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Comporting Ourselves to the Future: Of Time, Communication, and Nuclear Waste

Gregory Benford

Ten Thousand Years of Solitude

In 1989 I was contacted by an official at Sandia Laboratories in Albuquerque, New Mexico, which seemed a bit improbable. The House of Representatives had handed down a requirement for the Department of Energy. They wanted a panel of experts to consider a nuclear waste repository, and assess the risks that somebody might accidentally intrude on it over a ten thousand year period.

An impossible task, of course.

So it came to be that a few months later I descended in a wire-cage elevator, clad in hard hat with head lamp, 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 science fiction movie—engineers in blue jump suits whining past in golf carts, helmeted workers with fork lifts and clip boards, a neat, professional air.

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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...

A Brief History of Nuclear Waste and Its Treatment

Nuclear waste is an ever-growing problem. It comes in several kinds—highly radioactive fuel rods from reactors, shavings from nuclear warhead 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 into 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, 45 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 sprouted 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 Michelson 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 Phoenix.

So we members of the Expert Judgement 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?

Envisioning the Future

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 modern 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 corner, 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 were 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 warn 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 well affect hazards.

Our four-man panel (no women accepted the Sandia Lab invitations, for unknown reasons) 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 a story.

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. Quite possibly, 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. CATscan-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 science fiction 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* (1959)—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 US 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* (1968) 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 US 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.

The Nature of Risk

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 incurs extra risk for higher pay, and the coal users get energy without lung cancer. We who live near a heavily traveled highway—breathing fumes, because the rent is lower—are taking a small gamble. How much risk to accept is a personal decision. The ethical pivot is that people should know the dangers they undertake. People want to have some control over their risks.

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.

Refining the Scenario

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" (*The Magazine of Fantasy and Science Fiction*, September, 1993). After much wrangling, we settled on a ballpark estimate of less than 10 percent 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 from 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.

One Site or Many?

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 cigarette.

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 second-hand 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, and the site becomes large, truly important. This leads directly to the next question: How exactly do we warn the future about the generous package we've sent down the timeline? A whole new panel pondered that question.

Deep Time

Modern technology projects our grasp across great distances. Our Voyager space craft glide serenely beyond the solar system, headed out forever. Less obvious is our technology's reach through time.

We peer backward through tree ring dating (good to about 5000 years), Arctic ice bores (which measures layers of ice, good to about 200,000 years), and nuclear dating methods (good for the Earth's age, about 4.6 billion years). Through the astronomical time machine given by light's finite speed—the so-called "look-back" time—we can look out to several more billion years, culminating in the recent scrutiny of the early universe radiation. We have therein seen structure as it was about 15 billion years ago, only perhaps a few million years after the universe began.

We are much less aware of our reach in the other direction, the future. The Voyager probes carry plaques rhapsodizing over our culture, gestures which might be read billions of years from now. Cosmic time capsules. But on Earth, until this century, the Pharaohs were the champions at knowingly reaching down to their posterity—less than 6,000 years.

Nuclear physics changed all that. Now we leave a legacy—on the Earth's surface, not gliding serenely through space—through the long half-lives of the radioactive byproducts of nuclear power, weaponry, and medicine. These will be around for tens of thousands of years. Chemical wastes may also be as persistent.

I believe eventually even Not In My Back Yard politics will be unable to stop interment of wastes in the salt flats of southern New Mexico. Whether one regards this as a good idea or not, the political fact is that we have largely run out of time to decide how to store wastes. Increasingly, the public wants all sorts of wastes, nuclear or chemical or biological, interred far, far away from them.

Given this, how will we protect future generations from such deep-future hazards? How to warn them off the site? A second panel discussed the marker problem in detail, with necessarily science-fictional logic.

The Evanescence of Markers

One illuminating moment came after a day of intense discussion among the so-called Expert Judgment Panel. I was the only scientist there who was also a science fiction writer, but the group spanned most sciences, and included people like Theodore Taylor, the inventor of the Project Orion idea—spaceships driven by nuclear warhead explosions—in the 1950s.

We decided to detour near the Pilot Project site to find the site of another project—Project Gnome, which in turn had been part of a Project Plowshare. In 1961, Project Plowshare exploded a small warhead a thousand feet down in the same salt flat which the Pilot Project wanted to use for nuclear waste storage. The idea was to heat up rock salt and use the molten mass' residual heat to drive steam through electrical generators.

It failed. The blasted-out cavity soon caved in, burying the molten salt. One would think this might have occurred to an engineer before they tried it. But that was in the golden years of nuclear development, when ideas got tried for size right away, rather than spending a decade or so mounting up piles of paper studies.

We all got out of our government-gray cars and the drivers waved vaguely at the flat scrub desert, dust devils stirring among the sage. We spread out, shooing away grazing cattle. A hoot of discovery. A granite slab, tombstone-sized, bearing a copper plaque running green from oxidation. In big letters, PROJECT GNOME, followed by GLEN SEABORG, then Director of the Atomic Energy Commission, and in smaller type the generals and bureaucrats who had overseen this failed effort.

