GREGORY BENFORD - Ten Thousand Years Of Solitude

ONE OF THE chores of physics professors everywhere is fielding telephone calls which come into one's department. Sometimes they ask "What was that I saw in the sky last night?" -- to which I reply, "Could you describe it?" This makes for quick work; usually they've seen an aircraft or Venus.

Sometimes calls are from obvious cranks, the sort who earnestly implore you to look over their new theory of the cosmos, or their device for harnessing magnetism as a cure to the world's energy needs. These I accord a firm diplomacy. Any polite pivot that gets one off the line is quite all right. One of the few rules we do follow is that one may not deflect the call to another professor!

In 1989 I got a call which at first seemed normal, from a fellow who said he was from Sandia Laboratories in Albuquerque, New Mexico. Then I sniffed a definite, classic odor of ripe crank.

"Let me get this straight," I said. "The House of Representatives has handed down a requirement on the Department of Energy. They want a panel of experts to consider a nuclear waste repository and assess the risks that somebody might accidentally intrude on it for . . ."

"That's right, for ten thousand years."

I paused. He sounded solid, without the edgy fervor of the garden variety crank. Still . . .

"That's impossible, of course."

"Sure," he said. "I know that. But this is Congress."

We both laughed. I knew he was okay.

So it came to be that a few months later I descended in a wire-cage elevator, clad in hard hat with head lamp and goggles, and carrying on my belt an emergency oxygen pack. I had a numbered brass tag on my wrist, too -- "For identification," the safety officer had said.

"Why?" I had asked.

She looked uncomfortable. "Uh, in case you, uh . . ."

"In case my body can't be identified?"

"Well, we don't expect anything, of course, but you know rules."

We rattled downward for long minutes as I pondered the highest risk here: a flash fire that would overwhelm the air conduits, smothering everyone working in the kilometer-long Waste Isolation Pilot Plant outside Carlsbad, New Mexico.

We clattered to a stop 2150 feet down in the salt flat. The door slid aside and our party of congressionally authorized experts on the next ten thousand years filed out into a bright, broad corridor a full thirty-three feet wide and thirteen feet high. It stretched on like a demonstration of the laws of perspective, with smaller hallways branching off at regular intervals.

Huge machines had carved these rectangular certainties, leaving dirty-gray walls which felt cool and hard (and tasted salty, I couldn't resist). Flood lights brought everything into sharp detail, like a 1950s sf movie--engineers in blue jump suits whining past in golf cans, helmeted workers with fork lifts and clipboards, a neat, professional air.

We climbed into golf carts with WIPP DOE stenciled on them, and sped among the long corridors and roomy alcoves. Someone had quietly inquired into possible claustrophobic tendencies among our party, but there seemed little risk. The place resembles a sort of subterranean, Borgesian, infinite parking garage. It had taken fifteen years to plan and dig, at the mere cost of a billion dollars. Only the government, I mused idly, could afford such parking fees . . .

Nuclear waste is an ever-growing problem. It comes in several kinds --highly radioactive fuel rods from reactors, shavings from nuclear war-head manufacture, and a vast mass of lesser, lightly radioactive debris such as contaminated clothes, plastic liners, pyrex tubes, beakers, drills, pipes, boxes, and casings.

Fifty years into the Nuclear Age, no country has actually begun disposing of its waste in permanent geologic sites. Many methods have been proposed. The most plausible is placing waste in inert areas, such as salt flats. Also promising would be dropping waste to the deep sea bed and letting subduction (the sucking in of the earth's mantle material to lower depths) take it down. Subduction zones have a thick silt the consistency of peanut butter, so that a pointed canister packed with radioactives would slowly work its way down. Even canister leaks seem to prefer to ooze downward, not percolate back up. (A few million years later, fossil wrist watches and lab gear could appear in fresh mountain ranges.) Finally, the highest-tech solution would be launching it into the sun.

All these have good features and bad, but the more active solutions seem politically impossible. Law of the Sea treaties, opposition to launching anything radioactive, and a general, pervasive Not In My Backyard-ism are potent forces.

