and they were asked to review them and report any misstatements. No such comments were received. First, they had only given the exact shapes of the function relating probability of active controls and time for the continuity and radical-increase futures (Figures IV-10 and IV-11). We interpreted their qualitative judgments about the relationship of that curve to the curves for other futures as shown by the remaining plots. When calculating the probability of active controls for the first 200 years, we used the average probability of the respective function. For team members A-C, we assumed that this probability would be essentially zero after the first 200 years.

Similarly, we interpreted the qualitative judgments about the effectiveness of information as a function of time as follows. For the continuity and radical-increase futures, we assumed that the probability of effective information would be 0.5 during the first 200 years and 0 for the remaining 9,800 years. For the discontinuity future, we assumed that the probability of effective information would be 0.10 for the first 200 years and 0 for the remaining 9,800 years. For the steady-state future, we assumed that the probability of effective information would be 0.99 during the first 200 years and 0 thereafter.

Using this information, we could piece together the relevant probabilities required to analyze the tree in Figure IV-9 by using the average probabilities of team members A-C. An analysis was done separately for the first 200 years and for the 9,800 years thereafter because, for team members A-C, the first 200 years had special significance. Figure IV-12 shows the results for the first 200 years. Because the team members were not asked to provide all the conditional probabilities of intrusion, given the possible states of active controls on information, we inferred these conditional intrusion probabilities from their judgments about p(Intrusion|future) and from their statement that the probability of intrusion is twice as high in the case of no effective information compared to the case of effective information. If F is the possible future, AC and NAC stand for active and no active controls respectively, EI and NEI stand for effective and no effective information, and I and NI stand for intrusion and no intrusion, the team members' statements and judgments translate into the following equations:

$$p(I|F) = p(NAC|F)\ p(EI|NAC,F)\ p(I|EI,NAC,F) + p(NAC|F)\ p(NEI|NAC,F)\ p(I|NEI,NAC,F) \qquad \text{(IV-3)}$$

and

$$2p(I|EI,NAC,F) = P(I|NEI,NAC,F). \qquad \text{(IV-4)}$$

Because we have all but the two terms $p(I|EI,NAC,F)$ and $p(I|NEI,NAC,F)$, these two terms can be calculated from the two equations, as shown at the intrusion/no intrusion branches of Figure IV-12.

Figure IV-13 shows the "rolled back" version (showing the intermediate probabilities of intrusion working from intrusion/no intrusion back to the alternative futures) of the tree in Figure IV-12. In it, we designated all intrusion states with a value of 1 and all nonintrusion states with a value of 0. By taking expected values at each node going up the tree, we can determine the probability of intrusion, once that node is reached. Overall, the probability of intrusion during the first 200 years is 0.2346 (the sum of all the intrusion branches). The highest contributors are the radical-increase and the discontinuity futures, with the steady-state future being by far the smallest contributor.

A similar analysis is shown for the following 9,800 years, assuming that the respective probabilities of active controls and of effective information are essentially zero through most of that period (Figures IV-14 and IV-15). The overall probability of intrusion during the later time periods is 0.1736, and the main contributors are the continuity and discontinuity futures.

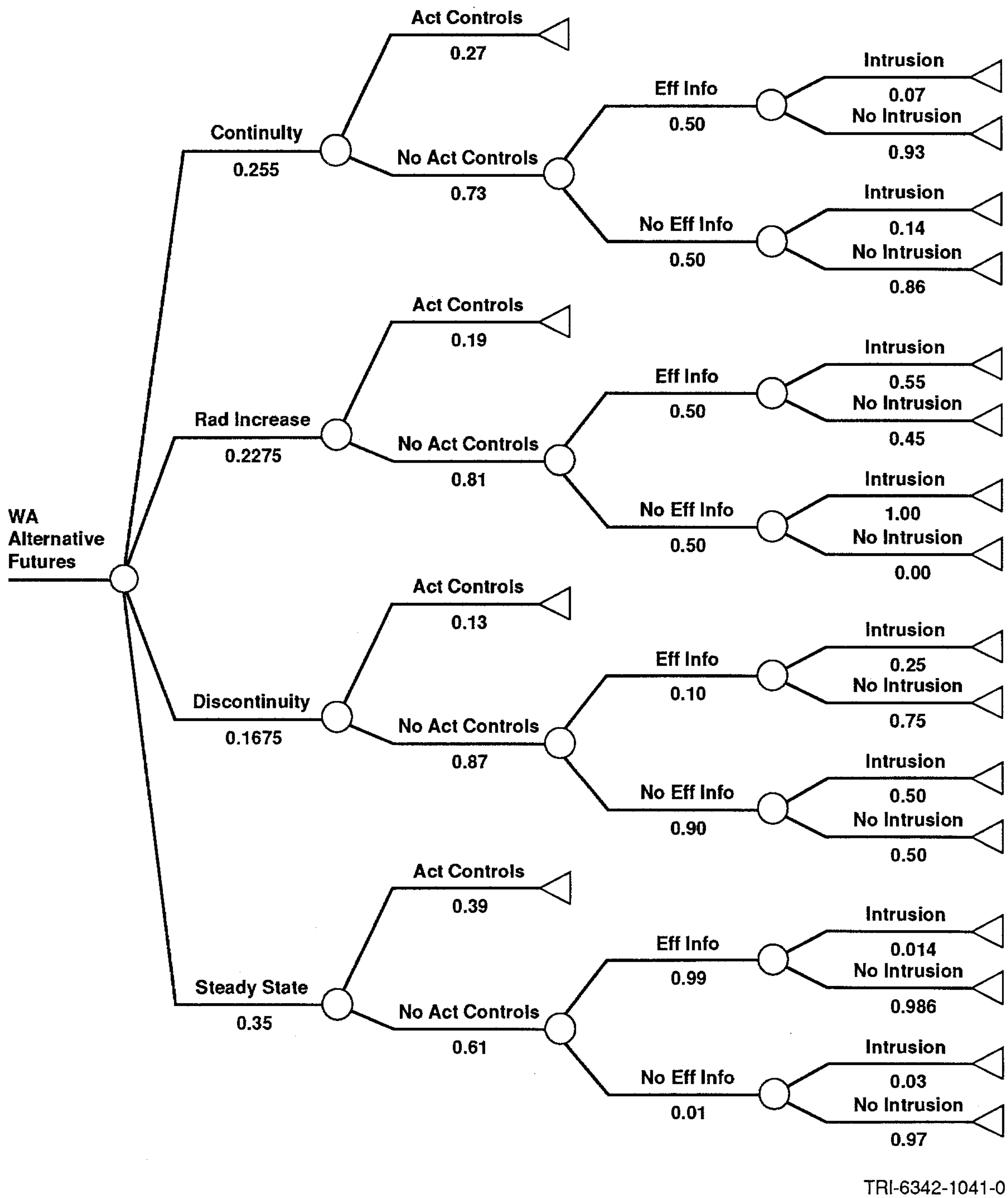

Figure IV-12. Washington A Team - Decomposed Assessments, Averages of Team Members A-C, First 200 Years.

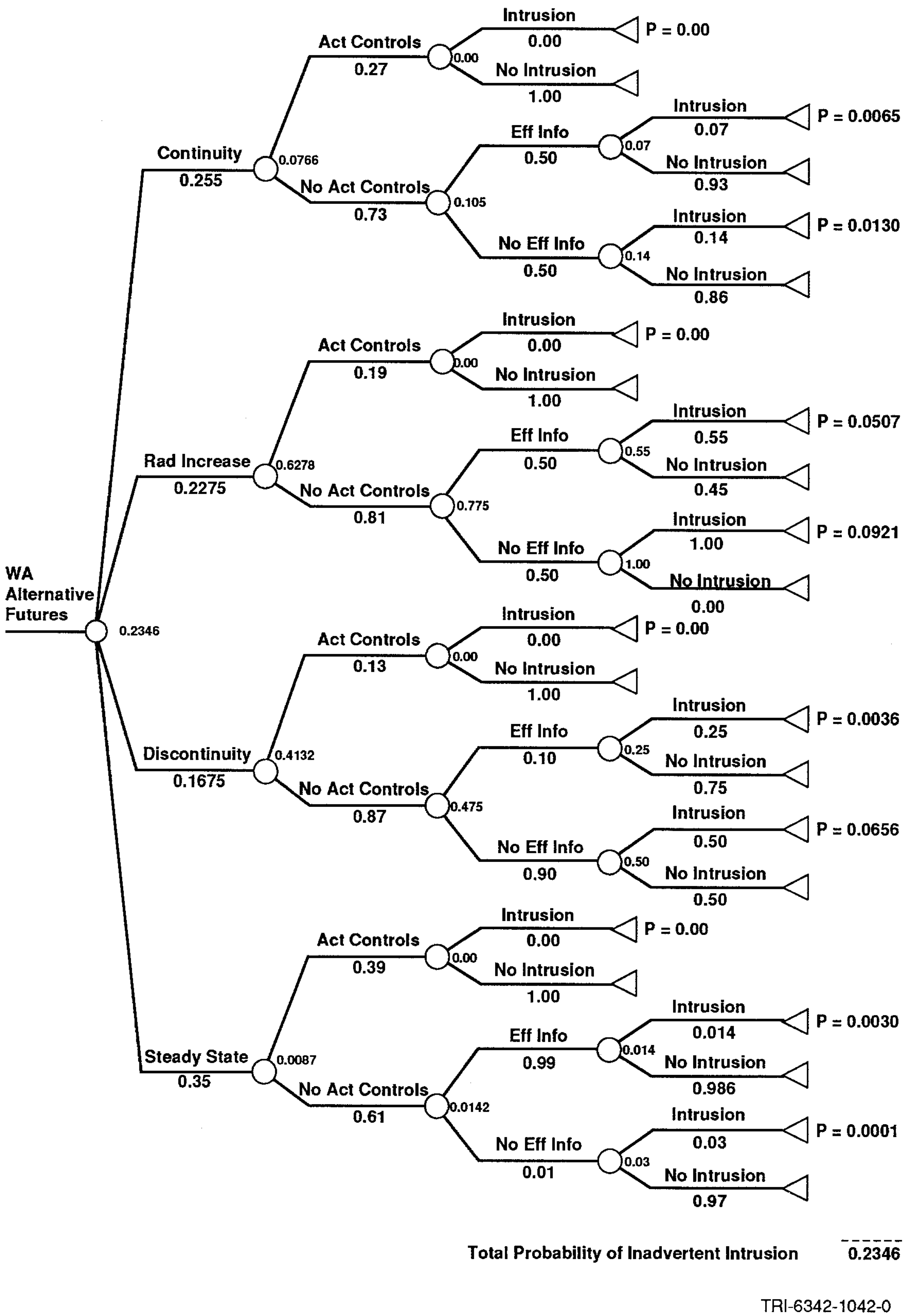

Figure IV-13. Washington A Team - Rolled-back Decomposed Assessments, Averages of Team Members A-C, First 200 Years.

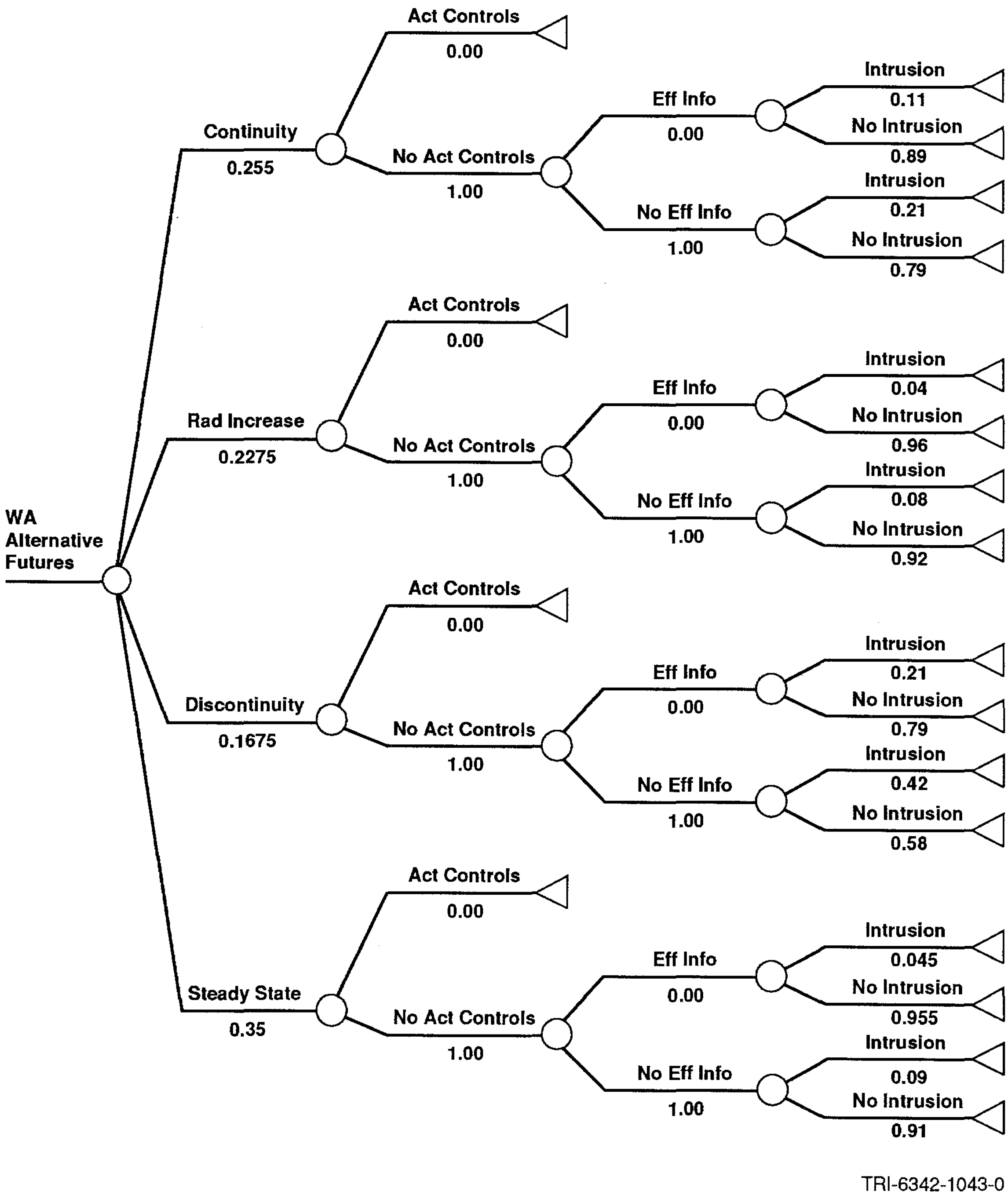

Figure IV-14. Washington A Team - Decomposed Assessments, Averages of Team Members A-C, Next 9,800 Years.

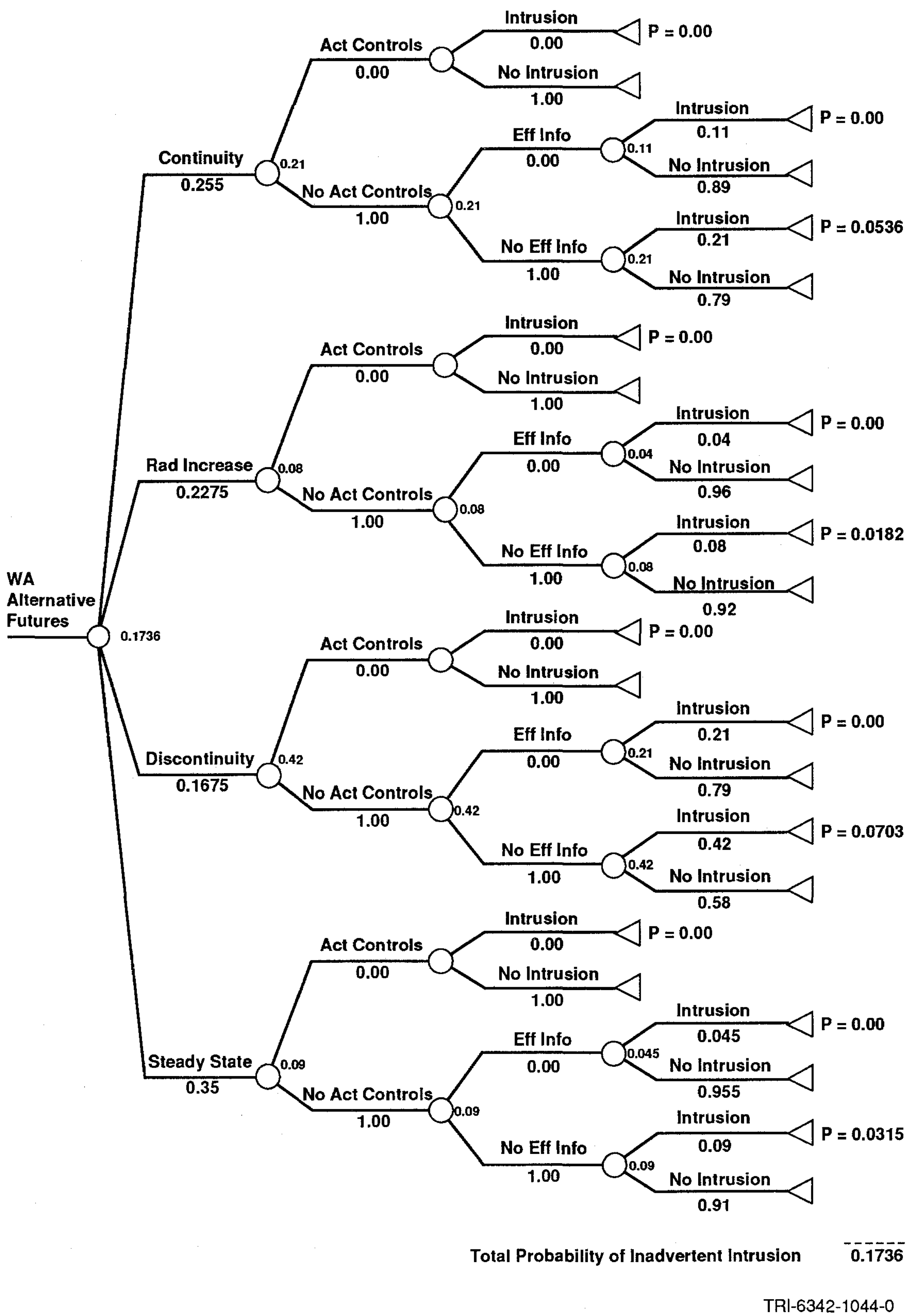

Figure IV-15. Washington A Team - Rolled-back Decomposed Assessments, Averages of Team Members A-C, Next 9,800 Years.

We did not carry out a similar time-dependent analysis for team member D because he did not provide time-dependent information of the probabilities of intrusion. However, it should be clear from his optimistic assessments of the probability of active controls during the first 200 years that he would consider it unlikely that intrusion would occur during those years. Thus, most of his initially assessed probability of intrusion of 0.07 should be attributed to the later years (year 2,000 and after), when he considers it very unlikely that active controls or effective information would exist any more.

CONCLUSIONS

Based on both their intuitive probability judgments and their calculated ones, the team members obviously consider the probability of intrusion moderately likely (0.07-0.50). Three teams members were in agreement that most of this probability is due to events that occur in the non-steady-state futures during the first 200 years after closure (0.2346). Given the nature of these alternative futures and the relative shortness of time to intrusion, the most likely modes considered were conventional drilling, excavation, and indirect effects.

The team members disagreed significantly regarding the probability of the effectiveness of active controls. Three team members (A-C) thought this effectiveness to be very unlikely after 200 years. The other team member gave it a fairly high probability, declining linearly over 2,000 years from 1 to 0. He realized that maintaining active controls would take a significant effort, with possible human and social costs, but he hoped that such control could be achieved as he considered this effort about the only way to avoid intrusion. In fact, without active controls, intrusion became almost an absolute for him under all alternative futures. Because of his optimism about maintaining active controls during the first 200 years, however, he disagreed in his intuitive judgment with the majority of the team by providing a rather low probability of intrusion during that period.

All team members agreed that maintaining active controls would be highly desirable, but they were uncertain about how to achieve that maintenance. They discussed alternative means of preventing intrusion without use of paramilitary controls. One idea was to create long-lived activities above the repository that would maintain effective knowledge as well as physically deter intrusion. Mention was made of a museum about the WIPP and nuclear waste issues.

All members agreed that the best chance to avoid intrusion would be by moving society to the steady-state future. In this future, the probability of intrusion is only about 0.03 in the far future, and the intrusions are most likely to occur from indirect effects rather than from drilling and excavation.

Washington B Team

APPROACH AND DECOMPOSITION

The Washington B Team employed four underlying factors that govern what the future may be like. These factors are the overall level of wealth and technology, the continuance of government control relative to the WIPP system, the climate, and future resource prices. Various levels of each of these four underlying factors were used to develop probabilities for each of the identified modes of intrusion. These modes of intrusion include resource exploration and extraction, drilling of wells for water, scientific investigation, and weather modification. The major factors governing the likelihood of each of the several modes of intrusion are shown in Table IV-26.

TABLE IV-26. WASHINGTON B TEAM - MODES OF INTRUSION AND UNDERLYING FACTORS

Intrusion Mode	Underlying Factors
Resource Exploration and Extraction	Prudent and Effective Government Control Resource Prices
Development of Water Wells	Prudent and Effective Government Control State of Wealth and Technology Climate
Scientific Investigation	Prudent and Effective Government Control
Weather Modification	Prudent and Effective Government Control State of Wealth and Technology Climate

The Washington B Team also considered catastrophic events that might interfere with the development of society and the persistence of knowledge that the likelihood of intrusion could be greatly increased. Such catastrophes include global nuclear war, almost runaway global warming, volcanic eruptions leading to long-term cooling, large-scale meteoric activity, the spread of unknown deadly diseases, and extraterrestrial attack. While each of these catastrophes might profoundly affect the course of society's development, each catastrophe is sufficiently unlikely to occur as to be overshadowed, in a probabilistic sense, by more mundane developments. Thus, although interesting, these events contribute little to the overall probabilities of inadvertent human intrusion.

Resource exploration and extraction was thought to be a relatively near-term phenomena, being completed during the first 500 years if undertaken in the study area at all. Two underlying factors were thought to control the likelihood of such exploration: the continuance of prudent and effective government control and the future level of resource prices. Probability assessments for two periods--the first 200 years after closure and the ensuing 300 years--were obtained under the conditions of rising resource prices and resource prices that are not rising.

The development of water wells in the WIPP area was thought to be possible if the government fails to exercise prudent and effective control, if the state of wealth and technology is high, and if the requisite technology for desalination is available.

Scientific investigation, including archaeological exploration, was treated holistically by the Washington B Team. The probability distribution for the number of attempted intrusions and the probability that an attempt would actually reach the material were both assessed.

The fourth mode of intrusion, the intentional modification of weather to augment rainfall, was assigned probabilities conditional on four factors. The two underlying factors that are shared with some other modes of intrusion are the level of wealth and technology and the presence of prudent and effective government control. In addition, the technology must have been developed for weather modification, and the technology must have been deployed in the WIPP area. Moreover, if the climate in the WIPP region becomes more humid and rainfall increases, there will be no need for weather modification.

PROBABILITY ASSESSMENTS

The Washington B Team provided probability assessments for two time periods, 0-200 years after closure and 200-10,000 years after closure. These time periods are referred to as the near future and far future, respectively. For resource exploration and extraction only, the far future was considered to be 200-500 years after closure, with no boreholes thereafter. The assessments are based on combinations of four underlying factors: a combined factor for wealth and technology, government control, climate, and resource prices.

Wealth and technology takes on one of three levels: high, moderate, or low. The definitions are relative, with today's level of wealth and technology considered to be moderate. In the near future, the probability of low wealth and technology is negligible, while the probabilities of moderate and high wealth and technology are equal. The assessed probabilities for the level of wealth and technology in the near future are shown in Table IV-27, along with probabilities of levels of the other underlying factors.

TABLE IV-27. WASHINGTON B TEAM - PROBABILITIES OF UNDERLYING FACTORS (TABLE IV-26)-NEAR FUTURE (0-200 YEARS)

Factor	Probability
WEALTH AND TECHNOLOGY	
High	0.5
Moderate	0.5
Low	0.0
GOVERNMENT CONTROL	
Prudent and Effective	0.8
Other	0.2
CLIMATE	
Hot and Drier	0.3
Unchanged	0.6
Humid	0.1
RESOURCE PRICES	
Rising	0.7
Not Rising	0.3

Government control is categorized as being either prudent and effective with regard to nuclear waste or not prudent and effective. The third factor, climate, takes on the levels hot and drier, unchanged (similar to today's weather), or humid. The fourth factor, resource prices, can take on one of two levels, rising (meaning more than doubling current levels) or not rising.

Table IV-28 shows the probability assessments for the far future. The descriptions of the factor levels in the far future are similar to those in the near future. The high level of wealth and technology in the far future is akin to the high plus moderate levels in the near future. The "not humid" level for climate in the far future encompasses both hot and drier and unchanged from today as used in the near future.

TABLE IV-28. WASHINGTON B TEAM - PROBABILITIES OF UNDERLYING FACTORS (TABLE IV-26)-FAR FUTURE (200-10,000 YEARS)

Factor	Probability
WEALTH AND TECHNOLOGY	
High	0.9
Not High	0.1
GOVERNMENT CONTROL	
Prudent and Effective	0.33
Other	0.67
CLIMATE	
Humid	0.6
Not Humid	0.4
RESOURCE PRICES	
Rising	0.67
Not Rising	0.33

Resource Exploration and Extraction

The exploration and extraction of resources in the near future is limited to drilling, primarily drilling for natural gas. Other resources are 0.2 to 0.1 times as likely to be exploited, and thus gas exploration dominates in the near future. Other modes of extraction are unlikely to intrude into the repository. Resource exploration and extraction depends upon mineral prices that are most likely to be high during the first 200-year period. Government control, if prudent and effective, will deter mineral exploration within the WIPP land-withdrawal area. This area is defined as the sixteen contiguous sections proposed to be withdrawn from public access.

In the absence of prudent and effective government control, and in the presence of rising resource prices, the probability of drilling for gas is 0.4. If resource prices are not rising, the probability of drilling is 0.2.

Given that drilling is undertaken, the distribution of the average number of wells per square mile was assessed as a triangular distribution on the interval from 0 to 4 with a mean of 2.

In the far future, drilling will not be undertaken if resources have already been removed. Thus, calculation of probability of drilling in the far future requires first calculating the probability that resources are removed during the first 200 years. If resources have not been removed during the first 200 years and there is not prudent and effective government control, the probability of drilling given rising resource prices is 0.4, while the probability of drilling given that resource prices are not rising is 0.2.

If exploration and extraction are undertaken, the average number of wells per square mile is once again represented by a triangular distribution with a mean of 2. Exploration and extraction of minerals will be essentially complete within 500 years.

Water Wells

Agricultural/water development is synonymous with drilling water wells. The drilling of water wells will only occur in the short run if wealth and technology are high, if there is demand for water at the WIPP, and if the technology exists for cost-effective desalination of the ground water. The drilling of water wells over the WIPP repository will occur only if there is a lack of prudent and effective government control. The joint probability that economically viable technology for desalination will be developed in the next 200 years and that demand will exist for water in the WIPP region was assessed as between 0.0001 and 0.001. If water wells are drilled, they will be drilled at a rate sufficient to keep four wells producing per square mile. The team did not have sufficient expertise to assess how often wells would need to be rehabilitated or new wells drilled. For this reason, the team suggested that the technical staff devise an estimate of the drilling rate using the information provided by the team and using other sources.

In the far future, 200 years after closure and beyond, the probability of developing water wells was deemed to be ten times as great as during the near-future period.

Scientific Investigation

The possibility of intrusive scientific inquiry into the WIPP repository in the near future was judged to be negligible. In the far future, with the absence of prudent and effective government control, the rate at which intrusion attempts might occur was assessed. Three team members responded that inadvertent intrusion attempts such as archaeological inquiry would occur at the rate of 1 to 2 attempts per 1,000 years (0.5 probability of 1 attempt and 0.5 probability of 2 attempts). The fourth team member responded that the rate would be 0.5 attempts (probability of 1.0) per 1,000 years. Using this input and assigning 3/4 of the weight to the joint estimates from the three team members, the distributions of probabilities were added to obtain an overall probability distribution of 0.25, 0.375, and 0.375 for intrusion rates of 0.5, 1, and 2 intrusion attempts per 1,000 years.

Each intrusion attempt need not result in reaching the material. The four team members provided a probability of 0.01 to 0.05 that any given attempt will actually reach the material.

Weather Modification

The Washington B Team also identified human modification of the climate as a potential mode of intrusion. Such a modification could result in a 20 to 30 percent increase in rainfall in the WIPP area. The circumstances under which weather modification would occur include high technology and lack of prudent government control. In the near future, the probability that the requisite technology will be developed is 0.2. Moreover, the probability that the technology would be applied at the WIPP is 0.5. In the far future, the probability of developing the technology to modify the climate is between 0.6 and 0.7. Weather modification will not occur, however, if the climate at the WIPP becomes more humid for natural reasons.

EVALUATION OF INTRUSION PROBABILITIES

The probability assessments provided by the Washington B Team were assembled into distributions for various modes of intrusion. For each mode of intrusion, the logic of the assembly and the resulting intrusion distribution are given.

Resource Exploration and Extraction

Resource drilling and exploration in the near future was assumed to depend exclusively upon resource prices. Moreover, drilling above and into the WIPP will not occur if the government retains prudent and effective control.

The probability of drilling is calculated as

$$P(\text{drilling}) = P(\text{drilling}|\text{rising prices})P(\text{rising prices}) + P(\text{drilling}|\text{not rising prices})P(\text{not rising prices}). \quad \text{(IV-5)}$$

Evaluating the above equation gives

$$(0.4)(0.7) + (0.2)(0.3) = 0.34.$$

Drilling above the WIPP can only occur, however, if the government fails to be prudent and effective. The probability of potential intrusion drilling is then

$$P(\text{drilling}) = P(\text{drilling})P(\text{not effective and prudent}) \qquad \text{(IV-6)}$$

$$= (0.34)(0.2) = 0.068.$$

Thus, the probability of no drilling is 1-0.068, or 0.932.

If drilling is undertaken, the average number of wells per square mile per 10,000 years was assessed as a triangular distribution with a mean of 2 and endpoints of 0 and 4. The probability density function for the average number of wells, given there is drilling, is

$$f(x) = \begin{cases} \frac{x}{4} & 0 \le x \le 2 \\ 1 - \frac{x}{4} & 2 < x \le 4. \end{cases}$$

The cumulative probability function, the cdf, is obtained by combining the 0.728 probability of no drilling and the above density. For x = 0, where x is the average number of boreholes, F(0) = 0.932. For $0 \le x \le 2$, the cumulative probability is

$$0.932 + (1 - 0.932) \int_0^x \frac{y}{4}\, dy \quad 0 \le x \le 2$$
$$= 0.932 + 0.068 \frac{x^2}{8}$$

For $2 < x \le 4$, the cumulative probability is

$$F(x) = 0.932 + (1 - 0.932) \left[\int_0^2 \frac{y}{4}\, dy + \int_2^x 1 - \frac{y}{4}\, dy \right]$$

$$= 0.932 + 0.068 \left[\frac{1}{2} + (x - \frac{x^2}{8} - 2 + \frac{1}{2})\right]$$

$$= 0.932 + 0.068 \left[x - (\frac{x^2}{8}) - 1\right] \quad 2 < x \le 4.$$

The resulting cumulative distribution function (cdf) for the average number of boreholes per square mile, taking into account the probabilities of resource prices and government control, is shown in Table IV-29.

TABLE IV-29. WASHINGTON B TEAM - CUMULATIVE DISTRIBUTION FUNCTION FOR THE AVERAGE NUMBER OF BOREHOLES PER SQUARE MILE PER 10,000 YEARS IN THE NEAR FUTURE (0-200 YEARS)

F(x)	x
0	$x<0$
0.932	$x=0$
$0.932+0.0085x^2$	$0<x\leq 2$
$0.932+0.068[x-(x^2/8)-1]$	$2<x\leq 4$
1	$4<x$

The cdf given above is found by combining a 0.728 probability of no potential intrusion drilling with the triangular distribution for the average number of wells. The mean of this distribution is

$$\text{mean} = (0)(0.728) + (2)(0.272) = 0.544 \text{ boreholes/mile}^2.$$

The probability assessments do not provide the spatial distribution of wells, nor do they provide the temporal distribution other than the drilling is accomplished in the first 200 years after closure.

In the period from 200 to 500 years, drilling will be undertaken only if drilling was not accomplished during the first 200 years. Thus, there is a 1-0.272 = 0.728 probability that the resources are still in the ground. The probability that drilling will be undertaken is then

$$P(\text{drilling}) = P(\text{resource remains})[P(\text{drilling}|\text{rising prices})P(\text{rising prices}) + P(\text{drilling}|\text{not rising prices})P(\text{not rising prices})]. \qquad (IV-7)$$

Evaluating the above equation gives

$$(0.728)[(0.4)(0.67) + (0.2)(0.33)] = 0.243.$$

Once again, drilling above the WIPP will only occur if the government's control is not prudent and effective. Thus, the probability of potentially intrusive drilling is (0.243)(0.2) = 0.0486. As in the case of the near future, if drilling commences, the uncertainty distribution for the average number of boreholes per square mile is triangular with a mean of 2. The resulting cdf is shown in Table IV-30.

As in the near future assessments, the spatial distribution of boreholes is not provided, nor is the temporal distribution other than the drilling is accomplished in the period from 200 to 500 years after closure.

TABLE IV-30. WASHINGTON B TEAM - CUMULATIVE DISTRIBUTION FUNCTION FOR THE AVERAGE NUMBER OF BOREHOLES PER SQUARE MILE PER 10,000 YEARS (200-500 YEARS)

F(x)	x
0	$x<0$
0.9514	$x=0$
$0.9514+0.006075x^2$	$0<x\leq 2$
$0.9514+0.0486[x-(x^2/8)-1]$	$2<x\leq 4$
1	$4<x$

Water Wells

In the near future, the assessment of drilling rates for water wells is based upon the alternative future of economic desalination of water in the WIPP area. Combining the probabilities of high technology, absence of government control, and a continuing dry climate with the probability of economically viable desalination yields

$$P(\text{drilling}) = P(\text{high technology})P(\text{government control not effective and prudent}) \, P(\text{not humid})P(\text{economically viable}). \tag{IV-8}$$

The last term was assessed by the team as a range of probabilities. Because this quantity is the probability of a single event rather than the probabilities of various frequencies of an event, it will be treated as a single value rather that a range of values. The value chosen is the geometric mean of the endpoints of the range (0.001 and 0.0001). Thus, the probability of drilling is

$$(0.5)(0.2)(0.9)[(0.001)(0.0001)]^{.5} = 0.0000285.$$

The probability of developing water wells is, then, very small. If wells are developed, the Washington B team stated that drilling rate should be assessed as the number of boreholes required to maintain an average of four operating water wells per square mile. The team did not provide such a drilling rate.

It is impossible to complete the cdf for water well development without additional information or assumptions about how long water wells will last, the likelihood of rehabilitating wells, and the need to drill new wells.

In the far future, the team estimated that the development of water wells, given high technology, is ten times more likely than in the near future. Thus,

$$P(\text{drilling}) = P(\text{high technology})P(\text{not effective and prudent})\,P(\text{not humid})P(\text{economically viable}) \qquad \text{(IV-8)}$$

or

$$(0.9)(0.67)(0.4)[(0.01)(0.001)]^{.5} = 0.0007627.$$

Once again, the cdf cannot be obtained without supplementary information. What was provided is an average of four operating wells per square mile as in the case of the near future. Additionally, because the far future extends for nearly 10,000 years, the water resource may become completely extracted at some point in time, and drilling would halt.

Scientific Investigation

Scientific investigation has a very small probability in the near future, which increases in the far future. The rates of intrusion given by the four experts were used to create the following cdf for the average number of attempted intrusions per 1,000 years in the far future (Table IV-31).

TABLE IV-31. WASHINGTON B TEAM - CUMULATIVE DISTRIBUTION FUNCTION FOR THE AVERAGE NUMBER OF ATTEMPTED INVESTIGATIONS PER 1,000 YEARS IN THE FAR FUTURE (200-10,000 YEARS)

F(x)	x
0	$x<0$
0.33	$x=0$
0.5	$0.5\leq x<1.0$
0.75	$1.0\leq x<2$
1.0	$2\leq x$

This cdf is equivalent to a 1/3 chance of no intrusions because of prudent and effective government control, a 1/6 chance of a 0.5/1,000-year intrusion rate, a 1/4 chance of a 1/1,000-year intrusion rate, and a 1/4 chance of a 2/1,000-year intrusion rate. Any given attempted intrusion may or may not result in the material being reached. The frequency of intrusion attempts reaching the material was assigned a uniform distribution on the interval [0.01,0.05].

The simulation of intrusions caused by scientific investigation (including archaeological studies) should be accomplished in the following manner. First, generate a uniform random variable on the interval [0.01,0.05]. Denote this random variable by the symbol Y. Next, draw an observation from the distribution F(x) given above. Denote this random variable by X. Using the value of X as the mean of an exponential distribution, generate the times of intrusion attempts from an exponential distribution with a mean of 9.8X. The 9.8 represents the number of millennia in the far future. Denote the intrusion times by $T_1,\ldots,T_M$, where M, the number of intrusion attempts is, itself, a random variable. Finally, generate M values of an indicator (zero-one) variable from a Bernoulli distribution with mean Y. These values are placed in correspondence with the intrusion times. A successful intrusion (one that reaches the material) occurs at each time T_i having a corresponding value of 1.

Weather Modification

The last mode of intrusion identified by the Washington B Team is weather modification. Weather modification can occur under either high or moderate technology. The probability that weather modification technology will be developed during the 200 years after closure is 0.2. Moreover, the probability that the technology will be deployed in the WIPP area is 0.5. The technology will be employed only if government control is not prudent and effective and the climate does not become more humid. The probability of weather modification affecting the WIPP during the next 200 years is then

$$\begin{aligned}P(\text{weather modification}) &= P(\text{high or moderate technology}) \\ &\quad P(\text{not prudent and effective})P(\text{not humid})P(\text{technology is developed}) \\ &\quad P(\text{technology is deployed}) \qquad \text{(IV-9)} \\ &= (1.0)(0.2)(0.9)(0.2)(0.5) = 0.018.\end{aligned}$$

Thus, there is a 0.018 probability that weather modification will be deployed and cause a 20 to 30 percent increase in rainfall at the WIPP during the 200 years after closure.

The analysis for the far future is similar to that for the near future with the exception that if the climate is more humid, weather modification will not be needed. Thus, the probability of weather modification for the far future is calculated as

$$\begin{aligned}P(\text{weather modification}) &= P(\text{not humid})P(\text{high or moderate technology}) \\ &\quad P(\text{not prudent and effective})P(\text{technology is developed}) \\ &\quad P(\text{technology is deployed}) \qquad \text{(IV-10)} \\ &= (0.4)(0.9)(0.67)(0.65)(0.5) = 0.078\end{aligned}$$

V. CONCLUSIONS

The goals outlined in Chapter I have been achieved through the use of the expert-judgment procedure documented in this report. A nationwide search was undertaken to locate qualified candidates for the expert panel. Government agencies, professional societies, and public interest organizations were solicited for nominations. An established selection criteria based on professional qualifications and diversity of disciplines was used to assemble the final panel. The panel was convened for three days of background information, expert-judgment training, discussion of the issue statement, and a tour of the WIPP. Background information included the topics of the history of the WIPP, the Standard, the performance-assessment process and scenario development, as well as the physical and cultural setting for the WIPP. After a working period, the teams were brought back together to be elicited for their judgments on the modes and probabilities of inadvertent human intrusion into the WIPP. This report documents the collection of these team judgments into coherent statements about future societies, the modes by which they might intrude upon the WIPP, and the probabilities of these intrusions. This report also contains the individual team reports to provide a complete explanation of the results.

The effort undertaken to assess the possible futures of society and how these futures may lead to inadvertent intrusion into radioactive waste repositories has produced a variety of findings--some of which are very speculative. The purpose of the report is to provide an overview of the process and provide quantitative assessments of the likelihoods of various types of inadvertent human intrusion. The report cannot convey the richness and variety of all the findings. Only a careful reading of the four team reports (Appendices C through F) will reveal the many astute thoughts that the sixteen authors have provided. The qualitative appreciations of the future that the team reports provide are, perhaps, the most important contributions of the project.

Clearly, the future may follow many paths--some more desirable than others. Several themes are so pervasive in the views of the future that they should be singled out for attention. First, in the time scale of nuclear waste decay, the continuity and stability of governments are insufficient to provide any assurance that humans will maintain active control of the repositories or be aware of the existence of buried nuclear waste. A second factor that recurs throughout the alternative futures is the rate of technological development and its persistence or lapse. While some may be confident that technology will increase, knowing what path it will follow is difficult. Will cancer be curable and thus nuclear waste less hazardous? Will autonomous robots perform mineral exploration? Will technology replace the human need to read the printed word? While the work of any group of experts cannot possibly define all the possible futures, let alone know which future will come to be, the futures envisioned by the experts involved in this project are sufficiently varied to alert us to the need to consider a very wide range of possibilities when designing markers and barriers to prevent human intrusion into radioactive waste repositories.

The findings of this study have several uses. First, the findings frame the work of the expert group assembled to design and evaluate marker systems for the WIPP. Both qualitative and quantitative aspects of the findings will be useful in the markers endeavor. While it was not specifically a part of their statement of work, two of the four teams comprising the Futures Panel recommended that a "no marker" strategy be considered for the WIPP because markers might draw attention to the WIPP. Second, the findings can be used in the performance and safety assessments for the WIPP. In the performance and safety assessments, the various modes of intrusion and their frequencies of occurrence will be useful. In the following sections, several important aspects of the findings are highlighted and interpreted.

While predicting what the future will be is folly, it is useful to consider what futures are possible. In particular, what might future societies be like in terms of technology, resource utilization and prices, and government control? Because each of the four teams used a different approach in developing their views of the future, it is not possible to provide a simple summary of each of these aspects averaged, in some sense, across the four teams. In the following discussion, the findings of each of the various teams will be emphasized at different times because their contributions bear more directly on each of these aspects of the future.

Technology in Future Societies

Each of the four teams treated technological progress in a somewhat different manner. The Boston Team used technological progress as a fundamental underlying determinant of what the future may be like. Therefore, direct assessments of the future can be found in their analysis. This analysis shows that the most likely future is one where technology is significantly more advanced than today's technology. Roughly speaking, more advanced technology is four times more likely than technology that is not more advanced than today's technology.

The Southwest Team was less sanguine about the future of technology. This team assigned probabilities indicating that growth in technology is as likely as not. In their view, while a continuing decline in technology was unlikely (a 1 in 10 chance), it is possible that technology might be lost and then regained at some time in the future (a 0.4 probability).