I walked around the slab and saw another plaque, its raised lettering rusted and nearly unreadable. We could barely make out some technical detail: kilotons, warhead type, purpose, amount of residual radioactivity. And at the very bottom:

THIS SITE WILL REMAIN DANGEROUS FOR 24,000 YEARS.

If we hadn't known our quarry, we would not have found it easily out on the dry plain. Drab, small, it did not announce itself.

We could tell, though, that it had been moved. Apparently, cattle needing a rubbing post had in thirty years nudged the slab several meters. How far away would it be in 24,000 years?

Marker Strategies

Our team, charged with estimating the chances of inadvertent intrusion into the Pilot Project salt flat buried 2150 feet down, also suggested possible strategies for placing

warning markers. We envisioned “miner moles” which would slowly tunnel through deep strata, searching for neglected lodes of valuable minerals. This implied a “spherical strategy”—deploying markers apparent from above, beside, and even below the deep repository.

The Pharaohs used one big, obvious marker for their tombs, the pyramid; we suggested small, dispersed tags as well, visible to “eyes” which could see magnetic or acoustic or radioactive signs. Acoustically obvious markers could be made—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 could be arrayed in two straight lines in the repository hallways, intersecting perpendicularly at the center: X marks the spot. Magnetic markers could produce a clearly artificial pattern, the simplest being a strong, single dipole located at the Pilot Project center. These could be magnetized iron deposits, flagrantly artificial. Specially made high-field permanent magnets could produce a clearly artificial pattern, the simplest being a strong, single dipole located at the hazard’s center. (This I took from Arthur C. Clarke’s *2001: A Space Odyssey*, 1968.)

Radioactive markers could be left at least meters outside the bulk of the waste rooms and drifts—say, small samples of common waste isotopes. Like similar weak but telltale markers left on or near the surface, these have the advantage of showing the potential intruder exactly what he or she is about to get into. No language problem.

All of these markers should be detectable from differing distances from the waste itself. Acoustic prospecting in the 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 might 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 slowly decaying.)

Can Warning Markers Be Self-Defeating?

But there’s a more basic decision: whether to mark hazardous sites at all. Perhaps the best warning is no warning. The only major unviolated burial site—King Tut’s Tomb—provided us with much of the Egyptian legacy; unmarked and forgotten because its entrance was soon buried under the tailings of a grander tomb, it escaped the grave robbers, who may well have included the priests of the time.

Could a hidden or forgotten hazard protect itself from harming future generations best of all? A “soft” surface marker which erodes in a few centuries would cover the short-term possibilities, I argued, and then avoid curiosity seekers in the far future. High technologies would still be able to sense the buried markers, after all.

Still, this imposes ignorance on our descendants, who may wish to avoid the place but not know quite where it is. Also, low-tech wildcatters drilling for scarce resources in some re-emergent future would have no warning.

Yet I proposed this anyway, mostly for fun. I suggested that standard-issue government concrete would be useful here: it disintegrates in about a century or so, providing everyone with a big, noticeable object for a reassuring lifetime, then erasing it.

Nobody much liked the idea, as I’d guessed. One of the major psychic payoffs in considering markers at all is the Pharaoh effect: the impulse to build a big monument

to ... well, oneself. Or at least one's era. They won't forget *us* right away! Even better if somebody else (the poor taxpayer) foots the bill.

Financial Considerations

Considering vast stretches of time tends to bring on lofty sentiments. But the present is mostly ruled by money, so as an example, the panel worked out the costs of erecting a Cheops pyramid, which has lasted 4,600 years. Using square blocks of granite, 9x9x9 feet, one could engrave all six sides with warning messages.

That way, if the exterior faces wear away, lifting one block would uncover a fresh inscription. The pyramid core could hold, not a Pharaoh, but a set of more detailed messages, for those in the future who will dig in out of simple curiosity (archaeologists), or those suspecting that there's a treasure in here somewhere, or else why go to all the trouble?

Making all the blocks of the same material eliminates problems arising from different thermal expansion rates, which can cause cracks. Tapering the pyramid less steeply than the natural slope of a sand pile would avoid much damage from earthquakes. Like the Cheops pyramid, the load bearing stress would be wholly compressive, using only gravity to hold it all together, with no tensile forces which open cracks.

Trouble is, that's expensive. If a single inscribed block costs \$5,000, they would cost \$62 million, about six percent of the to-date cost of the Pilot Project, though less than one percent of the projected cost over the site's entire active use.

This is no accident. Considering many different markers taught a tough lesson: longevity trades off against cost. There is no simple, good, cheap marker.

Thinking like a cost-conscious Pharaoh, suppose we make the blocks smaller, to ease assembly costs. That makes them easily climbed, increasing vandalism. It also means ordinary sized people can reach all the inscriptions without a ladder.

That opens a larger question: the greatest threat to the Pharaoh's pyramids and to a nuclear marker pyramid is pesky, grasping humans. In historic sites, metals quickly vanished, and buildings were quarried.

