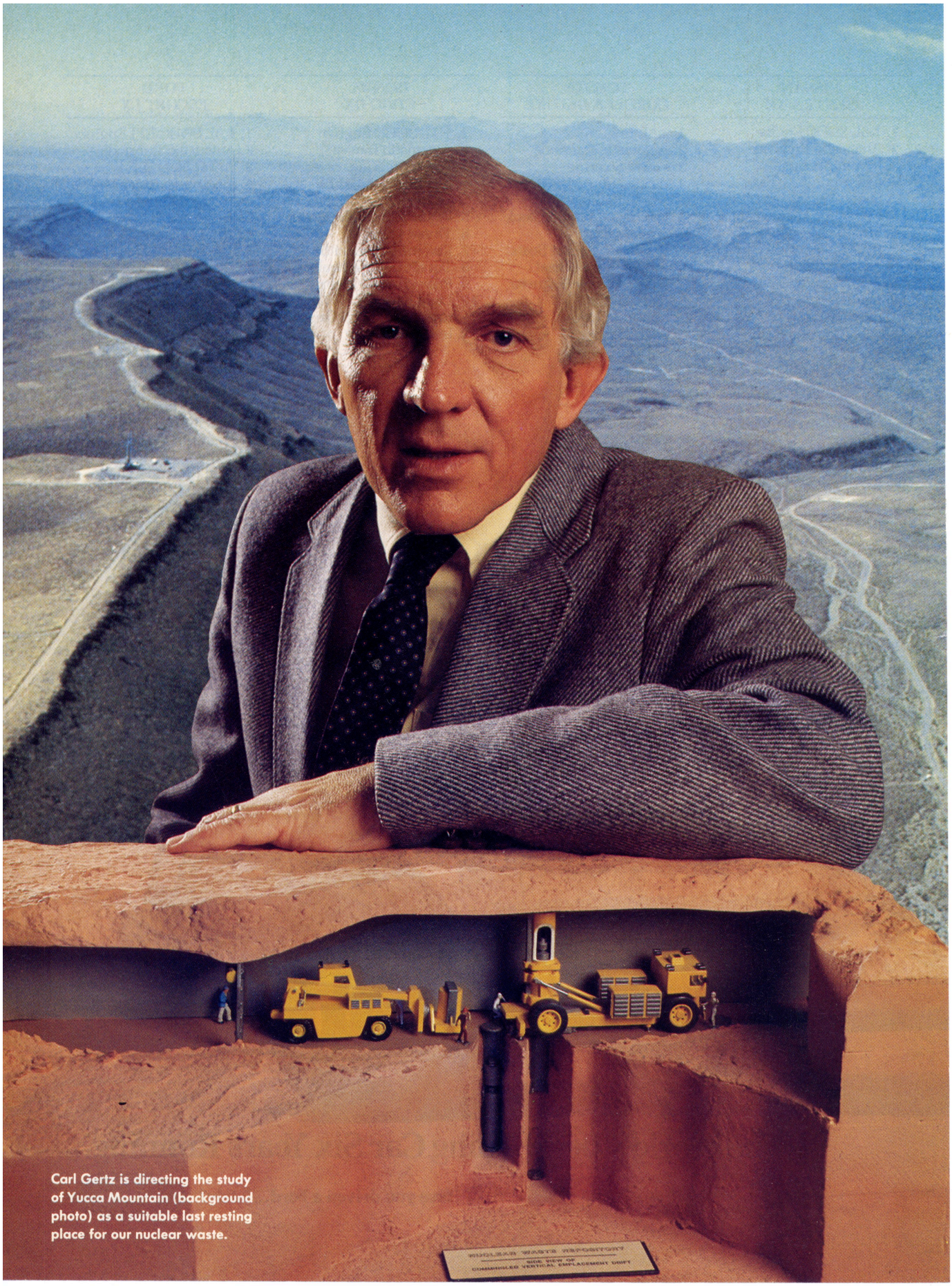



Carl Gertz is directing the study of Yucca Mountain (background photo) as a suitable last resting place for our nuclear waste.