Technology was not directly considered by the Washington A Team. Underlying their analysis was resource utilization characterized by either an extrapolation of the increase of today's utilization rates, a radical increase beyond today's utilization rates, a discontinuity in the future, or an environmentally sound world where recycling and renewable resources dominate. In the scenario of abrupt discontinuity, caused either by war or political upheaval and change, it is possible that some technological capability might be lost. This scenario was viewed as relatively less likely and was given approximately a 1 in 6 chance.

Wealth and technology were combined into a single underlying factor by the Washington B Team. Beyond 200 years after closure, significantly greater wealth and more advanced technology are 10 times more likely than not.

Overall, the judgment of the four teams is that continued development of technology is most likely. The probabilities assigned by the various teams to a more advanced technology ranged from 0.5 to 0.9. Excluding the Washington A Team, which did not address technology in a direct manner, the average of the three remaining teams probabilities of more advanced technology in the future is slightly greater than 0.7 in the far future.

Resource Utilization and Resource Prices

Another key factor in human intrusion is the demand for resources in the future. Scenarios with high demand for resources, and resulting higher prices, lead to greater exploration and extraction and, consequently, larger probabilities of inadvertent intrusion. The Boston Team considered resource demand through resource prices that were treated as either being high compared to current prices or low, the same as today's prices or lower. In the near future, 0-300 years after closure, the probabilities of high resource prices assigned by the Boston Team members ranged from 0.3 to 0.75 with an average near 0.5. In the more distant future, the probability of high resource prices assigned by the members ranged from 0.1 to 0.6 with an average of 0.325.

The Southwest Team did not consider resource demand directly in their elicited probabilities, although there is some discussion of resource scarcity in the representative scenarios described in their report. In contrast, the Washington A Team's analysis puts resource demand in a central position. As mentioned in the discussion of technology, the future may bring greater resource extraction rates than those of the current era. The Washington A Team's radical increase scenario was given probabilities ranging from 0.18 to 0.3 while the continuity scenario (extrapolation of current resource extraction activity) was given probabilities ranging from 0.21 to 0.30. Significantly lower resource utilization rates were visualized in the "steady-

TABLE V-1. APPROXIMATE PROBABILITIES OF ONE OR MORE INTRUSIONS

Team and Mode of Intrusion	Near Future	Far Future	Both Near and Far Future (Union)
Boston			
Drilling			
Hydrocarbons	0.037	0.000	0.037
Injection Wells (3 experts)	(0.003, 0.0004, 0.0006)	(0.288, 0.011, 0.823)	(0.290, 0.011, 0.823)
Archaeology[a,e]	0.002	0.030	0.032
Expansion[b,e]	0.423	0.120	0.492
Underground Tests[b,e]	0.007	0.091	0.097
Dams[c]	0.102	0.989	0.990
Southwest			
Mining[e]	0.000	0.009	0.009
Drilling and Excavation	0.010	0.060	0.069
Washington A			
Resource Exploration and Extraction	0.089	0.124	0.202
Machine Intrusion, Tunneling, etc.[e]	0.143	0.018	0.158
Indirect modes[c]	0.0001	0.031	0.031
Washington B			
Drilling			
Hydrocarbons	0.010	0.000	0.010
Water wells[d]	0.00003	0.0008	0.00083
Archaeological and Scientific[e]	0.000	0.030	0.030
Weather Modification[c]	0.018	0.078	0.095

Footnotes:

a Incomplete information was provided. It is assumed that each intrusion attempt has a .03 chance of reaching radioactive material as per the Washington B Team assessment.

b This mode of intrusion is not considered to be inadvertent.

c This activity does not result in a release to the biosphere.

d Incomplete information was provided. The values provided are upper bounds to the probability of intrusion.

e This mode of intrusion may be more severe than drilling. Modes of intrusion more severe than drilling need not be considered under the guidelines for performance assessment provided in 40 CFR 191.

possible extremes. The time periods shown in Table V-I have varying definitions for the several teams. For the Boston Team, the near future is 0-300 years after the lapse of active controls (100 years after closure.) The Southwest Team used a 100-500 year period after closure for the near future while the Washington A Team used the first 200 years after the lapse of active controls. The Washington B Team also adopted a 200-year definition for the near future.

Several of the modes of intrusion identified by the expert teams are not appropriate for use in the performance assessment for the WIPP. First, some modes of intrusion do not result in releases to the biosphere. Dams, irrigation, and weather modification are examples of human activities that are believed not to affect the WIPP system sufficiently to result in releases to the accessible environment during the 10,000-year performance period. Other activities, such as mining may result in releases that are more severe than those caused by drilling. However, 40 CFR Part 191 specifically provides that intrusion modes more severe than drilling need not be considered in the performance assessment.

The assessment for injection wells was not completed during the elicitation sessions with the Boston Team members. This has resulted in some difficulties in interpreting the results. A letter was sent to the four team members asking them to provide the rate of injection-well drilling in the near-, intermediate-, and far-future time periods. Three team members responded, the fourth was unable to respond due to extended travel. There is great variability among the rates provided and there is an absence of rationales for the judgments. It may be that the drilling rates are conditional on some disposal well activity being present. Moreover, no adjustments were provided for various information states as were provided for other intrusion modes by this team. With these ambivalences in mind, a probability of one or more intrusions into the waste has been calculated for each of the three responding team members. There is less than full confidence that these assessments are of the same quality as other assessments provided by this team, however.

The findings of this report are speculative in nature and provide a view of what <u>may</u> be rather than what <u>will</u> be. While the experts participating in this study have identified many possible modes of intrusion, conceiving of all modes that could occur in the future is not possible. Thus, the analysis is incomplete and must remain so.

The value of the report is that a reasoned approach has been taken in examining the possibility of inadvertent human intrusion. The qualitative findings, including the discussions of government control and the identification of possible modes of intrusion, are perhaps the most valuable contributions of the experts.

The quantitative assessments of intrusions, both probabilities and rates, can be used for the performance and safety analyses of the WIPP system. These probabilities and rates reflect the best judgment of sixteen experts drawn from diverse backgrounds and reflect a very uncertain state of knowledge about the future.

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APPENDIX A: CRITERIA FOR POST-CLOSURE PASSIVE MARKERS AT THE WIPP (October 23, 1989)

Rip - Your division should take the lead in this effort

6340 - #101.2

United States Government | Department of Energy

memorandum

Albuquerque Operations Office
Waste Isolation Pilot Plant
Carlsbad, New Mexico 88221

DATE: OCT 23 1989

REPLY TO ATTN OF: WIPP:TEL 89-1548

SUBJECT: Criteria for Post-Closure Passive Markers at WIPP

TO: Lamar Trego, General Manager, WID
Wendell Weart, Department Manager, 6430, SNL

The Project needs to clearly define the criteria which will be used to decide what kind of passive markers can be used at WIPP to significantly mitigate the effects of the human intrusion scenarios on performance assessment. Please develop jointly the criteria for this selection process and provide a document to me listing those criteria and explaining the rationale behind each. Sandia shall be the responsible lead organization for the development of criteria and Westinghouse shall be the lead for the proof of concept and inplementation of the passive markers selected. It is not necessary to recommend specific passive markers at this time; however, the task force will no doubt have to consider possible specific markers in the development of appropriate criteria.

Please provide a draft of the document by November 20, 1989 for review and comment. The project needs to finalize the document by mid-November.

If you have any questions, please contact Tom Lukow of my staff.

W. John Arthur III
Acting Project Manager

cc:
M. McFadden, AL
D. Deal, IT/WPO

APPENDIX B:
CRITERIA FOR POST-CLOSURE PASSIVE MARKERS AT THE WIPP
(February 15, 1990)

Sandia National Laboratories

Albuquerque, New Mexico 87185

date: February 15, 1990

to: A. E. Hunt, WPO

from: D. R. Anderson, 6342

subject: Criteria for Post-Closure Passive Markers at WIPP

John Arthur's October 23, 1989 memorandum, WIPP:TEL89-1548, stated that the project needs to define criteria for selection of post-closure passive markers at WIPP. Sandia and Westinghouse were asked to develop jointly the criteria for this selection process and to provide a document listing those criteria and explaining the rationale behind each.

Sandia was named the responsible lead organization for development of the criteria, and Westinghouse was assigned the lead for the proof of concepts and implementation of the passive markers selected. Recommendation of specific passive markers is not required at this time. However, it is expected that the task force will have to consider possible specific markers in the development of appropriate criteria.

Enclosed is an outline of the procedure that Sandia will use in the development of criteria for a post-closure passive marker and barrier system for WIPP. The interaction of criteria development with Performance Assessment (PA) activities is also described in the outline.

Please contact me if you have any questions regarding this approach to define the criteria for selection of post-closure passive markers at WIPP.

Enclosure

Copy to:
V. Daub, DOE/WPO
V. Likar, W/WPO
6340 W. D. Weart
6341 R. C. Lincoln
6342 S. G. Bertram-Howery
6342 M. G. Marietta
6342 R. P. Rechard
6343 T. M. Schultheis
6344 E. D. Gorham
6345 A. R. Lappin
6346 J. R. Tillerson

Outline of the Procedure for the Development of Criteria for Selection of WIPP Post-Closure Passive Marker and Barrier Systems and the Use of the Resultant Systems in Performance Assessment

The requirement for a passive marker and barrier system at WIPP is specified in Part 191.14 - Assurance Requirements of the draft Subpart B - Environmental Standards for Disposal of the Revised EPA Standards, 40 CFR Part 191, as follows:

191.14 Assurance Requirements

To provide the confidence needed for long-term compliance with the requirements of 191.13, disposal of spent nuclear fuel or high-level or transuranic wastes shall be conducted in accordance with the following provisions, except that these provisions do not apply to facilities regulated by the Commission (see 10 CFR Part 60 for comparable provisions applicable to facilities regulated by the Commission):

a. Active institutional controls over disposal sites should be maintained for as long a period of time as is practicable after disposal; however, performance assessments that assess isolation of the wastes from the accessible environment shall not consider any contributions from active institutional controls for more than 100 years after disposal.

b. Disposal systems shall be monitored after disposal to detect substantial and detrimental deviations from expected performance. This monitoring shall be done with techniques that do not jeopardize the isolation of the wastes and shall be conducted until there are no significant concerns to be addressed by further monitoring.

c. Disposal sites shall be designated by the most permanent markers, records, and other passive institutional controls practicable to indicate the dangers of the wastes and their location.

d. Disposal systems shall be selected and designed to keep releases to the accessible environment as small as reasonably achievable, taking into account technical, social, and economic considerations.

e. Disposal systems shall use different types of barriers to isolate the wastes from the accessible environment. Both engineered and natural barriers shall be included.

f. Places where there has been mining for resources, or where there is a reasonable expectation of exploration for scarce or easily accessible resources, or where there is a significant concentration of any material that is not widely available from other sources, should be avoided in selecting disposal sites. Resources to be considered shall include minerals, petroleum or natural gas, valuable geologic formations, and ground waters that are either irreplaceable because there is no reasonable alternative source of drinking water available for substantial populations or that are vital to the preservation of unique and sensitive ecosystems. Such places shall not be used for disposal of the wastes covered by this Part unless the favorable characteristics of such places compensate for their greater likelihood of being disturbed in the future.

g. Disposal systems shall be selected so that removal of most of the wastes is not precluded for a reasonable period of time after disposal.

Following is a procedural outline for development of criteria for post-closure passive marker and barrier systems for WIPP.

Part I:

Perform a PA system sensitivity study that will:

a. Vary the mean for time of first intrusion and time interval for passive institutional control over regulatory time interval.

b. Vary failure-ratio function for time of first intrusion within repository bounds (greater than zero and less than or equal to 30 boreholes/km^2/10^4 years).

(The above studies will develop a family of failure-rate functions for different assumptions concerning post-closure passive marker and barrier systems. Note that different failure-rate functions will result in different numbers of intrusions in 10^4 years.)

c. Vary plug-longevity, borehole-fill properties, and hole-closure estimates with failure-rate functions constructed above for different post-closure marker and barrier system assumptions.

This study will address the sensitivity of the WIPP system to each of the parameters listed above. From these analyses, it will be possible to identify not only the important parameters, but also their importance as a function of time after closure and loss of active institutional control.

Attached is a Sandia memo from M. Tierney, 6415, to Mel Marietta, dated January 2, 1990, that indicates Sandia's preliminary planning and sets some of the groundwork for using failure-rate functions described above to construct probability models of inadvertent drilling of the WIPP site in the future. (See Part 2 of the attached memo.)

Part II.

Conduct a literature review (building on the marker and barrier studies by the Office of Nuclear Waste Isolation and the Hanford Waste Site Disposal studies) on:

a. Marker and barrier system longevity: Including materials, construction, size, etc.

b. Technological levels and needs of future societies: Material needs, methods of exploration, methods of recovery, etc.

c. Methodology for transfer of information across time: Directed at transmitting information regarding "Danger," Nuclear Waste Below," "Do Not Drill Here," and "Plug Any Holes Using the Following Technology."

The responses of a, b, and c above will be combined and, along with the activities of Part I, will provide a basis for preparation of draft issue statements and assumptions and for the identification of appropriate members for the expert panels discussed in Part III.

Part III:

Organize and utilize expert panels to develop a quality expert opinion on each of the topics listed in Parts I and II. The procedure used by S. C. Hora and R. L. Iman for acquiring expert opinion in risk analysis titled "Expert Opinion and Risk Analysis: The NUREG-1150 Methodology," published in Nuclear Science and Engineering, Vol. 102, pp. 323-331, 1989, will be followed. (See attached article)

The procedure was developed for acquiring input for risk analysis when other sources of information are unavailable or are not cost effective. This methodology involves a ten-step procedure as follows:

1. Selection of issues,
2. Selection of experts,
3. Preparation of issue statements,
4. Elicitation training,
5. Presentation of issues,
6. Preparation of expert analysis by panel members,
7 Discussion of analyses,
8. Elicitation,
9. Recomposition and aggregation, and
10. Review by the panel members.

These steps are implemented in a multiple-meeting format that brings together experts from a variety of workplaces. The elicitation of the experts' opinions is performed by teams versed in decision analysis and in the particular aspects of nuclear waste management being investigated.

Part IV:

Use the positions developed by the expert panels on each of the functions listed in Parts I and II to define the criteria for passive marker and barrier systems and in all future PA calculations.

Part V:

Develop with Westinghouse a plan for construction of the above-developed marker and barrier systems and a plan for incremental improvements of these systems as technology advances throughout the lifetime of the WIPP facility (approximately 25 years).

Attachments

APPENDIX C:
BOSTON TEAM REPORT

Theodore J. Gordon (Futures Group, Founder)
Michael Baram (Boston University)
Wendell Bell (Yale University)
Bernard Cohen (University of Pittsburgh)

Inadvertent Intrusion into WIPP: Some Potential Futures

by

The Boston Team

Theodore J. Gordon, Consultant (Futures Research)
Michael Baram, Boston University (Law)
Wendell Bell, Yale University (Sociology)
Bernard Cohen, University of Pittsburgh (Physics)

October 10, 1990

Contents

Figures

I. Analytic Approach

The Boston team utilized two different perspectives to structure intrusion scenarios. The first or rational approach led to several "generic" scenarios to which probability analysis may be applied. The second or imaginative approach led to several "point" scenarios designed to stimulate qualitative thinking about future possibilities that may go beyond our present knowledge and beliefs.

Figure 1 illustrates the process used by the Boston Team in identifying the scenarios and studying the other topics discussed in this report.

Task 1. Framework for Analysis: Generic scenarios start with events to which WIPP will remain physically vulnerable based on current knowledge and work back along the chain of causality to find the circumstances that could trigger those events. These scenarios are called "generic" because many different circumstances could trigger the same intrusive event.

On the other hand, "point" scenarios begin with imaginative descriptions of future societies that intrude on WIPP. There are an infinite number of future societal configurations; therefore, there is no hope of being complete in this approach. Furthermore, because of their specificity, the scenarios presented are unlikely to occur as written. Nevertheless, they remind us of the great differences that might exist between our own and far future societies and how these differences might result in currently unanticipated motivations for inadvertent intrusion into WIPP.

In one sense, the generic scenarios are "bottom up," and the point scenarios are "top down"; that is, the former begin from the event of intrusion and work back to the society in which the intrusion occurred; the latter begin with the society and work through to the intrusion.

With this dual approach in mind, each member of the team took the responsibility to write one or more scenarios and make other contributions to this report. The team met once during this process to collate the work and produce an integrated report.

Task 2. Societal Factors: In this task, we attempted to list and forecast the attributes of future societies that would be important to any future intrusion. We considered factors that ranged from population size and density to administration of the WIPP site. Plausible ranges for the important socio-technical factors were proposed for 100, 1,000, and 10,000 years hence. Estimates for these ranges were entirely judgmental, based in part on current trends that will almost certainly be temporary on our extended time scale and our perceptions about breakthroughs and other new and important developments that seem plausible.

Task 3. Generic Scenarios: No expertise or methods of analysis exist for forecasting intrusions into WIPP on a time scale of 10,000 years with any degree of confidence or credibility. However, there is a method of probing far into the future to determine activities that would pose the threat of inadvertent intrusion. This method recognizes that WIPP is physically

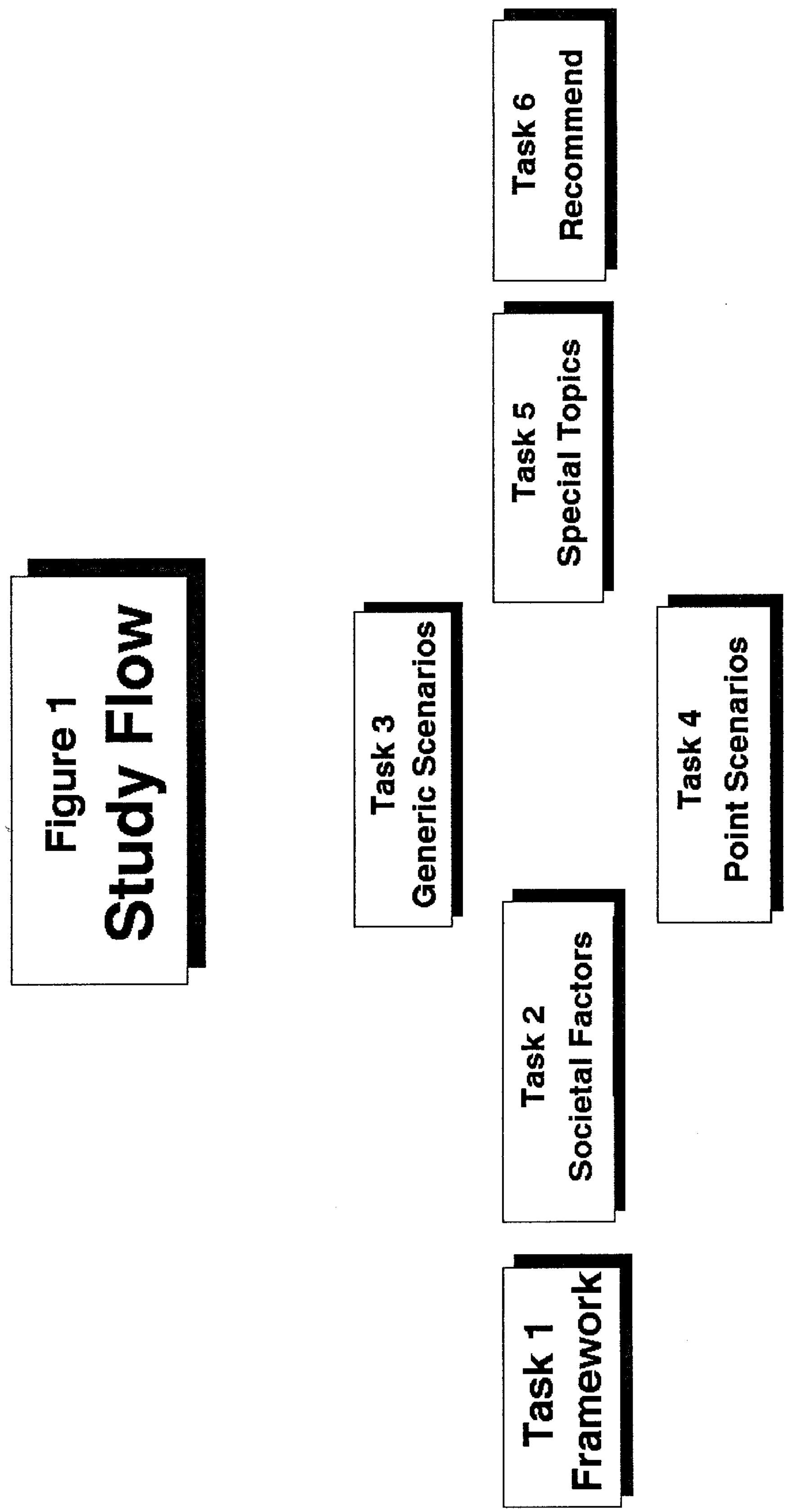

Figure 1. Study Flow

vulnerable to intrusion when certain events occur at the site or in proximity to it, such as boring into the earth, and that WIPP will remain vulnerable to such events whenever they occur.

In this generic approach, analysis of future societal *scenarios* that inadvertently endanger WIPP integrity starts with identification of those *events* to which WIPP will remain physically vulnerable. The next step is to determine what kinds of *human activities* are most likely to produce these events. The next step is to decide what kinds of *social conditions*, needs, or motives are most likely to stimulate the activities that trigger the harmful events. The final step is to apply *criteria for screening* the selected activities to find the conditions under which these can be designated as sources of inadvertent intrusion, a task that requires consideration of two variables: (1) the knowledge available to those who promote the activity and (2) their regard for the risk of intrusion.

This analysis technique was used to develop the scenarios that appear in Section III.

Task 4. Point Scenarios: These first three tasks led members of the study team to nominate several point scenarios that depicted possible intrusion into WIPP by future societies possessing new viewpoints and motivations. These imaginative scenarios were consistent with the societal projections of Task 2 and contrasted with the generic scenarios of Task 3. These scenarios appeared *plausible, different* from each other in terms of societal motivations and modes of intrusion, and *important* in the sense that they expanded our sensitivity to a wide range of future societal configurations of potential interest.

These point scenarios appear in Section IV of this report.

Task 5. Special Topics: Not all relevant matters could be efficiently included in the scenarios; therefore, in Task 5, several members of the team developed brief papers dealing with topics they felt to be important. These special topics papers appear in the Appendix to this report.

Task 6. Conclusions and Recommendations: Finally, the team derived a brief set of conclusions and recommendations, which appear in Section V.

II. Societal Factors

The central purpose of this task was to identify and forecast those factors in society ore, we are certain only of one fact: some far future historian reviewing our work would wonder why we had managed to omit the most important factors and miss the significant ranges by so much. At most, this will be a recording of our best efforts at judging what the long range future might hold; therefore, we recommend that if the WIPP is activated, this exercise be repeated approximately every 25 years so that new knowledge and perceptions can be incorporated and feasible remedial action be taken to limit intrusion.

	Development	100 Years	1,000 Years	10,000 Years
1	World Population	10-20 Billion	6-100 Billion	6-100 Billion
2	Life Expectancy	50-90 Years	50-500 Years	Uncertain
3	Pop Density nr WIPP	1 to 5 times now	1 to 30 times now	1 to 100 times now
4	Who Lives Near WIPP	As at present; specialized towns?	Uncertain; urban development?	Uncertain; urban development?
5	Water Supply	0 to low	0 to high	0 to high
6	Key Energy Sources	Fossil/solar/nuclear	Solar/nuclear?	Uncertain
7	Land Use Near WIPP	None to extractive, hydrogen production, solar harvesting, agriculture, habitat	None to extractive, hydrogen production, solar harvesting, agriculture, habitat	Uncertain
8	Subsurface Use WIPP	Storage, extraction, science	Storage, extraction, shelter, science, transport, other	Storage, shelter, science, transport, other
9	Value of Mtl at WIPP	100's of millions	0- billions	Uncertain

Figure 2. The Range of Future Possibilities

	Development	100 Years	1,000 Years	10,000 Years
10	Inquisitiveness	As at present	Satiated to inquisitive	Satiated to inquisitive
11	Knowledge of Past	As at present	Low to extensive	Low to extensive
12	How Information About the Past is Gathered and Stored	Dig, read, folklore, electronic data	Dig, read, folklore, electronic data, space storage	Dig, read, folklore, electronic data, space storage
13	Beliefs	Secularization, new religions, revision of old religions	Secularization, new religions, revision of old religions	Secularization, new religions, revision of old religions
14	Food Production	Genetic augmentation	Primarily genetic	Primarily genetic
15	Raw Materials in Use	Minerals, petro-chemicals	Minerals	Uncertain
16	Raw Material Sources	Geologic	Geologic, space, transmute	Geologic, space, transmute
17	Mining	As at present, free mole	As at present, free mole, micro hole	None to as at present, free mole, micro hole

Figure 2. The Range of Future Possibilities (Continued)

	Development	100 Years	1,000 Years	10,000 Years
18	Envirommental Ethics and Policy	Recognition of env. limits, regard for human health, regional and intl; growth of reg of private rights.	Continuing trend toward "spaceship earth" with govermt planning for and control of private activities.	Continuation; or uncertain
19	Environmental Law	Advanced risk estim- ating, proving causation. Prevent- ative legislation. Liability for incr. risk. Insurance replaces tort liabil system. Possible animal and eco rights.	Govmt structured insurance compen- sation for envirnmtl harm. Incr govmt control of risky activities-licensing and standards. --or- change in governance and legal doctrines; eg self governing corps, expert decision systems.	Uncertain

Figure 2. The Range of Future Possibilities (Continued)

	Development	100 Years	1,000 Years	10,000 Years
20	Deep Earth Mapping	Core drilling, non-invasive imaging.	Core drilling, non invasive imaging	Precise non invasive imaging
21	Robotics	100 times present	None to autonomous and intelligent	None to autonomous, and intelligent
22	Infor Storage and Retrieval	10 ^ 6 times present	None to 10 ^ 12 times present	None to essentially infinite
23	Desalination	Cost effective	Common	Common
24	Waste Disposal	Burial, burning, biologic	None to very deep burial, torch, sun probe (?), biologic	None to biologic, burial, torch, sun probe (?), transmute
25	Space capabilities	Manned Mars, lunar base, asteroid herding	None to planetary colonization, asteroid mining	None to inter-stellar
26	Diseases From Radioactivity	None to cancer, mutation	None to mutation	None to mutation

Figure 2. The Range of Future Possibilities (Continued)

	Development	100 Years	1,000 Years	10,000 Years
28	Stored at WIPP	Nothing to nuclear and other wastes	Nothing to nuclear and other wastes	Nothing to nuclear and other wastes
29	Security at WIPP	As at present to declining	None to military-like	None to military-like
30	Waste From Weapons Production	Planned to times 10	None to planned times 10 ^ 3	Uncertain
31	War and Terrorism	Conventional, nuclear capability, economic,psycho-logical, advanced chemical, biologic	Almost none to conventional, nuclear capability, economic, psycho-logical, advanced chemical, biologic	Uncertain

Figure 2. The Range of Future Possibilities (Concluded)

III. Generic Scenarios

As mentioned earlier, our approach to the creation of generic scenarios involved four

(1) Identifying *events* to which WIPP remains physically vulnerable.

(2) Identifying the human *activities* likely to require those events.

(3) Determining *social conditions* likely to stimulate the human activities.

(4) Applying *criteria to screen* the activities to determine the conditions under which these can be designated as sources of inadvertent intrusion.

We recognize the following events to which WIPP will remain vulnerable: (1) boring into the site or adjacent subsurface area, (2) water seepage into the site, (3) excavation at the site exposing it to natural or societal risks, and (4) explosions at or near the site affecting its structural integrity.

In addition, we recognize that following human activities could generate the events to which WIPP will remain vulnerable:

- Construction (e.g., subsurface works such as tunnels, repositories, habitat, pilings, etc.)
- Subsurface Research (e.g., geological, seismic, weapons testing, deep earth mapping, archaeological, etc.)
- Water Supply Impoundments (e.g., reservoirs created by dams for water storage.)
- Extraction (e.g., material stored or believed to be stored at WIPP, oil, gas, water, minerals, brine, salt, etc.)
- Additional Storage (e.g., subsurface storage of nuclear or other hazardous material, etc.)
- Disposal (e.g., reinjection wells for disposal, etc.)
- Other (e.g., shrine building, etc.)

In reviewing the societal factors of Task 2, it appears that five societal elements which are key to these generic scenarios:

- Population density near WIPP

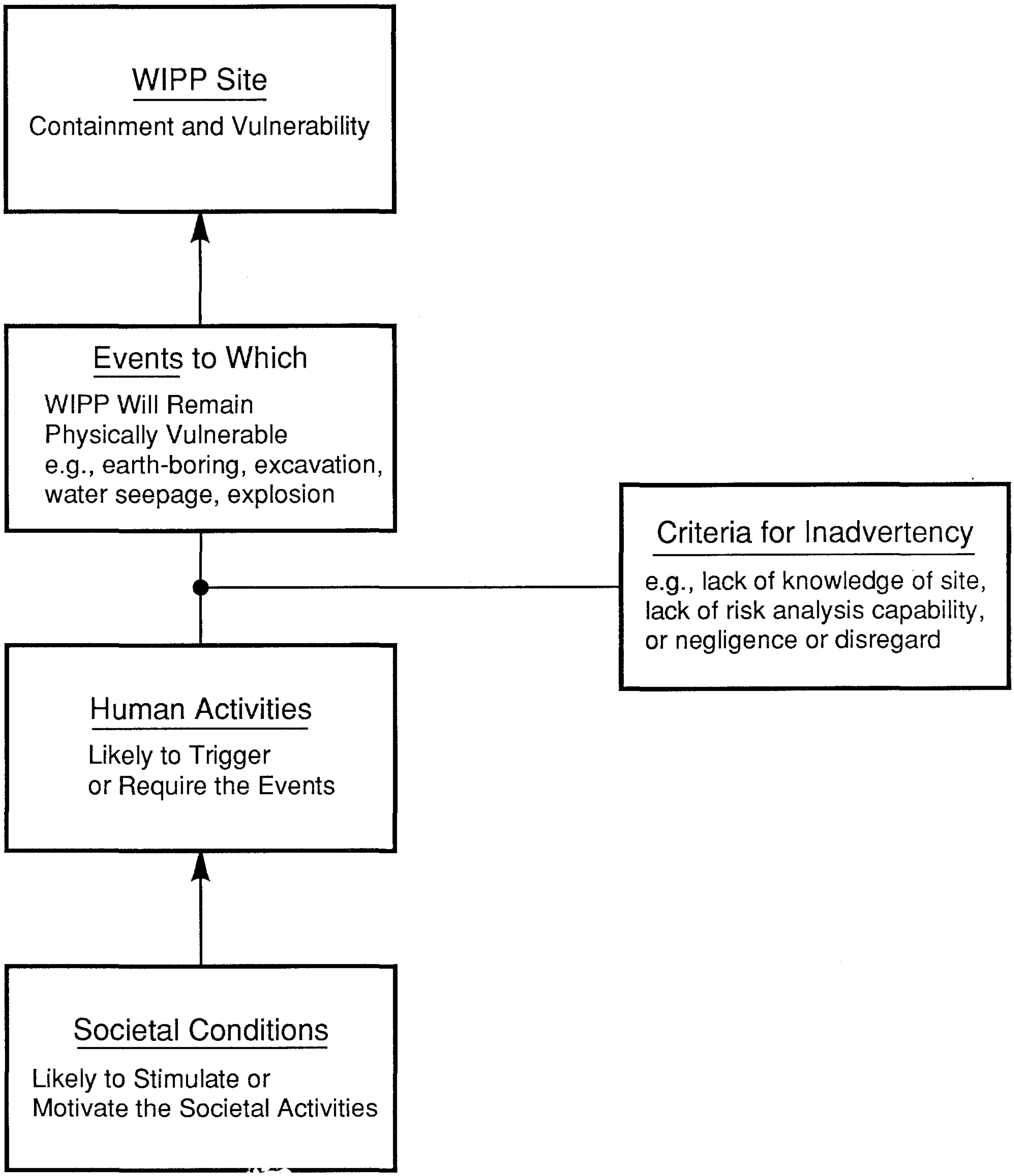

Figure 3. The Generic Scenario Process.

- Industrial activity near WIPP

- Value of the material stored or naturally available at or near the site

- Knowledge of the past

- State of technology

Given these three dimensions--events, activities, and societal factors--two matrices were formed. The first of these appears in Figure 4; it is a display of events and activities. In reviewing the cells of this matrix, it is apparent that some combinations are likely, others are possible, and still others are not likely. Similarly, Figure 5 presents a matrix composed of activities and societal factors. Again, the cells can be judged as likely, possible, or unlikely. This sorting process allowed us to form a set of generic scenarios that seemed appropriate to investigate further. These possibilities are summarized in Figure 6.

This scenario list of Figure 6 includes only those cells of the matrices that were judged as "yes" and omits the "possible" and "no" cells. Also, note that the societal factors were all stated as high levels; there are mirror image low levels that should be examined, as well.

But taking this set as a starting point, we chose the following scenarios on the basis of coverage, and interest:

- Excavation for Construction and Construction Materials (Case 13)

- Extraction of Resources (Case 14)

- Explosion (Case 21)

- Water Impoundment (Case 11)

Of course, this is not a complete set, but it does represent interesting and important scenarios.

In this section, we first demonstrate our approach with a specific example and then apply the approach to the selected cases. In each case, we addressed the following questions:

What material might be removed?

Was there a *priori* knowledge of WIPP?

What was the motivation and means?

What is the frequency of intrusion?

Could the intrusion be detected during the process?

Would markers or barriers serve as a deterrent?

What is the liklihood of key events and assumptions associated with the scenario?

The illustration and the generic scenarios follow.

	BORING	WATER SEEPAGE	EXCAVATION	EXPLOSION
CONSTRUCTION	YES	POSSIBLE	YES	YES
SUBSURF RESRCH	YES	POSSIBLE	POSSIBLE	POSSIBLE
WATER SUPPLY IMPOUND	POSSIBLE	YES	YES	POSSIBLE
EXTRACTION	YES	POSSIBLE	YES	POSSIBLE
ADDITIONAL STORAGE	YES	POSSIBLE	YES	POSSIBLE
DISPOSAL	YES	POSSIBLE	POSSIBLE	POSSIBLE
OTHER (Shrine Bldg)	POSSIBLE	POSSIBLE	POSSIBLE	POSSIBLE

Figure 4. Generic Scenarios, Events and Activities.

	HIGH POP DENSITY	HIGH INDUS ACTIVITY	HIGH VALUE OF MTL	HIGH KNOWL OF PAST	HIGH STATE OF TECHN
CONSTRUCTION	YES	YES	NO	NO	POSSIBLE
SUBSURF RESRCH	NO	YES	POSSIBLE	POSSIBLE	YES
WATER SUPPLY IMPOUN	YES	YES	NO	NO	NO
EXTRACTION	POSSIBLE	YES	YES	NO	NO
ADDITIONAL STORAGE	YES	YES	NO	NO	POSSIBLE
DISPOSAL	NO	YES	NO	NO	POSSIBLE
OTHER (Shrine Bldg)	NO	POSSIBLE	NO	POSSIBLE	NO

Figure 5. Generic Scenarios, Societal Factors and Activities.

	Event	Activity	Societal Factor
Case 1	Boring	Construction	Hi Popul Density
Case 2	Boring	Construction	Hi Indus Activity
Case 3	Boring	Subsurf Research	Hi Popul Density
Case 4	Boring	Subsurf Research	Hi Technology
Case 5	Boring	Added Storage	Hi Popul Density
Case 6	Boring	Added Storage	Hi Indus Activity
Case 7	Boring	Extraction	Hi Indus Activity
Case 8	Boring	Extraction	Hi Value of Mtl
Case 9	Boring	Disposal	Hi Indus Activity
Case 10	Water Seepage	Water Supply Impound	Hi Popul Density
Case 11	Water Seepage	Water Supply Impound	Hi Indus Activity
Case 12	Excavation	Construction	Hi Popul Density
Case 13	Excavation	Construction	Hi Indus Activity
Case 14	Excavation	Extraction	Hi Indus Activity
Case 15	Excavation	Extraction	Hi Value of Mtl
Case 16	Excavation	Added Storage	Hi Popul Density
Case 17	Excavation	Added Storage	Hi Indus Activity
Case 18	Excavation	Water Supply Impound	Hi Popul Density
Case 19	Excavation	Water Supply Impound	Hi Indus Activity
Case 20	Explosion	Construction	Hi Popul Density
Case 21	Explosion	Construction	Hi Indus Activity

Figure 6. Generic Scenarios, Combining the "YES" Cells of Figs. 3 and 4.

Demonstration of the General Scenario

The most obvious example of an *event* to which WIPP is and will forever remain physically vulnerable is boring into the earth at or near the WIPP site deep enough to reach or puncture the salt beds in which transuranic wastes are stored. Of the cases listed in Figure 5, boring is the event that most frequently triggers intrusion. This event could cause a release of radioactive material to the off-site environment either by fracturing the salt formation, by creating a pathway for water to intrude the site and destabilize its crystalline structure, or by injecting water to remove subsurface materials (extraction through solution mining).

What kinds of human *activities* might use this earth-boring event? Five types of activities are most likely:

(1) Construction (e.g., subsurface works such as tunnels, repositories, habitat, pilings),[1]

(2) Subsurface research (e.g., geological, seismic, or archeological),[2]

(3) Extraction of resources (e.g., of hard minerals such as magnesium or soft minerals such as oil and gas, ground-water, or the salt itself),[3]

(4) Additional storage (e.g., expansion of WIPP),

(5) Disposal (e.g., disposal of industrial waste fluids through injection).

What *societal conditions* or needs are likely to promote these five types of activities that would involve earth-boring at or near the WIPP site? To answer this question, each of the activities would have to be carefully assessed for diverse motivating factors, some of which have already been alluded to previously in describing the activities. For example:

Motives for construction will vary according to the functions that the construction is to serve and include, for example, need for subsurface facilities for transport, habitat, industrial production, and storage or waste disposal when constructing such facilities at alternative sites is not feasible due to technical or economic constraints, environmental concerns, political forces, or military requisites.

Motives for subsurface research may be scientific or historical interest or knowledge-seeking for no immediate pragmatic or operational purpose (e.g., geological, seismic, or archeological research); research for profit-seeking and market driven purposes (e.g., search for minerals for industrial or commercial energy needs); or research for public well-being purposes (e.g., search for water supply and fuels needed by the general public).

Motives for extraction of resources are narrower, namely to secure minerals, fuels or water supply for industrial or public consumption, particularly when tapping alternative sources (at other sites) is not feasible due to technical, economic, political or environmental factors.

Motives for additional storage will depend heavily on society's production of noxious and dangerous materials and facilities that exist for their storage or disposal.[4]

Motives for disposal depend on alternative means available for handling wastes and the intensity of industrial activity in the area.

Finally, when would the foregoing intrusion scenarios be properly characterized as *inadvertent* or unintentional? To answer this question, one needs criteria such as the following: the *knowledge about the site* (its location, contents, and safety parameters) possessed by persons responsible for the activity, the *knowledge* of these persons *as to the risks posed by their use of earth-boring methods* to the integrity of the WIPP site, and *their regard for potential risks* to human health and the environment. By using these criteria, several scenarios for inadvertent intrusion are possible:

- The activity employing earth-boring at or near the WIPP site is either conducted *without knowledge of the site* (location, contents, or safety parameters) as would be the case if markers, records, or warnings were absent, or with information about the site but *without the ability of persons managing the activity to understand the meaning of the information.*

- The activity is conducted with adequate knowledge of the site (location, contents, and safety parameters) but *without adequate knowledge of the risks to site integrity posed by the activity.*

- The activity is undertaken with full knowledge of the site and the risks that the activity poses to it, but persons directing the activity have been *negligent* and erred in assessing the appropriate margins of safety that are needed to protect the site, *or have shown a reckless disregard* for risk to the site, public health, and the environment.

Thus, lack of knowledge, inability to comprehend warnings or assess risks of the activity, and negligence or recklessness without intent to harm are the key criteria in determining which intrusions would be inadvertent. From this, it appears that markers and records to warn future generations are insufficient guarantees against inadvertent intrusion in that they do not prevent negligence or disregard for safety.

Case 13. Excavation

1. WIPP Vulnerability

At WIPP, the bedded salt formation containing transuranic waste would lose structural integrity and ability to contain the waste if its protective earth overlay were substantially removed by excavation.

2. Event

Excavation of the earth overly at WIPP would expose the salt formation and promote its erosion by natural forces (e.g., weather, wind, water) and also make it vulnerable to a broad range of small-scale activities at the site such as the construction of buildings.

3. Activities Requiring the Event

Since WIPP is over 2000 ft. below the earth's surface, the hypothetical excavation threatening its integrity would be a major project employing very heavy equipment such as the giant excavators and other earth-moving equipment that have already been used in surface mining of Black Mesa, Arizona (and elsewhere in the west).

Only a small range of human activities would require such major excavation, namely, construction of a major facility that requires a substantial foundation at the site or surface mining of hard minerals at the site that would inevitably create a large pit.

Construction of a large dam at the site, the most likely type of facility requiring such excavation, would be undertaken only if a major water impoundment and supply system were to be developed because of industrial, energy, agricultural, or residential growth. (See scenario on "Water Impoundment.")

Large scale surface-mining at the site would be undertaken if there is sufficient demand for the minerals contained in the earth overlay. For example, such mining could be undertaken for sand and gravel needed for large scale construction programs (e.g., highways). Although sand and gravel are found throughout the nation and offshore, many regulations now restrict its extraction because of environmental consequences, and costs of this essential material have escalated. Thus, it is conceivable that sand and gravel at the site would be excavated. (Surface mining of western oil shale, Black Mesa coal, Minnesota-Mesabi iron ore, and Chilean copper provide clear examples of actual activities involving substantial excavation).

Finally, it should be recognized that construction of a dam or other major facility requiring substantial earth-moving at the site would also trigger further excavation of sand and gravel at the site to make vast amounts of concrete (for the foundation of the facility) or to build earthen berms or walls to contain water supply (as is commonly done). Thus, certain activities would provide dual stimuli for excavation: to prepare the site for a foundation and to provide the materials for constructing the facility itself.

4. Conditions Promoting the Activities

As noted above, certain conditions are foreseeable as promoters of activities requiring such excavation. The need for water impoundment dams, created by industrial, agricultural, energy, or residential developments in the WIPP area, represents one set of conditions. The need for large volumes of low-cost sand and gravel or other high-bulk, low-value minerals in the earth overlay a the site for construction purposes represents the other major set of conditions that would promote activities requiring excavation.