The Problem of Vandalism

Useful, cubic blocks especially might be carted away. The Cheops pyramid lost all its cladding marble skin quite quickly; ancient Greek travelers remarked on how they could be seen as bright white beacons, far across the desert, but no modern observer has found any of that left. (Indeed, we ought to remember that the Washington Monument was vandalized immediately after it opened in 1886, and the interior stairwell had to be permanently closed. Vandals don't respect greatness.)

One could offset such problems. For example, using interlocking but irregularly shaped blocks would stop their use elsewhere. Making the materials outright obnoxious might help, too—but stones that exude a bad smell steadily evaporate away, destroying the structure.

A better path might be to make the marker hard to take apart. Here the clear winner is reinforced concrete. The Cheops would take much less work to tear down than it was to build up, but the reverse is true, for example, of the Maginot and Siegfried lines of

the World Wars. Despite intense political pressure from local communities, the bunkers have proved to be too costly to take away. Contrast the colosseum in Rome, which has suffered greatly, with most of its building stones “recycled” into houses.

Probably the ancients understood this principle quite well—Stonehenge (1500 BC) used blocks of up to 54 tons and English tombs (2000 to 3000 BC) used stones of up to 100 tons. They thought the trouble was worth long-term insurance.

Our experience with concrete goes back 2,000 years; six of the eight Roman bridges built across the Tiber are still in service! We must be a bit cautious here, though, because quite possibly Roman concrete was better than ours.

This is because strong concrete demands a low ratio of cement to water, a very stiff mix that is tough and pricey to work with. The Romans used slave labor to ram firm concrete into place, and today’s contractors pump a sloppy, muddy mix through pipes. This can make the concrete twenty times less durable than the dry, high-grade sort.

But even such precautions run into a sad lesson of history. Pyramids and other grand structures often mark honored events or people. This might be the primary message a pyramid sends: here’s something or somebody important. Why not come see? And surely such a big monument won’t miss this little chunk I can pry off here...

Holographs and Dirt

This led both panels of experts toward marker systems—different-sized components, relating to each other so that the whole exceeds the sum of the parts. Vandalism doesn’t usually take everything, so the message gets through in a holographic sense. (About a third of the Stonehenge stones are missing, yet we can infer the entire design without much dispute. People differ over whether there is evidence of Mycenaean Greek influence in the architectural niceties, or just what the building was truly for, but its layout is clear.)

The best way to insure survival of truly enormous structures against both weather and pilfering is to make them out of dirt. Prehistoric mounds last well. The Romans build a long wall to keep out the Teutonic tribes, stretching from the Danube to the Rhine. Even in that wet climate, although the wood is completely gone, the earth berms survive. Hadrian’s wall in England is a similar case. The record is held by a chambered passage grave which is today a simple mounded earthwork in Ireland, older than 5,000 years.

Our expert panels thought along truly gargantuan lines. A simple berm of, say, 35 meters wide and 15 meters high, completely ringing the Pilot Project area, would demand moving about 12 million cubic meters of earth. The Panama Canal moved 72.6 million cubic meters, and the Great Pyramid occupies 2.4 million cubic meters. So this would be one of the grandest public works in history.

That’s initially to greet tourists, who might mistake even a huge berm for a natural hill, 10,000 years from now. To get their attention, the panelists wanted a ring of monoliths, probably of granite, bearing a variety of symbolic, pictographic, and linguistic inscriptions.

Stonehenge and other sites have taught us that to keep monoliths upright, more must be buried than is exposed, or else they should be firmly stuck in a rock layer below. They will probably have to be erect, too, because slanted monoliths have a poor track record. They develop tensile stresses at the surface, and in brittle material like granite, once a crack develops, it reaches a critical length—and then the whole monolith splits.

There are good reasons to make none of these from composite materials. This means the monoliths will be imposing, homogeneous rock, arranged in patterns that convey our message of threat.

But prudence suggests that we should also scatter small markers around the site, perhaps slightly buried, which attract attention even if the monoliths somehow fail. The panelists considered electrically active markers, reasoning that thermoelectric power (which would use the temperature difference between the surface and 100 feet below) or solar power is available.

The trouble is that even the most reliable electronic components, such as those used in undersea cables, only last a few centuries. More reliably, we could embed contrasting dielectric materials in the site surface, which reflect radar differently. These would give a good, artificial signal to airplanes or even orbiting satellites.

We could also bury time capsules, just a bit below the usual souvenir-hunter's digging zone, made of tough stuff—baked clay, tektite-like glass. These might be tablets, far better than the mud tablets the Babylonians left (inadvertently).

A Central Chamber

Finally, everyone agreed that there should be some sort of central chamber, where detailed messages are left. It would have a lot of plane surfaces for messages and could be completely buried. It could also include buried magnets, which would be detectable with a good pocket compass even if all surface signs of the site vanish. Their fields could point at the buried waste.