# A NUCLEAR DUMP: THE EXPERIMENT BEGINS

**Deep beneath the Nevada desert, geologists are trying to give the nation's radioactive waste a decent burial.**

BY DAN GROSSMAN AND SETH SHULMAN

The train ride into the middle of Rainier Mesa is dark and deafening. As the dusty, roofless metal cars clang and screech their way into the blackness, an occasional incandescent bulb exposes the rough-hewn walls; the bulbs mark the closed-off entrances to the many passages branching from the main shaft of G-Tunnel. For an instant as the train rolls past, the dim yellow glow illuminates signs that warn of radioactive contamination in the side tunnels. Twenty-five years ago they were the site of some of the United States' earliest underground nuclear explosions.

A mile into the mesa and 1,400 feet underground the train slows as it reaches Bob Schuch's laboratory. Up an incline the tunnel widens to a large chamber where workers drill and saw into the volcanic rock; the area is cluttered with tools, instruments, and heavy machinery. Beneath the desolate landscape of the Nevada Test Site, in this subterranean maze that once thundered with explosions of our burgeoning nuclear arsenal, Schuch and his crew are part of a $2 billion, seven-year effort by the Department of Energy to settle on a final repository for the radioactive refuse of the nuclear age: the overflowing stacks of spent fuel from the nation's nuclear power plants and some of the deadly spoilage from our nuclear weapons factories. The radioactive waste already exceeds 22,500 tons. If Schuch's work pans out, a nearby ridge called Yucca Mountain will be riddled with passages in which the nuclear material will be stored.

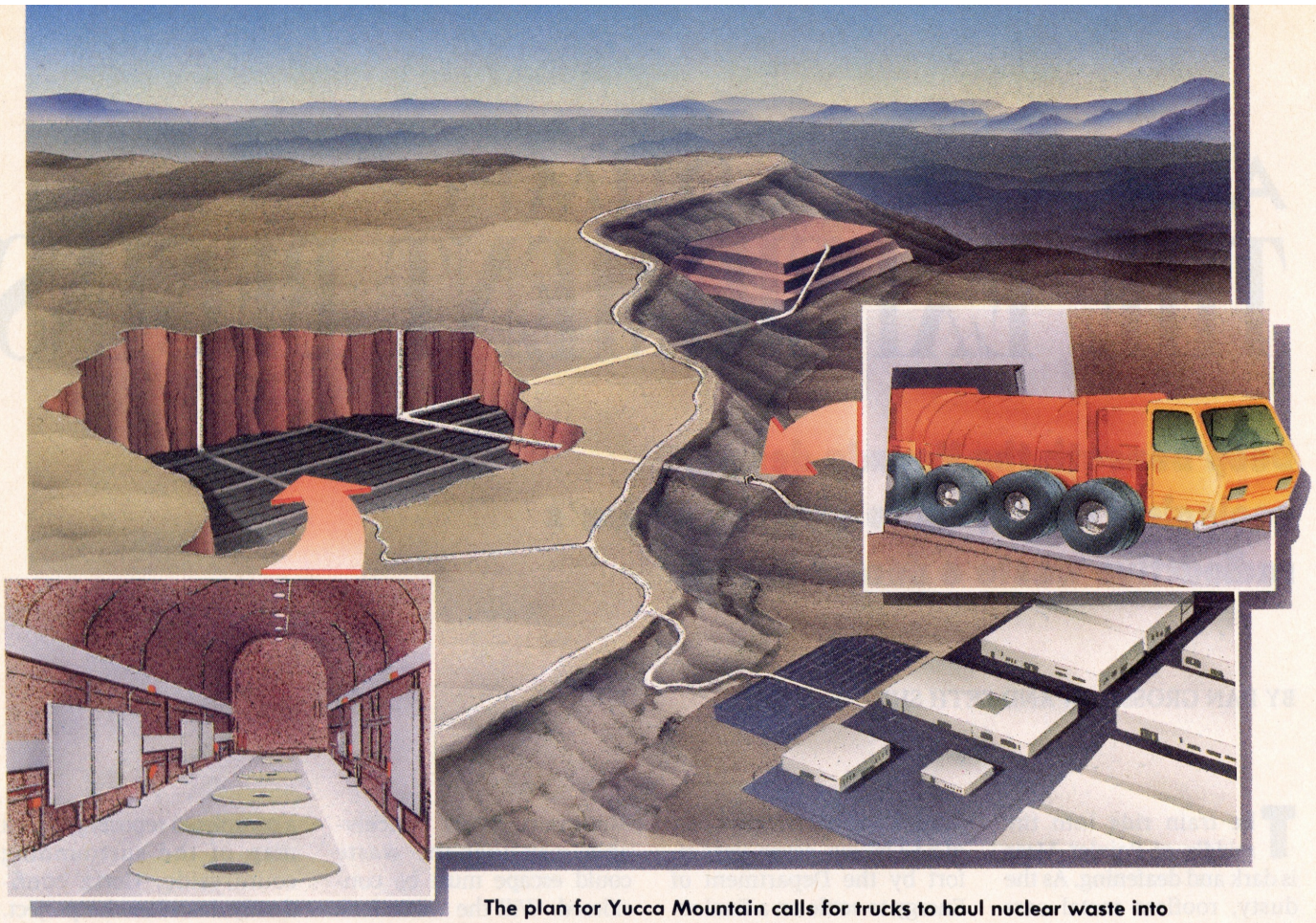
As test coordinator at G-Tunnel, Bob Schuch's job is to determine whether the volcanic rock in the area will provide the waste with a stable and contained resting place for at least 10,000 years—that's how long the Department of Energy says it will take for the slowly decaying material to lose its toxicity. Schuch must study the behavior of the rock under various stresses and predict what the fate of the region will be for millennia to come. Before any spent fuel can be buried at Yucca Mountain, every conceivable way that the waste could escape must be considered. Will the waste leak into the water table? Will it escape into the atmosphere? What will the weather be like for the next 10,000 years? What are the odds of a catastrophic earthquake or volcanic eruption?