5. Inadvertent Intrusion

If the activities meet certain criteria, then any intrusion arising from excavation can be characterized as "inadvertent." As with the other scenarios in this section of the report, these criteria include the following:

(1) The activity is undertaken without the knowledge of the site or its contents, due either to the absence of markers and warnings or the inability to comprehend them;

(2) The activity is undertaken with such knowledge of the site and its contents, but the managers of the activity lack sufficient analytic methods to determine accurately how excavation can be safely conducted without endangering WIPP; or

(3) Knowledge and analytic methods are appropriate, but excavation is done with disregard for site safety, as would be the case when societal demand or economic incentives for construction of a water supply dam or cheap sand and gravel override safety concerns.

Probabilities

The following are possibilities considered regarding excavation of the site and are listed with their level of risk:

- Developments in the region will occur requiring a major facility such as a dam to be constructed at the site--high;

- Societal need for sand and gravel or other high-bulk and low-value materials will promote excavation at the site--medium, but high in the case in which the minerals are needed for major facility construction at the site;

- Excavation would be so substantial as to expose WIPP salt beds and promote their vulnerability to intrusion--medium;

- Project proponents would lack knowledge of WIPP--medium to high;

- Project proponents would lack risk analytic methods--low to medium (since availability of heavy construction equipment is usually found only in relatively sophisticated industrial societies).

- Other factors would promote excavation with disregard for WIPP safety--medium, but high in the case in which it is economically and technically appealing to use sand and gravel for constructing a major facility at WIPP.

Case 14. Extraction of Resources

1. WIPP Vulnerability

The material stored at WIPP might be accidentally uncovered and exposed to the environment as a result of the attempts of a society to gain access to the subsurface resources in the vicinity of WIPP; these resources include the plutonium itself, potash, magnesium, salt, brine, oil and gas, or other materials not now considered valuable.

2. Event

The intrusion could occur in exploration for the material as a result of boring through a storage area or container, or during recovery as a result of excavation (while not explored in detail here, it is also possible to imagine situations in which the exploration or recovery attempts do not penetrate the radioactive material but somehow promote its migration to other substrates from which subsequent exposure to the environment occurs).

3. Activities Promoting This Event

No matter which material is considered, the activity leading to the event is extraction. Extraction, in general, can be through excavation, pumping of fluids, or solution mining of soluble materials. It is difficult to imagine significant additions to this list, even over our time scale. Nevertheless, it is likely that advancing technology will make exploration and identification of the resources easier, cheaper, and more precise (imagine a high precision surface-based assay that is nonintrusive and functions like a large scale CAT scanner). In addition, there may be new and efficient means of drilling, new fluids for solution mining, and new rapid means of excavating in the centuries to come.

Most extraction activities require large surface operations and therefore would be readily detectable unless efforts were made to conduct these operations clandestinely. The effort in extraction activities will probably require large organizations that can understand the markers should those data be available.

As a set, these are apt to be more highly automated and capable of operating deeper and more rapidly so that some currently marginal resources become economically attractive.

4. Conditions Promoting the Activity

Mining for Plutonim

By far the most valuable resource in WIPP is 8700 kg of plutonium-239, which at its present cost of $100,000 per kg, would be worth close to $1 billion. However, it is not economically feasible to recover it now, and even aside from excavation problems, it would be orders of magnitude more difficult to recover it when it is mixed in with tremendous quantities of salt. Therefore, unless economic and social conditions change greatly, there would be no economic sense in mining for plutonium after the repository is sealed.

Suppose that the production of plutonium is halted in the future and that more plutonium will later be needed. The material buried in WIPP represents less than 1% of the U.S. government production. The other 99% would surely be much more accessible. Moreover, plutonium production facilities could easily be started up to produce more.

If for any reason it would someday be decided to recover this plutonium, there would surely be an appreciation of its health hazards, and proper precautions would be taken.

One might consider the possibility of illicit mining by groups who have no access to normal sources of plutonium and might want it to make clandestine nuclear weapons. Excavation to a depth of 2100 feet and removal of huge volumes of material could not be a covert operation. It would require large equipment and months of effort.

Potash

Over 95% of potash is used as fertilizer. The U.S. now uses about 10 million tons per year with 3 million tons produced domestically. U.S. resources are estimated at about 6 billion tons, nearly all of it in MT, ND, UT, and MI, but NM now provides 89% of U.S. production. The NM reserves should be mined out within the next century, and attention will turn to other areas. World resources are about 250 billion tons, so if the rest of the world used it at the present per capita U.S. rate, there would be enough for about 1000 years. After that, alternatives will have to be developed. Potash mining can thus be a concern only for about 1000 years.

As long as potash mining and exploration continues, it seems likely that exploration records will be retained, and few places have more complete records than the WIPP area. There is thus little incentive for further exploration. If records are lost and there is future exploration, it would be confined to a very few deep drill holes before recognizing that the only potash of interest is at shallow depths. Mining of those shallow deposits, which would be very questionable because of their low grade, would hardly compromise the security of WIPP.

Magnesium

The ground water in the Rustler Formation just above the Salado Formation is rich in magnesium, with 20 times the concentration in seawater. This raises the possibility that this may be exploited for magnesium production. Since this is far above the WIPP repository, it does not seem reasonable that pumping out this water would compromise WIPP security. In fact, removing this water would tend to improve WIPP security.

Magnesium is, and always will be, extremely abundant, both in rock and in seawater or brine. The probability that any single localized source will be exploited is therefore very small. If we consider only electrolytic separation from salt water, the cost is largely in the electricity for the electrolysis, which is independent of the magnesium concentration in the water. Higher concentration means less water to be pumped, but this energy saving is counteracted by the extra energy, as compared with seawater, needed to withdraw brine from deep wells in the face of low transmissivity of water through the rock. It would also be easier to dispose of water water to the sea. Currently, magnesium is produced from rock, from seawater, from lake brines, but *not* from deep wells.

Production of magnesium from salt water is now done in locations where electricity is cheap and abundant. Solar photovoltaics may provide cheap electricity in the WIPP area, but if this is so, there are innumerable other places in the world where cheap solar energy is available adjacent to seawater. Great Salt Lake in Utah would be another example.

Since there are so many likely sources of salt water for electrolytic production of magnesium, the probability for the brine in the WIPP area to be used is extremely small, and event if it were used, WIPP security would probably not be compromised if only upper brines were tapped. (A scenario involving Bell Canyon brines is included in Section 4). Thus, the danger from magnesium extraction is negligible.

Salt Mines

Since WIPP is in salt and salt is commercially mined, the most obvious release mechanism is salt mining. Salt consumption in the U.S.[7] is about 3.6×10^7 tons per year; world consumption is about 19×10^7 tons per year, but if per capita use were equal to current U.S. use, it would be about 72×10^7 tons per year. The total quantity of salt in the world's rock is estimated to be 2×10^{16} tons[8], which means that if all salt production were from rock, the probability for any particular rock formation, such as the WIPP site, to be mined, would be about 3.6×10^{-8} per year or 4×10^{-4} (0.04%) over the next 10,000 years.

There are several possible modifications to this estimate. Only on-third of our salt is now derived from mining rock salt, which would reduce this estimate by a factor of 3. Solution mining would increase the probability, but that requires abundant water, which is not expected to be available in the area.

Since salt is so cheap and transportation is an important cost factor, salt is ordinarily produced close to where it is used. About 25% of salt is used for de-icing, which is not needed in the WIPP area. Most salt is used in industrial chemical processes that normally require lots of water and are therefore less likely to be located in that area. On the other hand, the industrial needs may well expand in the future. Almost half of all salt is used in chemical industries, and it is heavily used in a wide variety of other industries.

All things considered, the probability that the material buried in WIPP will be released by salt mining operations (assuming memory is lost) during the next 10,000 years is on the order of one chance in 10,000.

Mining for salt carries with it the possibility of releasing a large fraction of the material stored at WIPP.

Brine

Brine in deep underground aquifers is not considered to be a resource. The U.S. Bureau of Mines (B of M) and the U.S. Geological Survey pay virtually no attention to it. In a large university engineering library, there were 12 books on ground-water hydrology, groundwater resources, and related topics, but water hydrology, groundwater resources, and related topics, but none of them had a listing for "brine" in the index. There was no reference to it in the index to the 20 volume McGraw-Hill Encyclopedia of Science and Technology.

A Bureau of Mines specialist on salt knew of only one place where brine is pumped out and used to produce salt. This is in West Virginia, in an area remote from other sources of salt, and it provides only about 0.2% of present U.S. salt production. Enormous quantities of brine are pumped out in the course of oil production, but it is considered to be a nuisance to be discarded in the most reasonable way.

If the situation should change, making brine a valuable resource, there would be so much brine readily available that the probability for this particular brine to be used in the next 10,000 years would be very small. If it were to be extracted, a drill hole through WIPP would be no more likely than at any other location, so its probability would be only about 1%. If it were extracted by pumping via a drill hole through WIPP, its high salinity would diminish its ability to dissolve away WIPP material even if the well were not encased. Hence, the amount of buried waste that would be removed is likely to be small.

This release mode is therefore orders of magnitude less important than mining for other materials near WIPP.

Oil and Gas

Drilling for oil and gas is a very common practice in our age. "Rank wildcat" exploration is now carried out at a rate of about 3×10^{-4} drill holes per square kilometer per year, which would imply that there might be several holes through WIPP over the next 10,000 years. The consequences of such bore holes are treated in the WIPP reports (e.g., SAND 89-0462, UC-70, pages 8-17 to 8-22) and are not very grave.

The largest dose from a bore hole through WIPP results from contaminated stock wells and is given as 310 mrem whole body equivalent from ingestion of 206 grams of beef per day for one year--more probable estimates are only about 1% of this. The number of cattle drinking from such contaminated wells would be about 30 (grazing supports only 3 cattle per square mile), of which perhaps 10 per year would be slaughtered. These might provide 4,000 lbs. of edible meat, enough to give the 320 mrem dose to 25 people, or a dose commitment of 8 person-rem per year. With a cancer risk estimate of 260×10^{-6} per person-rem, this would lead to 2×10^{-3} deaths per year, or 20 deaths over 10,000 years. The most probable number of deaths is much less than <u>one</u>.

However, our age is very exceptional as a time for oil and gas exploration. The success rate and profit return on exploratory drilling has been declining for the past several years, and there is every reason to believe that it will continue to decline rapidly. In fact, predictions of how long the world' oil and gas supplies will last rarely exceed 100 years. Oil and gas from coal are very close to competitive, and other sources like shale oil and tar sands are not far behind. Our motor vehicles will be switching to electric power or hydrogen fuel within the next few decades and electrical home heating is already competitive with oil or gas in some areas.

It thus seems probable that drilling for oil and gas will be essentially finished by the end of the 21st century, and it is very difficult to see how it can survive the 22nd century. This entire time period is within the range when knowledge about WIPP will almost surely be available.

If there should be a disaster that disrupts civilization enough to destroy that knowledge within this time period, the consequences of that disaster would be so immense as to dwarf any consequences of intrusion into WIPP. World population would be drastically reduced, which means the untimely death of many billions of people. By comparison, the few (if any) deaths that might result from a bore hole through WIPP would be completely trivial.

If there were an interruption of civilization, would future civilizations explore for oil and gas? Probably not, because there would not be enough left to make it worthwhile. Our present large use developed gradually during a period when oil and gas were cheap and abundant. Demand for the product therefore grew very large, leading to steadily improving capability for finding and extracting it as the more available sources were becoming exhausted. For example, early exploratory holes were less than 100 ft. deep, but by now they reach to more than 10,000 ft., a much more difficult and expensive technology. If oil and gas had been scarce and expensive from the start, alternative technologies would have flourished and large use of oil and gas never would have developed. That will be the situation for future civilizations if they have to start without a knowledge of history.

We therefore conclude that regardless of what happens, the Earth may never again see a day when deep bore hole exploration for oil and gas is done on today's scale.

Extraction of Minerals Not Now Considered Valuable

It is difficult to imagine what minerals not now considered valuable might be the target of future mining, but this is always a possibility in view of our uncertainty about the future.

This century and the next are widely viewed as the "age of mining," during which essentially all valuable minerals will be mined out. After that, man will have to develop substitutes using materials with infinite surface abundance, like iron and aluminum, or obtainable from the sea, like magnesium, chlorine, etc. Interest in mining should diminish rapidly.

Under such circumstances, it is difficult to imagine that mining will ever exceed the scope of current coal mining, which removes 4×10^8 tons annually from underground in the U.S. The total excavation is perhaps 1×10^9 tons. The mass of rock under the U.S. down to 1000 meters is 3×10^{16} tons. Thus, coal mining removes 3×10^{-8} of underground rock (top 1000 meters) per year.

Since WIPP is no more likely than any other location to be the target of mining for minerals not now considered valuable, the probability for it to be involved is no more than 3 x 10^{-8} per year, or 0.03% over the next 10,000 years. A best estimate would be substantially less.

5. Inadvertent Intrusion

The mining described in this section can result in inadvertent intrusion in the following ways:

(1) Knowledge of WIPP exists, but through a mistake the radioactive material is exposed to the environment.

(2) Knowledge of WIPP does not exist but the barriers and markers are recognized (or the operation is detected by third parties responsible for WIPP), but a mistake occurs anyway.

(3) Knowledge of WIPP does not exist and the barriers and markers are not recognized (or third party detection of the operation fails).

The likelihood of all these modes should be studied.

6. Probabilities

The following are possibilities for extraction of resources and their likelihood.

Plutonium

- Plutonium production is halted in the future--medium.
- The value of the plutonium stored at WIPP continues to rise--high.
- Plutonium at sites other than WIPP is more easily accessed--high.
- If plutonium is in demand, it will be obtained by restarting production rather than recovery--high.
- Future recovery of plutonium will be accomplished by societies that appreciate its dangers--medium to high.
- Plutonium is recovered by groups that intend to use it for weapons--low.

Potash

- Potash reserves are depleted in about 1000 years--high.
- Potash is economically recovered from the ocean--medium to high.
- Potash exploration is restricted to shallow depths--low to medium.
- Any mining of potash requires large machinery and will be easily detected--medium to high.

Magnesium

- Ground water above the level of WIPP is used for magnesium recovery--medium.
- Electricity at the WIPP site becomes inexpensive--medium to high.
- Surface operations associated with pumping brine to the surface are large and detectable--medium to high.

Salt

- Mining (excavation) for salt occurs at WIPP--low to medium.
- Solution mining for salt occurs at WIPP--medium.
- Industrial needs for salt expand--medium.

Brine

- Brine becomes an important resource--low.
- If brine were removed from aquifers near WIPP, the operations could be easily detected--medium.

Oil and Gas

- An exploratory well passes through material stored at WIPP--low to medium.
- Economic depletion of oil and gas reserves occurs within 100 years--medium to high.
- Other sources of fuel become commonplace--high.
- After switching to other fuels (or a discontinuity occurs in our civilization) deep drilling for oil and gas exploration is reestablished--low.

Other Materials

- Other materials not now considered valuable will be mined at WIPP--low.
- Techniques other than mining become predominant in producing raw materials--high.

Case 21. Explosions

1. WIPP Vulnerability

At WIPP, the bedded salt formation containing transuranic waste would lose its structural integrity and ability to contain the waste if subjected to large physical shocks generated by substantial explosions.

2. Event

Explosions at or near the WIPP site, particularly if they occur underground, could fracture the salt formation and lead to sudden or slow and continuing release of the radioactive wastes. They could also change subsurface aquifer characteristics in a manner that threatens WIPP.

3. Activities Requiring the Event

Since WIPP is over 2000 feet below the earth's surface, the hypothetical explosion threatening its integrity would have to be very large even if detonation occurred underground. (See footnote 1 concerning small fractures caused by subsurface explosion of a 5 kiloton nuclear weapon in 1965).

The range of human activities requiring detonation of explosives at sufficient magnitude to threaten WIPP is quite limited and includes military and terrorist activities that are excluded from this study (and will not be addressed further); weapons testing; geologic and other subsurface research for scientific or mineral exploitation purposes; "earth moving" for construction or determining if subsurface conditions are suitable for supporting major construction activities on the surface; and rock fracturing to enable extraction of minerals.

4. Conditions Promoting the Activities

The need to test new explosive devices for military use is driven by national security considerations and advances in weapons technology, and it is likely that these conditions will continue to promote subsurface testing of devices as the safest procedure. Scientific and commercial mining interest in exploring subsurface areas are other persistent forces in society which could promote additional subsurface explosions. Finally, developmental forces (e.g., industrial, agricultural, recreational, energy, residential) in the WIPP region would promote surface and subsurface construction activities requiring explosives.

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1. Examples of these activities are sufficient to indicate their plausibility. Numerous tests of nuclear weapons, both surface and subsurface, have been conducted in remote regions of the western U.S. The setting of subsurface explosions of smaller magnitude is commonly used to conduct geologic research and minerals exploration. Surface and subsurface blasting of ledges is common in construction and in the recovery of numerous minerals including gravel. Thus, conduct of such activities in the WIPP region could trigger explosive forces that threaten WIPP safety.

5. Inadvertent Intrusion

If the activities meet certain criteria, then any intrusion arising from the explosions can be characterized as "inadvertent." As with the other scenarios in this section of the report, these criteria include the following:

(1) The activity is conducted without the knowledge of the site or its contents, due either to loss of markers or inability to comprehend them;

(2) The activity is done with such knowledge of the site and its contents, but managers of the activity lack sufficient analytic skills to determine accurately how explosions can be set without endangering WIPP; or

(3) Knowledge and analytic skills are appropriate, but explosions are set with disregard for site safety, as would be the case when societal demand or military needs for the activity requiring the explosions overrides safety concerns.

Given that weapons testing and geologic and minerals research of subsurface areas are characteristics of a relatively sophisticated technological society, it is unlikely that such activities would meet the second criterion above, but reasonably likely that they would meet the first or third criteria. However, construction activities involving explosives have been conducted by various types of societies, and are more likely to meet any of the three criteria.

Probabilities

The following are possibilities considered for explosions:

- Military needs will necessitate subsurface testing near the site of weapons with sufficient explosive force to threaten WIPP--medium to high.

- Interests in geologic and minerals research near the site will be sufficient to promote activities using explosives of sufficient force to threaten WIPP--medium to high.

- Social development will promote a variety of construction activities near the site using explosives of sufficient force to threaten WIPP--medium as to threat (since explosives of lesser magnitude would be used), but high as to likelihood.

- Project proponents would lack knowledge of site and contents--high.

- They would lack risk analytic methods needed to conduct explosions safely--low in the case of military, geologic, and minerals activity; high in the case of construction.

- They would disregard WIPP safety because of overriding socio-economic forces or security needs--high.

Case 13. Water Impoundment

1. WIPP Vulnerability

At WIPP, transuranic waste is to be stored in a bedded salt formation that would lose its structural integrity and ability to contain the wastes if exposed to significant amounts of water.

2. Event

Water at or near WIPP could endanger WIPP because the earth overlying and surrounding the repository is composed in part of highly permeable soils and may also contain bore holes or fractures. These conditions could permit the water to seep into the WIPP site, erode its integrity, and cause a release of the radioactive wastes. At present, only subsurface bodies of water (two aquifers) above and below the bedded salt now exist, and these have been studied and found to pose no risk to the site. Thus, the hypothetical *event* of concern is the seepage of new water to the site.

3. Activities Resulting in the Event

Given the severe limits on existing water supply in the arid area of the WIPP site, development of new industrial or energy facilities using process or cooling water would thereby require a new and reliable source of water and the storage of the water in surface or subsurface impoundments for routine use over time. New residential communities and commercial and recreational developments would have similar water impoundment requirements. Finally, the need for water impoundment could be triggered by severe drought conditions even in the absence of new industrial or other developments.[5]

The Southwest has already witnessed the creation of vast new water storage or impoundment facilities such as Lake Mead and Lake Powell, and in several instances, impoundments have failed, causing loss of water and severe damage to the environment and private property (at St. George, Utah, in 1989, for example). Thus, *several types of activities* (industrial, energy, agriculture, commercial service, residential growth, recreational, etc.) or *future drought conditions* would require the impoundment of water on a large scale and pose threats of sudden or slow (seepage) releases that would endanger WIPP.

4. Conditions Promoting the Activities

Activities requiring water impoundment at or near WIPP by private developers of industrial, energy, or commercial facilities could be stimulated on the basis of market demand for their products and services. Demand for the energy and commercial facilities would, in particular, be dependent on residential or industrial development of the region surrounding the WIPP site, whereas demand stimulating industrial facilities could arise from national or even global market conditions. Agricultural, residential, or recreational activities requiring water impoundment in the region could be stimulated by needs for subsistence, habitat, and pleasurable outdoor activity.

Given the sparse population in the region at this time, it would be relatively cost-effective for developers (public water supply agencies and private firms) to acquire and use the region for water storage and thereby induce such activities. Prolonged drought, with its severe socio-economic impacts, could also stimulate such developments.[6] The water sources could be underground aquifers, surface waters, and snow melt, and the sources could be hundreds or even thousands of miles from the site (at this time, communities in California already derive water from sources up to 500 miles away). Finally, political pressures for development of the WIPP region have already been felt, and are likely to intensify, particularly for retirement communities and "boom towns" based on mineral or gas extraction development.

Thus, *several foreseeable conditions* can serve as motivators for activities that could require water impoundment in the WIPP region. Experience to date in the Southwest strongly supports this analysis. Further, experience also indicates that loss of water due to failure of containment structures and chronic seepage due to permeable soils, geologic fractures, and leaking pipe joints is common occurrence. This further supports the scenario presented here.

5. Inadvertent Intrusion

Finally, there are several circumstances under which the foregoing scenarios could lead to intrusion that is *inadvertent*. These are the scenario subsets of most concern in this analysis. At the outset, it is noteworthy that federal agencies acknowledge their lack of information sharing, their lack of "common objectives," and other factors that prevent their coordination on water projects.[7] Thus, experience to date indicates the federal supervision of water development activities near WIPP is likely to be suboptimal.

The first subset is one in which records, markers, and other warnings are absent or incomprehensible to water project proponents who then proceed to cause the intrusive event. The second subset involves the availability of such knowledge to project proponents, but their lack of analytic or evaluation methods to estimate the threats that impoundment would pose risks to WIPP integrity so that their conduct of the project damages WIPP. In the third subset, all the foregoing knowledge and analytic methods are available, but overcome by societal needs for water (e.g., in a drought) or economic or political motivations. In this third subset, the major factor leading to WIPP damage is disregard for public health or environmental protection induced by other compelling factors, a very plausible scenario subject in that use of a risk-benefit approach to decision making as commonly practiced could produce the unfortunate result.

6. Probabilities

The following are possibilities considered for water impoundment:

- Industrial, agricultural or residential developments or drought will occur, requiring water impoundment at WIPP--high.
- Water impoundment would be conducted near WIPP--medium to high.

- Impoundment would lead to seepage into the site and damage it--medium to high.
- Project proponents would lack analytic methods to predict seepage outcome accurately--medium to high.
- Project proponents would have disregard for WIPP safety--high.

(Note: Many primitive societies that have practiced water impoundment have lacked knowledge of hazards and analytic tools. Note further that many sophisticated societies have practiced water impoundment despite clearcut knowledge of risks due to overwhelming social, political, or economic pressures.)

IV. Point Scenarios

Let it be clearly understood that we are not advocating the following "point" scenarios. They are, rather, our efforts to trigger the imagination of the reader. We have asked, "What social conditions and individual or group motivations might result in penetration into the WIPP repository--however outlandish, irrational, deviant, perverse, or even repugnant they may be to us personally?" How else can we conceive of the inconceivable and adequately do our job of challenging the ingenuity of the marker teams? Let all things be considered so that the marker teams can comprehensively devise ways of marking or creating passive barriers that reduce the probabilities of all imaginable penetrations becoming future reality. Thinking the unthinkable is part of our task.

The scenarios, however, may be less unthinkable than they first appear. Each is based on developments for which precursors already exist, from feminist theory and post-/(and anti-) positivist beliefs to rudimentary artificial intelligence, computer "viruses," and space travel. The references given are genuine and point to such precursors. What if phenomena that are deviant or only a mere idea today become dominant, the norm, the realities of tomorrow? Today's world is full of beliefs, attitudes, events, activities, processes, and products that most people only 100 years ago would have thought incredible. We are confident that in 100 years from now that statement will remain true. Thus, because something seems ridiculous to us today does not rule out its being regarded as normal or commonplace in the future.

Even though we have written the scenarios with an occasional attempt at humor, they have a serious purpose. They contain seemingly improbable things, but, we argue, they are real possibilities that, if they did occur, would have important social consequences.

Finally, each imagined type of penetration given in this section carries implications for its own prevention, although they are not always obvious.

In creating these point scenarios, we have assumed that WIPP designers and planners have done all that they can to make the WIPP facility safe and impenetrable and that the marker team will be trying to mark the site in ways that will prevent all conceivably possible inadvertent human intrusions. What we have tried to do is conceive of possibilities that may have been overlooked. We have tried to think of motivations, including nonobvious ones, that might result in human intrusions so that the marker teams, by anticipating them, can consider ways of preventing them. If these scenarios seem "far out," they are. We attempted to stretch the boundaries, but always within the limits of plausibility. We asked, in effect, what frames of reference might exist in the far future that put our markers into a different perspective.

These scenarios are quite detailed. As such they contain specific, imagined events or people. This does not necessarily limit the usefulness of these scenarios. The specificity is useful to give a sense of credibility to the setting. A person of a different name or a different event could give rise to the same sort of intrusion. Similar belief might be acquired in different ways, but with the same end result. Endless numbers of specific scenarios could be written illustrating the real possibilities of intrusion into the repository or of misreading or misbelieving a marker as a result of a particular motivation, perspective, or social or cultural setting. Thus, the probabilities, when assigned, refer not to the specific details of a scenario, but to the chances of intrusion as a result of a particular social and cultural setting, motivation, and perspective.

In all we examined ten cases, which we have named:

- A Feminist World, 2091
- Mysticism and Religion, 2091
- Buried Treasure, 2091
- WIPP as the Nation's Nuclear Waste Site, 2091
- A Houston to Los Angeles Tunnel, 2991
- Global Illiteracy, 2991
- Virus Impairs Computerized People, 11991
- Human Warriors Return from Space, 11991
- Nickey Nuke and WIPP Worlds, 11991
- Industrial WIPP, the Solar Desert, 2000 to 12,000

These scenarios follow.

SCENARIOS (100 YEARS)

A FEMINIST WORLD, 2091

Summary: Women dominated in society, numerically through the choice of having girl babies and socially. Extreme feminist values and perspectives also dominated. Twentieth-century science was discredited as misguided male aggressive epistemological arrogance. The Feminist Alternative Potash Corporation began mining in the WIPP site. Although the miners saw the markers, they dismissed the warnings as another example of inferior, inadequate, and muddled masculine thinking. They penetrated a storage area, releasing radionuclides.

* * *

In 2091, men no longer dominated the corridors of power in the polities, economies, and societies of the world. Nor did they dominate any longer in science, art, and literature. The new canons in all fields contained views derived from the feminist mystique, outlines of which were visible as early as the late 1960s. By 2091, women occupied more than 80 percent of the top decision-making positions in nearly all institutional sectors of society and their views of the world determined their--and many others'--actions.

The dominance of women in society was partly the result of many women having decided that the level of testosterone in the human community had exceeded its evolutionary usefulness. Men and their violent acts had nearly destroyed human civilization. Acting on this judgment, women deliberately chose the sex of their children, choosing, that is, to have girl rather than boy babies. Thus, the sex ratio in 2091 was "unnaturally" low, being only three men to every ten women.

Values attributed by feminists to masculine thinking, such as abstract and analytical thinking, quantification, objectivity, rationality, straightforwardness, clarity, concision, universality, modernity, mastery, domination, repression, and technical manipulation, had been discredited along with male aggressive epistemological arrogance. Indeed, misplaced confidence in such techniques as cost-benefit analysis in which human lives had been converted to money terms had led to official decisions that women judged to be immoral and inhumane.

In the place of such "masculine" values, extreme feminists put values and practices of attention to the feelings and emotions of particular individuals, qualitative methods, emancipatory theorizing, eros, nature, particularity, the development of self-consciousness, interpretationism, ethical decision-making, and constant challenges to what used to be taken for granted as "knowledge." Such "knowledge," by 2091, was understood as erroneous masculine definitions, constructions, and representations of reality (Bologh 1990, Harding 1986, 1987; Nicholson 1990).

Representatives of the Feminist Alternative Potash Corporation read the surface monoliths warning of radioactive waste buried at the former WIPP site. After studying the historical records of the age/gender/racial distributions of the major decision-makers, experts, and managers connected with the design and construction of the WIPP repository, they found that 97 percent of them had been middle-aged or older white males. Moreover, they found no evidence of surveys in which women's (or ethnic minorities') opinions had been sought on plans for WIPP. Thus, on the grounds of the obvious male (and class and race) biases that must have gone into the original thinking, they decided that the warnings were simply another example of inferior, inadequate, and muddled masculine thinking. Thus, they proceeded to mine for the potash that they believed to be there, inadvertently penetrating a disposal room and releasing radionuclides into the accessible environment.

Probabilities

- Low of women having 80 percent of top positions in political, economic, and social institutions, but probability high of women having half of them and totally dominating some institutional sectors.
- Very high of significant numbers of women and some men having "feminist views" that define 20th-century science as inferior, inadequate, and muddled masculine thinking.
- Middling of a feminist-dominated mining company in the area.
- High of knowing potash was at WIPP site.
- High of seeing markers.
- Low of dismissing them as false male thinking. [But why not survey a sample of women (and members of ethnic minorities) about plans for WIPP and let the record show that such a survey was done?]
- High of mining for potash, if the markers are dismissed.
- High of penetration into the repository/shaft system, if mining occurs.

MYSTICISM AND RELIGION, 2091

Summary: The Markuhnian Conspiracy was a religious cult that believed that there were different realities. It was particularly hostile to the beliefs of positivist science. After one of its leaders had a mystical experience, they came to believe that they could find the meaning of life buried somewhere in New Mexico. Eventually, they dug at the WIPP site. The markers were still in place and readable. The Markuhnians, however, discounted them as products of the arbitrary consensus of a particular group of scientists at a particular time in the past. Such a consensus, the Markuhnians believed, had no necessary relevance to their own versions of reality. They continued to dig for the meaning of life, penetrated a storage area, and released radionuclides.

* * *

Religion, that is, the belief that the supernatural affects events and conditions here on earth will always be with human society, because, as Stark and Bainbridge (1985: 7) claim, some "common human desires are so beyond direct, this-worldly satisfaction that only the gods can provide them." Although secularization and the steady erosion of supernatural, otherworldly beliefs are constantly taking place, even among members of dominant and established religious organizations themselves, so, too, are new religions being created. As they become more worldly, established religious organizations are challenged by more vigorous and less worldly religions, both by sects as they split off from them and revive supernatural faith and by cults as their leaders proclaim new faiths. Thus, the history of religion is both a story of continuing trends toward the secular and a story of continual recreation of the sacred, both of decline and of birth and growth.

Among the cults that flourished in the year 2091 was the Markuhnian Conspiracy. Its origins were multiple and not entirely known, but they included a book published in 1962 by Thomas S. Kuhn, and another published in 1964 by Herbert Marcuse. Other early contributors to Markuhnism were Feyerabend (1975), Lakatos (1968), Lincoln and Guba (1985), and Phillips (1973).

Markuhnism was a religious cult that was unrelentingly against both science and advanced technological civilization. The cult began innocuously at the margins of philosophy with a view, some people at the time said "perverse," of scientific activity. For Markuhnians, theories do not have tidy deductive structures, facts alone don't overturn theories, theories are incommensurable and cannot be tested against one another, and scientific beliefs are biased both by the cultural and social settings of researchers and by their personal life histories. These views evolved, despite the mostly forgotten protests of Kuhn himself before his death, to the beliefs that "knowledge" is simply the arbitrary consensus of some community of experts at a given time and place and, eventually, that there really are different realities. What is real or true for one group of people is not necessarily real or true for others.

Thus, according to Markuhnians in the year 2091, contradictory depictions of reality could each be true for the people who believed them, but irrelevant for those who believed to the contrary. It all depended on one's perspective, interests, social position, and prior beliefs and values. Markuhnians were, in other words, subjectivists and relativists and totally at odds with the assumptions of the positivist science that dominated the 20th century. Their beliefs clearly crossed the boundary into the supernatural when they deified their early views of intuition and insight as ways of "knowing" reality. Moreover, they regarded the established communities of scientists as undemocratic and authoritarian, with their efforts to convince others that there were true and false representations of reality and with their claims that they knew the difference between them.

Markuhnians were, of course, products of their times. Science and scientists had been generally discredited has having given false promises of the future benefits of technological innovations (e.g., nuclear power and space exploration), proposing policies that had damaged people rather than helped them (e.g., deliberate release of harmful levels of radiation, either with weapons or during experiments on unconsenting humans, and inadequate storage of nuclear waste in shallow trenches), and being immoral in their behavior, supporting expenditures that benefitted themselves at the expense of the health and welfare of the general population (the space stations and superconducting supercolliders). As the history of science was rewritten in the mid-21st century, money was still the root of all evil and human greed its handmaiden, but the money was what had been squandered on big science that might have been spent on small crucial projects and the greed was that of members of scientific communities.

From a larger perspective, human society and the environment necessary to its survival were in a period of decay and disintegration in 2091. The quality of life had deteriorated. The federal government could not pay its enormous debts to Japan and United Europe and was paralyzed with infighting among different federal agencies, while the state governments largely ignored directives from Washington and were mostly privately owned by multinational corporations.

Markuhnians blamed science and high technology for the chaos and were trying to lead a cultural revolution, a conspiracy of the converted, that stressed the spiritual, nonmaterial rewards of life in order to bring social harmony and individual happiness to human existence, not so much by changing the world but by ignoring it. Their goals were to change mind sets, to undermine science and inappropriately high technology, to build new ways of viewing the chaos and, thus, to tame it.

In New Mexico in 2091, thousands of Markuhnians were swarming over the countryside searching for some sign showing them where to dig to find the scrolls they believed would reveal to them the meaning of life. One of leaders of the cult, Semaj Senoj, had had a mystical experience visiting Carlsbad Caverns in 2090. Underground, he heard a voice that told him that he could discover the Markuhnian meaning of life on scrolls contained in capsules buried deep in the earth nearby [Much later, it was discovered that Senoj's great-grandfather had worked at WIPP; thus, conversations that he overheard when he was a child may have put the idea of something important buried in the area into his head.] The experience resulted in a global mind shift for Senoj. Subsequently, he founded the Markuhnian Conspiracy Center of Noetic

Studies in Albuquerque and spread the word that Markuhnians should make pilgrimages to Albuquerque to search for the site of the capsules and donate money for excavation.

They began drilling. The voice had said "buried deep." Senoj had been on the third level of Carlsbad Caverns, about 1,300 feet down, at the time. So they drilled deeper, to about 2,300 feet. They started with four abandoned archeological sites of pre-historical Indian cultures. Near one, about 40 km southeast of Carlsbad, they found a number of strange monoliths and decided to drill there, at what became known as "WIPP," an acronym made from a name on many of the monoliths.

They were able to read the inscriptions on the monoliths with the help of Markuhnians who had defected from science, but it was questionable whether or not it could be said that they understood them. The monoliths, which were dated 2016, told them not to disturb the site because nuclear waste was buried there and harmful radiation could be released. Consistent with their world views, however, they did not accept this version of reality for themselves. It was discounted as being the arbitrary creation of a particular group of scientists at a particular time in the past and became the source of considerable hilarity among Markuhnians. *Their* reality was that scrolls containing the meaning of life would be found if they mined for them at the WIPP site.

Thus, they penetrated the site, dismissing three layers of additional markers as they had dismissed the monoliths, and drilled until they located old shafts, and began a shaft of their own. They might have been stopped, if the federal government had not been in a period of chaos or if the government of New Mexico had not been controlled by financial institutions headquartered in Japan and Switzerland.

The Markuhnians abandoned the project when a geyser of radioactive salt water spewed up their shaft. Action to contain the leakage was slow in coming. Federal agencies debated whose responsibility it was. Meetings were held by state officials, but authorization to act was delayed from Japan and Switzerland. Finally, a Japanese auto manufacturing firm in Roswell began plugging the drill holes and stopping the leakage after its workers threatened to leave the area.

Semaj Senoj was not shaken in his beliefs. He pronounced the WIPP area a mistaken choice. The Markuhnians moved their mining equipment to Truth or Consequences, NM, and started a new mine to find the scrolls.

<u>Probabilities</u>

- Nearly 1.00 of cult groups with views similar to the Markuhnians arising (they already exist).

- Low of picking the WIPP site to search for the meaning of life.

- Middling of not believing the markers, if cult members had picked the WIPP site.

- High of intrusion, if the site is picked.

BURIED TREASURE, 2091

Summary: Memory of WIPP was lost during the chaos of New Mexico's secession from the United States and annexation by Mexico. It was lost, that is, except for local folklore that something valuable was dumped into the ground years ago somewhere near Carlsbad. "Treasure hunters" located the markers and read them as warning people to stay away from the "treasure," which, to their minds, confirmed their conviction that they had picked the correct site to dig. They penetrated a storage area, releasing radionuclides.

* * *

In the year 2091, there were 5 million people living in Nuevo Mejico, 90 percent of whom spoke Spanish. After having seceded from the United States in 2048, the people of Nuevo Mejico decided in a referendum to become a part of Mexico which they did in 2071, as southern sections of Arizona, California, and Texas had done a decade earlier. In a world economy dominated by Brazil and East Asian countries, the United States had become a second-rate power that had turned inward on itself and was absorbed with the problems of economic decline, large-scale drug use and wars between drug gangs, urban decay, the collapse of the educational system, racial and ethnic conflict, and such widespread corruption that carrying on the ordinary and essential tasks of a large-scale society had become nearly impossible.

Within Nuevo Mejico, little was left of the old American administration. Records had been lost or destroyed during the transition to Mexican rule and newly elected Mexican officials had no easy access to those that had been removed to Washington, D.C. There was a sense of starting over when secession occurred, with the exception of certain property claims dating back to the period between 1598 and 1848 that were honored by the Mexican government if claimants could document them. By 2091, there was an atmosphere of opportunity and anticipation in Nuevo Mejico that attracted a variety of adventurers, get-rich-quick schemers, and con artists from all over the Earth.

One legend that persisted was that years ago the Americans had dumped a lot of money into a hole in the ground about 40 km southeast of what had been known as the city of Carlsbad. Although the legend had many variations, all versions agreed that "money," "dollars," a "fortune," or the "wealth of a nation" had been "poured," "buried," "hidden," "thrown into," or "sunk" deep into the ground in salt deposits in the area. The fact was, of course, that the federal agencies of the United States had deposited valuable, though dangerous, materials and equipment deep into the ground at this site.

One international group of "treasure hunters" was well funded by a group of capitalist speculators from Minsk. They located the WIPP site, which still contained some warning markers. But they took the warnings as an effort to frighten away potential thieves. Thus, the markers had an effect opposite to that intended by the WIPP designers: the treasure hunters understood the warnings as confirming their selection of the site as containing something valuable and they started to excavate. As they encountered additional warning markers on different levels, they became increasingly convinced that they had picked the correct location.

Although they did not realize the consequences of what they had done until much later, at 2154 feet under the surface they penetrated a storage area containing high-level waste.

Probabilities

- Although the probability of the State of New Mexico seceding from the United States and then becoming part of Mexico is very low to nil, there are many other ways in which institutional memory could be lost, the probability being middling that memory will be lost.
- Middling that a legend about some kind of valuable materials having been put into the ground at WIPP will exist and spread (it is already spoken of that way by some people).
- Very high to certain that the WIPP site will be targeted, because that *is* where the "treasure" will be put.
- High that the "treasure hunters" will see the markers.
- Middling that they will misinterpret them as deliberately misleading claims of danger designed to frighten people away from the "treasure."
- High that penetration aimed at the recovery of "treasure" will occur, inadvertently releasing radionuclides into the accessible environment, if the above events occur.

SCENARIOS (100 Years)

WIPP AS THE NATION'S NUCLEAR WASTE SITE, 2091

Summary: This scenario points out the possibility of expansion of WIPP to receive materials for which it was not originally designed and the need for removal of stored materials over time as disposal techniques competitive with storage are developed.

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The evaluation of WIPP was far advanced over other high-level radiation waste disposal sites in the United States by 1995. Extensive geological, geophysical, cultural, sociological and economic studies had been accomplished. In addition to these paper studies, long duration of site testing had occurred that corroborated a number of the site's design assumptions. Long- range forecasts of the potential uses of the area and possible intrusion modes had been made. The investment in the area was so high and the possibility of miscalculation and intrusion so low that the decision was made to proceed with the storage of transuranic materials by 1998. There was joy in Albuquerque; WIPP was activated.

Likes tend to attract. Once WIPP was activated, it was natural for the site to be considered for other radioactive materials. Before sealing of the repository shafts had been completed, new shafts were being prepared to accept radioactive material that had not been originally designated for WIPP. This first phase of expansion called for doubling underground storage volume.

By the end of the first quarter of the 21st century, the site was being considered for the storage of radioactive waste materials produced by the nuclear electrical generation industry. It was also logical to consider the site for the storage of non-nuclear wastes; before long the site became the repository for materials surplus to the chemical and biological weapons industry, and in some instances, highly toxic chemicals produced by American industry.

With all of these additions, WIPP contained six times its original design capacity by 2050, and ten times by 2075. It became profit making at about this time and therefore WIPP management conducted extensive marketing campaigns to find new materials to store at increasingly high rents.

Since the rental, profit-making approach was generally followed by all storage sites in the country, there was a great incentive to develop new processes that could neutralize wastes. For example, if it cost a corporation $100 million dollars to store materials at WIPP and the corporation could develop an advanced technology disposal system for a tenth of that figure, then investment in disposal was a reasonable risk.

The R&D paid off occasionally and organizations with material stored at WIPP asked for the materials to be returned to them. Occasionally, mistakes were made: the wrong chambers were opened, the original material could not be found. By far the greatest exposure occurred when the wrong material was brought to the surface.

Probabilities

- Nearly 1 that WIPP will be expanded.
- Nearly 1 that methods for disposing of material that would otherwise be stored will be available.
- Making mistakes in retrieving material from WIPP is low to medium.

SCENARIOS (1,000 YEARS)

A HOUSTON TO LOS ANGELES TUNNEL, 2991

Summary: A tunnel for high-speed capsule transportation between Houston and Los Angeles was built with stops near Carlsbad and Phoenix. Underground urban development containing *gratte-terres* a mile deep meant that the capsule stations were built about 2000 feet underground. The tunnel came within a few hundred feet of the WIPP site. No markers were left on the site because they had all been removed by thieves for their intrinsic value. The original construction and vibrations of capsules resulted in the disturbance of the salt deposits. Radionuclides seeped into the water system and, eventually, into the accessible environment.