If we elect to put this central room above ground, there are several ways to go. We could use messages chiseled into granite, such as the biography of a Persian king, Darius I, which has lasted over 2000 years in open, dry weather. It had to contend with blown sand and carbonic acid in rain, but not with the sulfuric acid belched out by coal-fired plants, as now exist within a few hundred miles of the Pilot site.

Beyond 2000 years, consider a faint carving of a square-hilted dagger on the inner surface of a sarsen stone, which survived in an open field at Stonehenge for perhaps 4000 years. So expecting detailed messages to last 10,000 years is doubtful, though we have technologies unavailable to the ancients.

Probably a buried vault is our best bet—just what the Pharaohs chose. It would be the most interesting and complex marker in the whole site, well hidden, purposely designed to be the world's longest-lasting human artifact. If the above-ground monoliths were strikingly beautiful, maybe the locals would preserve the site because it is pleasing, rather than for its message—thus letting the message travel longer through time, perhaps to a more distant era which needs it more. Saving the striking, obvious structure would leave the vault below undisturbed.

A visitor would meet first the encircling earthworks, then a ring of monoliths—say, as wide as the length of a soccer field—and finally some central marker that would tell of (or suggest) the buried chamber. The idea is to draw them in, make them feel psychologically enclosed in the monolith circle, become “involved” with the stone monuments at the center, induced to read the pictographs and messages inscribed.

Transcending Language

Maybe we would be smart to convey the general emotional message in some direct way, independent of language. Suppose we erect some aerodynamically streamlined monoliths with gaps between them. These resonate in the wind, sending forth a hollow, mournful note. Most likely, such wailing rocks could establish a legend about the site that transcends language.

There's the rub—getting through to cultures and languages we cannot anticipate. The future may see our scientific age as a passing phenomenon, an idiosyncratic momentary deflection from some One True Path we would not even recognize. So how can we expect them to share our (often unspoken) assumptions, and thus read our warnings?

Generally, we can't. But there are ways of shaping a message so that it has some plausible chance of sailing intact across the great ocean of Deep Time. I'll take up those methods in the next section.

We may not be able to predict the future, but we can reach it nevertheless. One could characterize nuclear waste containers at WIPP as hazardous time capsules sent into the future, not knowing where they will land or what affect they will have, hoping (perhaps even assuming) that technology will solve the problems they currently represent.

In a sense the Pilot's task runs against powerful human archetypes. We aren't saying, as burial ceremonies do, "Take this child—his name is Klug." Or, "This mummy of our king we place here, for he needs resurrection." Instead, we're trying to say: We buried this and it's bad.

The only other alternative to this millennia-spanning waste problem is to forswear hazardous technologies in the first place; but we already have plenty of waste, with more accumulating from medical uses alone, so there really is no going back. Besides, how do you get people to give up x-rays and cancer treatments? We are stuck with our largely unrecognized reach into Deep Time. Seemingly minor acts today can amplify through Deep Time, leaving legacies we do not intend and in fact may not even know.

Consider Trinity Site, the spot where the first A-bomb was tested in 1945. At Ground Zero in White Sands, New Mexico, the blast left a glassy crater of fused aluminum silicates a quarter mile across and twenty-five feet deep.

Now there is nothing. Dry winds have cracked and filled the crater, tough desert plants have cracked it. Radiation levels are very slightly higher than the background of ordinary scrub desert. Life reclaimed its territory in a single human generation. The "message" of Trinity is gone.

The easy problem of Deep Time is time's rub. Greater still is the abyss of culture we must cross.

The barren Trinity site recalls Shelley's "Ozymandias":

*And on the pedestal these words appear:
"My name is Ozymandias. King of Kings:
Look on my works, ye Mighty, and despair!"
Nothing besides remains. Round the decay
Of that colossal wreck, boundless and bare
The lone and level sands stretch far away.*

Deep Time is as much the province of the poet as the scientist.

From Here to Eternity

Until lately, only science fiction writers thought about the truly distant future—beyond, say, 10,000 years. Now government is being forced to try.

I asked a computer-whiz friend how he thought we should mark the nuclear waste warning site, and he had a quick answer: "Scatter CD ROM disks around. People will pick them up, wonder what they say, read them—there you go."

After I stopped laughing, he said in a puzzled, offended tone, "Hey, it'll work. Digitizing is the wave of the future."

Actually, it's the wave of the present. This encounter made me think of our present fascination with speed and compression as the paradigms of communication.

I imagined my own works, stored in some library vault for future scholars (if there are any) who care about such ephemera of the Late TwenCen. A rumpled professor drags a cardboard box out of a dusty basement, and uncovers my collective works: hundreds of 3.5 inch floppy disks, ready to run on a DOS machine using Word Perfect 6.0.

Where does he get such a machine in 2094? Find such software? And if he carries the disks past some magnetic scanner while searching for these ancient artifacts, what happens to the carefully polished paragraphs, duly digitized on those magnetic grains?