The bustle of activity in G-Tunnel belies the long road ahead before a repository is finally built. It will take years of cutting and testing, both at Rainier Mesa and Yucca Mountain itself, before enough is known to determine whether Yucca Mountain is an appropriate site. Only then can the actual construction begin, at an eventual cost that current estimates place as high as $35 billion.

The person with overall responsibility for the project is Carl Gertz, who from his Las Vegas office directs an extended staff of more than 1,400 researchers and support personnel in four government laboratories across the West, in addition to many private contractors. Standing by a scale model of a completed repository and a map of the surrounding countryside, Gertz confidently describes the project. "We are right here," he says, aiming a pointer at 1988 on a time line of the project. If all goes according to plan, Gertz will finish the study of the site by 1995, about a foot to the right on the chart. Two feet to the right of Gertz's pointer is 2003, the year the agency hopes to open the repository. If the chart spanned the entire repository life, a marker 10,000 years from the opening of the facility would be located more than a quarter of a mile farther away.

According to Congress's plan, shafts like Schuch's G-Tunnel will honeycomb an area of more than 1,500 acres inside Yucca Mountain. The total length of tunnel will be 112 miles—nearly the size of the New York City subway system, the world's largest. Altogether the tunnels will accommodate some 63,500 tons of high-level nuclear waste—a staggering amount of radioactive material. Nevada officials have estimated that even with

PHOTOGRAPHS: BACKGROUND, COURTESY PAN AM PHOTOS; INSET, BY ERIC SANDER/GAMMA-LIAISON



**The plan for Yucca Mountain calls for trucks to haul nuclear waste into gently sloping tunnels that will descend more than 1,000 feet below the surface. The containers of radioactive material will be stored in the floors of a maze of storage tunnels (inset at left). After an estimated 90 years, and if no problems develop, the tunnels will be filled in and sealed, in hopes that the repository will remain undisturbed for ten millennia.**

trucks arriving at the site every workday at 90-minute intervals, it would take 28 years just to bring all the waste to Yucca Mountain.

Of course, that's all according to the plan as it's now formulated. By the end of those 28 years there could be tens of thousands more tons of waste to be dealt with. The Department of Energy is required to report to Congress before 2010 as to whether the repository must be expanded or whether a new site must be added.

If the struggle that led to the tentative choice of Yucca Mountain is any indication of the difficulties that lie between now and 2003, Gertz, Schuch, and their crew have their work cut out for them. The debate over what to do with radioactive waste is as old as the nuclear industry itself. Nearly all 114 existing U.S. commercial nuclear power plants were built long before any real solution to the waste problem was envisioned. And there are 16 more plants planned. It has just always been assumed that sooner or later a storage method and a site would be found. Former Nevada governor Grant Sawyer, chairman of the state's high-level nuclear waste commission, excoriates the nuclear industry and federal regulators for failing to find a solution. He likens the inaction to "sending John Glenn into orbit without figuring out how to bring him down."

