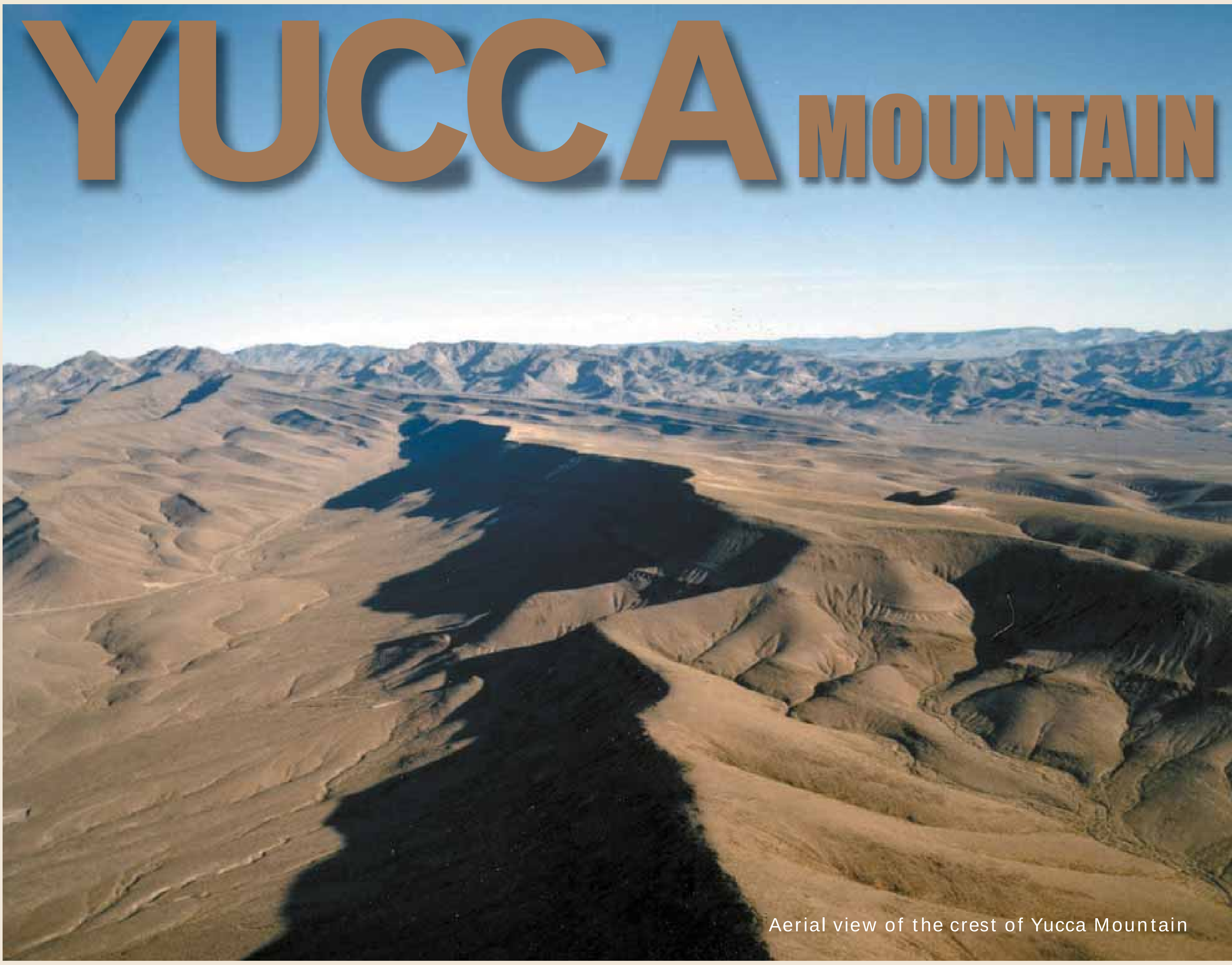
# YUCCA MOUNTAIN



Aerial view of the crest of Yucca Mountain

***Story by John German***

***Photos courtesy of US Department of Energy***

Estimate, with defensible scientific rigor and full acknowledgement of uncertainty, the expected risk from radiation that a hypothetical farmer one million years in the future might receive from a planned deep underground nuclear waste repository.

That's the technical challenge — required by the US Environmental Protection Agency (EPA) and the US Nuclear Regulatory Commission (NRC) — met in June 2008 when DOE's Office of Civilian Radioactive Waste Management (OCRWM) submitted to the NRC the license application for Yucca Mountain. The more than 8,600-page application seeks authorization to construct the nation's first repository for spent nuclear fuel and high-level radioactive waste.

Then, on Sept. 8, the NRC docketed DOE's license application, accepting it as sufficiently complete to begin the NRC's technical review. This acceptance, in turn, began the expected three- to four-year license application review and public hearing phase, during which DOE and its experts will be asked to provide additional information and testimony in support of the application.

## Steps forward

"We took several key steps toward opening a repository in 2008," says Tito Bonano (6780), Sandia's Yucca Mountain senior manager. "But we have a lot of challenges remaining."

As the OCRWM Lead Laboratory in the Yucca Mountain Project since 2006, Sandia's job was to support DOE in preparing and submitting a credible and supportable license application for the repository, including its technical and scientific basis.

The proposed Yucca Mountain Repository would, for the first time, provide a place to put some 70,000 metric tons of waste from commercial nuclear power plants and defense activities. Currently 58,000 metric tons of commercial spent nuclear reactor fuel is in storage at 114 reactors in 39 states, with an estimated 2,000 metric tons of additional spent fuel generated each year at the nation's 104 operating nuclear power plants.