The only method to survive political scrutiny is the Pilot Project, sitting in steel buildings amid utter desert waste forty-five minutes' drive from Carlsbad. The Department of Energy regards it as an experimental facility, and has fought endless rounds with environmentalists within and without New Mexico. Should they be allowed to fill this site with eight hundred thousand barrels of low-grade nuclear waste -- rags, rubber gloves, wiring, etc.? It is to be packed into ordinary 55-gallon soft-steel drums, which will then be stacked to the ceilings of the wide alcoves which sprout off from the ample halls.

We climbed out of our carts and inspected the chunks of dirty salt carved from the walls by the giant boring machines. Everything looks imposingly solid, especially when one remembers that 2150 feet of rock hang overhead.

But the point of the Pilot Project is that the walls are not firm at all. This Euclidean regularity was designed to flow, ooze, collapse.

We trooped into a circular room with a central shaft of carved salt. Meters placed around the area precisely recorded the temperature as electrical

heaters pumped out steady warmth. The air was close, uncomfortable. I blinked, feeling woozy. Were the walls straight? No --they bulged inward. There was nothing wrong with my eyes.

Salt creeps. Warm up rock salt and it steadily fills in any vacancy, free of cracks or seams. This room had begun to close in on the heaters in a mere year. Within fifteen years of heating by radioactive waste left here, the spacious alcoves would wrap a final hard embrace around the steel drums. The steel would pop, disgorging the waste. None would leak out because the dense salt makes perfect seals -- as attested by the lack of ground water penetration anywhere in the immense salt flat, nearly a hundred miles on a side.

"Pilot" is a bureaucrat's way of saying two things at once: "This is but the first," plus "we believe it will work, but . . ." Agencies despise uncertainties, but science is based on doing experiments which can fail.

Often, scientific "failure" teaches you more than success. When Michaelson and Morley searched for signs of the Earth's velocity through the hypothetical ether filling all space, they came up empty-handed. But this result pointed toward Einstein's Special Theory of Relativity, which assumed that such an ether did not exist, and that light had the same velocity no matter how fast one moved, or what direction.

An experiment which gives you a clear answer is not a failure; it can surprise you, though. Failure comes only when an experiment answers no question -- usually because it's been done with ignorance or sloppiness. The true trick in science is to know what question your experiment is truly asking.

Bureaucrats aren't scientists; they fear failure, by which they mean unpredictability. They tread a far more vexing territory: technology. The Pilot Project has been held up because equipment did not work quite right, because there are always uncertainties in geological data, and of course, because environmental impact statements can embrace myriad possibilities.

Ours was the furthest-out anyone in government had ever summoned forth. No high technology project is a child of science alone; politics governs. The pressure on this Pilot Project arose from the fifty years of waste loitering in "temporary" storage on the grounds of nuclear power plants, weapons manufacturers and assorted medical sites -- in "swimming pools" of water which absorb the heat (but can leak), in rusting drums stacked in open trenches or in warehouses built in the 1950s. The long paralysis of all nuclear waste programs is quite probably more dangerous than any other policy, for none of our present methods was ever designed to work for even this long. Already some sites have measured slight waste diffusion into topsoil; we are running out of time.

Of all sites in the USA, the Carlsbad area looked best. Its salt beds laid down in an evaporating ocean 240 million years ago testify to a stable geology, water free. The politics were favorable, too. Southern New Mexico is poor, envying Los Alamos and Albuquerque their techno-prosperity. Dry, scrub desert seems an unlikely place for a future megalopolis to sprout -- ignoring Los Angeles.

So we members of the Expert Judgment Panel split into four groups to separately reach an estimate of the probability that someone might accidentally intrude into the sprawling, embedded facility. We had some

intense discussions about big subjects, reflecting the general rule that issues arouse intense emotion in inverse proportion to how much is known about them. Should we be doing more to protect our descendants, perhaps many thousands of years in the future, from today's hazardous materials? How do we even know what future to prepare for?