About 17 percent of the waste slated for Yucca Mountain will come from military nuclear reactors, in the form of highly radioactive liquids that have been vitrified—encased in solid blocks of glasslike material. The other 83 percent of the waste will be in the form of spent fuel rods from nuclear power plants around the country. Fuel rods form the core of a nuclear reactor. They consist of thousands of uranium pellets encased in 12-foot metal tubes that are just twice the diameter of a pencil. A typical U.S. commercial reactor contains 40,000 fuel rods, bundled in "fuel assemblies" of around 200 rods each.

After three to four years in a nuclear power plant the fuel rods are spent; that is, they no longer can sustain a usable nuclear reaction. At this point they are among the most highly radioactive objects on Earth. About 4 percent of the weight of a rod is composed of extremely radioactive plutonium, strontium, cesium, and other isotopes created during the fission reaction that is the source of a reactor's power. The remainder contains less radioactive but still hazardous uranium isotopes. While there is little chance that the waste can explode like a nuclear bomb, even the briefest human contact with a fuel rod is fatal. The tiniest fleck of plutonium—say, a millionth of a gram—will cause lung cancer. And up to ten years after they're spent, the rods still give off, along with the radiation, 10 kilowatts' worth of energy in the form of heat, adding to the challenge of safe disposal.

Today the spent rods are stored in cooling ponds adjacent to the nation's nuclear reactors. Many of the cooling ponds are already near capacity; the ponds were designed, after all, only as temporary way stations for the fuel until a permanent disposal site was found. And as they've filled up, operators at many reactors have opted

ILLUSTRATION BY IAN WORPOLE

**With a diamond-tipped chain saw (embedded in the rock wall at upper right), technicians are able to cut large blocks of rock for testing.**

PHOTOGRAPH COURTESY U.S. DEPARTMENT OF ENERGY

that research he conducted for the Department of Energy showed this volcano to be fewer than 20,000 years old, not 300,000 as once believed. Wells made his estimate by comparing the physical features of the Lathrop Wells Volcano with a volcano in the Mojave Desert that's known to be 15,000 years old. In Lathrop Wells, he says, "there are no gullies or channels." This lack of erosion implies that the volcano may have appeared only 5,000 years ago, increasing the likelihood of another eruption. He is conducting further studies to pinpoint the age.

While this news could hardly be comforting to proponents of the site, Gertz remains undaunted. He emphasizes that the volcanoes in Crater Flat were formed from oozing lava and not from the kind of explosive eruptions that created Yucca Mountain itself over 9 million years ago. "Another eruption like we discovered at Lathrop Wells," he says, "would not hurt a thing." His office has, however, revised its estimate of the probability of an eruption actually occurring within the repository area: originally given as one in a billion per year, the probability is now said to be within a range that stretches from one in a billion down to one in 10 million.

The Department of Energy is also making plans to test a hypothesis that there may be a chamber filled with magma, or molten rock, deep under Yucca Mountain. Because rock generally reflects and refracts seismic waves differently when it's molten, explosives will be detonated to produce shock waves that travel deep underground; the waves will be distorted by differences between deposits, and if a molten body exists, it should return a distinctive signal.

Earthquakes are another concern, and Yucca Mountain sits between two prominent faults. Since 1857, when the region was settled, there have been eight major earthquakes—with a rating of at least 6.5 on the Richter scale—within about 250 miles of the site. Gertz says that the repercussions on the underground repository of even a sizable earthquake would probably be minimal because tremors diminish in effect that far below the surface. He acknowledges, however, that an earthquake could be devastating to the aboveground facility where the waste would be delivered and prepared for burial. But this would be a concern for only the next 100 years or so; after that the repository would be full and the waste-handling buildings dismantled or sealed in concrete. To lessen the short-term risk, however, the surface structures would be constructed to resist a severe quake.

