The 10,000-Year Test

Federal scientists focus their scrutiny and more than $1 billion on Nevada's Yucca Mountain, the probable site of the nation's first high-level radioactive waste dump

By RICHARD MONASTERSKY

Nuclear. The word has made its home in our generation, as a prefix before such terms as power, weapons and even medicine.

But three decades after the first full-scale nuclear power station went on line, four decades after an atomic explosion mushroomed over Hiroshima, we are still searching for a place to store the legacy of our nuclear age.

Accumulating in huge water pools at the 106 licensed nuclear power plants across the United States, there are approximately 15,000 metric tons of spent uranium fuel, still highly radioactive but unusable. The Department of Energy (DOE) has estimated that by the turn of the century, the fuel figure will near 50,000 tons. According to the Nuclear Regulatory Commission (NRC), which licenses the power plants, almost all of the plants will reach their present authorized capacity for storage within the next decade, and storage facilities will have to be expanded.

With the last days of 1987 at its heels, Congress passed an amendment to the Nuclear Waste Policy Act of 1983, which is the blueprint for the nation's plans to dispose of radioactive waste by burying it below ground. Abandoning part of the plan that required the DOE to characterize simultaneously three possible sites for a repository of high-level waste, Congress shifted gears and authorized the department to proceed in studying what it regards as the most promising site, at southern Nevada's Yucca Mountain on land adjacent to the Nuclear Weapons Testing Site (SN: 1/2/88, p.7).

According to the DOE, the present plan is to dig into the stone heart of Yucca Mountain and build the repository there. Once filled to capacity with 70,000 tons of waste around the year 2030, the repository will be completely sealed off and its entrance shafts refilled. The artificial, engineered barriers of the repository combined with the sheer bulk of Yucca Mountain will isolate the waste and protect the surface environment.

While it sounds simple, the plan is complicated by one sobering fact: The radioactive waste to be placed in the repository will remain dangerous for more than 10,000 years.

The canisters that contain the fuel are designed to resist corrosion for only 300 to 1,000 years. After that, it is up to the geology of Yucca Mountain to keep the radioactive atoms, called radionuclides, from leaking into the environment. During the next five years, the DOE will be working with the U.S. Geological Survey (USGS) and several national and private laboratories to see if Yucca Mountain can rise to the occasion.

Despite its impressive appellation, Yucca Mountain is actually a 6-mile-long ridge that stands only 1,000 to 1,500 feet above the surrounding canyons and desert flats.

Construction of the repository is set to begin in 1998, and the present schedule aims for an opening date in 2003, says Steven Kale, associate director for the DOE Office of Civilian Radioactive Waste. But before construction begins, the DOE must obtain a license by convincing the NRC that the proposed repository will meet certain safety standards.

There is no doubt that the repository will leak over the course of the next 10,000 years; it is not expected to contain 100 percent of the radionuclides. Rather, the NRC will be deciding whether the repository can sufficiently *limit* the radioactivity that reaches the environment.

In 1985, the Environmental Protection Agency (EPA) set standards for the disposal of radioactive waste. According to the standards, the radioactivity from a repository should not cause more than 1,000 human deaths over the next 10,000 years. This number was chosen because it represents an estimate of the deaths the uranium ore would cause if the ore had never been mined.

Individual annual doses of radiation are not supposed to exceed 25 millirems, which is about one-quarter the level of the background radiation that constantly bombards us each year in our normal environment. The standards also require that groundwater traveling from the repository to the accessible environment cannot take less than 1,000 years for the journey.

The repository will be located in volcanic rocks called tuff — a porous matrix of compacted ash — that are remnants of explosive eruptions dating back 8 million to 16 million years ago. At Yucca Mountain, the volcanic rocks extend to a depth of 6,500 feet, and the repository itself will sit about 1,000 feet below ground.

Even at such a depth, the level of the water table will be 700 to 1,400 feet below the repository, placing the repository in what scientists term the "unsaturated zone." Of the three potential locations the DOE was considering for the underground repository, the Yucca Mountain site was the only one located in the unsaturated zone, and it was primarily this feature that made it the most attractive possibility, say federal engineers.