Usually we envision the future by reviewing the past, seeking longterm trends. This can tell us little about the deep future beyond a thousand years. 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, extrapolation is useful in predicting at least the range and direction of what might happen. Going back 1,000 years takes us to the middle of the Middle Ages in Europe. Virtually no political institutions from this era survive, although the continuity of the Catholic Church suggests that religious institutions may enjoy longer lifetimes. Most history beyond 1,000 years is hazy, especially on a regional scale. Prior to the Norman invasion in 1066, English history is sketchy. Beyond 3000 years lie vast unknowns, nine thousand years exceeds the span of present human history. The probability of radical shifts in worldview and politics means that we cannot anticipate and warn future generations based on an understanding of the past, even when we anticipate the use of modem information storage capabilities. There are three types of future hazards. The best are those we can identify and reduce or eliminate, such as DDT and other chemicals. More ominous are those we know little or nothing about, such as some additive or emission -- for example, radioactivity wasn't thought to be harmful a century ago. Finally, there are hazards we know pose deep-future hazards but which we do not wish to ban -- long-lived nuclear waste, toxic chemicals essential to industry.

Instead, we decide to continue producing it and then shove it away in some dark comer, with warnings for the unwary and unaware. Ancient civilizations did this without a thought; Rome did not label its vast trash heaps, ripe with lead and disease. Working on the panel was intriguing but frustrating. We used scenarios to help fix specific possibilities firmly in the mind, allowing us to pick assumptions and work out their implications using common sense in a direct, story-telling way. Like extrapolating from the past, scenarios reduce infinite permutations to a manageable, if broad, group of possibilities. Watching the social scientists particularly grapple with the wealth of possibility open to them, I came to realize how rare are the instincts and training of science fiction readers. We do think differently.

Scenarios, as detailed stories, consider the physical as well as the social environment. They must also be bounded within some range of assumptions, or else the game becomes like tennis with the net down; not doing this negates the usefulness of scenarios in the first place.

Our initial assumptions were:

* • The repository will be closed after the proposed period of operation (25 years).

* • Only inadvertent intrusions were allowed; war, sabotage, terrorism, and similar activities are not addressed.

* • Active control will be maintained of the site during the "loading" and for a century after closure.

* • After active control, only passive measures will remain to warm potential intruders--no guards.

* • The radioactive materials will decay at currently projected rates, so the threat will be small in ten thousand years.

* • No fantastic (although possible within 10,000 years) events will occur, such as extraterrestrial visits, big asteroid impacts, or anti-gravity.

Modern geology can yield firm predictions because ten millennia is little on the time scale of major changes in arid regions like New Mexico. By contrast, myriad societal changes could affect hazards, as readers of science fiction know well.

Our four-man panel (no women accepted the Sandia Lab invitations) worked out three basic story-lines for life around the Pilot Project, based on the role of technology. There could be a steady rise in technology (Mole-Miner Scenario), a rise and fall (Seesaw Scenario), or altered political control of technology (The Free State of Chihuahua Scenario). Envisioning these, arguing them through, was remarkably like writing for Fantasy & Science Fiction.

The Mole Miner Scenario: If technology continues to advance, many problems disappear. As Arthur C. Clarke has remarked, "Any sufficiently advanced technology is indistinguishable from magic." A magically advanced technology is no worry, for holders of such lore scarcely need fear deep future hazards from present-day activities. Indeed, they may regard it as a valuable unnatural resource. Remember that the great pyramids, the grandest markers humanity has erected, were scavenged for their marble skins.

The societies which must concern us are advanced enough to intrude, yet not so far beyond us that the radioactive threat is trivial. Even though we here assume technology improves, its progress may be slow and geographically uneven--remember that while Europe slept through its "dark ages" China discovered gunpowder and paper. It is quite possible that advanced techniques could blunder in, yet not be able to patch the leaks.

As an example, 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 -- resource discovery.

The mole moves laterally through rock, perhaps fed by an external energy source (trailing cables), or an internal power plant. 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 into solid rock 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 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 Pilot Project. No surface markers will warn it off. Once intrusion occurs, isotopes could then escape along its already evacuated tunnel, out to the original bore hole, and into ground water.

This is the sort of technological trick sf so often explores. I contributed most of this story, while the social scientists considered less optimistic ones.