Along with geologic disruptions, the other great concern is water. The Yucca Mountain site—which is not far from Death Valley, the driest place in North America—was selected in part because of the lack of rainfall: the area receives only three to six inches of rain each year. This is important because rainwater could leach down through the rock and hasten the corrosion of the canisters that are designed to contain the waste for the first few hundred years. Water reaching the waste could ultimately cause it to seep down to the underground water table. Plans now call for the radioactive material inside Yucca Mountain to sit about a thousand feet above the water table but still well below the surface. Geologists call this the unsaturated zone.

Before it can be shown that a repository at Yucca Mountain can safely contain the waste, much more must be learned about the properties of this zone. Early estimates indicate that the amount of rainwater that would actually reach the depth of a repository is probably less than .02 inch per year, well below the amount that would be a concern. But little is known about the way water can travel through tuff—the volcanic rock that makes up Yucca Mountain—over thousands of years.

The tuff deposits forming the area were produced by volcanoes 13 million to 18 million years ago. Some of the volcanic deposits cooled more quickly than others, creating soft rock formations known as nonwelded tuff. The problem with nonwelded tuff is simple: the spongy material crumbles with just a slight kick. The Department of Energy will attempt to locate the repository in a layer of rock that cooled more slowly, in material known as densely welded tuff. This rock is still porous, but strong, with 12 times the compression strength of concrete. Densely welded tuff also happens to be one of the world's most difficult types of rock to excavate. In G-


**In G-Tunnel, deep beneath Rainier Mesa, tests are run to determine the structure of rock around nearby Yucca Mountain.**

PHOTOGRAPH COURTESY U.S. DEPARTMENT OF ENERGY

to store the rods closer together, at a density that the pools weren't designed to handle. Quite simply, there aren't too many other options. Some nuclear power plants have already applied for permission to build new, off-site cooling ponds to store their continuing accumulation of spent rods.

Initially Yucca Mountain was just one of several sites around the country that were to be studied as a home for the radioactive waste. The Nuclear Waste Policy Act of 1982 specified that several sites be evaluated and that two—one on either side of the Mississippi—ultimately be chosen based on technical suitability. On the last day of its 1987 session, however, Congress amended the law, voting to evaluate only Yucca Mountain for the nuclear dump.

Many Nevadans see that vote as a political decision that made a sacrificial lamb out of a state with one of the smallest delegations in Washington. Although debate on the floor focused on the cost savings of evaluating only one site, they have little doubt that the decision was designed to minimize opposition to the facility. In what Richard Bryan, U.S. senator from Nevada, says was "a feeding frenzy," 49 states "ganged up" on Nevada.

State officials and some scientists now worry that the work at Yucca Mountain will be biased toward finding the terrain acceptable. "Congress put all its nuclear eggs in one basket," says Bryan. Others outside the state agree. As Massachusetts congressman Edward Markey warned his colleagues: "If this site proves unsound . . . we will be left without a nuclear waste disposal program of any kind. As Nevada goes, so goes our nation's nuclear waste policy."

Everyone involved in the project can feel the pressure. Nevertheless, Gertz insists that the scientific conclusions will be technically sound. If the research does not prove the site to be safe, he vows, "then we don't want to build the repository there."

Increasingly, though, some scientists involved in the effort are complaining that the lack of alternatives is making acceptance of Yucca Mountain a foregone conclusion, no matter what the scientific evidence shows. Recently, for instance, some of Gertz's recruits from the U.S. Geological Survey wrote a disgruntled letter claiming that the work on the repository may have already "moved away from objective site characterization and into site construction." The 17 scientists and engineers stated that "in subjugating the technical program to satisfy Department of Energy political objectives, we may succeed in making the program comply with regulations, while being scientifically indefensible." Joe Downey, a hydrologist who signed the letter, says, "I've never seen the Survey involved in such a mess before. There are serious problems with Yucca Mountain that should be studied and fairly presented."

Standing on the summit of Yucca Mountain it is easy to imagine why the site was chosen. The view is an unbroken panorama, extending more than 50 miles in every direction, with the only evidence of civilization the single-lane dirt road leading to the mountain. In fact, very little life of any kind can be seen beyond the sparse, drab green brush and tan tufts of grass that put a slight fuzz on distant hills.

Despite its isolation, there is a long list of questions that must be answered before Yucca Mountain can get final approval. The concerns range from such "low probability but high consequence events" as volcanoes or earthquakes to the many questions concerning water, both deep in the Earth and falling as rain.