* * *

In 2991, the technology for digging, ventilating, and maintaining tunnels for high-speed capsule transportation underground had advanced greatly over that of 100 years earlier. Such underground transportation between major cities was nearly as fast, cheaper, and far more convenient than air travel. Several such tunnels had been built in the United States, e.g., between New York and Chicago in 2960, Chicago and Los Angeles in 2969, and Houston and Los Angeles in 2971.

Inadvertently, the last came within a few hundred feet of the WIPP site. Although the surface above the route of the tunnel had been examined by tunnel workers, it had been done haphazardly for the most part, since the technology for digging such a tunnel allowed work to proceed solely underground and since the tunnel was so deep at this point, about 2000 feet, that no great concern was shown for what was on the surface, except for those places designated as ventilation points.

The tunnel was deep near the WIPP site because the capsule stations, one of which was near Carlsbad, were deep. The stations were part of underground cities that contained gigantic *gratte-terres* ("earthscrapers"), which were buildings as deep as a mile into the ground where people lived, played, and worked. *Gratte-terres* had been the solution to the large population increases and high population densities that had characterized the entire Southwest as early as the year 2500. Thus, many of the people of Houston and Los Angeles lived underground, as did many people in Carlsbad and Phoenix, the two intervening stops on the Houston-Los Angeles capsule line. As the tunnel approached a station, it dropped down to over 2000 feet, a little above the center of the populations of the *gratte-terres*.

All the surface monoliths warning of the radioactive waste buried at the site had been hauled away for their intrinsic (decorative or symbolic) value by thieves (with the use of cranes and trucks since each monolith was extremely heavy and about three-and-a-half times taller than a human being). They now stood as proud status symbols on entrances to commerical and residential buildings or suites in *gratte-terres* or surface buildings of a few wealthy people, just as artificial pink flamingos used to be placed on some suburban lawns in the 20th century. The three levels of buried markers at the site were not disturbed since tunneling took place far below them and entry was from the side. Thus, no visible markers of any kind at the WIPP site had been found.

Disturbed by the original construction and then by twenty years of vibrations from the high-speed capsules, salt deposits between the tunnel and the WIPP repositories cracked, dissolved, and allowed water to seep through the repository/shaft system leaking radioactivity into water systems away from the site and eventually into the accessible environment.

Probabilities

- Middling of a transportation tunnel between Houston and Los Angeles.
- Very low of underground cities reaching a mile into the earth, hence very low of the tunnel being so deep.
- High of surface monoliths being taken away for their intrinsic (decorative or symbolic) value.
- Very high of markers being undiscovered, if they had been removed from the site.
- Middling of the tunnel coming near the WIPP site. (Depending on the exact locations of the capsule stations, the tunnel could make a direct hit on WIPP.)
- High of intrusion into the repository and release of radionuclides, if the tunnel comes near the site.

GLOBAL ILLITERACY, 2991

Summary: Institutional memory of WIPP was lost during the long struggle of the United States against Eastlandia, the breakdown of American government and society, and the occupation of the U.S. by Eastlandia. Eastlandia established prison mines in New Mexico and began mining, eventually at the WIPP site. Although some surface markers and many buried markers remained at the site, no one could read them. Generations of ethnotronic oral culture throughout the Earth had eliminated the need for humans to learn to read. The prisoners penetrated a storage area, releasing radionuclides.

* * *

In the year 2991, there were 25 billion people in the world, one billion of them in the United States. Eastlandia, with 13 billion people, dominated the Earth and Eastlandian proconsuls governed most of the globe. Eastlandia's North American empire proved difficult to govern, however, because of the continuing rebellion of urban guerillas. Some wealthy Americans had been quick to cooperate with the new Eastlandian rulers in exchange for being able to hold on to a portion of their wealth. Other groups followed. But some people, especially those living in America's inner cities, refused to cooperate and began a guerilla war against the Eastlandians.

The Eastlandian rulers in America established a large penal colony near the WIPP site and put American political prisoners and, in their terms "terrorists," to work mining potash. As the numbers of prisoners increased and mining activities spread out, the WIPP site itself become the location of a new mine.

In the course of the long struggle with Eastlandia, the American governments on all levels had collapsed, as had those of most of the United Federation's member nations, records had been destroyed, and many surface monoliths on the site had been removed by Eastlandian troops. They could not read them, even though one of the seven languages in which warnings on the monoliths were given was similar to Eastlandian, because, like most people in 2991 anywhere on Earth they could not read, just as they could not figure.

Generations of ethnotronics (Joseph 1980), verbal communication with computers, electronic calculators, and intelligent data storage accessors that used human speech had resulted in human beings losing their abilities to read, write, and calculate. Three buried levels of markers, as they were discovered, could not be read either. [No message came from them in the medium of sound of any kind, no verbal recorded speech in any ordinary language and no other sound such as a siren or warning beeps or clicks. No cyberspace holograms powered by the sun appeared to explain verbally the dangers of the site. The designers of the markers had limited their warnings to written language and pictures, all of which were totally incomprehensible to both the prisoners and their Eastlandian captors.]

Before the end of 2991, the WIPP repository had been penetrated. Radioactive material was released to the accessible environment.

Probabilities

- Very low for "Eastlandia" ruling North America (but this is only one of many ways in which institutional memory of WIPP could be lost). Probability middling that institutional memory will be lost by some means.

- Low, but significantly larger than zero, for most people not being able to read. (Can markers contain verbal and visual electronic media of communication that are triggered by human presence or disturbance of the ground near them?)

- Very low of the Eastlandians establishing a mining penal colony in New Mexico (but this is not the essential point since other events can put people who may not be able to read after centuries of ethnotronic verbal cultures at the site to mine).

- Very high of people finding the markers incomprehensible, given the other events.

- High for intrusion, given the other events.

SCENARIOS (10,000 YEARS)

VIRUS IMPAIRS COMPUTERIZED PEOPLE, 11991

Summary: Most of the work in society was done by computerized people, humanoid computer-robots. A virus infected them and spread to epidemic proportions. Computerized people constructing *gratte-terres* in New Mexico began drilling and constructing shafts compulsively in disregard of their programming prohibitions. Because of the disorienting virus, computerized workers ignored the markers at the WIPP site and penetrated the repository, releasing radionuclides.

* * *

The New Mexico chapter of the GACP (Global Association for Computerized People) met in Roswell, NM, during October 10-11, 11990. Two urgent issues dominated their agenda: the question of legal rights for "computerized people" and a new virus that was infecting computerized people and interfering with their basic programming.

"Computerized people" (CP) were the humanoid computer-robots that evolved from the crude 20th-century efforts to create artificial intelligence machines. They looked like human beings and could do all the things human beings could do, except engage in biological reproduction. They reproduced themselves in factories, incorporating improvements invented by CP designers and engineers in new models that were introduced every other year. Of course, they were able to do far more than humans could do because they incorporated both a greater range of sensors and enormous computing and reasoning capacities (Evans 1981; Joseph 1980; Toth 1990).

Computerized people constituted the second largest class of "persons" on Earth. "Persons"--superior persons at that--is what they considered themselves to be and GACP was leading a movement to have all computerized people incorporated into human society on an equal footing with humans where their distinctions did not deny it, as in such things as voting rights, freedom of expression, freedom of assembly, occupational safety, etc. Many natural people supported such a move if for no other reason than they wanted computerized people to be held legally accountable for their actions and be subject to legal suit.

The Unified Earth Society consisted of three broad social classes. At the top was a relatively small upper class of Kontrolniks. They were highly educated experts in science, engineering, social science, art, and literature. They had jobs and were paid a salary. They functioned mostly as planners, futurists, and controllers of the computerized people.

There was a large middle class of Recreatniks. They did not have jobs even though they received incomes, and spent each day in activities of their own choice, seeking self-realization through activities ranging from taking chemicals that altered their consciousness to space travel to other planets. Like the Kontrolniks, the Recreatniks were natural people.

The working class, about a third of all "people," was composed of computerized people. They did almost all the work of the society, producing all the goods and services, except for the activities of the Kontrolniks. They were sophisticated machines that ("who," they would prefer) had learned to learn, had the capacity of self-consciousness, and felt emotions.

They were successfully moving toward equality with natural humans with respect to civil and political rights until a virus broke out among them that disrupted their behavior. They had been taught, first and foremost, to do no harm and, second, to obey natural humans (as long as they were not ordered to do harm to themselves or to other people, both natural and computerized). But of late, some computerized people had malfunctioned, engaging in compulsive, repetitive, and sometimes harmful behavior. A virus had been identified and it had been spreading. An Earthwide alarm was in effect to discover and remove the virus, but Kontrolniks were too few to handle quickly all the investigations that had to be made and Recreatniks were incompetent to do so. CPs trained to respond to emergencies did so, but became infected with the virus themselves and malfunctioned.

By 11991, the virus had spread to epidemic proportions. In New Mexico some computerized people working in construction, building the *gratte-terres* of the underground cities, contacted the virus. They began drilling and constructing shafts compulsively, particularly in areas that had been declared off limits in their programming including the WIPP site. The monoliths and buried markers did not stop them, because the CPs proper functioning was impaired by the virus.

Before the overworked Kontrollers could turn their attention to New Mexico, the CP construction workers had penetrated the WIPP repository, releasing radionuclides. Although computerized people were not affected negatively by radiation, natural humans, of course, were.

Probabilities

- Very high to certain of having "computerized people" (or something very much like them).
- Middling of a debilitating virus that will affect the functioning of computerized people on such a widespread scale.
- Very low of the debility resulting in underground construction at WIPP.
- High of intrusion of WIPP, given the other events.

HUMAN WARRIORS RETURN FROM SPACE, 11991

Summary: Spacebattleship V was returning to Mesa Spaceport when the ship malfunctioned. With only partial control, the commander headed for the only nearby area clear of buildings and human habitation, the WIPP site. Although he saw a pattern of earth on the open area, he did not know what it meant. He saw no warning lights. His sensors received no electronic warning. Before he crashed, he fired his forward lasers to reduce the speed of impact. The laser blasting plus the exploding fuel and weapons during the crash penetrated the repository, releasing radionuclides.

* * *

In the year 11991, human exploration and settlement of space had proceeded well beyond the imaginations of the early Russian and American space pioneers of the 20th century. Flourishing human colonies existed on the moon and on Mars, free-floaters lived in a permanent space colony at the Lagrange libration point number five, frontier prospectors mined asteroids and gas giants, comsat relayers lived in small shuttles repairing communications, weather, and navigational satellites, and people living on Earth were known as "Dirtsiders" ("Solsys in Flux" 1989).

Spacebattleship V carrying a crew of 900 entered Earth orbit on its return from Mars from where it had been on patrol in the Venus sector looking for spaceships of unknown origin that sensors had detected there. Just before turning on its base leg on its landing approach to Mesa Spaceport in New Mexico, the ship's computer flight control system failed. Immediately, the commander took manual control of the flight, but power failures eliminated first one, then another of the boosters on the controls and part of the vertical stabilizer blew off.

With limited control of the ship and a power failure, the commander knew that the ship could not reach Mesa Spaceport. Instead, it veered south. The commander spotted an open area of land free of construction about 40 km southeast of Carlsbad. Struggling to control the ship, he headed for it so that the ship would not crash on people or buildings. All that he noted, from about 5,000 feet of altitude to impact, was a strange design and large mound of earth in the area. He saw no warning beacons, such as flashing red lights. He frantically scanned and probed the area electronically for any warning signals being broadcast. None were received by the ship's sensors.

Just before striking the ground, the commander fired all his forward rapid-fire lasers in an effort to reduce the severity of the coming impact. The repeated laser blasts produced a hole in the ground nearly 1,000 feet deep. The impact of the ship and subsequent repeated explosions of leftover fuel and weapons penetrated another 800 feet.

Within hours after the crash, the WIPP repository began to leak radioactive substances into the accessible environment.

Probabilities

- Very high that space settlements will exist on Mars and elsewhere in space.

- Low that a spaceport will be built somewhere within 500 miles or so of WIPP.
- High that a crash will occur during a spaceship's return to Earth.
- Very low that such a crash will occur at WIPP.
- High that eye-level markers will not be seen (or heard or electronically sensed) or understood as warnings if viewed from the airspace over the site.
- Middling that gross outlines or patterns on the ground will not be understood as warnings not to crash at the site.
- Low that such a crash at WIPP will penetrate the repository and allow a release of radionuclides into the accessible environment.

NICKEY NUKE AND WIPP WORLDS, 11991

Summary: The WIPP Museum and WIPP Worlds became permanent off-site, self-perpetuating, and self-financing markers, institutionalizing the memory of nuclear energy and the location and dangers of nuclear waste. Hundreds of thousands of visitors came each year to be both educated and entertained. Moreover, the deliberately created fictional character, Nickey Nuke, became the protagonist in stories, poems, films, live theatre, and other media featuring nuclear themes. As long as Nickey Nuke lives, so shall the story of WIPP--and Nickey Nuke, though a mere idea, does not rust, erode, or disappear. He may live forever.

* * *

In the year 11991, the WIPP Museum of Energy in Roswell, NM, remained a major attraction for tourists and classes of school children. Founded in 2016, it was the most comprehensive exhibition in existence telling the story of the development and spread of all forms of the human use of energy up to the present, including nuclear energy in the late 20th and early 21st centuries.

It included a comprehensive world map of nuclear waste repositories and a detailed account of the building of the nearby repository WIPP, complete with diagrams, photos, diaramas, and mockups of barrels of waste and a storage area. Oral histories from WIPP's planners and builders were seen on 3-dimensional motion holograms. In addition to its other educational purposes, the museum was designed to keep alive the memory of the location and dangers of nuclear waste. It was a marker of another kind, off site, self-perpetuating, and self-financing from visitors' fees.

The Museum included bus tours to the site itself so that monolith markers could be viewed, "hands off" of course. Caretakers repaired the surface markers as necessary as part of their general jobs around the Museum. WIPP Worlds, near the Museum itself, included hotels, restaurants, and entertainment facilities, but the main attraction of WIPP Worlds was a technological fair in which alternative worlds could be experienced with the ethnotronics of virtual realities. People came from all over the Earth to visit WIPP Worlds and the WIPP Museum. No child's education was considered complete without at least a week there.

The WIPP Museum from its beginning had commissioned the production of a series of legends in children's books, stories, narrative poems, puzzles, animated films, live theatre productions, and other media that told the story of nuclear development, nuclear waste, and repositories such as WIPP. They created a fictional character, Nickey Nuke, to be the main protagonist in the adventures depicted in these legends (just as the U.S. Forest Service, years earlier, had used "Smoky the Bear").

Long after metal had disintegrated and granite worn smooth of markings, the legends of Nickey Nuke remained in people's minds everywhere on Earth (much as Robinson Crusoe and his story were known by all peoples centuries after his creation in 1719, or as Alice in Wonderland or Mickey Mouse were universally recognized across cultures, space, and time, or even, if you please, as the story of the Garden of Eden had lasted thousands of years).

Fictional Nickey Nuke--stalwart, heroic, and duty-bound--carried the memory of WIPP and its dangers into the collective consciousness of the peoples of the Earth, forevermore.

Something as seemingly frail and unsubstantial as a story or poem, it turned out, was more durable than the most established social institution or the toughest metal, plastic, or stone.

No inadvertent intrusion into the nuclear waste repository occurred.

Probabilities

- Very low of something like a WIPP Museum, a WIPP Worlds, or a fictional character such as Nickey Nuke being created and surviving 10,000 years. (But why not provide a modest government subsidy for a commercial venture of this sort--or interest those speculative capitalists from Minsk? There may be more buried treasure here than meets the eye.)

- Low of deliberate creation of legends in poetry and other media.

- High of a museum and legends preventing memory loss of WIPP, if they existed.

SCENARIOS (2000-11,991)

The Industrial Scenario, 2000-11991

Summary: The desert near Carlsbad, NM, turns out to be ideal for "harvesting" solar energy. Ready availability of cheap energy makes it practical to locate industrial plants nearby and magnesium extraction and processing flourishes there using deep brines, eventually. Over the years, geologic and hydrologic stresses cause the stored radioactive material to migrate, and information about the precise location of the material is lost, resulting in an occasional "bore-through." The industrial cycle of build-up and decay is repeated many times in this period.

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Introduction

Industrial plants are located where there are special advantages to be found. When water power was a primary energy source, mills were located next to flowing streams. In this scenario we ask: what special advantages are offered by southeastern New Mexico that can attract industry to the area in the centuries ahead and thus increase the risk of intrusion at WIPP?

Southeastern New Mexico has plenty of sunlight and therefore progress in solar energy is likely to make the area and others like it attractive sites for solar collection. So the first industry that comes to mind is electrical power production with photovoltaic cells or solar-thermal processes. In addition, if the energy produced in southeastern New Mexico could be used on site, the need for electrical transmission of the energy would be minimized. What industries qualify? Any that use processes that require large quantities of electricity or heat. Among these might be:

- The production of hydrogen through the electrolysis of water. Hydrogen could be sent from the area via pipeline or in hydrides.

- The extraction of minerals from subsurface brine deposits near the site, using electrolysis. Particularly attractive would be extraction of magnesium from the Bell aquifer where it appears in concentrations over 50 times as great as sea water.

- Desalination of the water found in the vicinity of WIPP, initially from near surface aquifers, but ultimately from deep aquifers. The purified water might be reinjected into local aquifers or shipped via pipelines to urban centers and other distant users.

For our scenario, we choose the mineral extraction example. It is not the only possibility, but we think it might make economic sense sometime soon. Furthermore, this choice permits us to explore the consequences of industrial development in the area. We believe that once established, a facility of this sort might attract other similar installations that could share in the use of the solar energy or other resources. The solar/industrial seed, once planted, could grow in the desert.

The continued viability of this sort of operation on the time scale of our inquiry, however, is open to question. The abandoned textile mills by the streams of New England, the shift of steel and electronics production from the U.S. to Asia, the attractiveness of low-cost Third World labor--all speak to global forces that can shift cost-efficient production from one geographic location to another. Therefore, whatever the industrialists of the near future find attractive about southeastern New Mexico, is likely to be challenged by more modern methods that appeal to the industrialists of the more distant future. For the much more distant future, the whole notion of industrial production may be replaced by concepts not yet available to us.

These premises form the basis for this scenario: solar energy production in the desert will be economically attractive in the short term; the mining of magnesium from brines is economically viable; and the presence of one plant attracts others.

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Background

Magnesium is a silver-white metallic element that burns brightly. It is often used as an alloy, particularly with aluminum, to form extremely light and strong structural materials. The metal is extracted from sea water, lake brines, and dolomite. The supply of the material is essentially unlimited, and therefore as supplies of other materials diminish and their prices increase, magnesium will find ready use as a substitute. The world's production the metal is currently about 200,000 tons, and production of the metal's compounds is about 1,000,000 tons; principal producers are the U.S. and U.S.S.R.

The metal is produced from anhydrous magnesium chloride, primarily in electrolytic cells. These cells use low-voltage direct current flowing at high amperage levels between specially prepared carbon electrodes. In the contemporary sea water process, sea water is mixed with a slurry of calcium hydroxide and the magnesium is precipitated out as magnesium hydroxide. The magnesium hydroxide is filtered and neutralized with hydrochloric acid to form magnesium chloride that after dehydration in dryers is fed to electrolytic cells. This is a very energy intensive process; energy is consumed by the drying as well as the electrolysis. The brines that are a by-product of the process are usually rich in potassium, sodium, lithium, iodine, bromine, strontium, and calcium.

Production of electricity from the sun can develop in the desert in two ways: (1) photovoltaic cells might be spread across the desert floor in static or pointing arrays, or they might be located under light collecting lenses or mirrors; (2) alternately, the mechanism of conversion might be thermal electric. In these systems, mirrors focus sunlight on boilers that release steam to turbine generators. The water in the cycle is condensed and re-used. Both technologies are promising; neither process introduces appreciable pollution in the generation process. Photovoltaic costs are dropping rapidly, and efficiencies are still improving (28% for point-contact crystalline silicon cells and 35% for gallium arsenide stacked junction cells).

The thermal electric approach has already been demonstrated at large scale. About 275 megawatts have been installed in the Mojave desert, and another 400 megawatts or so is scheduled for operation in the next five years or so. We favor the thermal electric approach in our hypothetical desert magnesium plant, since both drying and electricity production could use similar mirror focusing systems and heat surplus to one could augment the other.

<u>The Rise and Fall of Desert Industrialization</u>

The world demand for magnesium was high in the last part of the 20th century, and researchers in the field had produced new high-efficiency electrolysis cells that made the extraction of the metal from brines even more economical than it had been. Four developments of particular importance that increased demand for magnesium were

(1) the development of metal/plastic hybrids that allowed materials engineers to form composites with the best properties of both,

(2) new means for welding magnesium alloys in the atmosphere,

(3) the increasing demand for high-performance refractories (a significant use of magnesium compounds) as a result of the need to improve the efficiency of steel and iron production, and

(4) the diminishing supplies and rising prices of competing materialas.

Concomitantly, the development of solar thermal systems progressed well under the stimulus of uncertain future petroleum supplies and the pressures of "greenhouse" to reduce combustion. The so-called "tower of power," a mirror system in which solar energy is concentrated on a boiler to produce steam for power-generating turbines, was economically competitive with combustion-based sources of electrical power production by the end of the century.

These two developments--the growing market for magnesium and the availability of inexpensive and reliable solar thermal power--led to the exploration for and use of near surface brines containing heavy concentrations of dissolved magnesium and other important minerals, particularly where insolation was high and cloud cover, low.

A U.S. company in the metals business looked for magnesium extraction sites around the country. The material was abundant, of course, but existing sites had fatal disadvantages. Brine and sea water extraction were preferred because mining of magnesium ores in solid form carried both economic and environmental penalties. Most existing sea water and brines sites in the U.S. were electricity limited. But southeastern New Mexico offered several advantages. Primarily the metal was abundant in the subsurface brines. Second, the incident solar energy, low cloud cover, and clear weather were attractive in a prospective solar site. In addition, because of the presence of WIPP, very good subsurface geological information existed, and extensive further exploration was not required. Finally, land use was largely under government control, and in this instance, industrial and national goals coincided. The company applied for and got mineral extraction rights. Shortly after the turn of the century, it built the first extensive operational solar/thermal system for producing magnesium from low-cost thermal electricity in the desert between Carlsbad and WIPP.

(Note that the scenario could as well have been developed to this point based on hydrogen or pure water production through desalination; any of these would have given us our first solar-based plant in the desert.)

In many economic endeavors, likes attract. Computer component companies concentrated on Route 124 near Boston; chip companies concentrated in silicon valley near Palo Alto. Similarly, the first company in the Carlsbad desert showed that a practical plant could be made to operate in desert conditions, and that the surface rent paid to collect the incident energy of the sun was much less expensive than other energy sources. Petroleum was, after all, in short and uncertain supply and, in any event, would be limited in availability when economically viable resources were depleted. The need to reduce combustion was stated in many "greenhouse" studies, and resulted in special taxes and other disincentives that were introduced in an attempt to make alternative energy sources more economically competitive. Nuclear power generation plants still operated, of course, but new ones were seldom built because of the public distrust of nuclear energy and the higher than anticipated costs of operation. Fusion plants were still a dream whose time had not yet come. Industrial production went where the sun shone long and reliably.

By 2050, the desert was largely occupied not only with plants producing useful materials from subsurface brines, but with other companies benefiting from cheap electricity and proximity to the prime producers. This increasing density of industry and population brought its own impacts: humidity began to rise, so controls on emissions became particularly stringent. Particulate emissions had to be controlled lest the availability of solar energy be compromised. Air conditioning took a significant fraction of the energy produced. Large bubble structures were built to control the environment for people and machines. Transportation infrastructure had to be improved to take the product out of the area to distant markets.

By 2100, the industrial desert, in the U.S. and abroad, was the mark of an advanced and flourishing society. England, the U.S.S.R., and Europe were at a disadvantage because they lacked such a favorable industrial climate. The mid-East countries, Israel, Australia, and the desert countries of Asia were at an advantage because of their luck in having a desert endowment. And it all began near Carlsbad.

During this time, the memory of what was buried at WIPP was maintained, of course. Because the use of nearby land was under government control, each application for underground or surface rights was scrutinized for intrusion possibilities and no penetration of the deposits took place. But extraction of the brines and reinjection of the wastes waters under pressure insidiously shifted the subsurface geological strata more rapidly than would have occurred naturally, and while officials knew the general location of the deposits, the precise location was lost. Several test wells were bored and capped during this 100-year interval to relocate and track the deposits.

After 2100, the salience and importance of the repository was dulled by the passage of time and other pressing interests. The people knew it was there, but it just was not as big a deal as the other pressing problems of the moment. Regulations, particularly those associated with reinjection, became more lax and permissive. The precise underground location of the radioisotope deposits was again lost, but this time, not precisely re-established.

Inevitably some old industrial plants near the shifted deposits drilled into the radioactive material as they sought deeper sources for their brine feedstocks and disposal wells. The plants were largely automated by this time, so very few workers were exposed to the radioactivity. The famous isotope incident of the mid 22nd century followed: small quantities of the radioisotopes were apparently included in the magnesium shipped from the area. These contaminated materials were not detected until after they were alloyed with many other metals. Their effect was greatly diluted, but the release had, after all, occurred. Reminiscent of the Brazilian and Mexican incidents of the 20th century, the metals found their way into buildings, automobiles, and tubing in half the states of the country. This incident resulted in further exploration of the subsurface to re-establish the precise location of the deposits that were, for the most part, still intact. Stringent controls were re-established.

As comes to all industrial areas, decline set in the 24th century and the once gleaming environmental bubbles of the desert were gradually depleted of their industries and people. By the year 2700, the population density in the area was down to today's levels, and the industrial output was no more than 10% of its prior peak. Historians argue yet about what caused the decline, but it may have any of the following origins: the use of non-earth materials from the moon and asteroids, the ethical changes associated with a static society that valued preservation of the Earth's remaining resources, the arrival of new energy sources, the increasing attractiveness of other locations such as the Arctic, the development of materials that made magnesium and other minerals extracted from the desert brines, obsolete; whatever the causes, the desert was being deserted. The plants that remained were the derelicts, operating close to their economic margin, producing what they could when world economic conditions permitted, going idle when they did not. This condition prevailed for 200 years. During this time control was lax, but the isotope incident of the 22nd century remained vivid enough to prevent repetition.

In the final years of the region's industrial decline, the last 100 years of the third millennium, the material itself became an industrial treasure to be mined. All sense of its location had been lost, although everyone knew it was down there somewhere. The situation was much like treasure hunting for sunken ships today: the knowledge that a ship was lost in a general region at a particular date in history is certain, but the exact location is difficult to pinpoint because of shifting ocean currents. In our case, the ocean was the near subsurface of the earth itself, shifting because of the extraction and reinjection of centuries. The treasure was real enough since the transuranics in the WIPP were rare and valuable; production of weapons yielding this sort of by-product had ceased 500 years earlier.

The plans of the groups seeking the treasure were simple: bore vertical holes in a grid that was fine enough in structure to reveal the presence of radioactivity when sensitive instruments were introduced down the holes. The seeker-moles that were employed to bore the exploratory holes sensed radioactivity. They ran free under the surface, telemetering their positions to surface trackers. The government custodians of the lost treasure were partners: half the profits from the materials went to the government. It was worth roughly a billion 1990 dollars to the team that found it. The plant to process it was to be built in the area, the first new industry in 300 years. Licenses were issued to three teams over the years, which recovered perhaps 10% of the originally deposited material. The rest was deemed too expensive to recover. These plants were short lived: in and out of the area in 25 years.

This history, taking us from the year 2000 to the year 4000, was repeated in one way or another in waves of economic incentive, industrialization, repopulation, growth and decline. The principal events triggering the cycles may have differed from cycle to cycle but the pattern was always similar. A valuable resource in the area--the insolation, water, magnesium, or other sub-surface materials--stimulated the initial build-up. Toward the end of this interval the materials sought were very far below the surface. Each cycle would grow until it would spend itself or the value of the once revered material would change through disinterest, or the arrival of cheaper or better competitors. At the beginning of each cycle, accidental penetrations would give new and tangible truth to the memory of the original burials; near the end of each cycle, deliberate but perhaps inadequately prepared searches for the material itself would take place. The forms of accidental release were, as mentioned earlier, inclusion in the product extracted from the brines and, in some instances, introduction of the radioisotopes into underground aquifers through the bore holes or underground flows. In the end, by 10,000 years from now, all the material would have been transported from the site to the environment or deliberately recovered.

Probabilities

	Year	Probability
1. Demand for magnesium is high	2000	Medium
2. More efficient Mg production methods are available	2000	Medium
3. Good solar thermal technology is available	2000	High
4. First SE New Mexico Industrial plant is established	2000	Medium
5. Brine deposits near WIPP prove a good source of Mg	2000	Medium
6. Industrial area near WIPP grows	2000-2050	Medium
7. Strict environmental controls are newly imposed on the industrial area	2050-2070	High

		Year	Probability
8.	Desert industry flourishes	2100	Medium
9.	Precise location of WIPP deposits is no longer known because of underground shifting	2100-2150	Medium
10.	First accidental penetration occurs, the "isotope incident."	2150-2175	Medium
11.	Stringent controls are re-established	2150-2175	Medium
12.	Industrialization in the area declines	2300-2700	Medium
13.	Radioisotope hunting occurs	2900-3200	High
14.	Availability of free-boring robot moles for exploration	2900-3200	High
15.	Radioisotope recovery plants built in area	2900-3200	Low
16.	Multiple penetrations as search and extraction efforts are occasionally made	3000-3500	High
17.	Industrial build-up begins again; new resources, same pattern	4000-4500	Low
18.	Pattern repeats	to 12,000	Low

What's Wrong with This Scenario?

We are unsure about the assumption that the extraction and reinjection that would accompany industrialization would shift the location of the WIPP deposits in a way that would cause the exact location of the deposits to be lost.

The underlying assumptions are that society will continue to be economically driven, that some earth minerals will be important despite the assumed lunar and asteroid mining, and that viable deposits of these minerals will be found under deserts. Any of these assumptions may be faulty.

The assumption that radionuclides will always be dangerous to health and the ecosystem may not be correct.

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V. Conclusions and Recommendations

Conclusions

1. We present this report with an inevitable sense of incompleteness. No matter how sophisticated the analysis techniques, no matter how thorough the understanding of the past, the future will hold surprises that are inaccessible to us. These surprises will be in technology, politics, the environment, the functioning of society, beliefs, attitudes, and law. These unnamed developments may prove important in understanding possible future intrusions.

   Nevertheless, exercises of the sort in which we engaged are valuable and important; they serve to illustrate the range of intrusions that must be considered, based on our best understanding of what the future may hold. Because that understanding is limited, we believe that it is necessary to repeat this kind of analysis periodically.

2. The intrusion events that appear most frequently on our list of plausible generic scenarios are drilling and extraction; the social factors most often involved in our intrusion scenarios are increasing population density and industrial development near WIPP; therefore, control of land use near WIPP is likely to remain a principal element of intrusion-control strategy.

3. Placing total reliance on markers, records, and warnings is inadequate because

   - Markers, records, and warnings may be lost
   - Markers, records, and warnings may be incomprehensible or misleading
   - Markers, records, and warnings do not necessarily assure risk analysis capability
   - Markers, records, and warnings do not necessarily assure continued government stewardship
   - Markers, records, and warnings do not necessarily prevent loss of memory
   - Markers, records, and warnings do not necessarily deter land development or industrial pressures that would threaten WIPP

4. Events likely to cause intrusion may, in certain instances, require sophisticated techniques and equipment (e.g., earth boring, heavy construction, major explosions) and are therefore likely to be conducted by societies with sufficient capability to comprehend the warnings and to use adequate risk analytic methods, but this does not assure against negligence or disregard (e.g., due to developmental pressure, economic trade-offs, etc.)

5. Other events likely to cause intrusion may not require sophisticated techniques and equipment (e.g., water impoundments and their structures) may be conducted by societies lacking capability to comprehend the warnings, or to use appropriate risk analysis methods, or to show proper care and regard for WIPP safety. These low-tech threatening events are of great concern.

6. Developmental pressure for activities likely to pose new risks to WIPP are already being expressed (e.g., use of WIPP for chemical wastes) and are likely to grow considerably. This calls for a high degree of coordination and vigilance by federal, state, and local agencies, and for care in using decision-making tools that are likely to promote trade-offs that could, in the aggregate, impair WIPP safety.

7. Opponents of new developments that threaten WIPP safety are a major safeguard and can play a continuing "watchdog" function (e.g., finding "lost memory"), and they should be fostered by DOE.

8. The events and activities of most concern to WIPP safety are those that are likely to arise from the following scenarios:

   - Activities most likely to occur, which are most likely to involve threatening events, which are most likely to be conducted without knowledge of WIPP or without risk analysis capability, or without proper care or regard for WIPP safety.

9. Our analysis has focused on the possibilities of external events; in the end, internal factors associated with stewardship and continuing responsibility for control and management of WIPP may be equally as important in determining the ultimate safety of the repository.

   The long-term nature of WIPP will place extraordinary demands on official commitment, to fulfill the public trust. This trust includes a responsibility to disclose threats, monitor conditions, correct deficiencies, and promote governmental communications at regional, state, and local levels.

Recommendations

1. An analysis of potential intrusions should be performed every 25 years or so, to accommodate new knowledge and perceptions. This process will accomplish several important and interesting objectives. First, it will lower the chances of surprise. Second it will provide a continuing input to the examination of the need for revision of markers and barriers. Third, it will improve the "memory" of the site. Fourth, it will provide a most instructive chronology of what a group of people thought the future might hold.

2. The marker panel should consider the possibility of not marking the site. There is at least some reason to believe that markings of any kind will

be attractive to a future society and draw special attention to the region of WIPP. Most of the potential intrusions we studied would, if truly inadvertent, be extremely unlucky to penetrate the repository by chance. For example, without knowledge of the specific location of the transuranics at WIPP, a future wild cat driller would have an extremely small chance of hitting the wastes stored at WIPP. We ask that the marker panel at least consider whether the small risk of a coincidental penetration is more or less favorable than attracting attention to the site with permanent markers. (Another panel on hearing this recommendation suggested subsurface markers - no markers on the surface - but clear markers underground near the site.)

3. We believe that it is appropriate for the marker panel to consider, explicitly, the viewpoints and concerns of local residents, women, and members of ethnic and minority groups (from a range of social classes) to obtain their reactions to plans for markers and passive barriers to the WIPP site. These people also might be asked if they can suggest better alternatives or make additional suggestions. This might be done after initial plans are made but before they are put in final form so that any new ideas that appear useful can be incorporated. The record should show that public discussion took place.

4. Consideration should be given to including markers that

- make warning sounds, give information in the form of human speech, or create visual images of people giving warnings in ordinary languages that are aimed at humans at the site in the immediate vicinity of such markers.

- activate on sensing potential intrusion and transmit electronic signals that can be received by radio and television sets at some modest distance from the site.

- can communicate with intelligent machines.

- Guard against intrusion from the side and perhaps below, as well as from above.

- Coloring agents that would color underground aquifers should leakage occur.

If current technology does not permit the development of markers with these capabilities in sufficiently durable form, then add these possibilities to the agenda of future planners.

5. Consideration should be given to deploying surface markers and mounds of earth in some large patterns or designs that would be clearly visible from the airspace around WIPP and that would communicate a warning to stay clear of the site.

6. An assessment should be made of the feasibility of creating something like a WIPP Museum of Nuclear Energy and WIPP World on or near the site that might become a financially self-supporting tourist attraction and would constitute a collective *aide-memoire* of the existence and nature of the site.

7. A graduate student fellowship might be created to endow a few select universities; the holders of these fellowships would have the responsibility to visit the site and inspect its security and degree of maintenance once a year or more often if appropriate. The fellowships would require reporting the findings of these visits to appropriate agencies as well as to the public and other holders of such fellowships at other universities.

8. Members of the human intrusion panel be invited to attend and participate in future meetings of the marker panel.

APPENDIX

SPECIAL TOPICS

During this work, we identified several topics that we felt needed additional description; these "white papers" are presented in this section:

Can Technology Be Lost? (B. Cohen)

Can Memory of WIPP be Retained? (M. Baram)

Mineral Extraction as a Threat to WIPP's Security. (B.Cohen)

Situations in Which the Problem Disappears.(B. Cohen)

Conditions Under Which WIPP Should be Delayed or Abandoned (B. Cohen)

Can Technology Be Lost?

B. Cohen

One can envision all sorts of possibilities for social catastrophies in the next few hundred years. There could be nuclear wars, socio-political upheavals, overpopulation or environmental disasters, anti-technology religious fervor, or just plain stupidity or failure to plan ahead. Could any of these worst case scenarios encompass the whole world to the extent that basic scientific and technological knowledge relevant to protecting WIPP would be lost? In my view such a situation could not exist.

Over the past few centuries, each technological age has benefited from history and has used prior technological knowledge to reach our current state of technological development. While cycling has occurred and will likely continue for the next several centuries, since I think we are less likely in the future to repeat past mistakes, the cycles are apt to be strongly damped in the future. Society will know how to secure ever higher standards of living and how to avoid catastrophies. After that, I see smooth sailing with a technology well advanced over its present status. Thus, population may be maintained at a sustainable level, and medical problems and health risks may be largely resolved or at least greatly reduced (including, most probably, cancer). Genetic control will eliminate many current problems. Racial and socioeconomic issues may be solved and stability and peace may reign. History will be a favorite subject, and knowledge of past catastrophies will prevent their recurrence.

Can Memory of WIPP Be Retained?

M. Baram

One can envision several plausible situations in which knowledge relevant to ensuring WIPP integrity is lost. These need not be based on imaginative scenarios of societal catastrophies, but can be based on mundane factors, such as lack of sustained interest over time by federal agencies and Congress due in part to diminution of media coverage and public concern; communication and record-keeping breakdowns; economic and political pressures that overwhelm agency stewardship over WIPP; and deliberate or accidental loss of records by agencies or private contractors.

Rather than argue pessimistically in the abstract, the recital of recent factual loss of history should stimulate concern. Consider, for example:

> The Lyons, Kansas, salt dome site was recommended for use as a waste site for radioactive material by the AEC in the early 1970s. Simple tests involving the placement of water in the site revealed the presence of numerous bore holes that made the site porous. These holes had been made by prior exploratory drilling for soft minerals, a history that had been lost and fortuitously recaptured by opponents to the project.

> The Massachusetts Bay site picked for dumping excavated earth as part of the current plan to construct major transportation systems in Boston (to begin in 1990) has now been identified by two environmental groups as the Mass Bay "foul area" where numerous drums of hazardous and radioactive waste were dumped by the Defense Department in the late 1940s (Manhattan Project wastes). The plan to dump at this site, which could break the drums and release their contents, is now being reconsidered. No one knows how many barrels were dumped here by the Department of Defense, and history was lost with a 45 year time span until the environmental groups "found" it again.(1)

(1) Boston Globe, July 26, 1990. p25.

Radiation releases at Hanford, beginning in 1944, exposed thousands of persons to radiation at levels known to be hazardous. The practice was kept secret by Hanford officials until a local citizen's group secured the information under the Freedom of Information Act in 1986. (2)

Private contractors used uranium mill tailings in Colorado to construct homes and other concrete structures, despite restrictions on access to the tailings, until the practice was discovered and stopped. Several structures had to be abandoned and destroyed.

Workers constructing a sewer line in 1982 inadvertently broke open a poison gas container buried by the Army when it closed an airfield in 1945. No records were available to the sewer project planners, a loss of "history" within 37 years. (3)

This sample of actual cases in which history was lost in under 50 years indicates that the pessimistic case is plausible and that new methods must be found to maintain knowledge and vigilance in protecting WIPP. Of note is that opponents of projects often play the useful role of rediscovering history because they are so highly motivated. Thus, establishing or reinforcing a "watchdog" or opposition function may be a useful option to protect WIPP in the future.

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(2) New York Times, July 12, 1990. p1., Toxic L. Rptr, September 5, 1990. p.467.

(3) OSM Retr., November 29, 189. p1189.

Mineral Extraction as a Threat to WIPP Security

B. Cohen

Our current era is recognized as "the age of mining" with minerals and fuels extracted largely from deep underneath the Earth's surface. It is also recognized that this process cannot continue for very long. Supplies of oil and natural gas, and of most metals, will be nearly exhausted within 200 years. Coal and a few other minerals may last a few hundred more years, but not much more unless very radical measures are introduced.

In any case, the present level of exploration for minerals will probably not extend beyond the twenty-second century, especially in the U.S., which has already been intensively explored. We should, therefore, not think of the distant future as one of continuous mineral exploration. Some exploration may continue for several centuries, but its cost per unit of resources found will escalate at a constantly increasing rate, constantly becoming less practical. Emphasis will shift over to substitution and "making do" with what is readily available on the surface of the Earth (e.g., aluminum, iron, silica) or from the seas (e.g., magnesium, potassium, chlorine). Only those mineral resources already identified will be mined.

If there is an interruption of civilization after that, it is doubtful whether later civilizations will find it profitable to do widespread exploration for minerals. Their technology will have to be based on other approaches, and it is difficult to see how it can develop to our present level. On the other hand, it seems incredible that all of the knowledge and understanding that we have developed may be irretrievably lost.

Situations in Which the Problem Disappears

B. Cohen

At least three situations can be envisioned in which the problem of intrusion into WIPP disappears:

(1) The health impacts of low-level radiation are found to be much below current estimates, or even beneficial.

(2) Medical progress greatly reduces the consequences of radiation exposure.

(3) Technology becomes available to remove easily the buried waste and dispose of it more safely.

We discuss each of these in turn.

1. In essentially all release scenarios, radiation exposure to individuals are far below 50 rem and dose rates are far below 10 rem per year. This is generally referred to as "low-level radiation."

Health effects of low-level radiation are now estimated by use of a linear/no-threshold hypothesis. It is assumed, for example, that the cancer risk of 1 rem is 1% of the known risk from 100 rem. There is no direct experimental evidence for the validity of the linear/no-threshold hypothesis. It fits well with current theories of how radiation initiates cancer, but could easily be modified.

For example, there is a wide interest in the theory of radiation hormesis--that low levels of radiation stimulate the immune system and thereby protect against cancer. Hormesis is supported, albeit not conclusively, by over 3000 experimental research papers.(1) Two international symposiums have been devoted to the subject, and interest is increasing. If hormesis were accepted, its effects would simply add to those of the linear no-threshold hypothesis, without challenging that hypothesis directly. I estimate that there is a 20% chance that hormesis will eventually become accepted.

But acceptance of hormesis is by no means necessary greatly to reduce the estimated health risks of low-level radiation. For example, it is well known that there are "repair processes" that repair the harmful effects of low-level radiation. One could easily justify an assumption that repair processes are more efficient and complete if there is less damage. There are many other huge gaps in our understanding of how radiation induces cancer that could easily explain large deviations from the linear/no-threshold hypothesis.

The most recent National Academy of Science Report (BEIR-V, p. 181) states that "the possibility that there may be no risks from exposure comparable to external natural background radiation cannot be ruled out. At such low doses and dose rates, it must be acknowledged that the lower limit of the range of uncertainty in the risk estimates extends to zero."