Ever since the Sumerians, in communications technology we have gone for the flimsy, fast, and futuristic. To them, giving up clay tablets for ephemeral paper—with its easily smudged marks, vulnerable to fire and water and recycling as a toilet aid—would have seemed loony.

Yet paper prevailed over clay, so that though Moses wrote the commandments on stone, we get them on paper. Paper and now our trusty computers make information cheaper to buy, store, and transmit.

Paper isn't for eternity. But even tombstones blur, and languages themselves are mortal. How to talk across the ages, to call out a warning? How to even get the future's attention? We have to learn to write largely, clearly, permanently. And largely may be most important of all.

Buildings of religious, emotional, or memorial impact tend to fare well. Cemeteries, for example, hold their own against urban encroachment. One of the striking images as one approaches Manhattan is the broad burial grounds, which remain after centuries, despite being near some of the world's most valuable real estate. In Asia and Europe, temples and churches survive better than the vast stacks of stones erected to sing the praises of more worldly power.

Of course, often they were better built, but also communities are hesitant about knocking them down. Often, new religions simply adopt the old sites. The Parthenon has survived first as a temple to Athena, then as a Byzantine church, later a mosque, and now it stands as a hallowed monument to the grandeur of the vanished Greeks who made it.

Sometimes conquest destroys even holy places, as when the Romans in 70 AD erased the Temple of Solomon. Perhaps some conqueror thousands of years from now would pass by the Pilot Project monoliths, berms, and buried rooms (if, indeed, the rooms haven't been exposed, turned into a tourist attraction...). Seeing them as tributes to a society now vanquished, a general might order them all knocked over, buried, their messages defaced.

Something comparable happened many times over as the Europeans moved across the planet a few hundred years ago, rubbing out the religious and literary past of whole peoples. The Mayans wrote on both paper and clay, but nearly all of their work is gone.

The Eyes of the Future/The Cues of the Past

Our charge from the Department of Energy was to consider inadvertent human intrusion into the Pilot Project. An important adjective.

I personally do not think the human species will remain intact for even the next thousand years, much less the next ten thousand. Unless we soon halt progress in biotechnology, and don't recapture the ability to tinker with our own genes, I expect that variants on our Cro-Magnon theme will appear.

Other post-human species will have ways of thinking quite different from our own. Still, even if they have extensive physical modifications (one finger like a screwdriver? a stomach that can digest cellulose into sugars? a better designed back?), I expect they will share the deep programming we primates picked up far back there on the African veldt.

Among that ancient legacy is a set of preferences for particular landscape features. Universally, we share likings because they were adaptive. Such "landscape archetypes" may well be so strong because Darwinnowing for them covered many hundreds of thousands of years as small hunter-gatherer bands made their way across rugged terrain.

Developing consciousness got imprinted while the whole mind-body integration proceeded with dazzling speed. Tied every moment to weather and the wiles of other species, our ancestors sensed themselves as part of a living unity, the wonderful oneness of nature. Our enormous emotional ties to that view are a form of nostalgia, no less powerful for its distant origin.

Pre-humans who preferred the savannah prospered; those who liked swamps or highlands did less well. These "hard-wired" preferences have little survival value today, but in our cerebral cortex, the past shouts and the future can only whisper.

The biologist John Appleton believes three types of cues rewarded pre-humans who could pick them up: hazards, prospects, and refuges. Hazard-rich images or smells reach right into the brain, arousing anxiety that can only be resolved by taking action: the flight-or-fight response.

Taking action relaxes us, dissipates energies, may even bring pleasure. People heavily into this go to scary movies or ride roller-coasters, and get a genuine, evolution-ordained kick out of it. Most of us simply prefer landscapes we recognize, ones that balance prospect (views) and offer refuge. Also intriguing are places that invite exploration, i.e., aren't boring.

The Role of Myth

This kind of thinking goes further, into mythic consciousness. Presumably our evolutionary record is written into our basic internal stories, because once these tales were true. They sit down in the unconscious, ready to spring out and make surrounding events coherent.

Candidates for these are father, mother, authority, self, childhood, femininity and masculinity, gathering food, eternity, circles and squares (Plato's divine forms, somehow

useful back on the savannah), devil/evil, god/goddess/good (note the similarity of these words even in as advanced a language as English), sleep, pain, death, communion. I would add number, space and time—but then, I'm a mathematical physicist. These may be the very substratum of human experience, how we construct meaning, whether it be in myth, language, religion, art—or artifacts.

Joseph Campbell became famous for popularizing the species-wide myth-themes: virgin birth, the great mother, the creation of All from a chaos of nothing, the fire-theft, the plentitude of Eden and the beauty of paradise, the return of chaos in flood or deluge, the land of the dead, the dying and resurrected hero/god, the great quest journey, the sacred versus the profane, redemption through suffering and sacrifice.

We extract these stories from our environment because we are hard-wired to “see” them popping out, patterns which spontaneously order a chaos. The argument here is that what seems to us to be meaning in the world is in fact our projection of meaning into the world. But all this came from the utility of such filters, which sort out a savannah-like plain into easy categories.