The view from the summit also makes it easy to understand why Gertz is concerned about geologically "high consequence events." The moonlike landscape surrounding the ridge bespeaks a violent past. Busted Butte, for example, a small peak only about five miles away, is sheared in half, the eastern side lifted several hundred feet upward. Yucca Mountain itself is bounded by a number of geologic faults, the most obvious being the Solitario Canyon Fault, which created a sheer cliff that plunges nearly 1,000 feet from the summit into Solitario Canyon.

Just to the west a handful of perfectly symmetrical volcanic cones rise above Crater Flat. One of these is the Lathrop Wells Volcano, only 12 miles from Yucca Mountain. Last March, Stephen Wells, a University of New Mexico geologist, reported

Tunnel, Schuch and other researchers are conducting a number of experiments on the rock. Some of them will be repeated in an exploratory shaft that will eventually be dug at Yucca Mountain itself.

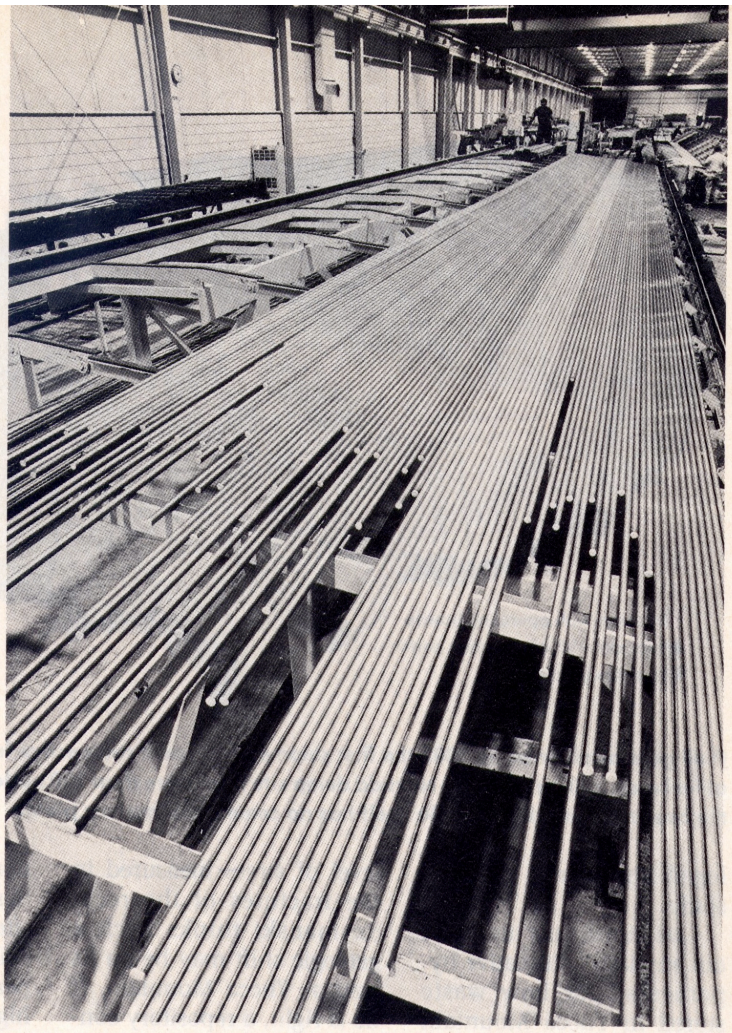
One of these experiments, known as the heated block, will help predict the performance of a repository filled with hot waste. Spent nuclear fuel continues to decay and generate heat long after it has been removed from a power plant. Schuch notes that tuff has many properties that make it ideal for holding such hot material. It is a good conductor of heat, so it won't melt. And its fractured structure would allow steam to escape if water seeping through pores in the rock reached the boiling point. Without these fractures, steam under high pressure could further weaken the rock.

The heated block is an eight-foot cube of rock cut into the tunnel floor. It looks like a huge square peg in a slightly larger square hole, remaining attached only on the bottom. Schuch's crew needed more than three months to form the block by drilling lines of adjacent holes and breaking the thin walls of stone between them. Since this block was formed a tool has been devised that will greatly ease the preparation of such experiments in the future: an eight-foot, remote-controlled, diamond-tipped chain saw that seems to eat away a slot almost effortlessly, shooting rock and debris against a Plexiglas shield. With the saw, a heated block can be created in less than a month.

