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# *Ten Thousand Years of Solitude?*

## *On Inadvertent Intrusion into the Waste Isolation Pilot Project Repository*

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## Table of Contents

## 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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# Ten Thousand Years of Solitude?

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by

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## 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

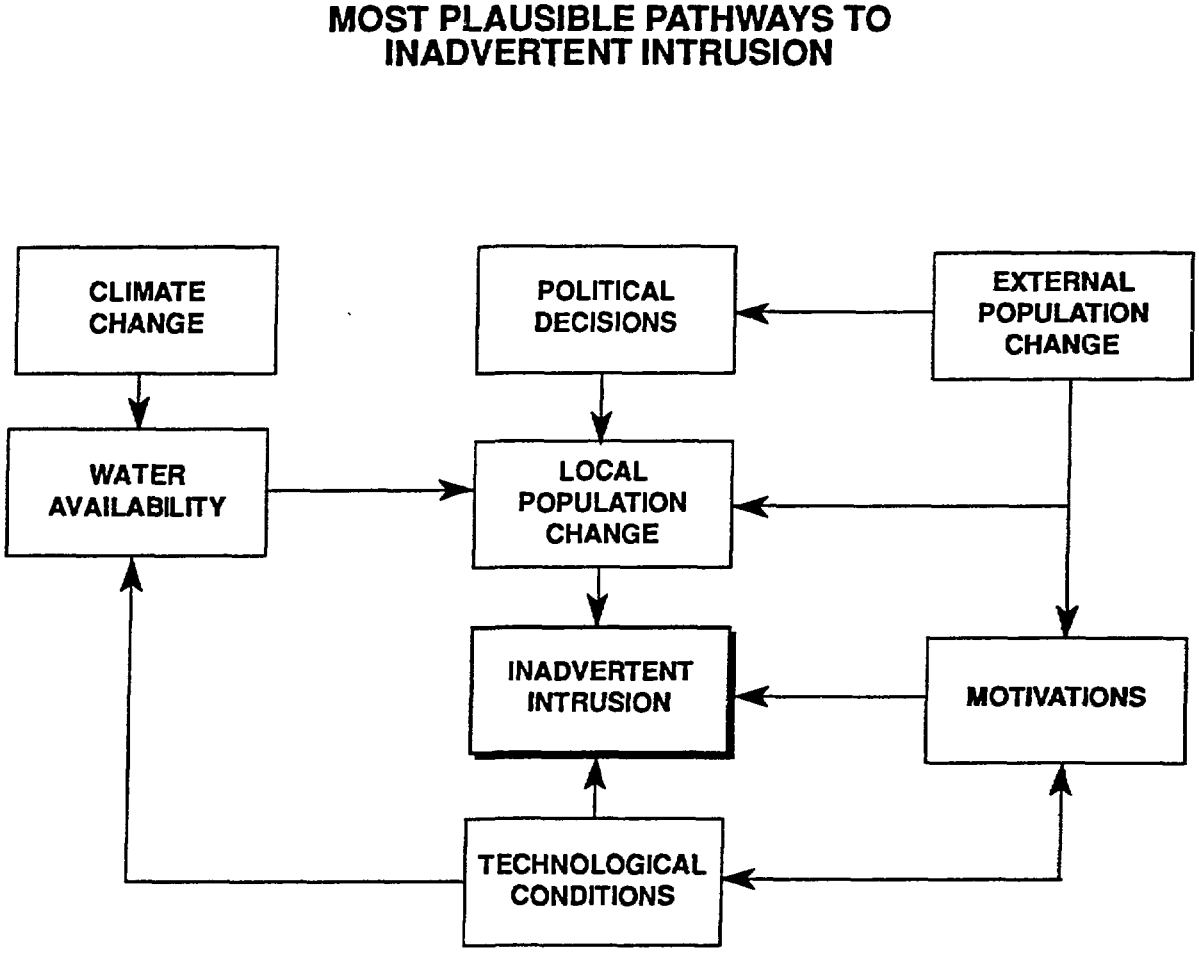


Figure 1. Relationships Among Key Factors