The present situation is that linear/no-threshold is accepted by all official groups charged with responsibility for estimating health effects of radiation because it is a safe and prudent procedure--there is abundant evidence that it does not underestimate effects of low-level radiation. However, if direct experimental evidence were forthcoming, there would be little resistance to changing that situation. In fact, testing the linear/no-threshold hypothesis is widely considered to be a top-priority item on the scientific agenda.

Excellent opportunities are now available for testing the linear/no-threshold hypothesis with data on radon in homes. The effects of high levels of radon exposure are well known from studies of miners, and they predict easily observable effects at the levels observed in many millions of homes. Several studies that have the power to determine whether these predicted effects actually occur are now in progress.

All things considered, the probability that current estimates of health impacts of low level radiation will be greatly reduced in the next century are probably in the range of 40%.

2. Medical progress in curing cancer has been steady in recent years, with 5 year survival probabilities (2) for all cancers in whites increasing from 39% in 1960-63 to 50% in 1977-83. Over this time period, 5 year survival rates for various types of cancer improved as follows:

	FROM	TO		FROM	TO
Oral cavity	45%	53%	Uterine corpus	73%	85%
Esophagus	4%	6%	Ovary	32%	38%
Stomach	11%	16%	Prostate	50%	71%
Colon	43%	53%	Testes	63%	89%
Rectum	38%	50%	Bladder	53%	76%
Liver	2%	3%	Kidney	37%	50%
Pancreas	1%	2%	Brain	18%	23%
Larynx	53%	67%	Thyroid	83%	92%
Lung	8%	13%	Hodgkin's	40%	74%
Melanoma	60%	80%	Lymphomas	31%	49%
Breast	63%	75%	Leukemia	14%	33%
Uterine Cervix	58%	67%	Myeloma	12%	24%
			All site	39%	50%

If this rate of improvement can be extrapolated into the future, cancer will be a curable disease within about a century. But such an extrapolation is hardly reliable as progress tends to come in jumps. It is very difficult to get quotable expert opinion on the future, but in off-the-record discussion, there is a great deal of optimism. Basic understanding is improving rapidly, and in other fields, such basic understanding has nearly always led to success in applications. A reasonable estimate of the probability that cancer will be highly curable within a few centuries is judged to be about 85%.

3. Excavation technology has been advancing rapidly during the second half of the twentieth century. It is now feasible to move mountains and to strip-

mine coal hundreds of feet below the surface. If this progress continues, within a few centuries it may be easy and cheap to excavate the repository.

If, at that time, the buried waste is still viewed as dangerous, and a better disposal method is available, the waste can be removed and disposed of by this improved technology. The probability for this scenario to materials is perhaps a few percent.

Reference

(1) T. D. Luckey, "Hormesis with Ionizing Radiation," CRC Press, 1980.

(2) E. Silverberg and J. Lubera, Cancer Statistics 1987, CA - A Cancer Journal for Clinicians 37, 1,2 (1987).

Conditions Under Which WIPP Should be Delayed or Abandoned

B. Cohen

If WIPP were not to be used because of fears about far future health effects, a billion dollars would have to be spent on alternatives. Even if operation of WIPP were to be delayed by a year or more, a hundred million dollars or more would be lost. Since this money would be spent to save far future lives, it is important to consider whether it could be spent more effectively for that purpose.

A. Alternative ways to spend money to save far future lives.

1. "Trust fund" approach: There is evidence (1) that it will probably always be possible to save lives at a price below $1M per life saved. It is also shown that over the past 5000 years, money could always draw interest of at least 3% per year over and above inflation. The simplest form of the "trust fund" approach is to set up a trust fund for future generations to spend for saving lives. At 3% interest, each dollar we put into a trust fund now will be worth $6 trillion (more than the current U.S. GNP) after 1000 years, enough to save millions of lives. By spending all but $1, which is reinvested each 1000 years, millions of lives could be saved each 1000 years, or an average of thousands of lives per year.

One might question the reliability of a trust fund over long time periods, but actually there is an easier approach--just don't spend the money. This will reduce the national debt, leaving future generations with more money to spend on life saving. The amounts of money come out the same as in setting up a trust fund.

2. Biomedical research approach: It is estimated that for each $4M invested in biomedical research, one U.S. life per year is saved thereafter. If life saving in other countries is included, this would be at least 10 lives per year. Over the next 1000 years, this $4 million would save 10,000 lives, or $400 per life saved.

With wither the "trust fund" or "biomedical research" approach, it is counterproductive to spend more than about $100 per far future life saved in improving WIPP because many more far future lives could be saved by spending that money in other ways.

B. People now living in underdeveloped countries.

Considering the way people migrate, there is no reason to believe that the human population around the WIPP site thousands of years from now will be the direct descendants of those living there now. (In fact, those living there now are not even the direct descendants of those who lived there 200 years ago.) Thus, the people being protected have no closer relationship to us than people now living in underdeveloped nations. There are many ways in which we could spend money very cost effectively to save lives in these nations. According to estimates by the U.S. Agency for International Development and World Health Organization(2), about 5 million deaths per year among children could be averted by immunization programs, at costs ranging from $50 per life saved from measles in Gambia and Cameroon to $210 per life saved by a combination of immunizations in Indonesia. In addition, WHO estimates that about 3 million childhood deaths each year could be averted by oral rehydration therapy for diarrhea at costs per life saved ranging from $150 in Honduras to $500 in Egypt. Since we are not spending this money to save present lives, it does not seem reasonable to spend more money to save far future lives. In fact, the amount we spend for the latter should be reduced by a factor representing the probability that a cure for cancer has not been found, and that low-level radiation has not been determined to be much less harmful than indicated by current estimates.

<u>Summary</u>

We have shown that we can save far future lives for about $400 each with biomedical research and for a very much lower price with a trust fund approach. We have also shown that we are not willing to spend $100 to save equivalent lives. It, therefore, does not seem reasonable to spend more than $1000 on WIPP to save a far future life. SInce abandoning WIPP would cost $1 billion and delaying it a year would cost $100 million, this implies that WIPP should not be abandoned unless it is found that this would save a million lives, and it should not be delayed a year unless that would save 100,000 lives.

A general objections to the above discussion is that the beneficiaries of our alternative approaches are not the same people who may be injured by WIPP. This is part of a broader problem in understanding these issues--the idea that we should do nothing that might be disadvantageous to future generations. This idea is completely impractical; we do many things that will be disadvantageous to them. Probably the most important is our voracious consumption of limited mineral resources, including oil, gas, coal, and metals that are in limited supply, like copper, zinc, tin, lead, silver, mercury, and many others. Other harmful legacies we leave them are over population, horrible military weapons, large public debts, a variety of sociopolitical problems, etc. The only realistic approach is to leave them enough beneficial legacies to compensate. Recent history gives a continuous record of success in this regard as each succeeding generation has lived longer and healthier lives at constantly improving standards of living. Our biomedical research and trust fund approaches represent methods of greatly over-compensating effects of any harm that may come from WIPP.

References

(1) B. L. Cohen, Discounting in Assessment of Future Radiation Effects, Health Phys. 45,687 (1983).

(2) PRITECH (Technologies for Primary Health Care Project), U.S. Agency for International Development, "Infant and Child Survival Technologies," Sept. 1984. Also several issues of Bulletin of World Health Organization.

APPENDIX D:
SOUTHWEST TEAM REPORT

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Ten Thousand Years of Solitude?

On Inadvertent Intrusion into the Waste Isolation Pilot Project Repository

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Preface

> TDY1142 released her sleeping cocoon and mumbled to her dressing robot, "Something blue." Then "news on." The announcer's image materialized above the kitchen table. "Good morning. In the top of the news today: The City Builders have discovered some prehistoric ruins at 2100 feet while moving south toward the Mexican isthmus. Following the disastrous release of the common cold last year from other ruins, they are proceeding with caution ..."

This report documents our work as an expert team advising the U. S. Department of Energy on modes of inadvertent intrusion over the next 10,000 years into the Waste Isolation Pilot Project (WIPP) nuclear waste repository. The WIPP, located 26 miles east of Carlsbad, New Mexico, is a defense activity of the Department of Energy which is to serve as a research and development facility to demonstrate the safe disposal, in natural bedded salt formations, of radioactive wastes resulting from the defense activities and programs of the U. S. Government. By late-1989, over 10 miles of underground structures had been excavated. This includes four deep shafts extending 2,150 feet below the surface, and horizontal tunnels and rooms at that depth. Underground rooms and connecting passageways are 13 feet high and 33 feet wide.

The WIPP will be storing two types of defense-generated transuranic wastes primarily:

- Contact-handled transuranic waste in metal drums or boxes. The radiation level on the outside of the drums and boxes is low enough that they can be safely managed in a hands-on manner.
- Remote-handled transuranic wastes with high enough radiation levels that they will require handling by remotely controlled equipment.

Our team is varied: An astrophysicist who also writes science fiction, a decision analyst, a physical scientist turned social scientist, and a geographer. We had never met before this work and are spread across three states. Our views on humanity and technology range from optimistic to cynically pessimistic. However, we believe we can provide a unique perspective from our vantage point as Southwesterners on future intrusions at the WIPP site.

While reviewing the material on markers provided by U. S. Department of Energy personnel and contractors, we were struck by the fact that these recommendations regarding markers implicitly assume that future potential inadvertent intruders will look basically like Twentieth Century archaeologists (except, perhaps, that they will not understand English very well). We hope our report gives images of how truly different the future is likely to be.

Those who travel Interstate Route 8 between Arizona and San Diego are familiar with the agricultural inspection and immigration (!) checkpoints. This is more control on transit than there is between some Western European nations, and it provides an appropriate image of the place of the Southwest in U. S. history. Antonio de Espejo crossed the WIPP region in 1582. This is, as the saying goes, an ancient land, and one where the impact of U. S. control is light and, possibly, transient.

The title of our report, with its reference to Gabriel García Márquez's acclaimed novel *One Hundred Years of Solitude,* conveys some of our sense of how different the future could be from the present. That novel sometimes seems alien to U. S. readers. Yet it was written in this century and just a few tens of hundreds of miles from Washington, D. C., by an author who shares our Western European cultural tradition. What will be the worldview of someone contemplating the WIPP site in 12,000 A.D.?

While all members of the team concur with the report, various members had prime responsibility for different sections. Martin Pasqualetti created the framework used to structure the set of scenarios. The prime authors of each scenario are indicated in the section title. Craig Kirkwood furnished the vignettes that open each chapter.

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Craig W. Kirkwood
Harry Otway
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Ten Thousand Years of Solitude?

On Inadvertent Intrusion into the Waste Isolation Pilot Project Repository

by

Gregory Benford, Craig W. Kirkwood,
Harry Otway, and Martin J. Pasqualetti

ABSTRACT

This report documents our work as an expert team advising the U. S. Department of Energy on modes of inadvertent intrusion over the next 10,000 years into the Waste Isolation Pilot Project (WIPP) nuclear waste repository. We estimate credible types of potential future accidental intrusions into the WIPP as a basis for creating warning markers to prevent inadvertent intrusion. We use a six-step process to structure possible scenarios for such intrusion, and we conclude that the probability of inadvertent intrusion into the WIPP repository over the next ten thousand years lies between one and twenty-five percent.

1. Introduction

> Ugh the Chieftain watched the sun rise over the pyramid with its mushroom-cloud markings and images of writhing people. His band had been fleeing the Zardocheros with increasing despair. They were almost out of food, and the dust cloud of their pursuers was ever present. However, when they came upon the pyramid, their luck changed. The artifacts around the monument furnished materials for spears, and they killed three deer. The Zardocheros seemed to have given up the chase. Perhaps they should settle here in the protective cover of the pyramid ...

We are probably no better at predicting changes and events over the next 10,000 years than were the people beginning plant and animal domestication in Mesopotamia 10,000 years ago at predicting our world. Only a few visionaries had an inkling at the beginning of this century of what could happen by the century's close.

Fortunately, our task is not really to visualize the next 10,000 years. Here we estimate credible types of potential future accidental intrusions into the Waste Isolation Pilot Project (WIPP), as a basis for creating warning markers to prevent inadvertent intrusion. This is more feasible because only a few aspects of future developments affect potential intruders' ability to detect and properly interpret markers.

Table 1
Steps in Structuring Scenarios for Inadvertent Intrusion (I. I.) into the WIPP

Step One	— Establish Assumptions
Step Two	— Identify Environmental Changes Enhancing I. I.
Step Three	— Identify Key Socioeconomic Factors Enhancing I. I.
Step Four	— Specify the Likelihood that Key Factors Enhance I. I.
Step Five	— Identify Scenarios
Step Six	— Describe Scenarios

This report is organized around answering the following question: What conditions would increase the likelihood of inadvertent intrusion (I. I.) into WIPP? We have used a six-step process (Table 1) to structure possible scenarios for such intrusion. Section 2 presents the first five steps of this process. Section 3 describes scenarios (step six) based on the specifications in Section 2. Section 4 draws conclusions from our analysis and makes recommendations.

Our work was conducted within a two-month period in mid-1990.

2. Basis for Selecting Scenarios

> The archaeological survey ship materialized above the third planet from Sol and dropped its preliminary probes. "Well," said Captain Beam, "Some people say this is the ancestral home of the human race." Probe Monitor Perkins looked up from the monitor screens and replied, "Whether or not it is, there are certainly transuranics down there."

Step One — Establish Assumptions

Based on briefings from U. S. Department of Energy personnel and contractors, we understand the following assumptions are to be made:

1. The repository will be closed after the proposed period of operation.
2. Only accidental intrusions are to be considered. That is, war, sabotage, terrorism, and similar activities are not to be addressed.
3. Active control will be maintained of the WIPP site during the period of use and for one hundred years following closure. Therefore, we can ignore this period in our analysis. We are to consider inadvertent intrusions over the 10,000 years following the end of active control.
4. Following the end of the period of active control, passive measures only will be taken to warn potential intruders. That is, whatever markers are used must not require any active maintenance after the period of active control ends.

We have also followed these added guidelines in our work:

5. The inherent danger in the radioactive materials will decay at currently projected rates.
6. No fantastic (although potentially possible) events will be considered. These include such things as
   - — Visits from extraterrestrials,
   - — Collisions with objects from space, and
   - — Ability to revoke gravity.
7. The further we consider into the future, the greater the variety of possible scenarios.

Looking back in time over the last 10,000 years gives some limited indication of the magnitude of changes we may expect in the future. Since active operation of the WIPP is currently projected to last for approximately 25 years, the end of the period of active control will be about 125 years from the time of opening. Based on a consideration of historical developments, we divide the period after the end of active control into three periods: 0–100 years ("Period I"), 100–1,000 years ("Period II"), and 1,000–10,000 years ("Period III"). Adding on the 125-year period of active control to 100 years yields 225 years from the time of opening as the end of Period I. Going back 225 years, what is now the Eastern United States was in the late English colonial period. At least in the European world, there were some resemblances to the current world—in fact, some countries have survived this long. For this period, therefore, it is possible to consider using extrapolation to predict what might happen.

Going back 1,000 years (plus the 125 years of active control) takes us to the middle of the Middle Ages in Europe. Virtually no political institutions from this far back have survived. However, some human institutions have survived this long (notably the Catholic Church in Western Europe) and some buildings from this far back are still in active use. Thus, while it is not realistic to consider extrapolation as a method of predicting this far in the future, history gives indication of some continuity over periods as long as Period II.

Much history beyond 1,000 years is hazy, especially on a regional scale. For example, English history is reasonably well known from the time of the Norman invasion in 1066. Prior to that, things are less well established. (Who was King Arthur?) Further back than a couple of thousand years, there is very little continuity in human institutions. Going back 10,000 years, we reach the time of the beginnings of agriculture, a time about which virtually all our understanding has been inferred from physical remnants of the time. Thus, even with the use of present information storage abilities, predictions for Period III will be highly speculative. Because of this expectation of unpredictability, we have included a broad range of scenarios so that the markers that are developed adequately address all plausible types and causes of intrusion.

We also note that there are many reasonable scenarios for future developments under which the WIPP either suffers no inadvertent intrusion or where inadvertent intrusion does not pose a threat to mankind. For example, if knowledge of the WIPP, its location, and its threat remains in the knowledge base of potential intruders, inadvertent intrusion, by definition, would not occur (with the one exception of the case where intrusion was intentional but exposure to the risk was not). Inadvertent intrusion could also occur but without negative consequence, as in the case where all dangers have been negated (either because the dangers in the materials can be neutralized, or because the harmful biological response has been nullified).

Some members of our team think it likely that the material to be buried will become a valuable resource in the relatively near future. If so, then the facility will either never be closed because the waste will have been retrieved or the waste will be retrieved soon after the facility is closed.

The potential scenarios reviewed in the preceding two paragraphs should be kept in mind while considering potential threats posed by the WIPP. However, we give them limited attention below. Our task is to consider the nature of potential intrusions assuming that no active measures are taken to prevent such intrusions and also not making assumptions about whether an inadvertent intrusion would be dangerous to the intruders and the larger human community.

To sum up, we assume that the WIPP will be well marked, remembered and possibly guarded during Period I. In Period II, there may be memory loss by society, or enough degrading of the "legend" of the WIPP that its threat is not understood. Significant marker loss can occur, except for very large or very clever markers. Period III holds a vast realm of unknowns, since it comprises more time than all human history. We can expect radical shifts in worldview, capabilities, and even the composition of the human species. Yet it is possible that the technology of that time will be unable to deal with radioactive isotopes because the entire nuclear technology will be not merely outdated but forgotten. This is like a "Mummy's Curse," where the explorers know something is down there but do not appreciate its nature or dangers.

Future Development of Technological Knowledge

In broad terms, the future level of technological knowledge can take four courses:

1. Knowledge generally increases,
2. There is a decline, and perhaps collapse, of relevant knowledge,
3. Knowledge generally stagnates at or near current levels, or
4. There is a cyclical decline and rebuilding of knowledge, with this cycle perhaps occurring more than once over the ten-thousand-year period of interest.

Other patterns of development are possible (for example, a growth of knowledge for a period, followed by stagnation at a significantly higher level than at present). However, if markers are developed to handle the four patterns specified above, then the markers should address other credible scenarios.

Each of the four development patterns poses its own threats of inadvertent intrusion. If knowledge generally increases, then it is possible that we will quickly move through the current atomic age into a time when something else is used as an energy source or weapon (perhaps solar power or complete conversion of matter to energy with no byproducts). Knowledge of atomic materials and the threats they pose might be lost in the great mass of new information that will be developed, so that nuclear materials will not be recognized as a threat as time goes on. Other potential threats of inadvertent intrusion under these conditions might come from new technology. For example, autonomous mining machines might be loosed in the area. These might not be intelligent enough to recognize the danger (or might not think of it as a danger because it posed no threat to the machines themselves).

If knowledge declines or collapses, then some working technology could still be around without the knowledge to understand the dangers that using it at the WIPP site poses. Someone might start drilling at the WIPP site without having the capability to properly identify the material that was released.

If knowledge stagnates at current levels, dangers might be posed due to loss of institutional control, as discussed later.

Perhaps the most often mentioned dangerous scenario is when technological knowledge decays and then rebuilds. Wildcatters with 1800s drilling technology (or year 5000 technology in the year 12,000) might come into the WIPP region and start drilling for oil or gas (which might be in short supply because of the extensive exploitation before the decline of civilization). While these explorationists would have the technology to intrude on the WIPP, they would not understand what nuclear material was. Hence, they might release radioactivity without understanding what they had done.

Knowledge of the WIPP

Four basic scenarios describe the level of knowledge that might remain about the WIPP at any point in the future prior to intrusion:

1. Knowledge remains of both the WIPP and the danger that it poses.
2. Knowledge remains of the WIPP, but not of the danger it poses. (In other words, the markers have done their job in identifying the WIPP but not in portraying what it is.)
3. Knowledge remains of the danger of the WIPP, but not where the WIPP is located.
4. No knowledge remains of either the WIPP or its danger.

It should be noted that the relevant "knowledge" for purposes of this section, as well as the technological knowledge in the preceding section, is the knowledge of the potential intruders. Thus, for example, knowledge might remain of the WIPP in the major human population centers, but the Southwest might be a primitive area with limited access to this knowledge. In this situation, the relevant knowledge is of those who might intrude.

The first situation, where knowledge remains of both the WIPP and its threat, does not impose a threat of inadvertent intrusion. The three remaining cases do. In case two, one can visualize future archaeologists digging into the site to retrieve ancient artifacts. In the third case, random drilling might intrude, although most likely the threat would be soon recognized. In the fourth case, random drilling might intrude, and the archaeologists mentioned above might then take over.

The exact implications of each of the four cases depend on the general level of technological knowledge of the people involved. For example, even if the intruders do not understand the danger posed by the WIPP, if there remains general knowledge about radioactivity, then this will likely be brought to bear soon after the first symptoms of radiation sickness show up in the involved archaeologists. Thus, while the implications of the intrusion might be very serious for the archaeologists, society may have means of coping with the released radioactivity before it poses a large-scale problem.

Use of the WIPP Region

Attempting to predict usage over 10,000 years is hopeless. The climatological and cultural resources briefings we received from Department of Energy personnel and contractors indicate that the climate and surface resources in the area have been substantially more fertile within periods of relevance for the 10,000 year time frame of interest. In addition, the activities of mankind could significantly influence the area within the foreseeable future. (Our activities already influence the climate over significant regions. In the future, we might change global climate, either deliberately or inadvertently.)

Out of Sight, Out of Mind—The Gnome Example

Perhaps the most striking aspect of the region around the WIPP site is its distance from organized political control. The nearby site of Project Plowshare's Gnome test provides a clear example. This was the underground detonation of a nuclear fission device in a salt formation to test, among other things, the feasibility of residual heat recovery. It left a concentrated region of intense, long-lived radioactivity at a depth of 1250 feet (900 feet closer to the surface than the WIPP repository). Less than thirty years later, and only about six miles from the WIPP, there is clearly little interest in controlling and marking the site. The single Gnome marker already shows signs of weathering and has obviously shifted from its original location. In any case, the marker contains much more information about the test than about any underground hazard. It is difficult to visualize a similar lack of interest if that site were, for example, fifty miles from Washington, D. C.

Step Two — Identify Environmental Changes Increasing the Likelihood of Inadvertent Intrusion

The most reasonable assumption is that sometime during the next 10,000 years the environment may be sufficiently desirable for almost any use. We concur with the presentations made by the Department of Energy which indicate that environmental changes at the WIPP site are unlikely to be great over that period. However, even relatively small environmental changes can lead to substantial socioeconomic changes. Such socioeconomic changes could increase the likelihood of

Table 2
Plausible Environmental Changes Increasing Likelihood of Inadvertent Intrusion

• Seismic activity
• Increased moisture
• Increased vegetative density
• Increased soil fertility

inadvertent intrusion. Plausible environmental changes which could have this contributory function are listed in Table 2.

Seismic activity is significant only if it facilitates intrusion. In light of the geological stability at the WIPP site itself, this is unlikely.

Increased moisture is feasible from several plausible environmental changes. Climate change is the most likely, but it is not plausible that such changes would exceed 100 percent. This increment, in whatever form (e.g., increased rainfall or decreased evapotranspiration losses) would have secondary consequences for many of the socioeconomic factors listed below. Climate changes could be natural or human-induced though mechanisms we now suspect, such as increases in greenhouse gases, or through some as-yet unimagined ability. Increased vegetative cover is likely with increased moisture availability. This could plausibly lead to increased agricultural and timber resource potential. Both these changes could, along with human intervention, substantially increase soil fertility.

Step Three — Identify Key Socioeconomic Factors Enhancing Inadvertent Intrusion

Eight key socioeconomic factors influence the likelihood of inadvertent intrusion into the WIPP repository (Table 3). Although the discussion below considers these factors individually, clearly various interactions among the factors are possible.

Table 3
Key Socioeconomic Factors in Plausible Inadvertent Intrusion

- Economics
- Water
- Population Change
- Technological Influences
- Memory Loss
- Altered Political Control
- Communication Changes
- Facility Management

Economics

Economics, as considered here, includes all types of economic incentives and inducements which might bring about inadvertent intrusion. The Department of Energy briefing emphasized that there are a variety of physical resources near the WIPP site with potential economic significance. Ten thousand years is a long time, and it is not possible to foresee what might be economically viable in this time frame. Therefore, any materials in the area could be economically valuable in the future, with intrusion resulting from exploration or extraction activities. Although exploration could take place by non-intrusive means, removal of such resources would involve drilling, underground mining, or surface mining techniques. One member of our team notes that if mankind has not left the face of the earth over this time frame, then we will have stripped the top few thousand feet off the earth in our quest for resources. Another member notes that if nothing else is exploited, then the very emptiness of the region is likely to be a resource in an increasingly urbanized world. One member also suggests that artifacts from the WIPP might be considered valuable. Realistically, we have little idea what might be a valuable resource in a few thousand years. After all, radioactive materials were not useful even a hundred years ago.

Water

Increased water availability in the WIPP region is far more likely through human actions than environmental changes. Specifically, increased availability could occur because of newly developed desalting techniques (either for existing local saline supplies or for sea water) and importation (of sea water or distant potable water).

Population Change

Population change, particularly population increase, would enhance the probability of inadvertent intrusion. Such population change could be produced by population spillover resulting from population pressures elsewhere; from a government policy decision which would induce (or direct) people to live in the vicinity of WIPP; from a voluntary relocation prompted by resource exploitation, enhanced agricultural possibilities, or recreation; and from use of the area as a corridor for transportation and migrations. Conversely, population decrease could reduce knowledge of the WIPP and hence increase the likelihood of inadvertent intrusion.

Technological Influences

Technological changes could influence the potential for inadvertent intrusion either because of stagnation or from innovation. Examples of impacts due to stagnation include the lack of developing any non-intrusive exploration methods, thereby ensuring that any future exploration would ultimately use intrusive means. Impacts due to technological innovation, a more likely prospect, include advanced drilling, high-volume water desalting (which would affect population change), deep strip mining techniques (which would reduce the cost of getting to nearby resource materials), cancer cures (which would reduce fear and thus memory of danger), the identification of new resources, and the use of autonomous mechanical mineral extraction techniques.

Memory Loss

Memory loss is one of the more obvious factors influencing the potential for inadvertent intrusion. This could come in several forms, including loss of memory about the facility, loss of memory about the danger (if not of the facility), and loss of local memory (if not institutional memory). If use of nuclear power occurs for only a short period in the history of energy development in the world, such an era might be thousands of years in the past, long forgotten. Some form of memory loss is likely.

Altered Political Control

If one assumes a continuation of the present political system and control, the possibility of inadvertent intrusion is substantially reduced. However, history is so full of unexpected political developments (e.g., reunification of Germany) that we consider such political changes certain in one form or another. Once this change occurs, there could be a loss of knowledge of the WIPP, a loss of knowledge about its dangers, or a change in the level of interest about such matters.

Communication Changes

Changes in basic forms of communication are likely in the next 10,000 years, perhaps moving completely away from present and past means to forms we cannot imagine. One possible change is in the written and oral forms of the present. Another change could be in the way we store information, making it difficult for future generations to access information we intend for them to receive. A middle possibility is a loss of the ability to access or interpret old information systems.

Facility Management

Facility management plays a large role in changing the chance for inadvertent intrusion. If the facility is enlarged, there will be a greater chance it can be encountered accidentally. If it is managed for a longer period than envisioned at present, its novelty could diminish to a point where little special care is given it—it just becomes part of the local environment. If no other or few other repositories are sited and the WIPP site continues in operation, the continued activity could increase the chance of accidental releases.

Step Four — Specify the Likelihood that Key Factors Enhance Inadvertent Intrusion

A breakdown of the immediately preceding discussion is provided in Table 4. Using a three-tiered qualitative scale, we have specified the likelihood that each listed factor will occur ***and also lead to inadvertent intrusion.*** We did not use a numerical probability scale because such a numerical scale may give a false sense of precision to the process and tempt one to derive an overall probability of inadvertent intrusion by a process that is difficult to defend. We have specified relative likelihoods in Table 4 using the qualitative indicators "low" (L), "medium" (M), and "high" (H).

Step Five — Identify Scenarios

The steps outlined above suggest plausible relationships among the various listed key factors which are presented graphically in Figure 1. The process has also identified the topics for the narrative scenarios found in the next section:

- Where technology continues to increase:
  - — Mole Miner Scenario
  - — Nanotechnology Scenario
- Where society stagnates and reverses: The Doom and Gloom Scenario
- Where technology cycles: The Cyclic Scenario
- Where political control changes: The Free State of Chihuahua Scenario
- The Stasis Scenario

Table 4
Detailed Breakdown of Key Factors

Key Factors	Probability of Enhancing Inad. Intrusion		
	0–100 yrs	100–1,000 yrs	1,000–10,000 yrs
1.0 Economic motivation			
1.1 Mineral extraction	L	M	H
1.2 Agricultural			
1.2.1 Dry farming	L	L	M
1.2.2 Grazing	L	M	M
1.2.3 Irrigated farming	L	M	M
1.3 Land development	L	L	M
1.4 Artifact recovery	L	M	M
2.0 Increased water			
2.1 Desalination	L	H	H
2.2 Importation	M	L	L
2.3 Climatic change	L	L	L
3.0 Population change			
3.1 Population pressure			
3.1.1 Increase	M	M	M
3.1.2 Decrease	L	L	L
3.2 Redistribution by policy	L	M	L
3.3 Voluntary motivation			
3.3.1 Resource exploitation	L	M	M
3.3.2 Agriculture			
3.3.2.1 Grazing	L	M	L
3.3.2.2 Crops	M	H	H
3.3.3 Recreation	L	L	L
3.4 Corridor use	M	M	M

L = Low, M = Medium, H = High

Table 4 (con't)
Detailed Breakdown of Key Factors

Key Factors	Probability of Enhancing Inad. Intrusion 0–100 yrs	100–1,000 yrs	1,000–10,000 yrs
4.0 Technological influences			
4.1 Technological stagnation			
4.1.1 No non-intrusive exploration methods	L	M	M
4.2 Technological innovation	L	M	H
4.2.1 Advanced drilling	M	H	H
4.2.2 High-volume water desalting	L	H	H
4.2.3 Deep strip mining	L	L	H
4.2.4 Cancer cured	L	L	M
4.2.5 Resource enhancement/discovery	L	M	M
4.2.6 Autonomous mineral extraction	L	M	M
5.0 Memory Loss			
5.1 About facility	L	M	M
5.2 About danger	L	M	M
5.3 Local loss of either	L	M	H
6.0 Altered political control	M	H	H
7.0 Communication changes			
7.1 Significantly different language	L	L	H
7.2 Different information storage	L	M	M
7.3 Lost ability to access the old systems	L	M	M
8.0 Facility management			
8.1 Expanded size of facility	M	M	M
8.2 Expanded years of active operations	M	M	M

L = Low, M = Medium, H = High

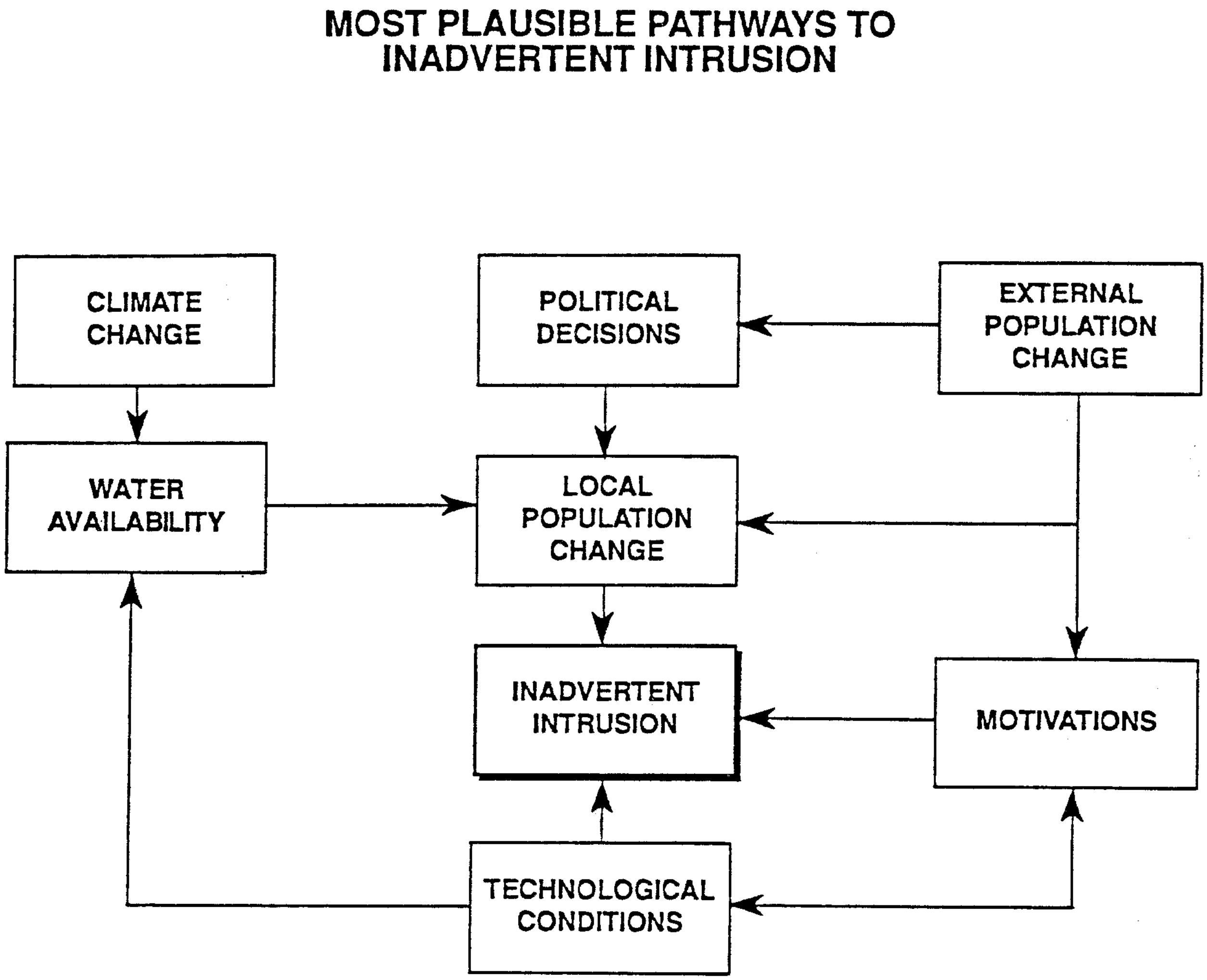

Figure 1. Relationships Among Key Factors

3. Scenarios for Developing Markers

Zzyg lifted his eyes from the visual scanner eyepieces on the survey ship orbiting the blue-green world and said, "It looks like another pre-conscious race didn't make it through their atomic age. That makes three so far this trip, and we have only come seventy-five light years." He sighed and brushed a tear from his center eye with his third-left tendril.

Technological Knowledge Increases (Gregory Benford)

As Arthur C. Clarke has remarked, "Any sufficiently advanced technology is indistinguishable from magic."

Yet a magically advanced technology is of no worry for us. Holders of such lore scarcely need fear radioactive waste; indeed, they may regard it as a valuable unnatural resource. It is worth remembering that the great pyramids, the grandest of markers humanity has erected, were scavenged for their marble skins.

The societies which must concern us are advanced enough to intrude upon WIPP, yet not so far beyond us that the radioactive threat is trivial or nonexistent. Even though we here assume technology improves, its progress may be slow and geographically uneven—recall that while Europe slept through its "dark ages" China discovered gunpowder and paper. It is quite possible that advanced techniques could intrude upon WIPP and yet not be able to deal with the subsequent leakage.

Mole Miner Scenario

As an example of the kind of technology which can intrude upon WIPP and has implications for markers, consider the evolution of mining exploration. Vertical or slant drilling is only a few centuries old. Its high present cost comes from equipment expenses and labor. An attractive alternative may arise with the development of artificial intelligences. A "smart mole" could be delivered to a desired depth through a conventional bored hole. The mole would have carefully designed expert systems for guidance and analysis, enough intelligence to assess results on its own, and motivation to labor ceaselessly in the cause of its masters—i. e., resource discovery.

The mole moves laterally through rock, perhaps fed by an external energy source (trailing cables) or an internal source. Speed is unnecessary here, so its tunneling rate can be quite low—perhaps a meter per day. It samples strata and moves along a self-correcting path to optimize its chances of finding the desired resource. Instead of a drill bit, it may use electron beams to chip away at the rock ahead of it. It will be able to "see" at least a short distance with acoustic pulses, which then reflect from nearby masses and tell the mole what lies in its neighborhood. CAT-scan-like unraveling of the echoes could yield a detailed picture. Communication with its surface masters can be through the cumbersome method of strung-out cables. A more likely picture is that the mole will use its seismological sensors to send messages—bursts of acoustic pulses of precise design which will tell surface listeners what the mole has found.

The details of the mole are unimportant. It represents the possibility of intrusion not from above, but from the sides or even below the WIPP. No surface markers will warn it off. Isotopes could then escape along its already evacuated tunnel, out to the original bore hole, and into ground water.

Implications for Markers

Clear signs of artificiality must be apparent from beside or below WIPP. No metal structure will survive intact more than a few centuries in the creeping salt beds. This suggests three possibilities:

A. Acoustically obvious markers. These could be solid rock unlikely to shatter and lose shape in the salt beds. Large granite disks or spheres might be easily perceived by acoustic probes. They might be arrayed in two straight lines in the WIPP drifts, intersecting perpendicularly at the center: X marks the spot.

B. Magnetic markers. These could be magnetized iron deposits lodged in the WIPP, arrayed artificially as described above. (The steel waste containers will collapse into an amorphous mass within a century, yielding some enhancement of the local magnetic field, but this will not be large.) Specially made high-field permanent magnets could produce a clearly artificial pattern, the simplest being a strong, single dipole located at the WIPP center.

C. Radioactive markers. Left at selected sites in the WIPP walls, but at least meters outside the bulk of the waste rooms and drifts, small samples of the isotopes contained in the WIPP could warn an approacher of impending intrusion. Like similar weak but telltale markers left on or near the surface, these have the advantage of showing the potential intruder exactly what he/she/it is about to get into. Their liability is that probably only certain approaches can be covered.

D. Markers detectable from a distance. Finally, these ideas point to a class of markers which can be seen at differing distances from the waste itself. Acoustic prospecting in the WIPP neighborhood could pick up the granite arrays. Magnetic detectors, perhaps even a pocket compass, could sense the deep iron markers from the surface. Ultra-sensitive particle detectors may detect the waste itself, or small tags with samples of the waste buried a safe distance below ground. (These would be small amounts, of no health risk to the curious—weaker than a radium watch, yet of long half life.)

Figure 2 depicts these possibilities.

The risk of marking at all is that future archaeologists, professional or amateur, will intrude without knowing what they are getting into—the "Mummy's Curse" idea, with the markers themselves as the lure.

Lastly, buried markers will work after all surface markers have vanished from erosion, vandalism or catastrophe. They would be the final backup.

* * *

We are acutely aware of our time-bound limitations—temporocentricity—and so offer a specific counter-example to ponder ...

Nanotechnology Scenario

Physics has dominated our century, but biology may well rule the next. The implications of the Human Genome Project and rapid progress in biotechnology remind us of a more general truth: *The most difficult realization about the future is that it can be qualitatively different.*

This means that simply envisioning bigger and better extensions of present civilization misses much. A prime example is Eric Drexler's book *Engines of Creation*, which proposes that manipulation of matter on scales of a single cell (a nano-meter, hence "nanotechnology") will emerge as a dominant theme within a century or two.

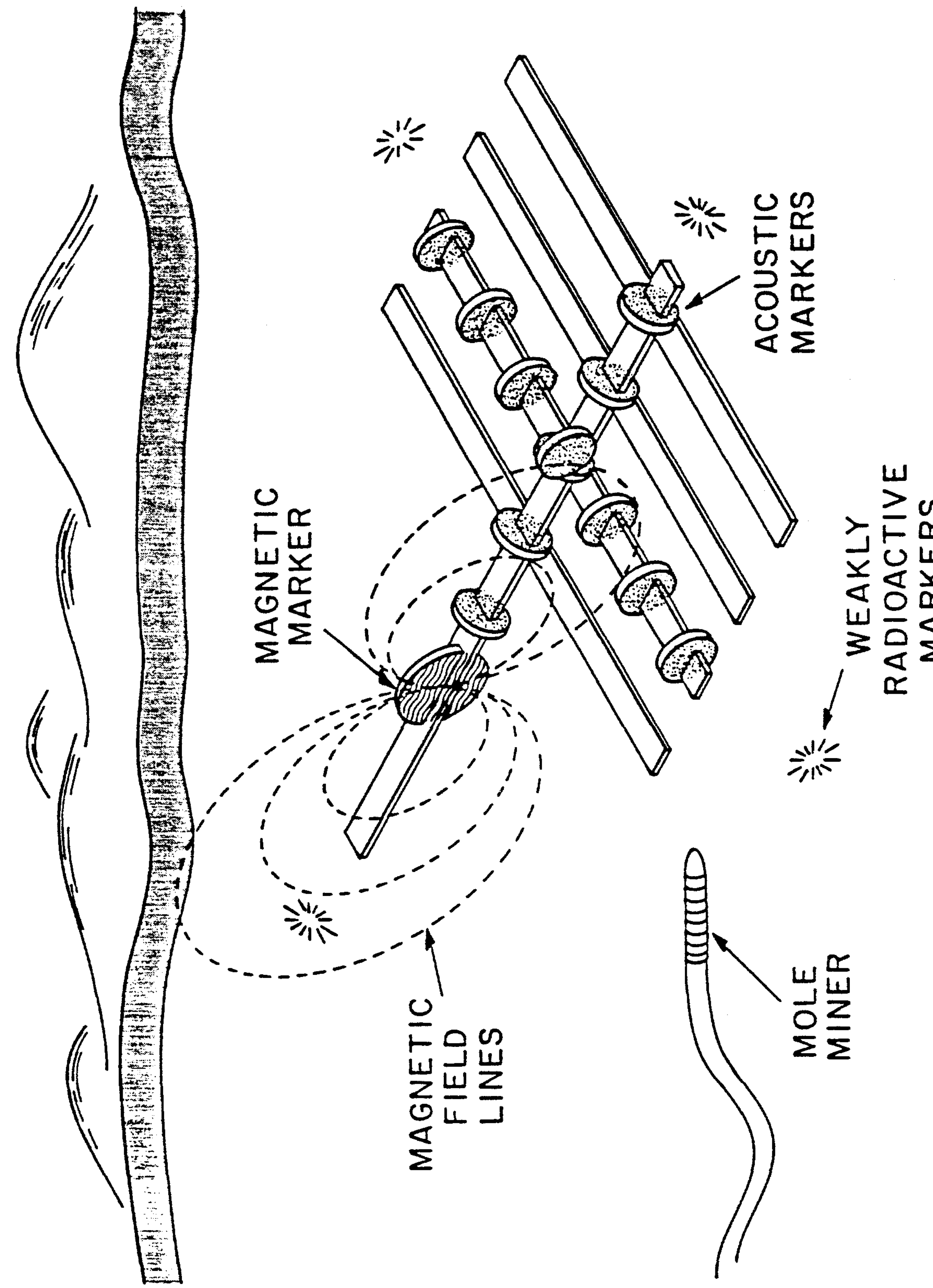

Figure 2. A Mole Miner Approaches the Marked WIPP Repository

Implications for the WIPP abound. Intrusion need not come from drilling bits, or even mining moles. Nature can already intrude into rocks for short distances with bacteria and lichen. It is not impossible that biological or bioteched mechanisms for prospecting and mining will be common within centuries. Some micro-organisms naturally precipitate uranium, and thus might be useful in prospecting for pitchblende—or for finding old waste sites.