Heaters placed in holes drilled in the block simulate the heat of waste canisters. Pressure is applied to the cube by steel chambers cemented between the block and the floor from which it was cut. More than 300 instruments, all connected to a central computer, stud the block and measure temperature, compression, and expansion.

For one experiment already performed at G-Tunnel, researchers applied pressure to the block in a variety of directions; they heated it to as high as 212 degrees Fahrenheit; and, after driving all of the water out of the block, they even flooded it. The idea was to apply every conceivable condition.

Other experiments will help determine exactly how water flows in unsaturated welded tuff. If water travels only by seeping between the pores of the rock, it will move much slower than if it flows through the tiny fractures found throughout the deposit. One of these tests will measure how quickly water travels between a series of bored holes and a sealed alcove that can be placed under pressure.



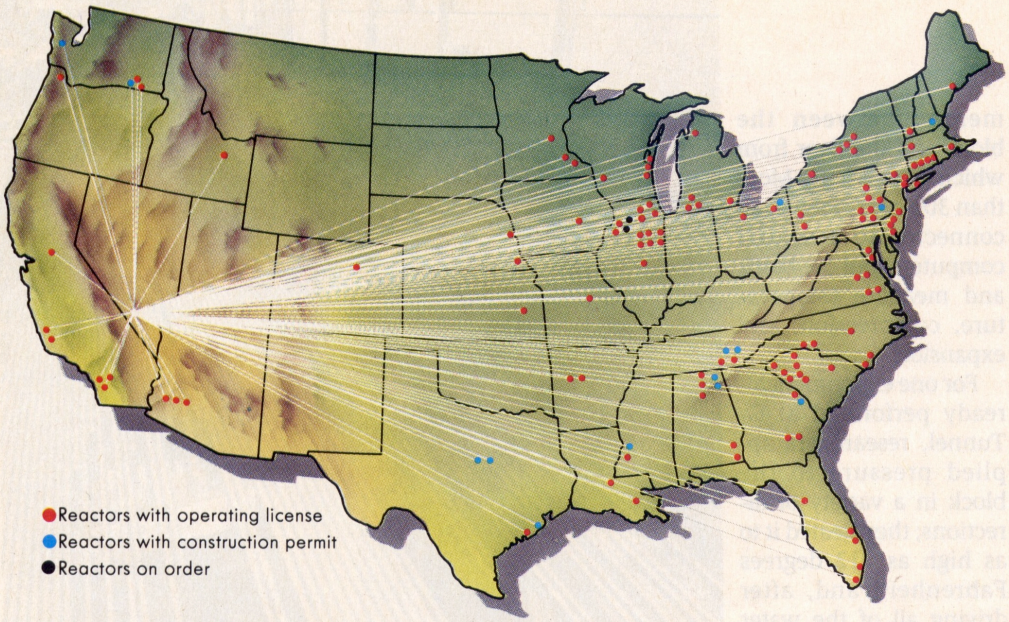
**Fuel rods can power nuclear plants for just three or four years. For the next 10,000 years they are dangerous radioactive waste.**

PHOTOGRAPH COURTESY U.S. COUNCIL FOR ENERGY AWARENESS

Given the importance of keeping water away from nuclear waste, it comes as a surprise that deep inside G-Tunnel a steady trickle of water can be seen dripping from the uneven ceiling. Schuch is quick to explain that this is only "perched water" and thus of little consequence. What he means is that these streams come from reservoirs deposited in the distant past somewhere in the mountain towering above the tunnel. Construction of the tunnel itself released the water and caused it to begin dripping. Schuch says these deposits are of limited size and would not threaten canisters of waste. Even Downey, the hydrologist who has criticized the Yucca Mountain research, confirms that this water is not a great concern. "It's really a small amount of water in the great scheme of things," he says. Just to be sure, however, the Geological Survey is working on ways to collect and measure the flows.