## 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.

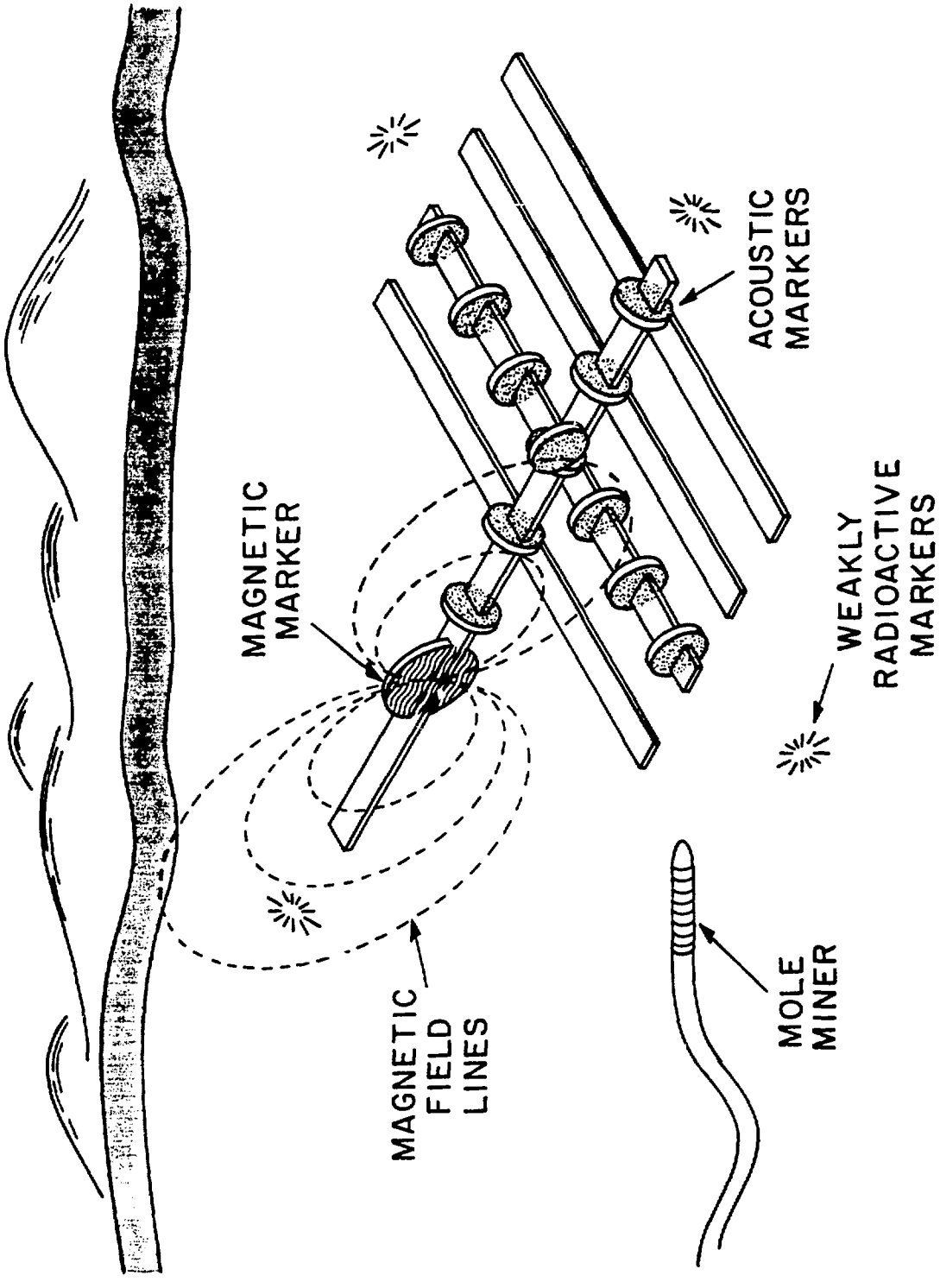


Figure 2. A Mole Miner Approaches the Marked WIPP Repository

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

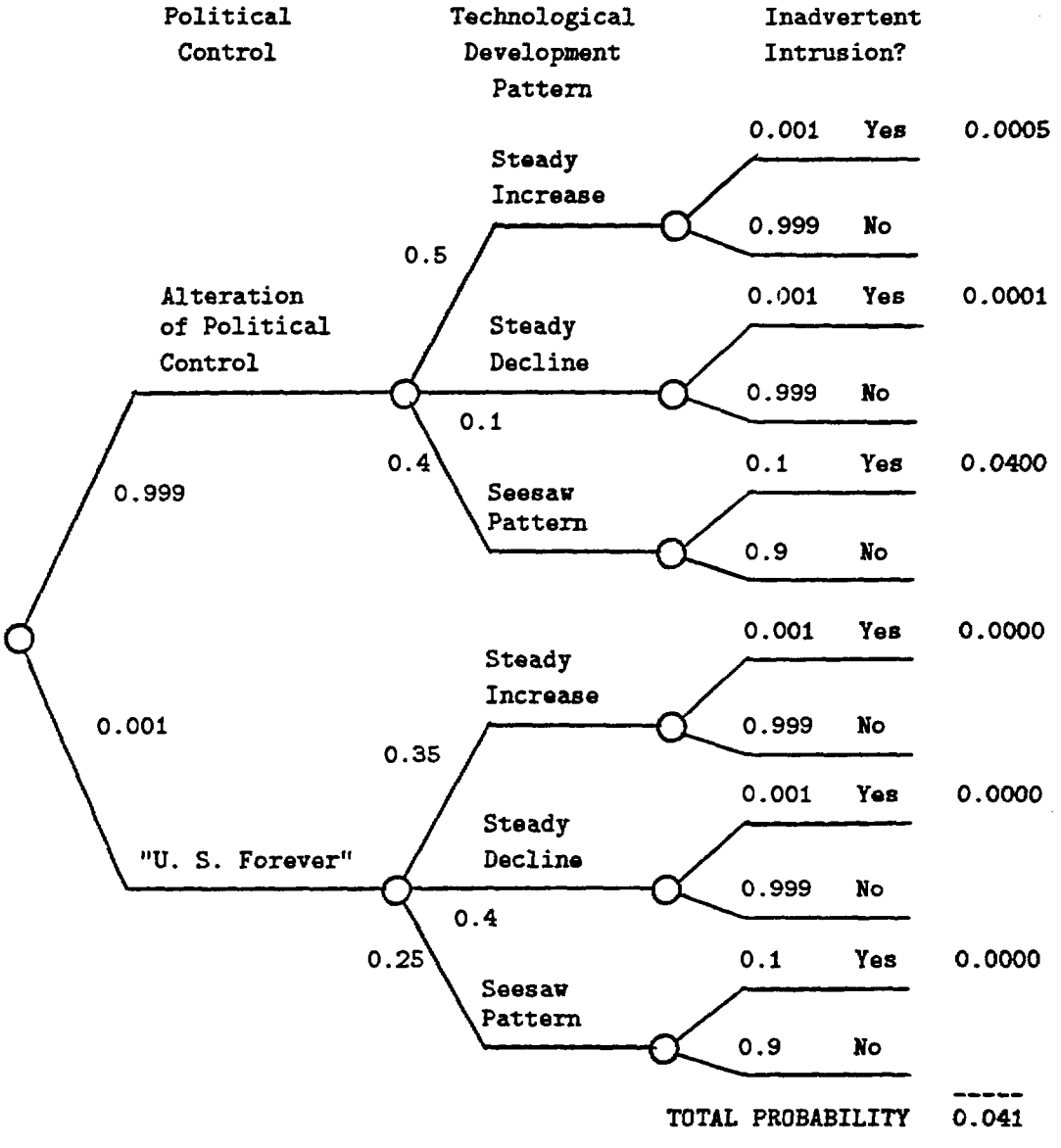


Figure 3. Probability of Inadvertent Intrusion

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.