We introduce this idea specifically because such intrusions do *not* lead obviously to any specific marker scheme, and thus are examples of what must necessarily be left out in any probability assessment. Surely nanotechnology would radically alter our ideas about resources, methods, and goals—but we cannot now reasonably anticipate such grand changes.

Technological Knowledge Decreases: Doom and Gloom Scenario (Martin Pasqualetti)

Despite the perception of a safer world that developed in the late 1980s, risks of calamity abound out of sight. As examples, no one yet knows the long-term results from continued emissions of carbon dioxide or chloroflourocarbons. Even a few-degree change in average world temperature will cause shifts in arable lands and populations. Flooding from glacial melting would inundate coastal areas now inhabited by billions of people. Increased cloudiness and temperature changes could profoundly change rainfall patterns. Any of these possibilities could induce increased population in the WIPP area, increasing drilling for minerals and water.

Of a greater degree of severity, the future may ironically hold disaster as a result of the use of nuclear power. The extraordinary precautions necessary for the development of nuclear power are so complex that future accidents are inevitable. Greater use of nuclear power may pollute the atmosphere and the biosphere, concentrating in the food chain all sorts of genetically-altering codes. This could result in loss of knowledge, abandonment of currently inhabited locations, and migration to less inhabited areas.

Other potential disasters loom in outer space. Asteroid collisions, unpredicted consequences of earth wobble, substantial fluctuations in the solar flux, interplanetary wars, and a multitude of other possibilities could bring about a reversal of present levels of knowledge and, with it, technological abilities to detect the WIPP repository before intrusion.

Any of these possibilities could reduce population greatly, but the opposite catalyst—population growth—could also have similar dire results. If there are no large-scale disasters and birth-control falters, then population could continue to increase at its current rate (somewhat under 2 percent per year), doubling worldwide in under 40 years. Population pressure, inadequate food resources, and other problems might move people into the area of the WIPP. Greater population pressure, especially when accompanied by partial or total loss of information from the past will result in greater risk of intrusion into the WIPP. In the event of such doom and gloom possibilities, markers must be designed for the most primitive understanding.

Decline and Rebuilding of Technological Knowledge: Seesaw Scenario (Kirkwood)

Scenario Script

Following the end of the cold war, active nuclear arms smuggling develops since these weapons are no longer as well controlled. Nuclear weapons are used in various regional conflicts, leading to increasing public opposition to nuclear energy in any form. In the Americas, the terror nukings of several cities and nuclear power plant disasters along the earthquake-prone "ring of fire" around the Pacific Basin lead to consistent election of antinuclear candidates.

In spite of opposition, the Waste Isolation Pilot Project repository goes into operation and is filled, closed, and marked.

The decline of nuclear power by itself does not lead to the decline of civilization, but there is also a persistent failure to develop a substitute for petroleum as an energy source. Energy becomes increasingly expensive. This, coupled with continuing worldwide crop failures following several releases of mutagenic substances, leads to a decline in worldwide standards of living. The world slips into its long slumber.

During the following centuries, church-related institutions maintain knowledge as they had during the Middle Ages. However, vernacular languages which had been relatively stable since standardization of spelling during the Eighteenth Century return to the more fluid patterns of the Middle Ages and before. Eventually, only a few church scholars can read the old books, and the meaning is obscured by unknown references.

The re-emergence of high technology is hindered by the lack of fossil fuels, since most of these had been mined or pumped out during the late Twentieth and early Twenty-First Centuries. Meanwhile, in the Middle East, climate changes brought on by the greenhouse effect lead to improved growing conditions. Later, as conditions return to pre-greenhouse status following the end of intensive use of fossil fuels, stable civilizations grow up around the irrigation systems that are developed to combat the decline in rainfall. A quest for better sources of power for the irrigation systems leads to the rediscovery of petroleum as a possible source of power. The political instabilities in the region during the late Oil Age had kept some of the oil from being pumped out, so oil-fueled power sources gradually re-emerge as the oil is exploited.

Travelers from North America return home from the Middle East with tales of the wonderful machines, and a search of old texts turns up directions on how to build these devices, but a lack of appropriate fuels limits development of the new technology in North America. Old records show that much oil drilling had been done in the Texas region, but all the oil seems to be gone in that area, so explorers turn their attention westward to the New Mexico region. Finally, in the spring of 5623 A. D. an oil exploration team comes upon the remains of an imposing artifact in Southeastern New Mexico.

"Perhaps they left it here to tell us that there is oil down below."

"Maybe there is danger. We should consult the church scholars to see if they know anything about this."

"Ah, you know these old artifacts—all rusted junk. Let's drill and find out if there is oil down there..."

Discussion of Scenario

The specific scenario given above for the decline and rebirth of technological civilization has some plausibility. In addition, there are a variety of other scenarios that can be developed for such a decline and rebirth. This topic has been a staple of science fiction for generations.

However, it is a little harder to generate a decline-and-rebirth scenario where dangers posed by the WIPP are not overshadowed by other dangers. What about all those nuclear weapons and nuclear reactors? Surely many more people are going to be killed by these than by the WIPP. In addition, most scenarios for a decline include many people dying from famine or disease.

Implications for Markers

It is reasonably straightforward to leave a marker that will be detected by a civilization that declines and then advances again. You probably don't have to worry about intruders coming at the site from underground or releasing autonomous mining machines in the area. A marker on the earth's surface that is big, long lasting, and not easy to destroy will do the job. The primary problem with a marker surviving is likely to be conscious attempts to destroy the marker during periods of "book burning."

A bigger problem is making a marker that conveys the appropriate message. Language is likely to be very fluid during a period of decline and rebirth. While there may be scholars around who still understand the ancient languages, it is not likely that they will be involved in mineral exploration. However, the comments in the last subsection are relevant—it is difficult to imagine decline-and-rebirth situations where there are not a lot of other nuclear materials around besides those in the WIPP. Unmistakable graphic references to the effects resulting from exposure to radioactivity may be sufficient to warn observers that this site is like others that are known to be dangerous.

Altered Political Control: The Free State of Chihuahua (Harry Otway)

This scenario, which is assumed to take place sometime within the next 1,000 years, illustrates a family of scenarios which have in common the alteration of political control over the WIPP site. Much of the detail provided is for dramatic effect; the scenario could equally well be imagined with different detail without changing its descriptive validity or its probability of occurrence appreciably.

The Scenario

The year is 2583. The past century has been one of political upheaval in what used to be known as the American Southwest. After centuries of wrangling about diverse interests, economic inequalities and political representation, the United States has fragmented into a cluster of smaller nation states. During this time period similar processes have affected the stability of Mexico, traditionally plagued by tensions between the relatively affluent North and centralized political control based in the South. Its northern provinces have formed the Free State of Chihuahua with its capital in Chihuahua City, "the jewel of the north."

The former states of New Mexico and Arizona, along with West Texas and southern Colorado, have had massive immigration from Mexico and Central America during the preceding centuries. They now have large Spanish-speaking, southward-looking majorities and, when both the United States and Mexico fragment within decades of each other, elect to join the Free State of Chihuahua. (Southern California and Baja California Norte, which differ substantially in historical and cultural traditions from the new Free State, form a separate, more technologically advanced nation.) The resulting political uncertainty leads to a large-scale exodus of Anglos, as well as many long-established Hispanic families, from the former U. S. territories. Accompanied by forces loyal to one or the other of the new U. S. countries, they practice a scorched earth policy, destroying most of the technological infrastructure, especially installations of potential military value, on the northern side of the former U. S./Mexico border. A similar process takes place in northern Mexico, with many of the intellectual elite from the universities of Monterrey and Tijuana migrating to join their counterparts in Mexico City. Diplomatic and trade relations between the young North American nation states and the Free State of Chihuahua are severed, and border skirmishes are frequent.

During the early centuries of the Third Millennium, the maquiladora industry had continued to grow in northern Mexico. This word, probably of Indian origin, emerged during the Spanish colonial days with respect to sharecropping practices, and now refers to the assembly of imported manufactured parts and their subsequent exportation. This industry flourished because of U. S. laws which taxed only the value added by assembly labor when finished products were imported back into the U. S. With increasing political instability in both the southwestern United States and Mexico, the maquiladora plants now lay idle, their semiskilled labor force unable to produce anything without a supply of prefabricated parts. The Free State of Chihuahua is left without an industrial base.

The Free State is also limited in terms of available natural resources. Most of Mexico's oil reserves are located in the South and are unavailable to the Free State. Although some natural gas reserves are found in Chihuahua, the technology for their distribution was damaged beyond repair in the turmoil. A similar fate has affected the coal reserves near Piedra Negra, where some coal is still mined, largely with hand tools, and distributed on a haphazard basis. The significant deposits of silver, copper, lead, and zinc are, in practice, unavailable because of the lack of technology and suitable energy supplies to mine and process them.

The demand for manufactured products of all kinds cannot be met by imports because of the Free State's lack of foreign exchange and poor credit rating. The Free State begins to evolve into a scavenger society, recovering, repairing, and reusing all available technical artifacts from earlier times. In a way reminiscent of the Soviet dismantling and appropriation of German industry after World War II, much of the Free State's intellectual resources are devoted to the location and recovery of usable articles, especially in the former U. S. territories, which had been inhabited by more highly developed technological societies and which are now constantly under the threat of invasion by the North American nation states.

While making excavations at the site of the former Sandia National Laboratories, Free State resource archaeologists discover references to the WIPP site which include photographs of waste barrels filled with abandoned tools, cables, and clothing. Fragmentary maps are also found, which allow the location of the site to be established. References to the radioactive nature of the waste are, however, not found during the excavation. In any case, knowledge of radiation is limited due to the discovery of better sources of energy during the Twenty-First Century.

Upon arriving at the WIPP site, Free State resource archaeologists find the remains of markers which indicate the location of the site without unambiguously transmitting the message that there is danger. There are two schools of thought. One is that there must be danger or else an extensive marker system would not have been erected. This school is overruled by one arguing that any danger would certainly not endure for over five hundred years and, furthermore, the site was more likely a primitive technological religious shrine where artifacts were deposited precisely for subsequent generations to find, similar to the Anglo custom of placing relics in cornerstones and time capsules. The value of the manufactured goods thought to be buried there carries the day and it is decided to enter.

To make a long story short, the WIPP site is intentionally mined by people unaware of the potential hazard, and all usable waste is exploited. During the mining operation, vessels containing transuranics are breached and contamination results.

A More Optimistic Variant

The political changes in the United States and Mexico are the same; however, the Free State of Chihuahua's liberation from the central controls of Mexico City releases the latent energies of the Northerners and stimulates a flowering of culture. Likewise, north of the former border, Mexican-American immigrants, having acquired American organizational and planning skills, join with the northern Mexican revolutionaries in a surge of Chihuahuan development.

The maquiladora industry has, in the meantime, been gradually converted into a full-scale manufacturing activity due to the introduction of enlightened management approaches. The Free State of Chihuahua has become a wealthy industrial power in its own right and the Technical University of Monterrey has become a world leader in developing advanced manufacturing techniques. Eager to document and define its cultural and technological heritage, the Free State sponsors extensive archaeological expeditions to record the achievements of the Northern Mexican-New Mexican culture. The WIPP site is only one of many excavated for classical archaeological reasons. As before, contamination results.

Discussion of Scenario

No nation in recent memory has survived for more than a few centuries. The trend is normally for large states to fragment into smaller ones. For example, consider the Austro-Hungarian Empire, which is today divided amongst at least nine smaller countries, or look at what is currently happening in the Soviet Union only seven decades after its inception. Union with northern Mexico is not critical to the scenario—one can visualize a variety of other ways for political control of the WIPP site to no longer to reside in Washington.

Interestingly enough, Borderland scholars with whom I have spoken (yes, there really *are* Borderland scholars!) consider a merger of Northern Mexico and the Hispanic American Southwest to be highly credible. In fact, they find fault only with the notion that it could take several hundred years for this to happen; they feel this is a possibility on a much shorter time scale, easily before the 125 years of active control of the WIPP site has elapsed. They see the present affiliation of the American Southwest with the United States as only a relatively short episode in its history when compared to its much longer relationship with Mexico-Spain. Further, they also recognize the possibility of Mexican political turmoil and feel that cultural ties could easily attract the two regions to each other, especially as the present Southwest continues its cultural shift as a result of ongoing immigration from the south.

Implications for Markers

This scenario requires the usual marker characteristics; that is, that they be passive, durable and easily decipherable by people who do not know English. Perhaps the one novel feature demonstrated here is that it would not be possible to do any required maintenance on the markers, for example, because relations between the Free State of Chihuahua and neighboring states have been ruptured.

Stasis: 10,000 Years of Solitude (Harry Otway and Gregory Benford)

While there are an almost infinite number of ways in which there could be inadvertent human intrusion into the WIPP site, the probability of any specified mode of intrusion is very small. The scenarios presented above are a non-random sample from a population of futures about which we know almost nothing. What is the meaning, then, of saying that their probabilities are very low?

As another approach to foreseeing what is possible, the scenario below looks at the likelihood that the WIPP site remains inviolate for 10,000 years. Understanding the message of this scenario requires some knowledge of elementary probability concepts. If a series of events are independent of each other, then the probability that all of the events will occur is the product of the probabilities of each event. For the WIPP site to remain inviolate, over the years a series of things must continue to "go right." The probability that any one of these things will go right is very high. However, ten thousand years is a long time ...

Suppose that the probability that any event will go right is 99.9 percent. If there are 100 of these events, the probability of them all going right is 90 percent. If there are 1000 of these events, the probability of all of them going right is 37 percent.

How many events must go right over 10,000 years for the WIPP site to remain inviolate?

The Scenario

The WIPP site goes into operation in 1995. It continues in operation for twenty-five years, although the increasing irrelevancy of nuclear weapons to national defense has caused a large reduction in the amount of intermediate-level military waste generated (probability = ?). This has made the WIPP site largely redundant by about 2007; it has been kept on a readiness-maintenance schedule since that time. It could likely have been closed without undue inconvenience except for the need to preserve political credibility by keeping it in operation in view of the confrontations that marred its opening.

At the end of its twenty-five years of operation in 2020, there is a spirited debate in Congress about its future. The first issue is the cost of site closure. To keep the site from being an attractive nuisance, the buildings and all other surface facilities must be razed and the rubble removed from the site. There are arguments made that, since the site has been largely inactive, the radioactive hazard is minimal, and the facilities might just as well be adapted to house the homeless, to use as overflow prisons, or to provide provisional quarters for the new University of the Saltlands. After some delay, funds for closing the site are appropriated (probability = ?).

The next issue is that of the markers. The markers recommended by a panel of experts convened by the now-defunct Department of Energy in 1990 are widely viewed as extravagant, especially in view of the fact that the WIPP repository has not been used to capacity and is such a controversial topic. It now seems unlikely that the site could ever be forgotten, its potential hazard is thought to be less than originally foreseen, and it seems politically dangerous to advocate large sums of money for it in view of the pressing current social problems which followed the costly conventional weapons buildup of the 1990s. After a protracted debate lasting several years, Congress finally appropriates money for markers (probability = ?), although design compromises must be made because it is not enough to pay for the extensive marker systems envisioned in 1990 (probability = ?).

[This brings us to the beginning of construction of the markers for the WIPP site, and we still have most of the 10,000 year planning period to go ...]

Discussion of Scenario

For the WIPP site to remain inviolate, many things must occur over the next 10,000 years. To consider the range of these, here are a few:

- There must be no unforeseen technological innovation which will make it simple and inexpensive to get into WIPP, and which could then fall into careless hands.
- There must be no major cultural shift which will affect the very way we view the problem of intrusion, transcending our (largely invisible to us) cultural biases, invalidating the assumptions of this document.
- There must arise no religious, cultist, or hobbyist group which fastens on ancient artifacts for nonscholarly reasons and blithely intrudes.
- There must be no unforeseen resources developed which make the WIPP neighborhood desirable. (Perhaps the salt itself?)
- There must be no irrational reason (hence unforeseeable) to drill randomly near the site.
- There must be no unsophisticated but capable archaeological interest in the site, perhaps occasioned by the markers themselves.
- Resource acquisition must not proceed to the point where human culture processes the upper several thousand feet of the earth's crust.

Estimating the probability of these "non-happenings" is difficult. Certainly, each of them has a high probability, but the product of many large probabilities can still be a small number.

4. Probabilities

> ...In summary, this body finds that in view of the low level of technological development in what was the Southwestern United States prior to the Fifty-First Century, there is no possibility that anything of worth or danger could have been buried at a depth greater than one thousand feet in that region prior to 4974. Records since that time are complete and document that there have been no deep burial activities in the region. Hence, valuable or dangerous antiquities pose absolutely no impediment to the proposed regional mile-deep strip mining project.
>
> —*Final Report of the Panel on Deep Strip Mining*
> (Subcommittee on Valuable Antiquities)
> January 17, 6432

This section estimates the probability of inadvertent intrusion into the WIPP repository. Figure 3 illustrates a probabilistic analysis based on the most relevant aspects of the Section 3 scenarios.

In our judgment, two elements of these scenarios most directly affect the likelihood of inadvertent intrusion: the nature of political control of the WIPP region and the pattern of future technological development in this region. Figure 3 shows the major possibilities for these two elements in a tree structure. Starting from the left side of this figure, political control is shown as either altering or remaining under the "U. S. Forever." Following these possibilities, branches show the primary technological development patterns: steady increase in technological knowledge, steady decline in technological knowledge, and a seesaw pattern where technological knowledge declines and then rebuilds. Finally, for each combination of political control and technological development, the rightmost branches of the tree show inadvertent intrusion either occurring or not over the next 10,000 years.

To complete a probabilistic analysis of the likelihood of inadvertent intrusion, an estimate is needed of the probability of each branch of this tree, given that all the events to the left of that branch occur. At the right of each path through this tree which leads to inadvertent intrusion, the probability for that path appears. This probability is the product of the probabilities of each branch along that path. The total probability of inadvertent intrusion is the sum of these path probabilities, which is approximately four percent.

Figure 3 illustrates the calculations for one possible set of probabilities. Note that with this set of probabilities, the conditional probability of inadvertent intrusion, given that the U. S. retains

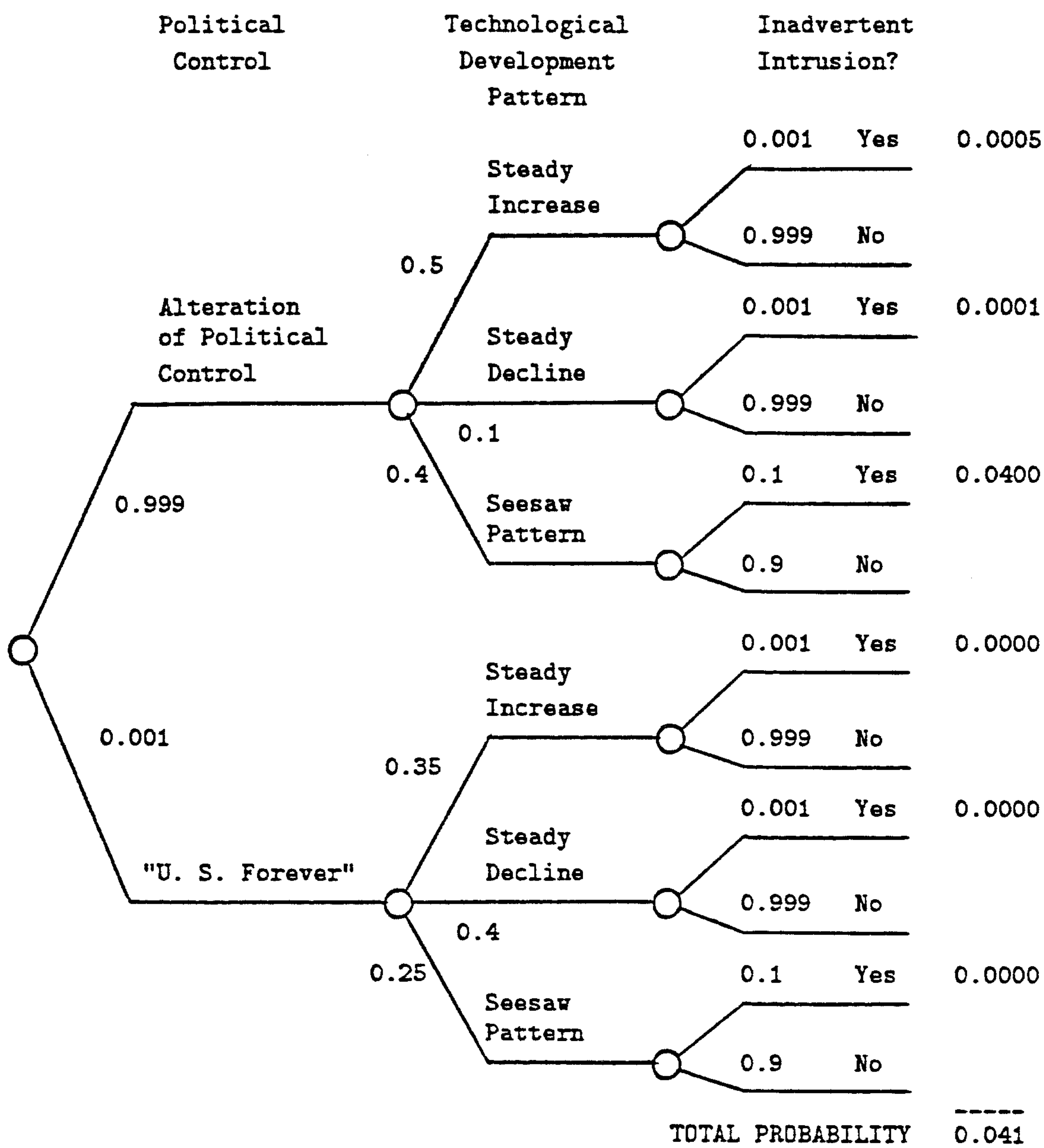

Figure 3. Probability of Inadvertent Intrusion

political control of the WIPP region forever, is $0.35 \times 0.001 + 0.4 \times 0.001 + 0.25 \times 0.1 = 0.026$ or about three percent. The conditional probability of inadvertent intrusion, given an alteration of political control, is $0.5 \times 0.001 + 0.1 \times 0.001 + 0.4 \times 0.1 = 0.041$ or about four percent. Thus, regardless of assumptions about political control of the region, the probability of inadvertent intrusion is a few percent.

The probabilities for all the branches of the tree in Figure 3 were elicited from each of the four authors by a decision analysis expert. The elicited probabilities are shown in Table 5. Part a of this table shows the consensus probabilities of the two possible states of political control for the four authors. Part b shows the probabilities for each of the three possible technological development patterns, conditional on the political control state, for each of the four authors (labeled "Set 1," "Set 2," "Set 3," and "Set 4."). Part c shows the probabilities of inadvertent intrusion, conditional on the state of political control and the technological development pattern. (Note that the illustrative probabilities in Figure 3 correspond to "Set 3" in Table 5.)

Using the numbers in Table 5, the overall probability of inadvertent intrusion for each of the sets of probabilities is as follows:

— Set 1: 0.030

— Set 2: 0.046

— Set 3: 0.041

— Set 4: 0.222

The analysis shows that a major risk of inadvertent intrusion comes from the seesaw scenario of technological decline and rebuilding. For this scenario, we can estimate the probability of drilling intrusion. The WIPP neighborhood (approximately 400 square miles) suffered roughly one drilling per year over the last century. Assuming random drilling, the WIPP apparent area of about half a square mile should then have a probability of about 0.001 per year of drilled intrusion. If over 10,000 years such eras occur a hundredth of the time—i.e., a century in all—then there is a one percent total probability. This is in general agreement with the probabilities shown in Table 5.

Taking both of the analyses presented in this section together, we conclude that the probability of inadvertent intrusion is a few percent.

Table 5
Probabilities for Inadvertent Intrusion Calculations

a. Probabilities for Political Control States

Probability Set	Political Control State	
	Alteration of Control	"U. S. Forever"
Consensus	0.999	0.001

b. Probabilities for Possible Technological Development Patterns, Conditional on the Political Control State

Probability Set	Technological Development Pattern		
	Steady Increase	Steady Decline	Seesaw Pattern
Political Control State: Alteration of Control			
Set 1	0.50	0.10	0.40
Set 2	0.60	0.05	0.35
Set 3	0.50	0.10	0.40
Set 4	0.30	0.10	0.60
Political Control State: "U. S. Forever"			
Set 1	0.67	0.13	0.20
Set 2	0.35	0.40	0.25
Set 3	0.35	0.40	0.25
Set 4	0.30	0.10	0.60

c. Probability of Inadvertent Intrusion, Conditional on the State of Political Control and the Technological Development Pattern

Probability Set	Technological Development Pattern		
	Steady Increase	Steady Decline	Seesaw Pattern
Political Control State: Alteration of Control			
Set 1	0.01	0.05	0.05
Set 2	0.01	0.10	0.10
Set 3	0.001	0.001	0.10
Set 4	0.06	0.30	0.30
Political Control State: "U. S. Forever"			
Set 1	0.01	0.05	0.05
Set 2	0.01	0.12	0.12
Set 3	0.001	0.001	0.10
Set 4	0.02	0.10	0.10

An Important Note on Deep-Future Consequences

It is crucial to recognize that we must free our thinking from Twentieth Century notions of consequences when considering inadvertent intrusion over the next 10,000 years. It would be surprising indeed if 120th Century drilling rigs were still drilling Twentieth Century three-and-a-half-inch bore holes. It is thinkable that a 120th Century rig would be able to excavate the entire WIPP site in, say, a day or in any case well before its operating crew was able to comprehend what it had done.

In short, the consequences of an inadvertent intrusion in the "deep future" are likely to be incomparably greater than those of a present-day intrusion.

5. Conclusions and Recommendations

> WIPP (hwĭp), *n.* [prob.<Eng. ***whip*** in reference to ancient religious flagellation rites] Ancient 18th century A. D. (approx.) underground religious shrine in honor of the salt goddess. Care with which the facility was aligned vertically within the salt stratum, precise geometric layout, and inclusion of valuable transuranics show the esteem accorded the salt goddess. (*Note*: Some authorities believe the shrine layout is a stylized image of a mythic sea monster in reference to the salt in the oceans.)
>
> —Encyclopedia Solarus
> 7615 A. X. Edition

An earlier comment bears repeating: The scenarios above are not meant to be ***exhaustive*** but rather ***representative*** of the range of situations that markers at the WIPP must address. There are a variety of noncredible scenarios that we have not addressed; e.g., if a civilization uses black holes, antigravity, or teleportion in their mining operations, then the radioactivity of the WIPP will probably not give them much trouble.

Conclusions

1. It is our consensus that

the probability of inadvertent intrusion into the WIPP repository over the next ten thousand years lies between one and twenty-five percent.

Other subsidiary conclusions are

2. Inadvertent intrusion from directions other than above the WIPP is credible. Inadvertent intrusion is possible from any spatial direction.
3. Great changes in society are likely. In particular, the loss of political control by the United States government as we now know it seems certain.
4. Knowledge of radiation dangers could decline. Thus, WIPP intruders may fail to fathom the threat or correctly interpret markers.
5. Changes in population density could affect the probability of inadvertent intrusion: Population increase could lead to land/resource use pressures, or population decrease could lead to a decline in local memory of the WIPP.
6. Better desalting techniques will probably arise, leading to greater water availability near the WIPP site.
7. Substances found in the area of the WIPP site, for example magnesium, are likely to become resources of value, especially if political changes result in a landlocked nation.
8. Inadvertent intrusion by persons unable to understand any present language is credible.

Recommendations

Marker Recommendations

1. **Range of markers.** Erect a wide range of markers which are detectable at a distance from the WIPP.
2. **Variety of Media.** Encode information about the site in a variety of media.
3. **Wide information dispersal.** Disperse information about the WIPP widely to libraries and other information repositories.
4. **Spherical marker strategy.** Stress a "spherical marker strategy" which deploys markers apparent from above, beside, and below the WIPP facility.
5. **Broad sensorium.** Include passive markers obvious to acoustic, magnetic, and radioactivity detectors. Consider detection by a non-human, technological sensorium. The markers must provide disincentives to drill or explore.
6. **No-marker strategy?** Consider a "no surface marker" strategy, or a "soft" marker which erodes in a few centuries, to meet short-term marking needs. Hidden markers could still be placed underground. This avoids attracting curiosity seekers, yet the hidden markers below can warn off high technological societies. The risk lies in the Seesaw Scenario, since wildcatters in a reviving era receive no warning at all.

Marker Development Process Recommendations

7. **Overlap and continuity.** Establish a standing group devoted both to further scenario analysis and to marker development. Membership of this group should emphasize continuity, starting with overlap between the Inadvertent Intrusion Panel and the Marker Panel, so that ideas need not be reinvented. The group should make continuing recommendations based on the evolution of the WIPP, political constraints, and results of further scenario refinement.
8. **Panel diversity.** Assure that the marker development team includes individuals with a wide variety of cultural/ethnic backgrounds, with particular emphasis on Hispanic cultures.
9. **Independent review.** Establish a regular review process by independent researchers to review the work of the marker development effort.
10. **To Mark or Not To Mark**

    The crucial decision confronting the Marker Panel is whether to use surface markers at all. A "soft" surface marker which erodes in a few centuries will cover the short-term possibilities, and then avoid curiosity seekers in the far future. High technologies will still be able to sense the buried markers.

    Much of the Egyptian legacy came from King Tut's tomb, the only major unviolated burial site. It was covered by the tailings of a later tomb. Unmarked, it escaped the grave robbers.

    But not marking the WIPP imposes ignorance on our descendants, who may wish to avoid the site but could no longer locate it well. Also, low-tech wildcatters in re-emergent technological societies would have no warning.

    This raises serious ethical issues which the Marker Panel should consider and document.

APPENDIX E:
WASHINGTON A TEAM REPORT

Duane Chapman (The World Bank, Cornell University)
Victor Ferkiss (Georgetown University)
Dan Reicher (Natural Resources Defense Council)
Theodore Taylor (Consultant)

INADVERTENT INTRUSION INTO THE WIPP REPOSITORY:
REPORT OF WASHINGTON AREA TEAM A
TO THE SANDIA NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

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INTRODUCTION

This is a report to the Sandia National Laboratory by Washington Area Team A of the Expert Judgment Panel. The Expert Judgment Panel was convened by the Sandia National Laboratory in August, 1990 to analyze the likelihood of inadvertent human intrusion into the Waste Isolation Pilot Plant (WIPP) in New Mexico. WIPP is a geologic repository developed by the U.S. Department of Energy for the disposal of defense transuranic waste.

Sandia National Laboratory divided the Panel's sixteen members into four teams, each of which separately analyzed the issue of inadvertent human intrusion. This is the report of Washington Area Team A which consisted of Duane Chapman, a resource economist, Victor Ferkiss, a political scientist, Dan Reicher, an environmental attorney, and Theodore Taylor, a nuclear physicist.

The report is divided into five sections: (1) Definition of Human Intrusion; (2) Factors Affecting the Likelihood of Human Intrusion; 3) Mineral resources at the WIPP Site; (4) Four Scenarios for Future Societies; and (5) Recommendations. The fourth section contains a case study that attempts to quantify the likelihood of inadvertent human intrusion into the WIPP site for natural gas exploration and extraction.

The exclusive focus of this analysis is on the possibilities for inadvertent intrusion in the WIPP repository. The results of this effort should not be taken to reflect the authors' individual or collective views concerning the wisdom or efficacy of proceeding with current plans for use of the WIPP facility or for continued production of transuranic wastes by the U.S. government or industry.

A. Definition of Human Intrusion

Inadvertent human intrusion occurs when the integrity of the WIPP repository is unintentionally compromised by the actions of humans in the vicinity of the repository in such a manner that may result in a release of radioactivity to the accessible environment. Inadvertent human intrusion may occur when individuals are unaware of the presence of the buried radioactive waste and undertake actions which disturb it. It may also occur when individuals, although aware of the waste and not intending to disturb it, undertake actions which accidentally result in its disturbance. Individuals may disturb the waste directly by physically impinging on it through, for example, drilling or excavation. Individuals may also disturb the waste indirectly through off-site actions which affect the hydrology or geology of the site, for example withdrawal wells or explosions.

B. Factors Affecting the Likelihood of Human Intrusion

There are several important factors that will determine the likelihood of inadvertent human intrusion in future societies. These include: (1) whether a society has sufficient information about the existence of the WIPP wastes and their danger to avoid intrusion; (2) whether a society has the technical ability to disturb the waste; and (3) the degree to which a society interacts directly or indirectly with the WIPP site.

1. Sufficiency of Information

There are many reasons a future society may not have sufficient information to avoid intruding on the WIPP site.

a. Inadequate Records

All records, including site markers, may have been destroyed by violent action -- war, terrorism, natural disasters or by more discriminate action aimed at obliterating the historical record of human accumulations of wastes. Future societies may also destroy records to clear repositories of information no longer considered worth preserving. Records may also physically deteriorate or be obscured to a point where their message value is lost.

Records may exist in future societies but the information they contain may not have been recorded in an accurate and/or complete fashion. Also, a future society may attempt to reconstruct records from fragmentary information or personal recollections but the information derived may be inaccurate or incomplete.

It should be noted that in the absence of adequate records, future societies might still have the ability to learn, by non-intrusive means, that materials are emplaced and that they are radioactive, assuming geologic and radiologic monitoring capabilities continue to advance. On the other hand, this may well be a capability beyond the reach of many future societies.

A related issue is whether a future society with the ability to detect deeply buried radioactive wastes non-intrusively also understands that they are dangerous. A future society with the technical ability to detect the radioactive materials at great depths may well have an appreciation of their potential health impacts. On the other hand, one can envision the evolution of a technologically advanced society which neither engages in nor has knowledge of nuclear fission and its hazardous byproducts. Detecting the presence of the buried material might arouse substantial curiosity in such a society; but lacking an understanding of the dangers posed, individuals might be put at substantial risk if they intrude.

b. <u>Records Exist But Are Not Accessible to Intruders</u>

In a future society there may be no effective method for distributing information to the population with the potential for intruding. This may be a function of technical inadequacies in information distribution systems. In our own society, for example, gas pipelines are struck frequently in construction despite the existence of detailed information and numerous markers. Segments of a future society may also withhold records from another segment of society that has control over operations in the vicinity of WIPP. For example, those who hold the information may be "foreign" and antagonistic towards those who may potentially intrude.

c. Records Are Accessible But Not Understood

The languages and symbols used in WIPP records may be meaningless to the intruders and they may have no access to "interpreters." Alternatively, the languages/symbols may be understood but the concepts referred to are unfamiliar, e.g. nuclear radiation and radiation damage. Additionally, the sensory apparatus of the intruders could be inappropriate for interpreting the content of the records, e.g. the intruders are blind, deaf or communicate by senses not familiar to present humans.

d. Records Are Accessible and Understood But Ignored

In a future society the hazards of intrusion may not be considered significant, e.g. the intruders know how to prevent or easily cure the biological effects of radiation. Other hazards facing the intruders' society may also be considered much more important, e.g. residual radiation from fallout from nuclear war, starvation or severe shortage of fresh water. The future society might also routinely deal with such large quantities of radioactive materials that any increment represented by the WIPP inventory is considered relatively small. And in some future societies death or illness may not be considered particularly undesirable, either because it is so prevalent that it is generally accepted, or because human attitudes towards death and illness have changed drastically from those of the present.

e. Records Are Accessible and Understood but Information is Lacking Regarding the Effects of Nearby Activities

Future societies may undertake activities in the WIPP region without adequate information about their potential effects on WIPP. These activities include, for example, large-scale mining, water withdrawal, or explosions.

2. Ability to Intrude

Assuming records, markers or newly developed information are not sufficient to warn potential intruders, the next issue is whether a future society has the technical capability to disturb the waste. Clearly, one can envision societies where the ability to disturb the waste is lacking. On the other hand, for many decades our present society has had the ability to intrude directly on material at the depth WIPP waste would be buried. For a similar period of time, society has also had the ability to disturb material buried at the WIPP depth by indirect means, e.g. water withdrawal or explosions.

3. <u>Interactions with the WIPP Site</u>

Assuming that sufficient knowledge of the WIPP wastes does not exist and that a society has the ability to intrude (directly or indirectly), it becomes important to determine the degree to which individuals in a future society may interact in some way with the WIPP site. There are many possible interactions. They may be generally divided into two categories: interactions based upon resources at or near the site and interactions based on the location of the site.

Resource interactions include human activities that impinge upon the site or its vicinity because something of value to a particular society exists there. For example, a future society might be interested in economic resources such as potash, oil, gas, water, magnesium, or salt. A society might also be interested in the site surface or subsurface for development (e.g. solar power production), storage of resources (e.g. petroleum in the salt deposit) or waste disposal (e.g. underground injection). A society might also be motivated by the potential for archaeological resources, either connected with the waste facility itself or some earlier or later cultural remain.

The other set of interactions include human activities that impinge upon the site simply because of its location. For example, a society might develop a dam, drill a field of wells, set off large explosions or engage in some other substantial off-site activity that affects the geohydrology of the WIPP site.

Even if they were aware of WIPP's existence and nature -- but especially if they were not -- such activities undertaken elsewhere in the region could have the effect of altering the composition and dynamics of the area of WIPP to such an extent as to release its contents into the environment. A future society might also happen to drill or tunnel horizontally through the site in locating a resource pipeline or some other conveyance.

C. Mineral Resources at the WIPP Site

In terms of potential economic value, the principal mineral resources below the controlled area of the WIPP site (about 80 square kilometers) are contained in the bedded salt. The bedded salt contains a variety of industrially useful chemical elements in soluble forms: the bulk salt itself, without further chemical processing; high concentrations (greater than 10,000 ppm) of chlorine, sodium, magnesium, potassium, calcium, and sulfur; and much smaller concentrations of many other elements. With some important differences in relative concentration of various elements, the WIPP area salt resembles the dissolved materials in seawater, but at an overall mass concentration that is about 30 times that in seawater (typically about 3% dissolved substances). In addition to these particular mineral resources in the bedded salt, there are potentially exploitable reserves of oil and natural gas beneath the salt layer.

Table I indicates the estimated total resources represented by various minerals under the WIPP controlled area. These resources are given in terms of estimated total quantities, the current average U.S. prices per unit of each material, and the aggregate current market value of total estimated inventories of each material after extraction and purification. The estimated quantities are taken from presentations to the WIPP Expert Judgment Panel at the August, 1990 meetings in Albuquerque. The estimated unit market values are from the 1989 edition of the Statistical Abstract of the United States and communications with the Chemical Manufacturers' Association in Washington, D.C. They indicate that the Salado formation in which the WIPP facility has been developed may be an attractive potential source of industrially important chemicals such as magnesium and chlorine. This, of course, would depend on production costs and profitability.

The quantities of gypsum, bulk salt, magnesium, chlorine, and potash are extremely large compared with present U.S. (and world) annual consumption rates. See Table I. The quantities of crude oil and natural gas, in contrast, correspond to less than one year's present U.S. consumption. Present U.S. annual consumption of metallic magnesium, for example, is only about 300,000 metric tons, less than 1/20,000 of the magnesium in the bedded salt in the WIPP controlled area.

Since the quantity and potential value of the magnesium in the WIPP region bedded salt are large, we give it special, albeit preliminary, consideration below. We first compare the bedded salt, especially in the Salado formation, with seawater as a

TABLE 1 - MINERAL RESOURCES WITHIN WIPP CONTROLLED AREA

Mineral*	Quantity	Present U.S. Unit Market Value After Processing	Total Potential Market Value (Billions of $)
Gypsum	1.3 billion tons	$7/Ton	9.1
Salt	200 billion tons	$18/Ton (Bulk Salt)	3,600
Magnesium	8-20 billion tons	$3,000/Ton (Metal)	24,000 - 60,000
Chlorine	120 billion tons	$100/Ton (Gas or HCl)	12,000
Potash	480 million tons	$120/Ton	60
Crude Oil	37.5 million barrels	$40/Barrel	1.5
Natural Gas	490 billion cu. ft.	$3/1,000 cu. ft.	1.5

* Note: There may be other mineral resources within the WIPP controlled area that could become economically important in the future.

source of magnesium. If we assume that the material composition of the bedded salt is similar to the composition of dissolved solids in brine from the contact zone in the vicinity of WIPP, the mass fraction of the salt that is magnesium is in the vicinity of 0.06 to 0.20. This corresponds to 60 to 200 kilograms of magnesium per ton of salt. For comparison, a ton of seawater contains about 1.3 kilograms of magnesium. In both cases, the concentrated compound containing the magnesium is principally magnesium chloride (MgCl2).

Extraction of magnesium from seawater first requires separation of the magnesium from the sodium chloride. This is generally done by adding sodium hydroxide to precipitate out the magnesium as magnesium hydroxide. Once filtered, it is treated with hydrochloric acid to convert it back to soluble magnesium chloride. The magnesium chloride is then electrolyzed to produce metallic magnesium and gaseous chlorine (which can be an important byproduct).

The electrical energy consumed by electrolysis corresponds to about 10 kilowatt hours per kilogram of magnesium metal extracted, assuming an overall efficiency of 70%. At $0.05/kw.hr. electric power cost, this corresponds to about $0.50 per kilogram of magnesium. This is about 1/6 the current average market value. This strongly suggests that other stages in the magnesium production process, such as precipitating the magnesium hydroxide from relatively dilute seawater, account for larger fractions of the total cost than does electricity, even if a substantial fraction of the price is profit. We have not, however, carried out a detailed analysis of the various steps in the process.

The electrolysis energy needed would presumably be the same if the magnesium is extracted from bedded salt instead of seawater. Separating the magnesium from the other soluble compounds in bedded salt could make use of the same methods used for seawater, but using much more concentrated solutions. In both cases, an interesting possibility is use of partial freezing of the saturated liquid to precipitate physically separable ice and different compounds by careful control of temperatures at which the freezing occurs. This would be somewhat analogous to fractional distillation for chemical separation. We have not investigated this option in any detail.