Below the water table, in the area called the saturated zone, water is under pressure and moves relatively rapidly through the rock. But in the unsaturated zone, water is scarce and slowly percolates through the tuff, says Dan Gillies, acting chief of the nuclear hydrology program at the USGS in Denver.

Approximately 6 inches of rain fall onto

the barren slopes of Yucca Mountain each year. But most of the water cannot seep into the almost soilless ground; it just runs off the rock into the ephemeral washes that appear only during rainfall. Of the water that does penetrate the surface, much will evaporate, even if it sinks several feet into the ground. Hydrologists estimate that only 0.02 inch of the annual rainfall ever reaches the deeply buried saturated zone.

Geoscientists think the radioactive material in the repository is most likely to contaminate the environment if it is in liquid form. From the repository, it could percolate down to the saturated zone and then flow into aquifers, which feed into public water supplies.

However, most of the repository waste will be solid and packed in canisters, and the DOE believes that the scarcity of water in the unsaturated zone should help keep the waste from developing into an oozing threat. Low moisture means the canisters can resist corrosion, perhaps for centuries longer than their expected lifetime. When rust finally does breach the containers, there will be relatively little water to dissolve the waste.

The waste that does dissolve in water will become mobile, and therefore dangerous. But federal scientists say they are confident that the snail-paced flow through the unsaturated zone will prevent dissolved radionuclides from quickly reaching the human environment.

"There is good reason to believe that in the unsaturated zone, the groundwater travel time from the repository to the accessible environment greatly exceeds 1,000 years," says Gillies. In fact, according to the Yucca Mountain Site Characterization Plan issued last month by the DOE, the current evidence indicates that it takes groundwater longer than 10,000 years to flow from the repository through the unsaturated zone and into the saturated zone. After such a long period, much of the waste will no longer be radioactive.

Yucca Mountain's arid environment will play a major role in slowing the leakage of radionuclides from the repository. But it's hard to forecast what the weather will be like for the next 10,000 years. A glimpse that far back into the past, for example, shows a world that was significantly cooler, with huge ice sheets covering sections of North America and Eurasia.

"If there is a major change in the climate, it could increase the water flux through the unsaturated zone, and it could also raise the water table," says Gillies. Either of these changes might significantly lessen the time it takes radionuclides to leak into the environment.

One way of reading the possible climates of the future is to page through the geology of the past. The USGS researchers are going to study how the climate of southern Nevada has changed over the past 2 million years. Soil records, salt beds formed by evaporation and the evidence of ancient lakes can help scientists recreate the rainfall rates and environments of previous millennia.

"I'm not terribly concerned about the tectonics. I'm far more concerned about whether we, the scientific community, can make an argument that is sufficient to satisfy the licensing requirements and the public perceptions."

Even the fossilized nests of pack rats can aid the study. These animals make their nests from leaves, twigs and any other available material. The age and content of each nest reveals the kind of climate that surrounded Yucca Mountain at the time.

"You know you're not going to find a pine cone out there in the middle of a desert," says Gillies. A nest with a pine cone, therefore, would suggest a more temperate, wetter climate.

Hydrologists also need to develop a better understanding of the way water moves through both the saturated and unsaturated zones. Besides filtering through the tuff matrix, water can flow through fractures in the rock. Instruments inserted into boreholes will help gauge the present flow rates of water, and modelers can use these data to provide estimates for future water movement.

Geochemists will be examining the way the tuff chemically interacts with the radionuclides and retards their movement. Many dangerous atoms are expected to precipitate out of solution instead of traveling with the groundwater, and others might adsorb onto the rock.

By analyzing the chemical state of the groundwater itself, other researchers can determine how quickly water will dissolve the waste. Moreover, those designing the canisters will need to know the groundwater chemistry near Yucca Mountain in order to choose a material that is most resistant to corrosion.

Since the waste will still be generating heat during the early years of the repository, some scientists will be examining the thermal properties of the tuff. This heat, they believe, should help dry out the rock surrounding the canisters, thereby limiting the corrosion of the metal.

Still unclear is the best position of the canisters in the repository—for instance, whether they should sit horizontally or vertically. In either case, engineers plan to leave an air gap between the container and the surrounding tuff. Because moisture moves through pores within the rock and is predominantly confined to the rock, the air gap should prevent water from reaching the canisters.