Cognitive Structures at the Site

There are four classes of knowledge to convey at the site: simple (“humans made this”), cautionary (“danger!”), basic (“this is old and technical”) and detailed (“radioactives—leave alone”). The first is essential, because the others emerge only if the site is clearly artificial.

Seen from eye level, the whole pattern should strike one in a single glance. (The huge stone circle at Avesbury, not far from Stonehenge, fails to do this. It is not widely known because its stones are small compared to the circle, so one can stand in it and not realize the whole design.) Further, the site will compete with a plethora of all present monuments and an undoubted plentitude to come: statuary from the Civil War and wars to come, stumps from old freeways, the carcasses of banks and stadiums.

Most monuments proudly announce that the great Kilroy was here, so pay respect. The Pilot Project is self-effacing: we were here, so stay away. How can we get that message through, when posterity will by habit expect the usual one?

Some basic designs emerged. To honor important people or events we erect beautiful, soaring monuments which mirror our aspirations—the pyramids, Cleopatra's Needle, the Washington Monument, even the monolith in 2001. The waste site has to send the opposite message, straight into the collective unconscious, drawing the eye yet repelling the spirit. Perhaps we could learn from the Holocaust memorial in Berlin zig-zags, its hard edges offering no comfort or nobility.

Consider the *Black Hole*: a black basalt slab, unbearably hot from accumulated sun's heat. Laced with thick, crazy-quilt expansion joints like cracks in parched plains, it forbids farming or drilling.

Or the *Rubble Landscape*: the local stone, dynamited and bulldozed into a crude square pile covering the whole Project. It rears above the landscape, hard to hike through, a place destroyed, not made.

With a bit more trouble, *Forbidding Blocks*: that same broken stone, cast into mixed concrete/stone blocks 25 feet on a side, dyed black, irregular, distorted. They define a square, with chaotic “streets” five feet wide between blocks.

But the streets lead nowhere and no one could live or farm there. The blocks get very hot, and the whole crudely ordered array massively denies use. Some granite blocks stand out, covered with inscriptions, warnings.

The *Plain of Thorns* sprouts 80 feet high basalt spikes, erupting from the ground. They jut at all angles, which can cause cracking and faster erosion. To offset this, perhaps use a *Field of Spikes*, perfectly vertical, interspersed among the *Thorns*. If the *Thorns* can't fall and damage the *Spikes*, eventually only the *Spikes* remain, in a field of rubble.

The favorite of many panel members was a fifty-foot-high *Menacing Earthworks*, all radiating outward from the bare site center. These are lightning-shaped, jagged, crowding in on the tiny traveler, cutting off views of the horizon, chaotic. At the open center is the existing Pilot Project concrete hot cell, going to ruin.

Beside it, a vast walk-on world map of all repositories of waste. Also, a map of New Mexico showing this site. The map is of granite and slightly domed, so sand blows off, rain can't pool. A room buried beneath holds details about what lies in the salt bed below, as do four smaller buried rooms beneath the largest earthworks. Inscribed "reading walls" of granite appear throughout the site.

The common ideas here are irregular geometries and anti-craftsmanship. This contradicts human archetypes of perfection in our imperfect world, echoed by circles, squares, pyramids, and spires. Using crooked forms when plainly the designers knew "better" suggests a deliberate shunning of the ideal, a lack of value here.

People value craft, too, so these designs are roughly made, of materials such as rubble and great earthen mounds that discourage workmanship. Yet they are large, important—suggesting that there is no pride or honor here.

The Message and the Medium

This theme should echo through the inscriptions. Awe, apprehension, outright fear— independent of language or culture. Human figures and especially faces, made clearer by using bas relief. A face with hands, sculpted in abject horror, as in Edvard Munch's well-known painting, "The Scream," Or perhaps an eloquent warped face, nauseated.

With the wind blowing through the monoliths, coaxing mournful resonances from their curves, a dissonant and wailing aura should surround the place. Whatever cultures come and go, they should inherit a legend of a spooky, disagreeable place—whether or not anybody knows exactly why it is that way any longer.

Details such as that await the intruder who digs. Each design had a buried room at the center. There would lie plenty of duplicate technical detail, from lists of radioactive elements in the site to a periodic table of the elements itself, for correlation with the notation on the walls.

The buried vault might be plundered, though. Here the Sumerians left us a valuable lesson. Around the third millennium BC, they began writing on little clay tablets, letting them pile up in such numbers into the Christian era. This left us an unbroken line of hard documents with dazzling detail about religion, beliefs, economics, customs.

Similarly, we should seed the waste site with small, ceramic plates, carrying compressed warnings and information. This could offset vandals who wreck the big, imposing monuments, or natural disasters. As erosion changes, buried plates get exposed: time-released information.

If the locals can read them. But our current languages are not going to make it across the sea of millennia.