An interesting possibility for supplying the needed electrolytic energy at the WIPP location is to use low-cost, amorphous silicon solar electric cells to supply the needed low voltage direct current electric power. This source could also meet other needs for electrical process energy, such as driving compressors for partial freezing of the concentrated brine. The annual average insolation at the surface of the WIPP site is about 249 watts per square meter. This is less than 10% lower than the regions of the U.S. with the highest insolation, such as Yuma, Arizona. An assumed electrical conversion efficiency of 25% corresponds to an annual average electric power output of 60 watts per square meter. This is sufficient for electrolysis to produce about 10 kilograms of metallic magnesium per year. If about 10% of the 80 square kilometer control area of the WIPP site were devoted to such cells, the resulting annual average power of about 1,000 megawatts could produce the total amount of magnesium consumed in the U.S. today.

Cost of mining the bedded salt should be relatively small, compared with the value of the contained magnesium. For a bulk magnesium concentration of the salt of 80 kilograms per ton, for example, the market value of the extracted magnesium would be $240/ton of salt. At a salt density twice that of water, this would correspond to about $500 per cubic meter of salt. This value is at least an order of magnitude greater than the cost of deep mining of other resources, such as coal. Therefore the mining should not be a major contributor to the overall economics of producing magnesium metal.

To summarize, mineral resources at the WIPP location may be important to societies that control the area in the future. There are large deposits of highly concentrated chemicals (both metal and non-metals) that are of industrial importance.

D. Four Scenarios for Future Societies

In the following section we describe four scenarios (with associated subscenarios) for human activity over the next ten thousand years with particular relevance to the WIPP site and the likelihood of human intrusion. Scenarios I through III all involve population growth equal or greater than the current rate and substantial resource extraction activities. Under these scenarios the natural environment is viewed principally as a source of materials and energy to be manipulated in ways that help meet human demands. Scenario IV involves a population that is stable or declining and a more or less steady-state natural resource base as a result of conservation, efficiency, recycling and increased reliance on renewable energy supplies. Under this scenario the natural environment is treated as a complex system that will sustain human life only to the extent that the system's overall integrity is maintained.

The four scenarios are as follows:

- I. "Continuity"
- II. "Radical Increase"
- III. "Discontinuity"
- IV. "Steady-State Resources"

The future need not necessarily follow any particular scenario. It might shift among the scenarios presented -- and many others -- and such shifts might happen several times in the next several thousand years. Any of the scenarios could develop in the near future -- before the end of the next century.

The potential modes of intrusion are similar among the four scenarios. They focus primarily on: (1) drilling or digging for resources (potash, gas, oil, magnesium, water etc.); and (2) off-site activities (often resource-related) with hydrologic or geologic impacts (water withdrawal, explosions etc.).

Scenario I -- "Continuity"

In Scenario I society continues much as at present, with a value system which postulates that the resources of the earth exist to be developed by man as soon and as completely as possible with relatively little respect paid to environmental constraints. It also assumes roughly the current level of extractive technology, the current rate of population growth both from natural increase and immigration, and the current rate of resource consumption per capita.

Under such a scenario it would be likely that some kind of intrusion would take place at the WIPP site within a few generations most likely related to resource extraction. Such an intrusion would probably be, strictly speaking, inadvertent; the inadvertence resulting from inadequate transmission of site information, or from a mistaken belief that the resources -- gas, potash, water, etc. -- could be extracted without damaging its integrity. This scenario also involves sub-scenarios in which activity of a hydrologic or seismic nature takes place -- for whatever reason -- at a distance from the WIPP site which results in an altering of the current dynamics of the site and release of radioactivity into the environment. These off-site activities are themselves likely to be resource-related.

Some of these sub-scenarios require that knowledge about the WIPP site has been effectively lost. Should societal continuity be maintained it is obvious that all knowledge about WIPP cannot perish, records will most likely exist somewhere in some form. The real issue is whether, given the vast amount of information available in any future epoch, whoever undertakes the on-site or off-site activity will be aware of the information about WIPP in a timely fashion. The question is not one of technical information retrieval possibilities, but of societal-bureaucratic availability. These are not the same thing.

The mere existence of information is not enough. It must be easily retrievable by those who need it. Over the course of hundreds and thousands of years all sorts of information will come to be stored in the world's computerized memory banks in almost infinite magnitude. But what is to guarantee that the relevant information about WIPP will be in the grasp of those who might be in a position to violate its integrity at the moment intrusion might take place? It is quite possible that despite the vast technical capacities for information retrieval available, sheer information overload compounded by human inadequacies might allow intrusion to take place.

The time at which such intrusion might take place would be in turn dependent on the variable of the world position of the United States. If one starts with the assumption that present values remain dominant in the United States and the developed world generally, America's world position becomes important. If the American polity remains militarily and economically dominant in the world, the hunger for resources might well be satisfied by the exploitation of resources outside the American continent. If, as seems somewhat more likely, America's world debt position continues to worsen, it will be under greater pressure to utilize all the physical resources available domestically including, in time, those of southern New Mexico. Current advocacy of new oil drilling in Alaska and offshore because of the Persian Gulf crisis indicates nation what would take place. It would of course be exacerbated by large scale foreign ownership of relevant American corporations.

A CASE STUDY REGARDING NATURAL GAS

This case study develops from the motivation to define one of the more possible examples of intrusion in the "Continuity" Scenario, and to evaluate the probability associated with it. Natural gas exists in commercial quantities in the region at depths below the 2100 foot WIPP level.[1] Production is current, and 1029 exploration and development wells were drilled in the 69 years commencing in 1919.[2] There are two major types of economic factors that influence drilling rates.

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1 From Robert Guzowski, "An Overview of the Natural Resources at the Waste Isolation Pilot Plant," section 4 in Sandia National Laboratories, Expert Judgement on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant, Background Papers, Aug. 13-15, 1990, Albuquerque, New Mexico, and personal communications, R. Guzowski, Sep. 1990.

2 Ibid.

The first is expected profitability, and the second is the existence of a natural gas system that can use the output from a particular well. This latter factor reflects the time horizon for use of the remaining stock of natural gas. In other words, a well could have the same production cost parameters in 2200 as in 2199, but if the gas pipeline system closes in 2200, the well's gas couldn't be sold.

A rough figure for the expected time horizon of natural gas use might be about 200 years. This is based upon dividing possible world remaining natural gas resources of 7 quadrillion cubic feet by annual world consumption of 50 trillion feet and rounding upward.[3] A similar calculation for remaining U.S. resources results in a figure of 43 years for the U.S.[4] (These figures include geological extrapolation as well as proven reserves). To emphasize risk, we assume that the U.S. will maintain its natural gas system with imports for some time after domestic resources become inadequate to meet domestic demand. The implication is that gas drilling in the WIPP region for pipeline use could go on for as long as 200 years. For localized on-site use the time horizon could be longer.

The rate of drilling and its expected profitability has many influences. On the demand side, rising population and income will increase gas demand. In addition, pollution problems

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[3] Duane Chapman, Energy Resources and Energy Corporations, Cornell University Press, 1983, p.155.

[4] Data from Mast et al, discussed in Guzowski.

associated with coal and oil will further increase gas demand. Finally, rising oil prices will also increase natural gas demand, and raise natural gas price and profitability. For this case in the continuity scenario, we assume that the price-driven drilling rate over time would be parabolic, peaking at twice the historical average and declining to zero in 200 years.[5]

Actual drilling in the WIPP area could not take place unless security collapses, and also knowledge about the danger of drilling is lost. The security decay problem can be represented as a linear relationship, beginning at zero in 1990 and slowly growing to 0.1 after 200 years. Loss of knowledge about the WIPP hazard is conditional on security collapse, and will be assumed to be 0.5.

The physical size of the contaminated area is an important determinant of the probability of any given WIPP area gas well contacting nuclear waste. We assume the original size will be .5 square kilometers, and is spreading on both horizontal dimensions at two meters per year.[6] The resultant probability curve of inadvertent intrusion peaks at .0003192 in year 2131 and declines to zero by year 2190. The sum of probabilities over the full 200 years is .035 (3.5%). <u>See</u> Graph I. Since this case assumes that no drilling for gas in the WIPP region will occur after world

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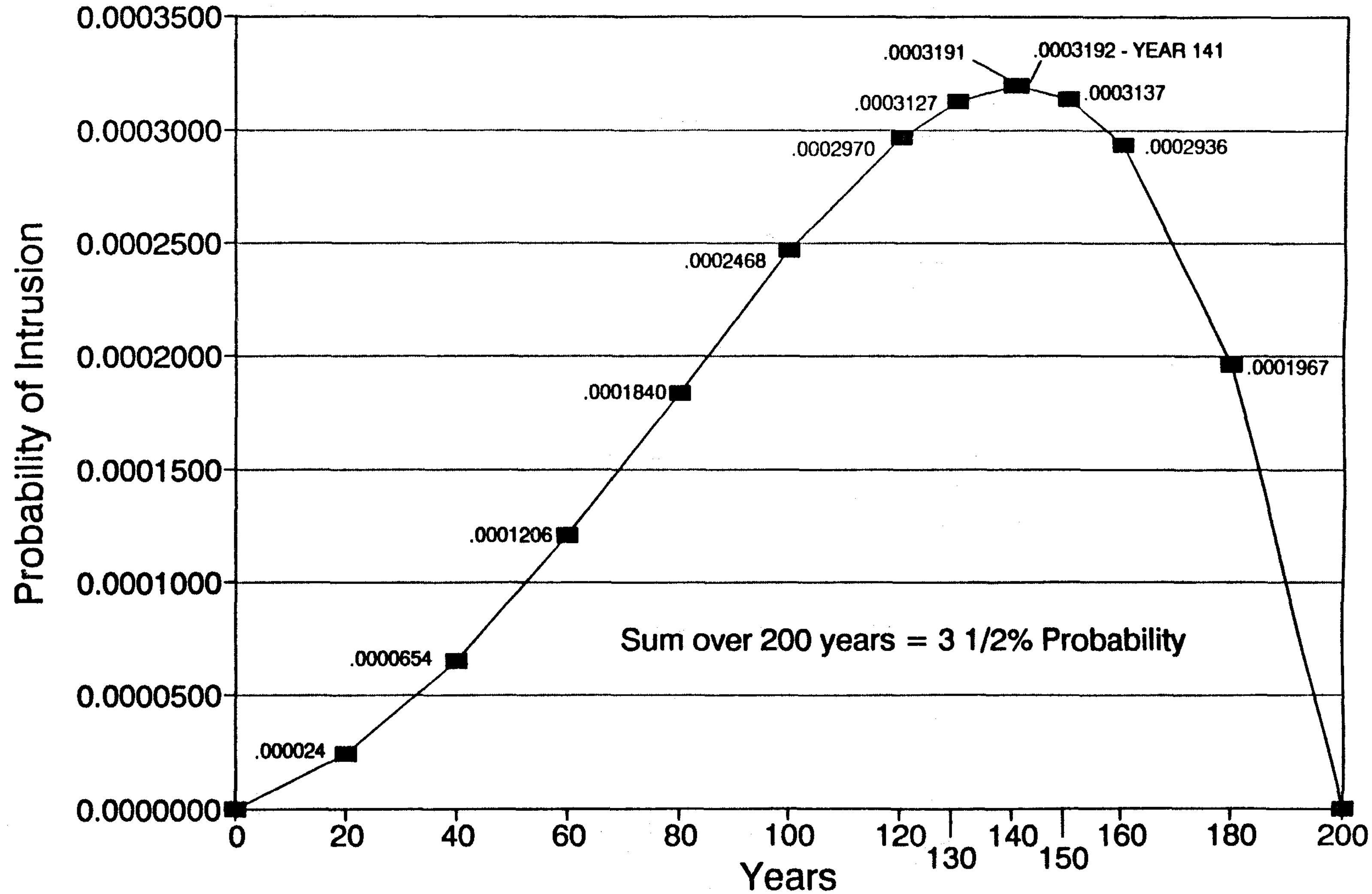
[5] PROB = .006*(1+.025t-.00015t**2)/sq km/y. This is for drilling probability. The other probabilities are PROB[security collapse] = t/10,000; and PROB[knowledge loss] = .5.

[6] Panel size (in square kilometers) = ((707+2t)**2)/1,000,000.

GRAPH I

Illustration of Annual Probability of Inadvertant Human Intrusion Natural Gas Case Study



natural gas is exhausted, the probability of intrusion over 10,000 years is also .035.

If security collapse probability is 0 in 1990 and rises linearly to 1 by 200 years, the end of natural gas pipeline use, then the probability of intrusion defined in this case is .35. For comparison, if security collapse is immediate, the probability of intrusion is .71 even though the probabilities for individual years vary over a much lower range between 0 and .005.

A policy implication is that plans should be made to continue physical security at the site for as long as natural gas production is profitable, or at least 200 years.

Scenario II - "Radical Increase"

Scenario II -- "Radical Increase" -- postulates a massive increase in the current willingness to use all the earth's resources for human material needs, and a major increase in our technological ability to do so. It makes the same assumptions about population growth as in Scenario I. Under this scenario the possibility of accidental intrusion increases as agents are both more eager to get at whatever resources exist and more confident of their ability to do so safely.

Scenario II could lead, in less than 100 years, to a world in which stresses among humans and with our habitat become extreme. At the present global average rate of growth of nearly 2% per year, the world population would increase about seven times in the next 100 years, and 50 times in 200 years. The corresponding growth in the demands for raw materials needed to achieve and sustain a real per capita economic growth rate of 2% per year would be 50 times present consumption in 100 years, and more than 2000 in 200 years. It is therefore obvious that the likelihood of human intrusion under this scenario is greater than under the other three scenarios discussed.

This scenario also includes the possibility that excavation and drilling technology has progressed greatly and that the activities of such machines may be considered human intrusion. In such a case the possibility of accidental intrusion would be greater than at present for two reasons: (1) the use of machines presumably not subject to the same hazards from contact with radiation as human beings would increase the willingness of drillers to take risks; (2) the existence of such technology may lead to overconfidence in the ability of their human directors to employ them without accident. As seen in events such as the Hubble Telescope and the Challenger such confidence is not always well-founded.

Pressure to exploit resources would of course be increased if either population increased at a faster rate than at present or the amount of resources consumed per capita increased. Such an increase in per capita resource demand could result from either a desire on the part of the present economic upper class to consume more, or, logically, from a greater equalization in the American economy which made increased resource extraction on behalf of those now less well off a priority.

Scenario III -- "Radical Discontinuity"

Scenario III -- "Radical Discontinuity" -- is more complicated, and has several sub-scenarios. While throughout human history the human species as a whole has evolved in the general direction of greater ability to manipulate its environment, decline and disruption on the regional level has occurred relatively frequently. Many civilizations have simply perished due to internal or external causes, notably the Aztecs, Maya, Incas, Roman empire, Mohenjo-Daro, ancient Babylon etc. Their descendants have lived at lower levels of technology, social order and culture. Discontinuity is a fact of human life, and modern technology with its vast powers to affect not only human society but the physical environment itself promises greater and more rapid changes than in the past. Therefore in planning for the future security of WIPP we must be aware that almost any simple linear scenario is extremely precarious and our ability to assess probabilities is very limited.

In the first sub-scenario of Scenario III a major war takes place (nuclear or otherwise) which leads to a regression in civilization and a loss of knowledge about WIPP and its nature. The war is likely to be fought over control of material and energy resources and living space with a reduction in global population. But civilization rebuilds and resumes a pattern of technological advance, population growth, and resource exploitation similar to our own. In such a scenario direct or indirect intrusion into WIPP may be just a matter of time.

In another sub-scenario, political changes over a period of generations lead to an erosion of conditions in southern New Mexico so that it comes to resemble a current Third World country, with complete cessation of the authority of the Federal government. This might be the result of a simple collapse of national government generally, with radical decentralization of political power.

Alternatively, it could involve the disintegration of the current United States with New Mexico either becoming an independent nation or, perhaps joining a segment of northern Mexico in a new nation-state of, for example, "Nuevo Sonora" after a dissolution of the current Republic of Mexico. Although knowledge about WIPP might exist somewhere in the world, it is ignored at the site and intrusion based on resource hunger takes place. In such a scenario the probability of rapid population increase is high both because such growth is a general feature of Third World cultures and large scale immigration from the rest of the hemisphere, especially southern Mexico, is likely. Such growth would of course increase pressures to explore and exploit WIPP resources.

Scenario IV -- "Steady-State Resources"

Scenario IV -- "Steady-State Resources" --involves a future in which current attitudes toward the control of nature through technology have been radically altered, at least as far as whatever political and economic entity controlling the WIPP site is concerned. Growth for growth's sake, regardless of the ecological consequences, has been repudiated as a dominant societal ideal. Something like a "steady-state" economy exists, and renewable forms of energy (solar, wind etc.) predominate. In this scenario, population is stable or is actually decreasing to some degree.

Scenario IV is characterized by substantial harmony among humans and with their environment. It could, however, include a wide diversity of societies, each pursuing activities of interest to them in a relatively peaceful manner. The world population remains small enough to avoid any serious material or energy stresses on the regional or global environments. Development emphasizes opening up new choices to individuals and societies rather than acquisition of goods.

More and more people argue persuasively that zero (or slightly negative) world and regional population growth within less than 100 years is a necessary condition for the overall well being of humans. At the same time, a shift to recycling of nearly all waste materials now looks technically and economically possible within a few generations. Note that an increase of 3% per year in the fraction of all material wastes that are recycled would reduce the need for raw materials, for a constant rate of production of new goods, by a factor of about 20 in 100 years.

Under such a scenario there would be little pressure to drill for gas or oil at or near the WIPP site, and almost certainly less interest in other possible resources. As long as such values prevailed, the likelihood of inadvertent intrusion at WIPP would be minimized.

The change in values inherent in Scenario IV itself involves two sub-scenarios. In one sub-scenario, the conversion occurs in our current civilization or one in direct continuity with it, and knowledge of the site exists. In the other sub-scenario radical discontinuity takes place -- whether as a result of war or other developments -- and it is a successor civilization in which the new values prevail. In either case it would not be necessary for knowledge of WIPP and its significance to continue to exist for the site to be relatively secure. Such a nature-friendly rather than nature-hostile society would almost by definition be less likely to engage in the geology or hydrology-disturbing activities dealt with in other scenarios.

Other Scenarios

More scenarios can of course be logically generated than are discussed here. But all of them would only affect our basic inquiry into the extent and intensity of humanity's propensity to impinge upon the WIPP site and its environs for reasons of resources or location. For example, should significant human economic activity occur in space, it could take the form of exploiting minerals found on the moon and in the asteroids. Such minerals could be used for the earth economy or in support of space activities themselves. Under such a scenario the technology for further earth exploitation which might imperil WIPP would certainly be available, and knowledge of its existence and significance might or might not exist in useful form. But while it would imply a civilization dedicated to maximum utilization of nature, it could also mean a situation in which it was cheaper economically to use the materials derived from space than to further exploit New Mexico. In either case, the danger to WIPP would still be a function of the total human hunger for its resources at a given time, and the extent of socially effective knowledge of the wastes and their danger.

Given the nature of the site and nearby territory, little motivation for traditional conventional archeology exists in light of the paucity of indigenous Indian cultural material. However, the site might excite the curiosity of those concerned with the past of our industrial civilization, and would be in some limited sense advertent, presupposing that there was something down there. Paradoxically, markers with ineffective messages or incomplete or incomprehensible records could pique the curiosity of future generations leading to truly inadvertent intrusion.

Most other scenarios are variants of the four basic ones outlined above in terms of a continuum of degree of human desire and capability of exploiting the planet for human gain. This being the case, it would seem that protecting the WIPP site against inadvertent intrusion is less dependent upon such factors as the kind of marking system which is decided upon, as it is upon the attitudes and values which future human societies have toward the use of technology to exploit nature for human material gain.

An associated issue is the degree to which society believes that continued overall growth in the total human population is desirable. Just as WIPP would not exist in the first place were it not for certain human perceptions about desirable forms of military technology and the nature of the international order, its integrity in the future depends upon human society's perceptions about desirable forms of economic and population growth and social order. We cannot of course change the past and make the material to be stored in the site vanish -- though we can of course decide not to generate further transuranic waste -- but we can do something to discourage societal attitudes which threaten its integrity and affect the possibility of accidental human intrusion.

E. Recommendations

Based on our analysis, we propose the following actions to help decrease the likelihood of unintended human intrusion into the WIPP facility:

1. Establish and maintain a global inventory of accumulated potentially hazardous waste products of human activity. The principal purpose of such a project would be to assure that detailed knowledge of the locations, contents and

quantities of hazardous waste accumulations throughout the world are assembled, securely preserved, and made widely accessible for the foreseeable future. This is necessary to assure that future generations, throughout the world, can be fully aware of the locations and content of all significant accumulations of hazardous waste materials when considering the great variety of possible future options for human development. It would specifically reduce the chances of unintended intrusion in the WIPP by providing an overall context within which unintended intrusion into <u>any</u> significant hazardous waste accumulations becomes less likely.

The overall project would require international participation, perhaps coordinated by an agency of the United Nations. Among the numerous types of waste accumulations that should be included in the inventory would be sites with radioactive wastes from nuclear energy generation and nuclear weapons production and testing, mining residues, hazardous waste landfills, injection wells, areas of contaminant migration and fallout, and marine locations where hazardous waste concentrations have not been diluted to insignificant levels.

2. Initiate detailed studies of productive and environmentally responsible long-term activities that could be established on the surface above the WIPP disposal region to reduce the chances of unintended intrusion. One especially interesting possibility is a facility for using solar electric cells to produce hydrogen by electrolysis of water. This could

provide a fairly short term, as well as very long term substitute for natural gas as a fuel.[7]

3. Develop a program which emphasizes the significance of physical security to prevent natural gas exploration or production and other resource exploitation on the site for a minimum of 200 years. There should be considerable effort involved in developing an advanced educational standard and sufficient wages to attract capable and stable persons for security positions.

4. Consider the security force problem in the context of the overall nuclear waste management responsibilities for the U.S. and perhaps even internationally. There are similar security problems related to all forms of nuclear waste. The future security of the WIPP site should not be considered in isolation.

5. Give the lay and expert public substantial opportunity to participate in the analysis and decisionmaking regarding human intrusion. Human intrusion is emerging as one of the most difficult challenges facing the WIPP project. Public support for the decisions eventually made about use of the facility will be reduced if analysis and debate regarding the intrusion issue is limited.

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7 See Ogden, J. et al, "Solar Hydrogen," World Resources Institute, 1989.

APPENDIX F:
WASHINGTON B TEAM REPORT

Theodore Glickman (Resources for the Future)
Max Singer (The Potomac Organization)
Norman Rosenberg (Resources for the Future)
Maris Vinovskis (University of Michigan)

THE REPORT OF THE WASHINGTON AREA SECOND TEAM ON
FUTURE INADVERTENT HUMAN INTRUSION INTO THE WIPP REPOSITORY

Final Version

1.0 Introduction

This report reflects the efforts made by the Second Washington Area Team to respond to the issues put forth by Sandia National Laboratories regarding the potential for future inadvertent human intrusion into the WIPP repository. The team consists of a risk analyst, a futurist, a climatologist and a historian. We met several times in Albuquerque and twice thereafter in Washington to discuss the issues and exchange ideas. The results of our efforts are documented below, beginning with a description of the methodology for structuring the analysis, followed by background discussions of three important determinants of the future states of society: (1) economic and technological developments, (2) the influence of soil, climate and water factors, and (3) the occurrence of catastrophes. Then, based on these ideas, we present our views of the most reasonable scenarios for the future states of society. The final section describes how these outcomes might combine with other major influences on the possibility that an inadvertent human intrusion would occur within 10,000 years, culminating in our views as to which combinations of eventualities are most likely to result in such an intrusion.

2.0 Methodology (Theodore Glickman)

Our approach to identifying the possible inadvertent human intrusions into the WIPP repository and assigning associated probabilities relies on what we call the "SLAM Model" of human intrusion, a conceptual framework in which the probability of any such intrusion, which we call an "intrusion event," is a function of four random variables, as represented by the following notation:

S = the future state of society, local and worldwide

L = the level of awareness about the repository hazard

A = the conduct of a potentially intrusive human activity

M = the mode of inadvertent intrusion into the repository

The associated probability relationship of interest is then:

$$P(SLAM) = P(S) \times P(L|S) \times P(A|SL) \times P(M|SLA).$$

In other words, the overall probability of any particular intrusion event, as characterized by a particular combination of possibilities for the four variables, is the product of four individual probabilities: (1) the probability of the state of society; (2) the conditional probability of the level of awareness about the hazard, given the state of society; (3) the conditional probability of the potentially intrusive activity, given the combination of state of society and level of awareness; and (4) the conditional probability of the mode of intrusion, given the combination of state of society, level of awareness, and activity.

Hence, we looked upon our task as one of postulating the set of most reasonable possibilities for each of the variables S, L, A and M, and making a judgment of the corresponding probability or conditional probability of each of these possibilities. All other possibilities are lumped together as alternatives which we considered to be relatively implausible. When the probabilities we assign to the possibilities for the various outcomes of these variables are ultimately combined (i.e., multiplied) to produce the associated joint probabilities, the result will be a probability distribution for the possible intrusion events.

Recognizing that the possible outcomes for the four variables and their corresponding probabilities depend on what point in the future is being considered, we established two aggregate time periods, which we refer to as the near future (0-200 years) and the far future (200-10,000 years). Thus, when we refer to the probability of an intrusion event, we mean the probability that it occurs once at any point in the time period of interest. Originally, we had divided the future into three periods, with the far future having two parts, one ranging from 200 to 1,000 years and the other ranging from 1,000 to 10,000 years. However, when we found our probability assignments to be the same in each of these two parts, we combined them into one period.

3.0 Background

3.1 Economic and Technological Developments (Max Singer)

To consider the possibility of inadvertent intrusion into the WIPP we need to consider both the societies that will be living in the area and general worldwide societies of the future. Over a period of 10,000 years --50 times longer than the history of the U.S.--we must assume that there is a possibility that for some periods of time the WIPP area will be occupied by societies that are not part of the U.S. Therefore the characteristics of the society occupying the WIPP area are not necessarily those either of the U.S. or the worldwide average. The people in the WIPP area could be either substantially more or substantially less "advanced" than the world in general, and they certainly could be different or special in various ways.

The two general parameters that are of most importance for thinking about the possibility of human intrusion into the WIPP are the levels of wealth (and/or income) and of technical development of the WIPP area societies, and of world-as-a-whole societies. These two parameters are partially related. Wealth is both a cause and a result of technology. However, since technology can flow through the world, a society may have more advanced technology than it is rich enough to develop for itself. (That is why poor countries today have higher life expectancies than the U.S. did when it was at the same income level.) The two parameters, wealth and technology, are also similar in a deeper way. They both are essentially measures of knowledge. Income is primarily the effect of productivity, and productivity is mostly the result of the society's, and the individual's understanding of how to work effectively. (Tangible and intangible capital are also important to wealth, but these are the both the result of past productivity.) One of the most profound and illuminating ways of understanding the process of economic development -- including the increasing wealth of the most advanced countries -- is to think of it as a community learning process. ("Learning" is used partly metaphorically, to mean not only rational learning, but also developing community attitudes, mores etc., which are analogical to individual psychological and emotional factors.)

Obviously the increase in level of technology is also a learning process. Scientific understanding and technological state of the art advance by rational accumulation of understanding and invention. The practical application of science and technology through society depends also on economics and on less rational factors. But it is not unreasonable to think of the advance of technology within a society also as a community learning experience. Any learning process has a strong tendency to be cumulative. It can slow down or stop, but it is relatively hard to make it go backwards. And of course over long periods it is highly likely to increase. Going backwards implies that the community has "unlearned" what it once knew. Of course a country can suffer economic set-backs without going backward to a lower level of understanding. For example, an economy that is heavily dependent on trade, especially the export of raw materials, can be badly hurt if the terms of trade turn against it. Or capital stock can be destroyed by war.

These examples show that income level is not solely a function of the community's understanding of how to be productive. Comparisons with societies that have risen and fallen through most of human history are of limited applicability. Until the last century there has never been a society with as much long-term, widely spread, growth of wealth and technology as there has been in many countries during the last two centuries. (I.e., a few countries beginning at the end of the 18th century, more during the 19th century, many having begun in this century, and a few barely begun even today.) But even within this period there have been societies where economic growth has stopped, or even gone back somewhat. Nevertheless, apart from wars, no society that has developed very far (say to $3,000 per capita) has ever gone back half way to the level all human societies lived at before 1800 (less than $500 per capita).

Furthermore, the experience with societies after wars shows that it is much quicker and easier for a society to regain a previous level of wealth than it was to get there the first time. This is very consistent with the metaphor of wealth as the result of learning. Both parameters, wealth and technology have strong -- but not absolute -- tendency to be like ratchets, that is to have much stronger resistance to going down than to going up. There are many forces in a society that prevent it from losing wealth and having income decline very far. And these resistances to decline are much stronger for large groups of societies, or the whole world, than they are for any individual society.

If one thinks about level of technology the low probability of substantial decline is even more apparent. Here we have to emphasize the difference between the most advanced science and technology and the average level, or the level in any particular society. For the world as a whole the highest level of science and technology is the level in the most advanced society. If all the advanced societies except one suddenly fall to a lower level the highest level in the world doesn't fall at all. Therefore it is very hard to make scenarios in which the level of science and technology, measured by what is known somewhere, falls substantially. If some time in the future, through war or decadence, most societies have a severe decline, the most advanced science and technology will be preserved in the one or few countries that are not victims of the widespread decline. Later, when the societies that fell apart put themselves together, they will not have to invent all over again the science and technology that they once had. They will be able to learn it from the societies in which advanced science and technology was kept alive.

The same pattern holds for economic productivity -- but more weakly. A community can lose its understanding of how to be productive, but it probably takes three generations for the loss not to be relatively quickly recoverable. The level of technology in the society and in the world will influence the ability to drill holes into the WIPP and also the ability to limit harm from intrusion into the radioactive material. Level of technology and wealth will also influence the raw material demand that might drive decisions to drill holes in the WIPP area. Wealth will also strongly influence the safety practices that drillers who penetrate the WIPP might use. People act as if safety is what economists call a luxury good, that is, something that people spend more on as they become wealthier. Drillers from a wealthy, technically advanced society are more likely to discover radiation releases from an inadvertent penetration of the WIPP than drillers from a poor, less advanced society. And drillers in a more advanced society are likely to be able to protect themselves and others from radioactive material, both that in the hole and that which has been brought to the surface. (It is even possible that future societies will be very much less threatened by radiation because they may have discovered medical methods of controlling cancer.)

The expected level of income of the society in the WIPP area, at the 95% probability point, can conservatively be assumed to be $5,000 per capita (1990 $). In other words, for any intrusion throughout the next 10,000 years there is less than one chance in twenty (at most a fairly low probability) that the society making the intrusion will have a per capita income of less than $5,000. During the next five or six centuries, if the WIPP area is not part of the U.S. or of a society which has substantial continuity with the U.S. society, there is a reasonable chance that it could be occupied by a society with an income of less than $5,000. After about 2600 the probability that $5,000 is the minimum is dominated by the high worldwide average income.

Worldwide average per capita income since it is now lower than that of the society occupying the WIPP area (the U.S.) should be estimated lower for the next few centuries. But there will be a crossover point, after which the 95% probability minimum for the world will be higher than that for the WIPP area. The reason for this is that the variability among societies in the world will be greater than the fluctuation of world average income. At any point during the next 10,000 years it is reasonably likely that some society will have an average income of only 10% of the world average. On the other hand, while average world income may decline for some periods, it is relatively unlikely to decline by a factor of ten. Therefore the 95% probability minimum worldwide average per capita income can conservatively be taken as $2,000 until 2100 and as twice as high in each subsequent century until it reaches $50,000, probably before 2600. Subsequently it will become less and less likely that worldwide average income is less than $50,000, and less and less likely that the society in the WIPP area is less than $5,000.

If there are rejectionist communities (that is communities who reject the modern wealthy world and choose some kind of more primitive (simple) life style) that separate themselves from more advanced states, the WIPP area is the kind of place that these communities might be allowed to keep for themselves. On the other hand, it is much more likely that the WIPP area will be occupied by people whose living standards are typical of the world as a whole. And even if the WIPP area is occupied by a poor rejectionist community, the richer part of the world will have the power to come into the WIPP area.

To project the future of world wealth three judgments must be made: how long will the most wealthy societies choose to continue to increase their wealth? how long will it take the major share of people to cross the threshold to modern levels of living standards -- say $3,000 (1990) per capita? what will be the long term ratio between the richest countries and those at the 75th or 80th percentile? (The question of the income level of the poorest 10 or 20 per cent of people is a special kind of problem which does not have much effect on the overall wealth of the world.) The richest countries are now at the level of roughly $20,000 per capita. It is clear that the mass of people in these societies have many unsatisfied desires for things that can be purchased, and that they are willing to work to be able to have higher incomes. Most of the richest countries are growing at about the rate of 2%/year/capita. It seems fairly low probability that these countries will lose interest in increasing their average wealth before another two doublings. At recent rates this would take about 70 years. If the rate is cut in half, two more doublings will take 140 years. In any event, it is a high probability that the richest 10 or 20 percent of the world will reach average income levels of $60,000 to $100,000 early in the period of interest.

The next question is what will happen to the nations with the mass of the population -- primarily China and India. That middle 60% of the world will finish crossing the threshold to historic wealth, that is to modern life, say a minimum per capita income of $3,000, probably by 2100, possibly decades sooner, almost certainly not as much as a century later. It is hard to see why this great mass that will be in the $3,000 - $6,000 per capita range in about 2100 would not grow reasonably steadily until they reach substantially higher levels. "Steadily" does not mean that each country would grow monotonically, or that they would all move in parallel. But the average should increase at least 1% year over terms of 50 or 100 years. The best bet is probably 2% average growth rates. The best way to predict the end point for the growth of the mass of countries is probably to guess the ratio between the GNP per capita of the top 10% and the third quartile.

Over a 10,000 year period the 90% probability range for the GNP/capita of the richest countries is $100,000 to $1,000,000. (At 1/2% per year it takes much less than 1,000 years to go from 100,000 to 1,000,000.) The 90% probability range for the long-term ratio of richest 10% to third quartile countries seems likely to be 2 to 5. That is, when the richest countries stop growing, it seems unlikely that the third quartile will stop growing while it is more than 5 times as poor. If the top 10% of countries stabilize at say $250,000 per capita, and the third quartile stabilizes at say $80,000, worldwide per capita income would be about $120,000. This is about 40 times higher than today. At 1%/yr it would take about 400 years to reach this level.

Of course even if average income levels in the world stabilize, individual countries may have rising or falling income at any time.

Therefore it is highly conservative to think that for most of the next 10,000 years average incomes for the people of the world will be in excess of $100,000 per year.

What is the meaning of such high average incomes? Does the meaning we currently attach to the idea of an income of $250,000 have any relation to the meaning such incomes will have when they are very common? In many ways it is impossible to know, or even to speculate intelligently. However there are some aspects of future life for which we can make reasonably confident predictions.

The spike of high world population growth rates that began in the 17th century, and went as high as 2% year, will end in the 21st century with world population about 10 - 15 billion people, some twenty times as many as when the spike began. Subsequently world population may grow or decline or fluctuate. If population begins to grow, even slowly, it can reach very high levels well within 10,000 years. At only 1/10 per cent growth per year it would grow from 10 to 100 billion in only 2,300 years. So at the same very low average rate, world population could grow to 1,000 billion people less than half-way through the period we are considering.

We can ask how much population growth would there have to be to fundamentally change the character of life from what it is in advanced societies today. The answer is that a population of 100 billion would probably not require fundamental changes. That is, human food could be grown in familiar ways; cities would not have to be more dense than we see today. The biggest change would have to be that most people would be living in cities. But the great majority of habitable land could still be outside of the cities. There could be immense wilderness areas and a very large amount of park land.

On the other hand it is difficult to speculate about the character of life if there were 1,000 billion people living on Earth. Life expectancy is a very important parameter affecting the quality and character of life. Through most of history almost all humans lived in communities where life expectancy was below 30. Today there are a number of countries where life expectancy is in the middle 70s, and world-wide life expectancy is now over 60. Without a change in the basic physical characteristics of the human species, life expectancy can not be increased above about 85. It is reasonably likely that this level will be approached on a world-wide basis in the 22d century. Changes above and beyond that can only be speculative

-- and probably depend on changing a number of genes. It is not unreasonable to expect that life expectancy, even 10,000 years from now, will not so greatly exceed 85 that we would perceive that the character of human life had changed from that in advanced countries today. (Although it is clear that the character of human life has changed in societies where life expectancy is now well over 70 instead of under 30.

In the future, as is true today in advanced society, people will spend the great majority of their time thinking about human creations like commerce, politics, science, entertainment, war, crime, sports, etc. They will not, like the people of the previous 10,000 years, spend the majority of their time on concerns about nature.

A number of economic characteristics of the future can be predicted with reasonable confidence. First of all, human time will continue to become more valuable. This is a fundamental variable that affects almost all aspects of life and the economy. Hourly wages and annual salaries will rise more or less proportionately to GNP/capita. Goods and services requiring personal service or individual attention from people are likely to continue to become relatively more expensive. Time-saving and convenience will continue to become more and more important.

On the other hand it is very likely that the number of hours that people have to work to pay for the raw materials used in their food will continue to decline. Food taken from the ground is likely to require a very small percent of human effort. Similarly for raw materials other than fuels. It is very unlikely that people will spend as much as 5% of their effort taking raw materials (other than energy) from the ground. Even today the United States spends less than 3% of its effort getting raw materials (other than fuel) from the ground. And this share has been declining since modern economic growth began. Of course there is no way of knowing whether this decline will continue. However it is very difficult -- with world population in the range of 10 to 100 billion -- to imagine conditions such that 10% of GWP had to be spent getting non-fuel raw materials from the ground.

It is possible that energy costs will rise. It seems reasonably likely that between 10% and 40% of GWP will be spend on providing primary energy supplies. With a population of less than 100 billion people, solar energy is probably capable of providing the energy required at acceptable costs. However it is possible that other energy sources will be preferable for some substantial share of the energy. And solar energy might not be sufficient for populations substantially in excess of 100 billion.

There is a good chance that natural gas will be at least as valuable as it is today, or more valuable. Through human history the average person had at most a few years of school. Today the world wide average may be about 6-10 years of schooling for 25-year-olds. In the U.S. the average now is about 12. It seems reasonably plausible that as average incomes world-wide rise to $50,000, average years of schooling will rise to perhaps about 16. It may well be that education will continue to occupy more and more time even after 16 years of school for young people becomes standard. But it is quite possible that further growth of education will not be in the form of more years of schooling. Measures of amount of education are likely to have to become more complex.

Almost certainly the amount of living space per household will increase greatly from current levels. Even in the U.S. the average today is only about 1,700 square feet, and world-wide the average is much less. One major use of the very high incomes discussed above is likely to be substantial increase in living space per person.

While we cannot know what technology will bring, it seems safe to predict that people will be able to afford much greater travel, at higher speeds, than today. Even more overwhelming will be the amount of information that will be available to people and the convenience with which they will be able to get it. Perhaps the most important area of "technical" development is what might be called information selection. That is, we will have the power to get masses of information (for work or for play), the problem will be to know what is available and what we want. In other words indexing, cataloging, and organizing information are critical.

Perhaps we can have some reasonable feel -- on the basis of experience and some imagination -- for life at the level of $100,000 per capita income (i.e., average family incomes of $250,000 per year). But if people choose to work enough to raise levels of income much higher than that it is hard to imagine the nature of their lives or of economies.

At some point, perhaps quite early, it seems likely that people will choose to work less, or to combine work and pleasure more by choosing not the work that brings the most income but that which is most satisfying. This may be the principal way in which economic growth comes to an end.

During their lifetime people's time is divided among dependency, education, work, and retirement. Both the number of years spent working, and the average number of hours per year worked, may now be peaking in a country like Korea today where there is a 59 hour average work week. This gives a maximum of say 150,000 hours of work in a lifetime. In a very rich world people may average more like 40,000 hours of paid work during their lifetimes. For a person who live 85 years this is only 6% of his time. On the other hand people may spend almost as much time on education during their life as they do on work.

Here are some of the other indicators that could shed some light on the quality and nature of life. The per cent of people killed by wars each year. The per cent of people killed by their government each year. (During this century more people have been killed by their government than by war.) Also the number of people living in free countries governing themselves (as measured, for example, by Freedom House). This number was low throughout history. It has recently been about 1/3 of the world population. There is reason to think that it can continue to grow, but it might not.

Another dimension of life could be measured by lives lost, or workdays lost, because of air pollution. Or the per cent of tree cover in the world. Or the per cent of the world covered by parks or wilderness. Or the per cent of people/days spent in natural parks or the equivalent.

Another variable in scenarios of the distant future is the condition of government. Certainly we cannot assume that the nation-state system in its current form will continue for most or all of the next 10,000 years. But what can we say about what will come next?

In most places people now have about five levels of government. For example, someone may be governed primarily by the Town of Somerset, Montgomery County, the State of Maryland, the U.S.A., and the U.N. The first and the last of these are much less significant. Someone who lived in a small city might have an extra level of government. One principal variable is the way in which authority and loyalty are spread over these approximately 5 or 6 levels of government, and over other governmental units with overlapping and cross-cutting authorities and responsibilities.

But we should be interested not only in what governments there are and how responsibility and authority is divided among them. Another key issue is how power is divided between people and all governments. How many people live in freedom? How and how much does government influence the economy? How much are people's emotions engaged in political and governmental matters?

3.2 Soil, Climate and Water Factors (Norman Rosenberg)

The density of the population in the WIPP area will in some way be related to the risks of inadvertent intrusion -- more people in the vicinity, a greater likelihood of mischief-making. Even if that presumption is not fully defensible one can still argue that more people in the area increases the seriousness of any intrusion into the WIPP that results in the release of radionuclides. The physiography, soils, climate and water resources of southeastern New Mexico are not currently conducive to the growth of populous human settlements for the following reasons: (1) while it has some charm for the lover of arid lands, the scenery is not likely to draw large numbers of settlers or retirees or unless people somehow change their views of what constitutes natural beauty; (2) the productive potential of the soils is currently quite limited; (3) the climate is semi-arid and permits only the grazing of cattle; (4) supplies of water for human and animal needs are very limited. Items 2, 3 and 4 are discussed below in greater detail.

3.2.1 Soils

Soils in the WIPP region have been mapped in surveys of Eddy County, in which the site is located, and of adjacent Lea County, as belonging to the Berino, Pajarito, Kermit and Maljamar series. Of these, Maljamar and Kermit describe the situation quite well. Maljamar is a soil formed in wind-deposited sandy loams and sands on uplands. Slopes are 0-3%. Vegetation is of mid-height and tall grasses. The soils are well drained and have a sandy clay loam subsoil. Indurated caliche is at a depth of 40 to 60 inches. The Kermit soil series is described as deep light-colored, non-calcareous, excessively drained loose sands. The surface is undulating to billowy and stabilized dune sands rise 3 to 15 feet or more. Most fines have been winnowed out and blown away. This soil material resists weathering. Dunes are stabilized by Havard oak and mesquite.