Much of the work at G-Tunnel is designed to improve the tools and techniques for studying water in the unsaturated zone. For example, most methods for drilling and cutting tunnels use water to cool the tools and to prevent rock powder from becoming airborne, where it can endanger the health of workers. But excessive water usage at Yucca Mountain's exploratory shaft would contaminate the studies of water movement and could even make the deposit unsuitable for waste storage. Researchers from Los Alamos National Laboratory are testing dry cutting methods that remove dust with powerful air blowers, like a vacuum cleaner, rather than jets of water. Another technique, for tools that cannot operate dry, involves recirculating and recovering as much water as possible.

The tests of water content in the rock samples are critical, and so great care is being taken not to contaminate cores of extracted rock. A special drill coats the samples with a plastic tube as fast as they are extracted from the deposit so that the traces of water found at each depth are retained. These "sealed cores" will be cata-




**If all goes as planned, in 2003 the first shipments of spent radioactive fuel, mostly in the form of fuel rods, will arrive at the Nevada dump site from more than 100 nuclear power plants around the country. Ironically, Nevada itself has no commercial nuclear plants.**

loged and stored for later study.

Last April, just to ferret out any last "alternative hypotheses" for how waste stored in Yucca Mountain might be disturbed and contaminate the environment, the Department of Energy held an open conference. According to Gertz, the only theory any of the 150 participants could come up with that was not already being studied closely was proposed by Jerry Szymanski, a Department of Energy physical scientist. According to Szymanski's theory, which is detailed in a maverick report that originally reached the public after it was released by the Nevada governor's office, the region around Yucca Mountain is in the midst of a cyclical state of geologic activity that causes the volcanic rock to contract and expand over time.

Every 20,000 to 30,000 years, Szymanski believes, these cycles may cause a large shift in the depth of the region's aquifer, pushing the water table up as much as 1,000 feet. Given the current level of stress measured in the fractures of the rock, Szymanski thinks such a geologic shift may be on its way at Yucca Mountain. If he is right, a repository constructed at Yucca Mountain could someday be flooded. The current level of the water table is, he says, "purely a matter of tectonic consensus, subject to change without notice."

One of the key clues that led to Szymanski's theory was the discovery of mineral deposits—what Szymanski calls "footprints of the past"—on and just under the surface of the area around Yucca Mountain that indicated that water had been there at one time. If the mineral deposits came from rainwater, says Szymanski, they will peter out with depth. But if they were formed by a rising water table they will extend deep underground. The only way to know for sure would be to conduct further investigations. If the theory is corroborated by new evidence, Szymanski's report concludes, "serious consideration should be given to abandoning the Yucca Mountain site and declaring it as unsuitable for the purpose of permanent disposal of the high-level nuclear wastes."

Szymanski believes that a concerted effort could settle the issue in just three to four months, although he concedes that the characterization program will eventually gather the necessary data in any event. "We're going to study everything he's recommended," says Gertz, but he has no plans to give Szymanski's theory a higher priority than is given to any other.

More doubts about Yucca Mountain were raised in November by researchers from the University of Nevada and Arizona State. They questioned a method used by government scientists to determine the date of geologic disturbances. The technique analyzes a paper-thin coating of minerals that formed on rock surfaces that were exposed to the air by past landslides, earthquakes, or other geologic disturbances. Over time, various elements leach out of such layers, allowing an estimation of the date when the rock was first exposed. The disagreement is over the rate at which the elements dissolve. The university geologists claim the age of geologic disturbances is being overestimated. The project scientists agree that the technique at least needs to be refined.

Even as doubts linger about the suitability of Yucca Mountain and the quality of the research there, growing disclosures of mismanagement of nuclear facilities around the country by the Department of Energy have eroded public confidence in the department's ability to handle such materials. Many of the nation's largest and most important facilities producing nuclear weapons materials have recently been shut down because of contamination and safety violations. Equally disturbing, a long-awaited storage facility for liquid nuclear waste from military reactors, built near Carlsbad, New Mexico, continues to be stalled because water leaks in the deep salt caverns underneath the desert were found even before the facility officially opened.

Frank Clements, office manager at the state-sponsored Nuclear Waste Task Force in Las Vegas, sums up the discontent and unease felt by many: "The Department of Energy maintains a hundred twenty-seven facilities, and it seems that ninety percent of them leak. Coming from a gaming town, those don't sound like good odds to me." ❑

ILLUSTRATION BY IAN WORPOLE

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