As another element in the characterization process, geologists will be investigating Yucca Mountain for the presence of natural resources such as mineral deposits, oil and natural gas. Those developing the repository want to ensure that there is no special reason why future generations will drill into territory near the site, giving radionuclides an easy path to the surface. The EPA standards require that the DOE consider such a scenario, and there are plans to build monuments that would warn away denizens of the centuries to come.

Scientists working on this part of the project will have to consider issues that seem more at home in a science fiction novel than as part of a federal project. It will be difficult to guess what materials may be valuable in the future. So geologists are trying to determine whether the Yucca Mountain area possesses any substance that is not common elsewhere in the Southwest. As well, those designing the monuments will have to decide what language or signs will greet potential intruders over the next 10,000 years.

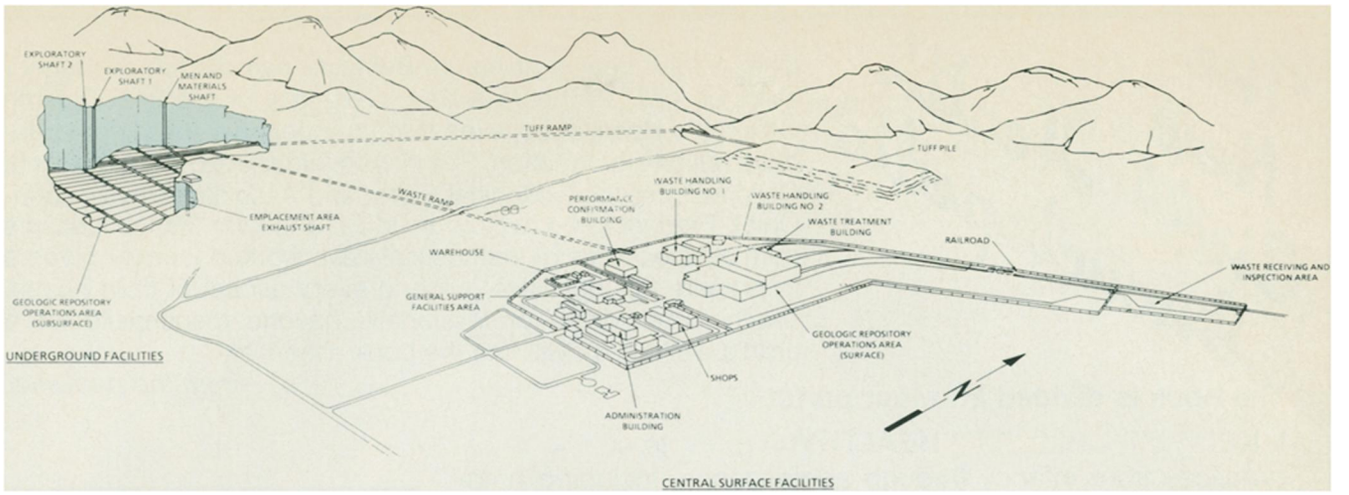
Yucca Mountain sits in an area that has seen a fair share of earthquakes and volcanic eruptions, and such events loom within the nightmares of a public that is already wary of things nuclear.

But geologists involved in characterizing Yucca Mountain believe these kinds of natural disasters pose little threat to the repository within the next 10,000 years.

"For tectonic reasons, the chances of there being a volcanic episode right at the site are not that great," says Robert Raup, who coordinates the USGS geologic division in Denver.

As for earthquakes, geologists find it difficult to make predictions for the next 10,000 years. But seismicity predictions over that period might not be necessary, because the federal scientists believe that quakes would not significantly impair the performance of the underground repository. Says Raup, "Faults, fractures and shaking underground don't seem to be much of a problem. They *would* be a problem at the surface facility."

While the repository is open and receiving waste, there will be buildings at



DOE

A home for more than 10,000 years: Located 1,000 to 1,500 feet below the top of Yucca Mountain, the underground grid of disposal rooms (shown in cutaway) will be the final resting place for high-level waste from nuclear power plants and nuclear weapons construction. The temporary surface facility will sit on land to the east of the mountain. As part of the characterization process, the DOE will start drilling the first of the two exploratory shafts (cutaway) in June of 1989.

the surface where workers will prepare and package the waste, and it is this surface facility that will be the most vulnerable to strong ground motion.