The Mutability of Language

Languages change unpredictably. They are so complex that tendencies to simplify one part (say, in grammar, when English shed the masculine/feminine/neutral articles and verb forms) will quite likely trigger complication in another (in English, more irregular verbs). Historical accidents bring great change. The main reason that English differs so profoundly from its closest German relative, Frisian (spoken in the northern Netherlands) is that the Angles were invaded by French-speaking Normans, and the Frisians were not.

No artificial language can avoid this, either. Esperanto, which once had about 50,000 speakers, was effectively killed when the U.S. and U.S.S.R vetoed using it as the working language of the U.N. However, there may well be no “natural” language emerging in isolation, as the great past tongues did. Our world is cross-linked by media and travel, so language evolution will be different, sophisticated. How? We can’t tell, because we have no general theory of how our amazing verbal arts evolve. *[Editor’s Note: Nonetheless, we can expect that the rate of language change may slow due to the globalization of media and culture: the relatively isolated pockets of culture in which accents evolved into dialects which in turn evolved into new language groups are less numerous and less isolated in an age of television, in which all ears hear the same voices. The continuing electronic and photochemical revolutions in media which began in the 19th century are a quantum break with all past communication systems, in terms of both speed of dissemination and preservation.—PL]*

So there will never be a science which predicts future languages, and the problem of writing in the Pilot Project markers becomes immense. After a few centuries, only experts can read even early forms of their own language; we can struggle through the original Chaucer, but forget Beowulf. If there is no great cultural discontinuity, probably a few antiquarians will be able to decipher English or any other current tongue. But antiquarians seldom consort with vandals.

Symbols and Narrative

The finders of these many buried messages might not be able to read the languages inscribed, but they might recognize a symbol. Our evolutionary legacy gives us some predispositions to seeing gestalt wholes, so we naturally group objects if they are enclosed by a line. We’re sensitive to edges, and pick figures out of ground readily. Breaking down information from large chunks into bits comes easily to us.

Symbols should play to this. We like narratives, and proved so 11,500 years ago when the big explosion of human sign artifacts began with Spanish Levantine rock art. These were pictographs showing hunters, weapons, clothing, prey, sexes.

Similar simplified line drawings could show stick figures burying the waste, warning others away. Others could present people digging or drilling into the site, ground water flushing through the hole, and then people getting sick, falling down, dying, then others mourning them.

The story should unfold in different ways, touching on the great mythic stories where possible. The Bayeux Tapestry of 12th century France, the Japanese scroll of “The Mongol Invasion,” and the Lakota Sioux picture story “The Battle of the Greasy Grass” (to us, Custer’s Last Stand)—all gather their power through successive images.

Storytelling is itself a powerful current linking eras. Why not use the oral tradition of the region to carry our warning? The *Iliad* and the *Odyssey* of Homer made their way to us through millennia as purely spoken stories, after all. Even after they were written down in the sixth century BC, the final text did not settle down for four centuries. A great saga commissioned to lend mythic status to the Pilot Project might do just as well.

But of course, nobody can reliably order up mythic works. Even if the work survived, told and retold, it will evolve, maybe lose its essential warning function. And experience shows that once oral traditions get written down, they fade as great tales. Books entomb storytellers.

Pictures

So we are left with a picture story. While a picture may be worth a thousand words, there’s always the problem of knowing which thousand words are evoked. In just this century, the swastika went from a positive religious symbol of India to the hated Nazi emblem. We want to call across the millennia, “poison—radioactive materials—don’t intrude”.

The panel of experts considered our most common symbol for radioactive materials, the “uranium” of three ellipses centered on a dot. But this merely describes, doesn’t warn. And some people think it’s a solar system.

The “radiation” symbol is international: a “trefoil” of a black circle with three vanes sticking outward. But it’s not an icon, it’s just an arbitrary design, and nothing about it that relates to the idea of radioactives. Some see it as floral or like a Japanese mon, a clan crest. One team member quipped, “Ummm—why are they burying all those submarine propellers?”

The skull and crossbones go back to medieval alchemists, who saw in it Adam’s skull and crossed bones promising resurrection. Only later did it come to mean poison, and though it’s international, it has problems. In an experiment with three-year-olds shown the symbol, they immediately shouted “Pirates!” Put it on a bottle and they shouted “Poison!”

There is, though, a certain basic horror built into the image of disembodied heads. Steve Harris, a UCLA research physician, pointed out to me that skull motifs evoke a primal primate fear, like fear of snakes. Chimps are alarmed by isolated chimp heads or other body parts. This is understandable in evolutionary terms, since animals that snack on chimps tend to leave such “markers” in their wake. Humans seem to share this. (In fact, I’m convinced that Shelley’s “Ozymandias” derives some of its power from the great, isolated head image.)

Even if no symbol will probably last ten thousand years, perhaps a cluster of them would help. The “Mr. Yuk,” a recently adopted poison warning, is a Happy Face reversed into a scowl, tongue sticking out, eyes squinting. Put that together, say, with a slashed circle, and X’ed out other symbols.

But what to X out? A drilling tower is easily mistaken for a monument itself. A pictograph of a stick figure digging doesn't hit the mark, because in fact nobody could reach the salt bed that way.