The Seesaw Scenario. Many events could bring about a devastating and long-lasting world recession: famine, disease, population explosion, nuclear war, hoarding of remaining fossil fuels, global warming, ozone depletion. Then the rigors of institutional memory and maintenance would diminish, fade, and evaporate. Warning markers -- and what they signify -- could crumble into unintelligible rubble. Later, perhaps centuries later, society could rebuild in areas especially suitable to agriculture and sedentary life. A tilt in the weather has brought moisture to what used to be southeastern New Mexico. Explorers would again probe the earth's crust for things they need. The political instabilities in the region during the dimly remembered Late Oil Age had kept some of the oil from being pumped out. A quest for better power sources for the irrigation systems of this reborn civilization then leads to the rediscovery of petroleum as an energy source. A search of old texts shows that much oil drilling had been done in the Texas region. Since all the oil was known to have been removed from that region, explorers turn westward to New Mexico. 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 scholars to see if they know anything about this."

"Ah, you know these old artifacts -- all rusted junk. Let's drill and see if there's oil. . . ."

This strongly recalls Walter Miller's classic A Canticle for Leibowitz -- our "Expert Judgment" recreating the genre, in clunkier prose.

The Free State of Chihuahua: The year is 2583, just after a century of political upheaval in the former American Southwest. After endless wrangling caused by regional interests and perceived inequities in political representation, the United States has fragmented into a cluster of smaller nation states. Similar processes have affected the stability of Mexico, traditionally plagued by tensions between the relatively affluent North and the centralized political control of the South. Its northern provinces have formed the Free State of Chihuahua.

Political uncertainty in the Free State leads to a large-scale exodus of Anglo-Saxons, as well as many long-established Hispanic families, from the former U.S. territories. They are escorted by forces loyal to one or the other of the new countries, who 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.

The Free State lacks foreign exchange and has a poor credit rating. Because it is limited in available natural resources, its people evolve into a scavenger

society, recovering, repairing and reusing all available technical artifacts from earlier times. While making excavations at the former site of Sandia Laboratory, Free State "resource archaeologists" (fancy-named scavengers) discover references to the ancient Pilot Project site, including photographs of waste barrels filled with abandoned tools, cables and clothing. They find fragmentary maps locating the site, but no references to radioactivity. In any case, social knowledge of radiation is limited, due to the development of non-nuclear energy sources during the 21st century -- the Age of Ecology now long past.

Arriving at the site, Free State resource archaeologists find the remains of markers which locate the site but do not transmit unambiguously the message that there is danger. They decide to enter. Later, the site is intentionally mined by people unaware of the potential hazard. They breach the site. Ground water gushes up the drill, driven by the long-sealed heat of radioactive decay. This scenario reminds us that no nation has survived for more than a few centuries. Large states tend to fragment into smaller, more culturally coherent ones. For example, the Austro-Hungarian Empire is today divided amongst at least nine smaller countries, and something similar seems to be underway in the ex-Soviet Union only seven decades after its inception. Union with northern Mexico is not critical to the scenario --one can visualize a variety of ways for political control to change. As political control alters, the possibilities of inadvertent intrusion rise.

Gabriel Marquez's One Hundred Years of Solitude alerted many of us to the subtle cultural differences between North and South America. Trying to store waste for ten thousand years of solitude reminds us, in turn, that cultural and geographical boundaries make no difference over such eras.

For example, an unspoken constraint on the U.S. program is that the waste must be stored within the country. Why not find better spots elsewhere? Mexico has many salt flats larger than the Carlsbad one.

One of the ethical philosophers on the sixteen-man Expert Judgment panel found this abhorrent. "Risk," he pronounced, "is not morally transferrable."

But of course it is. Anyone who works in a coal mine or lives near a heavily traveled highway incurs extra risk for some gain. How much risk to accept is a personal decision. The ethical pivot is that people should know the dangers they undertake.

But the Pilot Project points to a deeper problem. Over ten thousand years, no continuity of kinship or culture respects borders. Mexicans are the same as, say, New Yorkers--populations shift, societies alter. Risks resolutely kept in New Mexico are the same as risks piled up in Mexico City, for the people diffuse over these passing perimeters within a few centuries. The idea of nationality fades. We really are all in this together, in the long run.