In terms of earthquakes, therefore, geologists must focus their predictions on the next 100 years and decide on the best position for the surface facility. However, these tasks are not out of the range of ordinary seismology.

"I'm not terribly concerned about the tectonics," says Raup. "I'm far more concerned about whether we, the scientific community, can make an argument that is sufficient to satisfy the licensing requirements and the public perceptions."

There is no doubt that the DOE will have an armful in dealing with public perceptions of nuclear waste. Throughout last fall, as Congress considered the amendment to the Nuclear Waste Policy Act, representatives of Nevada pitched an all-out battle to keep the nation's waste from settling in their backyard.

A recurring theme in this struggle was the charge that politics rather than science had led to the selection of Yucca Mountain. In reference to the amendment, Sen. Harry Reid (D-Nev.) said, "The proposal is an act of naked and unprovoked aggression by the people of several states against a state which is smaller and which has less power." Since no state would volunteer to babysit the nation's radioactive waste, it was politically expedient to gang up on Nevada and dump the waste there, says Reid.

For the most part, opponents of the amendment have not raised scientific objections to the Yucca Mountain area. As yet, there is no direct evidence that Yucca Mountain is ill-suited for housing the repository.

Nonetheless, the DOE is not free from criticism. In particular, there are concerns about the methods the department is using to assess how the repository will affect future generations.

Gordon Thompson, head of the Institute for Resource and Security Studies in Cambridge, Mass., has worked for the State of Washington on risk analysis of a repository sited in Hanford, Wash., which was one of the three choices the DOE was exploring. He has looked at the kinds of risk analyses the DOE was performing — analyses that will play a key role in the evaluations of the Yucca Mountain site.

"There were a lot of analysis procedures used that I think are basically smoke and mirrors," he says. According to Thompson, the DOE should have been more conservative in estimating the risk of exposure to radiation.

Moreover, he says: "You're stretching science to and beyond its limits to project the [radiation] doses tens of thousands of years into the future."

While political opposition is not the concern of the scientists involved in the Yucca Mountain project, this last point is not easily dismissed. Weighing on the minds of many researchers are questions about the limits of scientific certainty.

For example, if there is an increase in stress on the rock underground, the pores in the saturated zone could shrink. Like a hand squeezing a sponge, this would reduce the amount of water the saturated zone could hold, and in turn would raise the level of the water table.

According to Raup, geologists consider such a scenario to be most unlikely during the next 10,000 years. "But that's not enough for licensing requirements. We're going to have to back that up with facts and observations and multiple hypotheses," he says.

When the NRC decides whether to license the construction and operation of the repository, it will be judging whether there is a "reasonable assurance" that the repository will meet the safety standards. It will be asking about the certainty of the scientific predictions.

And these predictions will have to satisfy safety requirements that may be more stringent than the present EPA standards. Last summer, a federal appeals court decided that the EPA's standards for radioactive waste disposal contained several inconsistencies that had to be either resolved or explained, a finding that sent EPA back to the drafting tables. The new standards, like the previous ones, will be incorporated into the NRC's own guidelines.

According to Scott Sinnock, supervisor of the Geoscience Analysis Division at Sandia National Laboratory in Albuquerque, N.M., the DOE will face a daunting task in trying to prove that the repository can meet the standards. "Whoever has the burden of proof in science loses," says Sinnock. "In other words, if we have to prove the site is good, beyond any doubt, that's an impossible scientific task. I don't care what the mission is. But if someone has to prove that there is a significant likelihood the site will fail, they will lose. It depends on where the burden of proof is thrown."

Somewhere between these two extremes lie the requirements for the NRC's decision. Investigations will probably not find a factor that obviously invalidates the site, says Sinnock. Rather, the decision-making process will be much more subtle, relying on the best predictions that scientists can offer.

Will these be good enough? Sinnock wonders. "The geotechnical community," he says, "has never been asked to predict for 10,000 years or longer as the basis of a current political-social decision." □