A big problem is that exposure to radioactive materials usually takes many years to do damage. One possible way to convey this is to tell a story, starting with a child figure encountering the waste (represented, say, by the trefoil). Then comes a panel with the symbol now on the figure's chest and young, short trees nearby. Next panel, the trees have grown and the child is an adult—lying down, scowling, feeling bad. Simple, direct—See Dick Run From Radioactive Death.

These may help convey meaning after all language connection with us is lost. A few antiquarians may know how to decipher the inscriptions, but wildcatters won't necessarily call on a distant university for help.

The Longevity of Beauty/The Ambiguity of Art

Some experts felt that while the monuments should be discordant, to carry the essential threatening message, they should have aesthetic appeal. "Beauty is conserved, ugliness discarded," one said. The pyramids may have survived in part because they are striking—they alone endure, of the ancient world's Seven Wonders—and the same might prove a useful strategy for the Pilot Project markers. "A gift from our century to the future," one suggested. Another proposed commissioning artists for a large scale environmental sculpture.

Trouble lurks here, I feel. So did panel member Jon Lomberg, who with Carl Sagan designed some of the interstellar diagrams on board the Voyager spacecraft. Even if we think our markers are ugly, he said, "How can you be sure it won't be mistaken for art?"

Art is ambiguous. As a universal language it tells little of the artist's intent. Cave paintings of animals don't tell us why they were made. Representational art fares better than symbolic, but the marker designs were quite symbolic, as is most large scale sculpture. Recall how often you've heard audiences puzzle over the intent of abstract painters.

Further, said Lomberg, "Even if we could commission some monument great enough to become a wonder of the world whose fame would be carried down through three hundred generations, the very fact that the marker was so impressive could lead to the belief that the purpose of the marker was artistic rather than communicative." A big, powerful sculpture isolated amid desert wastes could be seen as like Mt. Rushmore, a spot with a sole, uplifting message. A tourist attraction.

Art often has no function; it is an experience, period. Even art trying to be ugly, as with the fearful faces, can miss its supposed target. Picasso's "Guernica" wasn't really warning us about the Spanish Civil War. It spoke of a more general horror and anguish.

Worse, art draws a crowd. "We want people to stay away from this site, not travel from distant places to see it," Lomberg remarked. Suppose it draws tourists, come to see the ancient wonder. They need a hotel to stay, which needs water, so drilling begins ...

And does anyone expect that our government can commission great art? It has enough trouble agreeing on mildly interesting but intensely controversial photographers and performance artists. Lomberg remarked that for every successful commission there are a hundred failures, from the Prince Albert Memorial in London ("an architectural laughing-stock") to the Airman's Memorial in Toronto, locally known as "Gumby Goes to Heaven."

Lomberg pointed out that much of the art world is anti-scientific, anti-representational, and favors detached, nihilistic work. He doubted that our present art community would be well qualified to create or even select a design that was informed about the many scientific and technical intricacies needed—aspects like encroachment of sand dunes, material durability, future technologies.

Announcing a grand competition for ideas virtually promises that something will be chosen, adequate or not. “They’re likely to end up picking a giant inflatable hamburger to mark the site,” Lomberg said, grinning.

Suppose further that this Pilot Project does turn out to be the model of future sites. Will the French or Chinese use a marker system—symbols, art and all—like ours? Or will national rivalry rear its head? Two thousand years from now, people will be hard pressed to tell that these variously designed places scattered around the world have some common story to tell.

Bottom Line

Thus the present, irascible humanity of us all could well propagate into the far, far future. The Pilot Project will not be filled and need marking until around 2030, but thinking about it has begun precisely because we need to mull our way into that inconceivable perspective—a time when not merely we will have vanished, but probably our entire culture. This is the first radioactive sepulcher in the world, and may set the standard for all others, nuclear or otherwise.

This is merely our first conscious attempt to communicate across the abyss of deep time. There will be others, and unconscious aspects of how we present ourselves may be our longest-lasting legacy. The people of that time may know us mostly by our waste—and by our foresight.

About the Author

Gregory Benford is Professor of Physics at the University of California, Irvine. He conducts research in plasma turbulence theory and experiment, and in astrophysics, having published over a hundred scientific papers. He is a Woodrow Wilson Fellow and a visiting fellow at Cambridge University. Throughout the last decade he has worked as an advisor to the Department of Energy, NASA, and the White House Council on Space Policy. In 1989 he was host and scriptwriter for the television series *A Galactic Odyssey*, which describes modern physics and astronomy from the perspective of the evolution of the galaxy. His articles on science have appeared in *The Smithsonian Magazine*, *Natural History*, *New Scientist*, and *Omni*. He is also the author of over a dozen novels, among them *Timescape* (a Nebula award winner) and his most recent, *Beyond the Fall of Night*, written with Arthur C. Clarke. He has won the Nebula Award twice, the John W. Campbell award, and the Australian award for international novel. In 1989 he won the United Nations Medal in Literature.