Of course, the above scenarios don't exhaust the possibilities; they only sketch out the conceptual ground. We also considered a "USA Forever" yarn which assumed government could indeed keep continuous control. It yielded a smaller risk, but we thought it had much smaller probability of coming true.

Such stories are fine, but how could we use them to predict quantitative probabilities? Congress wanted a number, not a short story anthology.

We believed two elements of these scenarios most directly affect the

likelihood of inadvertent intrusion: political control of the site region, and the pattern of future technological development. How could we use this intuition?

Here we used a "probability tree," which links chains of events in a numerical way akin to the simple estimates I discussed in "Calculating the Future," (F&SF, September 1993). After much wrangling, we settled on a ballpark estimate of less than 10% chance the site would suffer intrusion.

The major risk came from the seesaw scenario of technological decline and rebuilding. For this we estimated the probability of drilling intrusion. The neighborhood (approximately 400 square miles) suffered roughly one drilling per year over the last century. Assuming random drilling, the buried waste's 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. Adding in other scenarios gives a final sum of a few percent.

Do I believe this? Of course not, in its details. When we wrote up our result, and found that the other three teams of four each had gotten the same few percent result, I reassured the head of the program that we could even guarantee the answer. "If there's an intrusion, I'll pay back ten times my consulting fee . . . ten thousand years from now."

Then I learned that since we finished our report first, the other teams knew our answer before they finished theirs -- bad technique. A convergence of opinion is common in all prognosticating, and "experts" like us were not immune to it.

I had further worries. 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 than the present and past. This implies that an irreducible unknown in all our estimates arises from our very worldview itself, which is inevitably ethnocentric and timebound. Are we being too arrogant when we assume we can accurately anticipate far future hazards or protection mechanisms? Probably -- but we have no choice. Waste of all sorts stacks up and we must do our best to offset its long term effects.

The Department of Energy was happy with our estimate. They and Congress could tolerate risks up to about ten percent. At present, the Pilot Project staff is gearing up for a trial run to further study the salt creep, how it seals, etc.

Personally, I believe the Pilot Project will be filled, and that's only the beginning. Storing all our accumulated nuclear waste, not just the low-radioactivity debris the Pilot Project is designed for, would take about ten more such vaults.

What's the point, politically or practically, in dispersing the sites? The only other site for disposal, Yucca Mountain in Nevada, is under heavy technical and political pressure. All our waste for a century could go into that single salt flat near Carlsbad.

Confining the area both lowers costs, reduces total risk, and localizes damage if it occurs. It's also politically astute. The locals want the work and the

opponents in northern New Mexico have nearly run out of legal delays. They seemed to operate out of a Not In My Back Yard psychology, with no alternatives. Part of the problem with waste of all sorts is that fears have been blown so high, few really perceive the rather minute level of risk. That was why Congressional fretting over ten thousand years from now seemed so bizarre to the panel, who actually knew something about real risks.

During our deliberations, television stations sent their cameras and environmentalists demonstrated. I asked one of the placard-carrying men where he was from. "Santa Fe," he answered. I was surprised; he lives many hundreds of miles from the site.

"They might bring some of that waste through my town, though," he said. He was right. Spills during transport are a real, if remote, possibility. I wanted to talk to him further about sentiment in Santa Fe, which leads opposition to the site, but I couldn't tolerate his company any longer. He was puffing steadily on a Marlboro.

He could well claim that smoking was his choice, his risk -- and unless he spoke out, he had no control whatever over nuclear waste. But then, there is always secondhand smoke. And the waste was generated by the federal government, an obligation settled upon all of us.

Neither Congress nor the Department of Energy has pondered the long-term issue of disposal in one site yet, but I think it is obviously coming. The waste must go somewhere.

If we halted all nuclear power and weapons production tomorrow, we would still have a vast pile of medical contamination to care for. Nobody, I believe, wants to do away with cancer diagnostics and treatments, which produce great volumes of mildly radioactive waste.

Suppose I'm right. This leads directly to the next question: How do we warn the future about the dangerous package we've sent down the timeline? A whole new panel pondered that question. I'll report on it next time.

Comments (and objections!) to this column are welcome. Please send them to Gregory Benford, Physics Department, Univ. Calif., Irvine, CA 92717.