Sands are SiO_2 and coated with Fe_2O_3, which amounts to no more than 0.2% of their total mass. Prof. Harold Dregne of Texas Tech University, a noted authority on arid lands, believes that a 25% or greater increase in precipitation would be required to significantly increase the vegetative cover on the soils of the WIPP region (personal communication. Sept. 5, 1990). Certain other soils in the region are gypsiferous. It would take a 50% increase in precipitation over a long period of time to wash enough gypsum out of the solum before the productivity of these soils would increase notably. Further, Professor Dregne believes that even a sharp decline in precipitation would not change the landscape in the WIPP area greatly. Aridity sufficient to kill the mesquite would be required before the sands would begin to blow again. In the near term that seems unlikely but the prospect of such aridity cannot be ignored in our analysis.

3.2.2 Climate

The climate of the WIPP area is semi-arid. Average annual precipitation is in the 12 to 14 inch range. As is typical in such regions the interannual variability in precipitation is great. The rainfall regime is monsoonal and peak amounts are received in summer.

3.2.3 Water Supply

The prospects for an alteration in the status of locally available supplies of water suitable for domestic and stock-watering needs are unclear. Water encountered in exploratory drillings in and near the WIPP site are for the most part extremely brackish and could be made potable only at extreme cost by currently available desalinization techniques. (Some wells--H7, 8, and 9--produce water with TDS considerably less than that of sea water. As to whether this water would be treatable or potable without treatment needs to be clarified).

There are some perched water tables in the WIPP area. A question worthy of exploration is this: in the event of increased precipitation (induced by greenhouse warming or natural climate change) would water tend to accumulate in the region through storage in perched water tables? Peter Swift of TECH REPS Inc. feels that this question cannot be answered without dedicated experiments that have not yet been considered (personal communication, Sept 6, 1990). Observation made under dry conditions are unreliable in Karst topography for predicting permeability and flow under wet conditions. There does exist the possibility that if precipitation were to increase, significant quantities of runoff water could be ponded on the surface. In Swift's opinion the caliche found in the WIPP area could be used as a base for such ponds if a lining of clay is applied.

3.2.4 Related Technological Changes

A number of technological changes could occur that might alter the prospects for the WIPP region. If the need exists at any time in the future to intensify use of the land in the WIPP area, and if economics so justify, technologies will probably be developed to let it happen. Relevant technologies already in development or readily foreseeable include:

For soils and crops

- -- enrichment of sandy soils with sewage sludge and other municipal or industrial wastes
- -- drought resistance bred into crops and forages by conventional means or by biotechnology
- -- nitrogen-fixation capacity in non-leguminous plants by conventional means or by biotechnology
- -- disease and insect resistance by conventional means or by biotechnology
- -- introduction of new xerophytic species
- -- breeding or discovery of crops irrigable with brackish water

For climate amelioration

- -- advertent weather modification by cloud seeding, albedo modification, or construction of large scale controlled climate facilities

For improved water supply

- -- importation of water during years of excess from adjacent regions for storage in large underground aquifers, natural or constructed
- -- construction of dams and other impoundments where surface topography is appropriate
- -- desalinization of locally extractable brackish waters

3.3 Catastrophic Events (Maris Vinovskis)

3.3.1 Total Global Disasters

There are several scenarios in which a total global disaster (every human dying) might occur, but they all have an extremely low probability of occurring in the next 10,000 years. Runaway global warming might destroy the human race; very large meteors might strike the earth and wreck total havoc with the living environment; unknown diseases might prove fatal to all human beings; and extra-terrestrial invaders might systematically destroy all human beings.

If a total global catastrophe were to occur, we would not have to worry about unintentional human intrusions at the WIPP site because everyone would already be dead by definition. Therefore, while a total global catastrophe is a logical, though not a very probable, scenario, we do not need to devote much attention to its occurrence or impact on the WIPP site.

3.3.2 Massive Global Catastrophes

We have defined a massive global catastrophe as a situation where at least 50 percent of humans perish within a short time, but enough survive to continue the human race. Among the ways in which this might occur are (1) global nuclear war; (2) almost runaway global warming; (3) volcanic eruptions leading to long- term cooling; (4) large-scale meteoric activity; (5) spread of unknown deadly diseases; or (6) extra-terrestrial attack.

Of the six different paths to a massive global catastrophe, the most likely one is a global nuclear war in which massive amounts of radiation are released as well as enough dust to cause a nuclear winter. Our group felt that there was a very low to low probability of such an occurrence in the near future and a low to fairly low probability of it happening in the far future. With the proliferation of nuclear weapons among smaller nations as well as the likelihood of continued warfare in the future, we would not be very surprised by a major global nuclear war in the next 10,000 years. (Although there is only a low probability that such a war would kill half of the world population.)

An almost runaway global warming might occur--particularly in the nearest period as we struggle to understand its causes and consequences without necessarily having the political will or scientific knowledge to prevent it. Over time the likelihood of a massive global catastrophe due to an almost runaway warming will probably diminish as we become more knowledgeable about its causes and prevention. Thus, in the nearest period the likelihood of an almost runaway global warming is very low to low and in the farthest period it becomes very low.

A third source of a massive global catastrophe is volcanic eruptions which would deposit sufficient dust in the atmosphere to lead to long-term cooling (Bullard, 1984). The largest eruption in recent history of the Tambora Volcano lead to a "year without a summer" for parts of the world, but only had a limited long-term impact (Lamb, 1970). While volcanic activity of the magnitude to alter seriously the long-term climate of the globe may have occurred in the distant past, the group felt there was only a very low probability that it would happen in the next 10,000 years.

Another potential cause of massive global catastrophe is a shower of meteors which would devastate the earth and lead to a cosmic winter. Some scholars argue that ancient civilizations like the Myceneans disappeared because of the climatic aftermath of such a massive meteor shower over 3000 years ago (Clube & Napier, 1990). Certainly this may have occurred in the past, but again the group felt that there is a very low probability of such a shower of meteors during the coming 10,000 years.

A fifth possible source of massive devastation of human life is the spread of some currently unknown form of deadly disease. Experimentation with biotechnology might create such as disease (Nosal & Coppel, 1989; Zilinskas & Zimmerman, 1986) or it may evolve naturally among humans (Culliton, 1990). There is speculation that human decadence itself might contribute to the development and spread of such a disease. Perhaps space vehicles returning to the earth might inadvertently bring a new form of deadly disease. The group felt that the probability of the introduction of some new, deadly disease which would destroy at least 50 percent of humans had a very low probability for both time periods.

Finally, there is the remote possibility that the earth will be subjected to an extra-terrestrial attack which would kill a large proportion of the human population. The group assigned a very low probability to such a development over the next 10,000 years.

3.3.3 Post-Catastrophic Disruption of Civilization

One of the more interesting questions is whether civilization as we now know it would be terminated by any of the massive global scenarios we have outlined (for the purposes of our discussion, we define a disruption of civilization as the situation where all human society reverts back to at least a preindustrial stage of development). If modern civilization were to be lost entirely, it certainly might have a major impact on the likelihood of the WIPP site being inadvertently intruded by human activity.

Some analysts might argue that our civilization is now so interdependent on each other and so fragile that any massive global catastrophe might lead to reversion to at least a preindustrial era (if not to an even more basic form of society such as hunting and gathering). Overall, our group is skeptical that if any of the six scenarios described above were to occur, we would lose almost entirely our knowledge of the current civilization and become a primitive, preindustrial society. Furthermore, the likelihood of that occurring probably would diminish over time as society becomes more scientifically and technologically advanced and therefore more able to compensate for any massive global catastrophes.

Some early studies of the impact of an all out global nuclear war predicted that the radiation and subsequent nuclear winter might destroy civilization entirely, but more thorough, informed, and competent studies indicated the contrary. More recent studies suggest that though the devastation of a global nuclear war could be tremendous, civilization would endure (Hartwell & Hutchinson, 1985; Pittock et al., 1986; Turco et al., 1990). For the less 20 years the trend has been toward smaller nuclear weapons (especially in the U.S.) as accuracies have improved. Since a nuclear winter scenario depends on a very high volume of ground-burst megatonnage, this trend has tended to further reduce the likelihood of a nuclear winter after a nuclear war.

Less technologically advanced and poorer countries might try to maintain the threat of a global nuclear winter through some type of "doomsday machine" in order to achieve a threat to balance against military superiority. Nevertheless, the group believes that if a massive global nuclear war did occur, in either time period, the probability of civilization reverting back to at least a preindustrial level is very low.

If an almost runaway global warming did occur in the near future, the likelihood that all of civilization would be disrupted is very low to low. Civilization could survive in areas of the globe which would become much warmer, but still inhabitable by human beings. With scientific and technological advances, the likelihood of civilization collapsing entirely in the farthest period would be reduced to a very low probability.

Volcanic disruptions causing a long-term cooling of the earth would disrupt the present patterns of settlement and life styles, but the likelihood of civilization ending has an extremely low probability because areas of the globe could adjust and maintain a modified, but highly sophisticated civilization.

Massive global catastrophe caused by a shower of meteors would only have a very low probability of ending civilization in the nearest period. With technological improvements, the likelihood of such a catastrophe ending civilization in the future would be reduced to very low.

In the near period, a massive global disaster due to the introduction of some unknown deadly disease has a fairly low probability of ending civilization. With improved technology and medical knowledge over time, however, the probability of civilization being disrupted entirely by an unknown disease becomes low.

Finally, if an extra-terrestrial attack on the earth destroyed at least 50 percent of the human population, the likelihood of civilization ending is moderate because the invaders would have the means and perhaps the desire to reduce the human population to a primitive, preindustrial state. Indeed, in the past civilizations were frequently conquered and systematically destroyed by a group of close or distant neighboring invaders (McNeil, 1979).

If civilization were suddenly disrupted, the likelihood of an intrusion at the WIPP site would be temporarily reduced since the survivors would have neither the technology nor the desire to intrude upon such a deep nuclear waste storage site. Even under these circumstances, however, it is likely that the surviving population would eventually recover and rediscover technology appropriate for drilling and excavating. Moreover enough fragments of the past civilization probably would be discovered and eventually decoded that the time period needed for recovery would be less than it took for advanced societies to develop the necessary technology historically. The loss of civilization and its gradual recover also means that information about the WIPP site would be lost or forgotten and therefore increase the eventual likelihood of an inadvertent human intrusion.

Furthermore, when such a massive global catastrophe occurs would also influence the likelihood of an inadvertent human intrusion. If a massive global catastrophe sufficient to temporarily disrupt civilization occurred 8000 or 9000 years from now, the likelihood of inadvertent human intrusion within the next one or two thousand years would be much less than if that catastrophe occurred only 1000 or 2000 years from now since in the former situation less time would remain for rediscovering the technology and need for drilling or excavating at the WIPP site.

3.3.4 Post-Catastrophic Continuation of Civilization

If a massive global catastrophe were to occur, it is our opinion that there would be a high probability of civilization surviving despite the high loss of population. Nevertheless, a massive global catastrophe might still have an impact on the likelihood of an inadvertent human intrusion at the WIPP site.

If the specific location of most of our massive global catastrophe scenarios (such as nuclear war, volcanic eruptions, meteor showers, diseases, or extra-terrestrial attack) were to occur on near the WIPP site, naturally that area would be particularly affected. In most situations, however, a direct nuclear attack or a volcanic eruption occurring on near the WIPP site is very unlikely given the small geographic area involved and the nature of probable development on that site.

3.3.5 References on Catastrophes

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4.0 Future States of Society (Norman Rosenberg and Theodore Glickman)

The future states of society that bear on the prospects for human intrusion into the WIPP repository will be determined by the interplay of a number of factors. These include climatic change, status of the world food economy, the energy economy, the mineral economy, the nature of technologies for mineral extraction and the form(s) of governance that exist in the WIPP region. The results do not reflect the influence of catastrophes, the occurrence of which we consider to be highly unlikely.

4.1 Climatic Change

We consider three possible climatic states for the WIPP region: unchanged, more arid, more humid. The importance of climate change for WIPP is in its effects on economic activity (farming and ranching primarily) and on population growth or decline. Climate will also determine whether there will be enough water, locally collected or importable, to justify the creation of artificial reservoirs that might affect the integrity of the repository. These climate considerations apply to both the near and far term. Of course, the WIPP region may (more likely will) experience all three conditions and probably more than once.

4.2 Energy Futures

We consider only one energy future for both the near and far term, viz. that energy cost relative to per capita wealth continue to rise.

4.3 Food Futures

For the near term we consider two futures, viz., (1) that global food demands are easily met by suppliers outside the WIPP region and (2) that demand for food so exceeds world supply that the WIPP region's production is needed to redress the balance. Agricultural activity affects population and also the need for water transport and storage structures in the region. The same two futures (adequate and inadequate global food supplies) can be postulated for the far term. In addition, we must consider the possibility that food, feed, and fiber production will be industrial rather than soil-based in the future. The substrates for an industrial production system may be minerals or biomass. If from minerals, agricultural activity would vanish from the surface of the WIPP region. If from biomass, the extensive cover of hardy perennials like Havard oak and mesquite might to cultivated or at least managed to provide sustainable supplies.

4.4 Mineral Futures and Future Technology

For our purposes, minerals include extractable hydrocarbons, potash, anhydrite and salt as well as materials not yet discovered on the site and/or materials the value of which may not yet be recognized. We confine our view of technology to its impacts on mineral extraction. The scenarios are based on the question of whether or not technology eases the extraction and hence influences the economics of mineral extraction. The future states to consider are then: (1) demand exists for minerals that can be mined economically in the WIPP region, and (2) whether or not demand exists, the minerals cannot be economically mined in the region.

4.5 Governance

The future governance (or lack thereof) of the WIPP region--or, rather, all of New Mexico or the US Southwest--could have an impact on the population size and the degree of control over human activities, including farming, ranching. mining and water resource management. Even the degree of control exerted over archaeological research activities would depend on the degree of governmental control of the area. The two states of governance we consider are: (1) prudential effective, and (2) otherwise.

4.6 Results

The table below shows only those scenarios for the future states of society which represent plausible combinations of (a) wealth and technology in the world and at WIPP, (b) climate at WIPP, (c) gas or mineral prices, and (d) government control of WIPP in the near future and the far future. These conclusions, which were derived from the preceding discussion, are the only scenarios that we deemed to be reasonable; any others are considered to have negligible probabilities.

	Level	
Factor	Near Future	Far Future
Wealth and Technology	(1) Moderate (2) High	High
WIPP Climate	Same or Less Humid	(1) More Humid (2) Same or Less Humid
Gas or Mineral Prices	Rising (Doubling)	(1) Rising (Doubling) (2) Less than Doubling
Government Control	(1) Prudent & Effective (2) Other	(1) Prudent & Effective (2) Other

5.0 Combinations of Influences on Intrusion (Theodore Glickman)

5.1 Levels of Hazard Awareness

By level of awareness of the hazard of intrusion, we mean the degree of knowledge of the WIPP's precise location, its contents, its vulnerability to inadvertent human intrusion, and the environmental consequences associated with such intrusion. The magnitude of the level of hazard awareness depends on the state of society, on the time period in which the intrusion might occur, and on the effectiveness of the marker system at that time. Some states of society might hamper the performance or threaten the very existence of the marker system, thereby reducing or totally negating its effectiveness, particularly when there has been a catastrophic disruption due to massive physical destruction in the immediate vicinity. We assume that no marker design could preclude this possibility, but that apart from the effect of particular catastrophic disruptions, a design will be achieved for which there will be no significant reduction in effectiveness in the near future, with a continually small but possibly rising probability that this could occur in the far future. This assumption also reflects the belief that it would be unreasonable to expect a major discontinuity in current languages in the absence of an extraordinarily catastrophic disruption.

Therefore, we concluded that the only reasonable possibility is that the level of hazard awareness will be high throughout both time periods, unless a catastrophic disruption were to occur, in which case the possibility also exists that it will be low, as a result of the marker system being destroyed or the records about the repository being lost or the inability of the affected society to properly interpret the available information. However, we deemed the probability of a catastrophic disruption to be so low as to be negligible in each time period.

5.2 Potentially Intrusive Activities and Modes of Inadvertent Intrusion

Our conjectures of the potentially intrusive activities are listed in the following table, which contains our judgments of whether it is reasonable to expect them to apply in each of the future time periods. These descriptions are intentionally terse and generic in nature, reflecting the high degree of uncertainty involved in postulating what conditions will exist many years from now.

	Future Time Period	
Potentially Intrusive Activity	Near	Far
Resource Exploration/Extraction	x	x
Non-Agricultural Development/Construction	x	x
Agricultural/Water Development		x
Scientific/Archaeological Investigation	x	x
Weather Modification		x
Cultural/Religious Activity		x

Our initial conjectures of the modes of inadvertent human intrusion are similarly terse and generic, but based on what we might reasonably expect to happen in the future, they are intended to be exhaustive nonetheless. Thus we identified three reasonable modes of inadvertent human intrusion: drilling, excavation and destabilization. By "drilling," we mean any narrow and deep physical penetration of the earth, whether the means are mechanical, electrical, sonic or otherwise. By "excavation," we mean a broader, higher-volume removal of materials from the earth by any means, including digging and blasting. By "destabilization," we mean any other localized destruction of the integrity of the earth's structure, whether sudden or gradual, such as a fracture caused by the detonation of an explosive or disintegration caused by water seepage.

The following table shows our judgments of how these modes of intrusion relate to the two future time periods.

Mode of Intrusion	Future Time Period: Near	Future Time Period: Far
Drilling	x	x
Excavation		x
Destabilization	x	x

The question of which potentially intrusive activity might be reasonably expected to lead to each possible mode of inadvertent human intrusion is addressed in the following table, which shows our judgments as to whether there is a conceivable relationship between these two parameters in either time period. We then decided that only some of these possibilities could be reasonably expected to occur, as indicated by the underlined entries in the table. These results indicate that, in our judgment, the only reasonable possibilities for future inadvertent human intrusion exist when drilling is conducted in association with the potentially intrusive activities of resource exploration/extraction, agricultural/water development and scientific/archaeological investigation and when weather modification leads to destabilization of the local geological formations.

Potentially Intrusive Activity	Mode of Intrusion: Drilling	Excavation	Destabilization
Resource Exploration/Extraction	<u>x</u>	x	x
Non-Agricultural Development/Construction	x	x	x
Agricultural/Water Development	<u>x</u>		x
Scientific/Archaeological Investigation	<u>x</u>	x	x
Weather Modification			<u>x</u>
Cultural/Religious Activity		x	

6.0 Independent Conclusions (Max Singer)

The most likely intrusion into WIPP is by someone who is drilling for natural gas. The likelihood of this happening depends on how much drilling for gas there is and on the likelihood that awareness of the WIPP is lost. (If there is awareness there is no inadvertant intrusion.)

An inadvertant intrusion by a gas well means a well driven through the WIPP because by random chance it is located in exactly the wrong place. For this to have an appreciable probability there would have to be a very large number of wells drilled in the general area. If 2,500′ deep wells are drilled on five mile centers throughout the area there is much less than one chance in a hundred that one of them would penetrate the WIPP if no one knew it was there. (If the wells are drilled on one mile centers there is still less than one chance in ten that one will penetrate the WIPP.)

How much drilling for gas there will be depends on the value of gas and on the cost of drilling. (Of course cheap drilling tends to make the value of gas drop by increasing supply, and cheap drilling may require cheap energy. Nevertheless demand may be great enough to make high gas values even when drilling is cheap.)

Drilling for other resources is also possible in the area. But the area is so poor in other resources that are not at least equally available elsewhere that gas seems to be a more likely objective than all other potential resources put together.

Drilling is also possible for scientific (including archaeological) reasons or for curiosity, if it is known that there was unusual human activity on the site, although knowledge of the WIPP has been lost. This possibility may be as large as the possibility of drilling for gas, but it seems hard to predict.

Gas prices (in 1990 dollars) may be roughly equal to today's prices -- plus or minus a factor of three -- or much higher, up to perhaps ten times today's value. (In the U.S. gas is now selling for about $2/mcf, which is less than half the price of oil with the same amount of energy.) Average energy costs may rise as much as six or eight times, and gas might become more valuable than other forms of energy. But gas prices cannot for long exceed ten times today's price. They will be limited by competition from other forms of energy -- including solar energy. If unit costs of energy rise by ten times and the amount of energy used per dollar of GNP only declines by three times, then the share of GWP used for energy would go from about 12% to about 36%.

In the near term (2,000 - 2,200), we would guess that in any given year gas is at least three times as likely to be within a factor of three of today's prices as it is to be higher than that (and we would ignore the chance that it is more than three times lower than today). In the long term we have to assume that there is somewhat greater chance that gas will be worth a lot more than it is today, but we believe that for any randomly chosen year during this period it is less than even money that gas will be more than three times higher than today's prices.

There is a moderate probability that the costs of drilling to 2,000 or 5,000 feet will come down greatly. Taken together we believe that there is a moderate probability (at least one chance in ten) that a very large number of holes will be drilled for gas (or possibly other resources) in Southern New Mexico sometime during the next 10,000 years. (That is, enough holes so that there is at least a low probability that one would penetrate the WIPP as a result of random placement in the area.) The uncertainty about this probability is so great that the estimate is not changed by the possibility that other resources than gas will be found in the area.

There are two ways that there might be a loss of awareness of the WIPP: after a break in civilization caused by a massive catastrophe, or just by carelessness and forgetting. That is, over 10,000 years our society and our records might become so unimportant and so little cared about that people would act as if there was no record of WIPP -- even though there might be ample information about it in the bowels of the great libraries of the time.

People could forget about our civilization rather easily; that is lose touch with us in the mass of data that will be available in the future. But that is not "losing contact" in the relevant sense. The future civilization that forgets us will be in contact with a more recent future civilization that didn't forget us. That is, there is an unbroken chain of civilizations.

A massive global catastrophe is much more likely than a break in civilization. A global catastrophe we have defined as something which reduces world population by 50% within a relatively short time. A civilization break is something which separates people after the break from the civilization before the break. This probably would require either almost total destruction of all urban areas or else an extraordinary and profound social/psychological shock.

Lost civilizations of the past are very limited precedents for the possibility that our civilization might be lost too. Never have there been civilizations with even one tenth as many people or one hundredth as much writing as our civilization. Knowledge of it is spread all over the globe. Even immense destruction of people, equipment, books, and cities would leave a widespread record of our civilization and ample basis for its reconstruction. Our success provides great motivation for the survivors of a catastrophe to refuse to allow themselves to become separated from our civilization.

This is not to deny that great destruction and economic set-backs are possible. One can imagine GWP being reduced by factors of five or ten, GWP/capita by factors of two to four, or even more for short periods of time. But catch-up growth is almost always easiest. And even if such growth is only 3%/year it can overcome a factor of four set-back in GWP/capita in less than half a century.

It is difficult to imagine the kind of social shock that would cut people off from modern Western civilization. Perhaps the believers in a fanatic religion or ideology (like the Khmer Rouge) could use nuclear weapons to conquer and then largely destroy the Western powers and subjugate the survivors, forcing them to completely reject Western civilization for several generations. This seems to be a very low probability.

Another possibility is some kind of disease which attacks the mind or the emotions. Such a disease might so change human behavior that there would be a civilization break. While there is no way of ruling out such a possibility completely, not only is there no obvious precedent or basis for predicting it, but also if such a disease came into existence and began to spread, there would be tremendous resources of science and money available to prevent it from affecting everyone. It seems like a very low probability, even for as long as 10,000 years.

One uncertainty is the nature and level of future technology (apart from its effect on the price of gas and the cost of drilling). The main question is whether technology at the time of a WIPP intrusion would be such as to make that intrusion not a serious harm or danger to the intruding society. This might happen because of the level of technology gave the society a good ability to recognize and deal with radioactive material without harm to people. Or it might happen because medical science had advanced to the point that radiation-induced cancers were no longer life-threatening.

In the near future there may be only a fairly low chance that technology will render an intrusion into the WIPP essentially harmless. For most of the far future it seems to us as if this is at least a moderate probability.

Of course no one can predict what form of governance the WIPP area will have for 10,000 years. There may be a world government, current size nation-states may continue, or perhaps government may be primarily carried out at much more nearly the local level. Nor can one predict what kind of governance would provide the best protection against harm from WIPP. Our experience in recent generations is that the most harm to people and nature has come from the strongest form of government, i.e., that of the Soviet Union. So predictions about the nature of government are not necessarily very important for predicting the possibility of harm from intrusions.

Our review of scenarios for potential inadvertant intrusion in the WIPP and consequent harm to people makes one conclusion overwhelmingly clear. Any substantial funds spend on improving the WIPP can be expected to represent a net sacrifice of lives, compared to the use of a fraction of such funds for saving lives now in other programs.

APPENDIX G:
ISSUE STATEMENT
AND
TASK STATEMENT

ISSUE STATEMENT

MODES AND FREQUENCIES OF HUMAN INTRUSION INTO THE WIPP REPOSITORY

The overall objective of the WIPP performance assessment is to obtain probability distributions over cumulative radionuclide releases for a period 10,000 years following disposal. Radionuclide releases could possibly result from inadvertent human intrusion into the repository.

The likelihood of inadvertent human intrusion depends on a complex number of factors, including, among other things, the characteristics of future societies, societies' needs for resources, their land uses, the state of active controls at the repository, the integrity of barriers and markers, the state of information that future societies have about the repository, and the ability of societies to detect radioactive waste prior to and during intrusion. In addition, the likelihood of inadvertent intrusion depends on whether radioactive wastes have been extracted as a resource prior to inadvertent intrusion. Moreover, the consequences of human intrusion depend upon whether radioactive nuclear wastes have been rendered harmless.

The future human intrusions team members are asked to address primarily the issues related to societal development and activities that could lead to inadvertent human intrusion in a time frame that extends 10,000 years after disposal. Other expert teams will address the issues related to marker and barrier development. Responses by the future human intrusion teams concerning development of society will provide fundamental background information for both the marker and barrier development panels.

The Issues

The specific issues are listed below. Note that many of them require responses that vary as a function of time.

1. Identification of Possible Future Societies and How They May Intrude.

What are the (mutually exclusive) reasonable foreseeable futures for human societies between now and the year 12,000? For each future, (a) how might the activities of society lead to inadvertent intrusion into the WIPP repository and (b) to what extent will society be able to interpret and heed warnings that nuclear waste has been buried at the WIPP site?

2. Probabilities of Future Societies and Probabilities of Various Intrusions.

What are the probabilities or relative likelihoods of the various foreseeable futures? How complete is the list of foreseeable futures, i.e. what is the probability or relative likelihood of the set of foreseeable futures vs. those not foreseen?

For each foreseeable future:

3. Existence and Harmfulness of Waste

What is the likelihood that the radioactive waste has been extracted as a resource, removed for redisposal, neutralized or made harmless through a technology not available today, or is no longer hazardous to man due to advances in medicine?

4. Active Controls

Assuming that the radioactive waste exists and is harmful, what is the likelihood that active controls (continued management of the site) have been maintained to prevent inadvertent intrusions?

5. Continued Existence of Information About WIPP

In the absence of active controls, what is the likelihood that information about the disposal of radioactive waste has persisted to the extent that society will have knowledge of the WIPP site? It should be assumed that markers or signs placed to deter human intrusion have vanished or are no longer effective.

6. Modes and Frequencies of Intrusions

Given the absence of the conditions described in items 3 though 5, what are the potential modes of intrusion and how many times is each mode apt to occur? How are these intrusions distributed over time?

7. Detection of the Waste

What is the likelihood that the technology exists and will be used to detect radioactive waste prior to or during intrusion?

Issues 1 and 2 must be addressed before issues 3, 4, 5, 6 and 7 since these last five issues presuppose the state of society. However, the development of responses to the first two questions must be made considering the information required to formulate responses to questions 3, 4, 5, 6 and 7.

Scenario Analysis

The teams are free to address these issues in any manner believed appropriate as long as the findings provide answers to the specific questions. Developing the reasonable foreseeable futures of human societies is a speculative task requiring broad-based knowledge and creativity. The most common approach to addressing such an issue is scenario analysis. The creation of scenarios can proceed in several ways —working from the present to the future, for example, or working from possible futures backward to the present to determine the mechanisms that might propel society to each future. Scenarios can be constructed by considering alternative projections of basic trends in society. These trends may include population growth, technological development, and the utilization and scarcity of resources, among others. Transcending these factors are events that interrupt, modify or reinforce the development of society. Such events may include war, disease, pestilence, fortuitous discovery of new technologies, human induced climatic changes, and so forth.

Each scenario provides a picture of the characteristics of society at various points in the future. These characteristics will, in turn, provide information about those activities that are likely to take place and pose threats to integrity of the WIPP. Such activities may include extractive industry, particularly mining for potash or drilling for oil and gas, and drilling for water for use in agriculture, industry, or for other purposes. Other types of intrusion may include various kinds of excavation or intrusive activities not currently practiced.

From the states of societies and their potentially intrusive activities, modes of intrusion and motivations for these intrusions can be inferred. Similarly, from scenarios and the resulting states of society one can assess whether knowledge concerning underground disposal of nuclear waste would exist, whether the waste itself would continue to exist, and whether there would exist a means to detect waste before or during intrusion.

Assessing What We Do Not Know

Unfortunately, our views of the future are most often incomplete. We are unaware of or unable to conceive of all possible states of the future. It is anticipated, therefore, that the foreseeable futures generated in this study will not be complete and will likely be less complete for more distant times. Issue 2 directly confronts the problem of completeness. Although we cannot see all futures, we can attempt to assess quantitatively how much we do not know or are unable to know.

The responses to the first two questions are relevant to the performance of the WIPP repository only because they provide the conditions for questions 3 through 7. Grouping of futures, then, can be made so that futures that produce similar answers to questions 3 through 7 are combined. The conditional nature of the last five questions also introduces a probabilistic dependence among these answers. For example, a society that has gone through a major catastrophe resulting in loss of information about radioactive wastes, may not have recovered the technologies for intrusion, nor have the capability to detect the radioactive waste.

Categorizing Futures

The futures can be placed, perhaps somewhat roughly, into three classes —futures where inadvertent intrusion is extremely unlikely at any time, futures where inadvertent intrusion is a reasonable possibility at some times, and futures that we are unable to analyze or perhaps conceive.

The first futures class consists of scenarios where, at all times, one or more of the following is in effect.

Active control of the repository has been maintained.

Information has persisted or been rediscovered that precludes inadvertent intrusion.

The technology exists and is used to detect radioactive waste prior to intrusion.

Society does not engage in activities leading to intrusions.

The radioactive material has been removed or rendered harmless.

Futures belonging to the second class are those where inadvertent intrusion has a reasonable potential of occurring. That is, at some time while the material is in place and hazardous, potentially intrusive activities take place in the WIPP region, there is an absence of both active control at and information about the WIPP, and the technology to detect radioactive waste prior to intrusion is not applied.

The third futures class contains those futures that are not conceived of at this time, and those futures where nothing can be said about intrusive activities, the persistence or rediscovery of knowledge about radioactive waste, and the ability to detect radioactive waste. The purpose of this class is to provide a measure of the lack of completeness about the identified possible futures.

The performance evaluation of the WIPP repository is based, in part, on the probabilities of various inadvertent intrusions. Since all futures in the first class preclude inadvertent intrusion, it is only necessary to obtain a single probability for the entire class.

The requirements for information about futures in the second class are much more stringent. For these futures, it is necessary to obtain descriptions of the possible intrusions including the mechanism for intrusion, and the size and depth of the resulting intrusion. It is also necessary to obtain probabilities of each mode of intrusion as a function of time, and probabilities that the material is in place, that active control is absent, that information about the radioactive waste has been lost, and that radioactive waste is not detected prior to the intrusion. In addition to identifying possible mechanisms of intrusion, it is also necessary to obtain descriptions regarding the ability of future societies to interpret and heed any information that exists or has been passed on about the presence of nuclear waste.

While the first and second classes of futures are mutually exclusive, they are not collectively exhaustive, that is their probabilities are not complementary. The slack is taken up by the third class of futures —those futures where little or nothing is conceivable.

Communication of Findings

We ask that each team provide responses to the above questions and the rationales supporting these responses. The responses should be in the form of a draft report that includes descriptions of the foreseeable futures and the assumptions, methods, rationales, and other information used to reach these conclusions.

The assessment of probabilities of these futures, as well as possible modification of the views of the future, will take place during the second meeting of the teams. Each team of experts is expected to make a presentation of their findings to the other teams, the project staff, and the panel studying markers during the second meeting. Similarly, while the teams are asked to identify the modes of intrusion associated with members of the second class of futures, the assessment of probabilities and numbers of intrusions will be accomplished during the second meeting. The numerical responses to issues 3, 4, 5, 6, and 7 will also be gathered during the second meeting. This is not to say that the expert participants should not give deep and careful consideration to the assignment of these probabilities, however. The intention here is to preclude the fixing of positions until after an exchange of ideas takes place among the several teams. Further, it is desired that the actual assessment of probabilities be done in conjunction with the decision analysts participating in this project.

THE EXPERT JUDGMENT GROUP TO ASSESS MODES AND LIKELIHOODS OF FUTURE INADVERTENT INTRUSIONS INTO THE WIPP REPOSITORY

TASK STATEMENT

The expert judgment effort to establish modes and likelihoods of inadvertent intrusive activities into the WIPP repository provides the foundation for the development of characteristics for markers and obstacles designed to prevent human intrusion. Inadvertent human intrusion has been identified as the predominant contributor to risk from radioactive releases to the environment and, therefore, is central to the performance of the site. The expert group studying future societies will be asked to address a number of issues. These issues are all directed at determining the modes of intrusion and the likelihoods of these intrusions.

Because the performance period for the WIPP site spans a 10,000 year period, it is necessary to consider the possible future states of society. One approach to assessing possible futures is to create scenarios of the development of society. These scenarios can be constructed by considering alternative projections of basic trends in society. These trends may include population growth, technological development, and the utilization and scarcity of resources, among others. Transcending these factors are events that interrupt, modify or reinforce the development of society. Such events may include nuclear war, disease, pestilence, fortuitous discovery of new technologies, climatic changes, and so forth. The creation of a reasonable set of scenarios provides the first step in evaluating the types and likelihoods of intrusive activities. It is not possible, however, to insure that all possible futures are considered. It is not even reasonable to assume that man is able to conceive of all possible future societies. It is possible, however, to assess the confidence in the degree of completeness of such scenarios. The further into the future we delve, the less complete these scenarios are likely to be.

Each scenario will provide a picture the characteristics of society at various points in the future. These characteristics will, in turn, provide information about those activities that are likely to take place and pose threats to integrity of the WIPP site. Such activities may include extractive industry, particularly mining for potash or drilling for oil and gas, and drilling for water for use in agriculture, industry, or for other purposes. It may be that several scenarios provide similar future societies and thus these scenarios can be combined.

The states of societies and the types of potentially intrusive activities provide modes of intrusion and motivations for these intrusions. The scenarios and the states of society also provide information about the existence of knowledge concerning underground disposal of nuclear waste, the continued existence of the waste itself, the availability of means to detect waste prior to, during, or after intrusion. The products of the expert judgment group to assess future societies and inadvertent intrusions will include scenarios of development and descriptions of possible futures along with the rationales supporting the possibilities of these futures. These rationales will be conveyed as papers or reports and will serve as a method of documenting the experts' findings. Modes of intrusion will be analyzed using the scenarios and states of society and quantitative (probabilisitic) assessments of the frequencies of various intrusions will be developed. Quantitative assessments of the likelihoods of various scenarios will also be assessed.

The work required to develop the assessments for human intrusion will be accomplished through two meetings of the experts and study period between the two meetings. At the first meeting, the issues to be addressed by the experts will be presented by the Sandia staff, presentation of previous research findings and research materials will be given, training in probability assessment will be take place, and a tour of the WIPP site will be provided.

During the two month period following the first meeting, the experts will study the issues and prepare analyses of future societies and their activities with special attention to those activities that may impact the repository. It is expected that approximately two weeks of effort will be spent by each expert in preparing these analyses.

The second meeting will provide a forum for the discussion of the analyses. After the presentation and discussion of issues, the experts will participate in a formal probability assessment conducted by specialist in expert judgment elicitation. The experts will be asked to provide assessments of the likelihoods of various scenarios, an assessment of the completeness of the scenarios, and assessments of the frequencies of various types of intrusions given each scenario.

Following the second meeting, the findings of the group will be organized and returned to the experts for review, correction, and revision.

APPENDIX H:
LETTER REQUESTING NOMINATIONS

Sandia National Laboratories

Albuquerque, New Mexico 87185

June 1, 1990

<fn> <ln>
<co>
<jt>
<add1>
<add2>
<add3>
<ct>, <st> <zip>

Dear <ti> <ln>:

The safe disposal of nuclear waste is one of the most pressing issues facing the United States today. The Waste Isolation Pilot Plant (WIPP), located in New Mexico, is to be the first of this nation's nuclear waste repositories. The geologic and hydrologic properties of the site indicate that the WIPP system will serve as an effective repository, if left undisturbed. Inadvertent human intrusion, however, might result in radioactive releases to the biosphere. Knowledge of the types of possible intrusions and their likelihoods is essential for assessing the performance of the site and developing strategies to deter these intrusions. We seek your assistance in nominating persons to participate in a study of civilization's future and the possible impacts that future societies may have on the integrity of the WIPP system. If your qualifications are appropriate for this study, we encourage you to place your own name in nomination.

Because the performance period for the site extends far into the future (10,000 years) and the future modes of intrusion may be different than those of today, we seek experts who have a broad scope of knowledge as well as an interest in dealing with alternative futures. Moreover, because the knowledge necessary to deal with such issues can be found across many of our traditional disciplines of study, it has been decided to group the experts into teams—each team having the responsibility of providing an assessment of what the future may bring, of how certain or uncertain are alternative futures, and an appreciation of what we are not capable of knowing at this time. Each team will be composed of three or four members, with at least one member having particular expertise in the physical sciences. Each team will also have at least one member who has made contributions through studies of the future. We will attempt to construct teams so that we can take advantage of the geographic proximity of the members.

Attached is a more detailed description of the tasks to be accomplished. While the total effort required from the various team members may vary because of their backgrounds and areas of responsibility, we envision a commitment of about three weeks effort including two meetings to be held in New Mexico during late summer and early fall of this year. Expenses and an honorarium in lieu of professional fees will be provided by Sandia National Laboratories.

Please send your nominations to me by June 8, 1990. Your inclusion of complete addresses and telephone numbers (both voice and FAX if available) will be greatly appreciated. We will contact the nominees shortly thereafter and request credentials. The selection of participants will be based on tangible evidence of expertise, previous work in related areas, availability, and freedom from conflicts of interest.

If you need additional information, please contact Mr. Dan Scott at (505) 844-1917. If you wish, you may send your nominations by FAX to Mr. Scott at (505) 844-1723 or you may mail them directly to me.

Thank you for your assistance with this important issue.

Sincerely,

D. R. Anderson

D. Richard Anderson
Performance Assessment
Division 6342
Sandia National Laboratories
Albuquerque, NM 87185

Enclosure

APPENDIX I:
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Department of Agricultural Economics
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Vice President and Chairperson,
The Citizen Education and Advocacy Committees,
League of Women Voters
Amity, OR

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National Resources Defense Council
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Director,
Institute of Environmental Sciences
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George Washington University
Washington, D.C.

APPENDIX J:
LETTER TO NOMINEES

Sandia National Laboratories

Albuquerque, New Mexico 87185

June 6, 1990

<fn> <ln>
<co>
<jt>
<add1>
<add2>
<add3>
<ct>, <st> <zip>

Dear <ti> <ln>:

The safe disposal of nuclear waste is one of the most pressing issues facing the United States today. The Waste Isolation Pilot Plant (WIPP), located in New Mexico, is to be the first of this nation's nuclear waste repositories. The geologic and hydrologic properties of the site indicate that the WIPP system will serve as an effective repository, if left undisturbed. Inadvertent human intrusion, however, might result in radioactive releases to the biosphere. Knowledge of the types of possible intrusions and their likelihoods is essential for assessing the performance of the site and developing strategies to deter these intrusions.

You have been nominated to participate in a study of civilization's future and the possible impacts that future societies may have on the integrity of the WIPP system. A brief description of the problem, the criteria for selecting participants from the nominees, and scheduling information follow.

Because the performance period for the site extends far into the future—10,000 years—and the future modes of intrusion may be different than those of today, the successful nominees must have a broad scope of knowledge as well as an interest in dealing with alternative futures. Moreover, because the knowledge necessary to deal with such issues can be found across many of our traditional disciplines of study, it has been decided to group the experts into teams—each team having the responsibility of providing an assessment of what the future may bring, of how certain or uncertain are alternative futures, and an appreciation of what we are not capable of knowing at this time. Each team will be composed of three or four members, with at least one member having particular expertise in the physical sciences and one member with particular expertise in the social sciences. Each team will also have at least one member who has made contributions through studies of the future. We will attempt to construct teams so that we can take advantage of the geographic proximity of the members.

Attached is a more detailed description of the tasks to be accomplished. While the total effort required from the various team members may vary because of their backgrounds and areas of responsibility, we envision a commitment of about three weeks effort including two meetings to be held in New Mexico: one during late summer (August 13 through 15) and another two months following the first meeting (October 10 through 11). Expenses and an honorarium in lieu of professional fees will be provided by Sandia National Laboratories.

If you are interested in serving on this project, please send me your resume and a letter stating your interest by June 18, 1990. This letter should include a brief description of why you feel you are qualified to serve. Citing work you have accomplished that is germane to this study would be helpful to our selection committee. You should also show that you will be able to attend the required meetings and perform the assigned work between the two meetings. The selection of participants will be based on tangible evidence of expertise, curriculum vitae, previous work in related areas, availability, and freedom from conflicts of interest.

If you need additional information, please contact Mr. Dan Scott at (505) 844-1917. If you wish, you may send your letter requesting to serve on the study by FAX to Mr. Scott at (505) 844-1723 or you may mail them directly to me.

Thank you for your assistance with this important issue.

Sincerely,

D. Richard Anderson
Performance Assessment
Division 6342
Sandia National Laboratories
Albuquerque, NM 87185

Enclosure

APPENDIX K:
EXPERT PANEL SELECTION CRITERIA

EXPERT PANEL SELECTION CRITERIA

Each member of the selection committee evaluated the nominees based on the following criteria:

tangible evidence of expertise,

professional reputation,

availability and willingness to participate,

understanding of the general problem area,

impartiality,

lack of economic or personal stake in the potential findings,

balance among team members so that each team has the needed breadth of expertise,

physical proximity to other participants so that teams can work effectively,

balance among all participants so that various constituent groups are represented.

Distribution

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