Yucca Mountain — a ridge of porous, fractured, volcanic rock located 90 miles northwest of Las Vegas — could be the most studied geologic feature on Earth. Bored into the side of the mountain is a 25-foot-diameter tunnel that reaches more than 1,000 feet below the surface.

Inside the repository's emplacement tunnels, called drifts, lined end to end would be specially designed cylindrical containers made of some of mankind's toughest metals and most corrosion-resistant alloys, confining the byproducts of six decades of nuclear power plant operations, defense research, submarine and ship propulsion, and other US nuclear activities.

Some of the radionuclides proposed for disposal at Yucca Mountain, such as cesium-137 and strontium-90, generate high levels of radiation but have relatively short half-lives of several tens of years. Other radionuclides such as plutonium-239 and -242, neptunium-237, technetium-99, and iodine-129 have half-lives in the tens of thousands of years.

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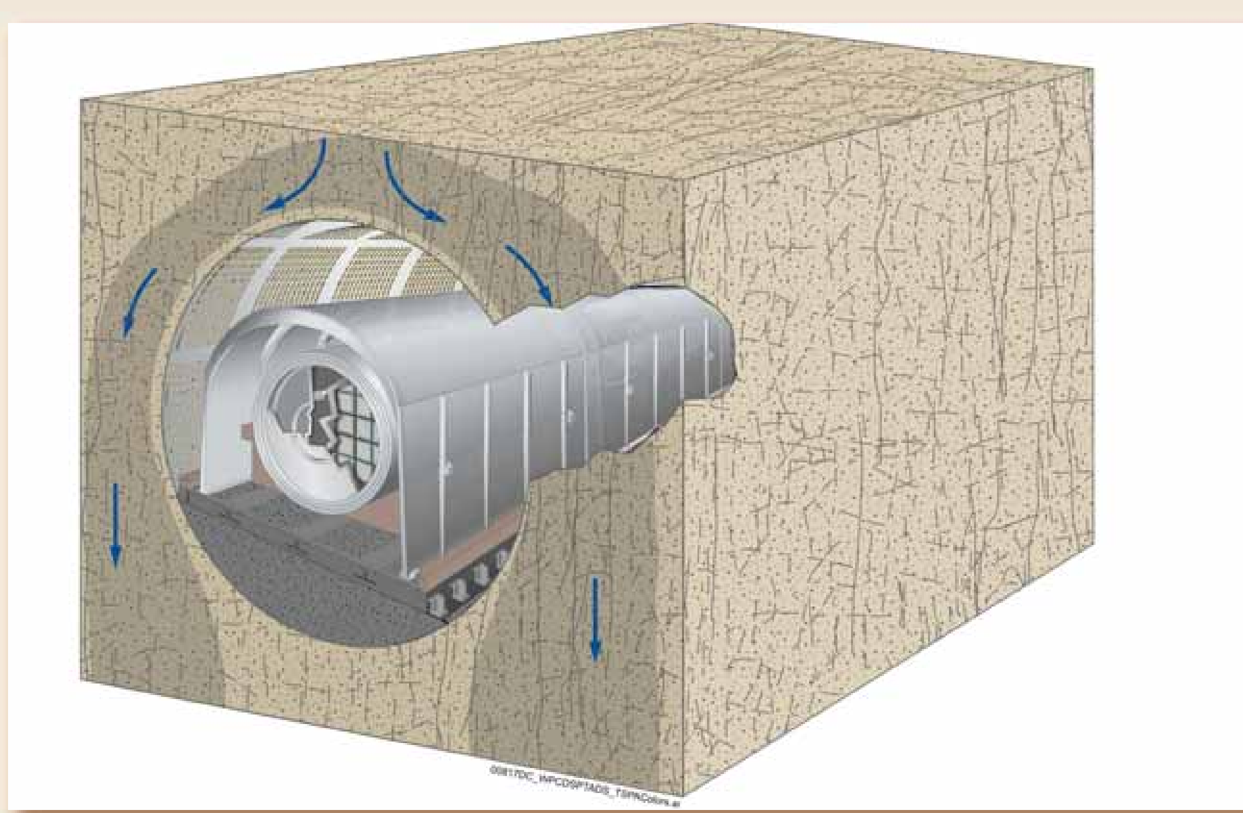

CUTAWAY ILLUSTRATION showing an emplacement tunnel, drip shield, waste packages, and the expected flow of water around a tunnel.

A MINING MACHINE excavates alcoves and niches for experiments.

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## Million-year performance

"Developing a license application for the site was a science and engineering problem unmatched in its complexity," says Tito. At its heart, the application assesses the likelihood that the repository system — the combination of natural barriers and man-made barriers working jointly and redundantly — would effectively isolate the waste for up to a million years, that estimated doses would comply with regulatory requirements, and that the site would ensure public health and safety.

"In a sense, this is the ultimate multidisciplinary program," says Tito. "It involved geology, hydrology, climate, physics, math, and engineering, all wrapped into one massive computer simulation, and culminating in a set of dose estimations."

Opening a high-level radioactive waste repository in the US is necessary for three reasons, he says: 1) DOE is required by federal law to take possession of spent fuel from the nation's commercial nuclear power plants; 2) expanded nuclear energy capacity in the future means the US soon must have a method of dealing with spent fuel; and 3) as the beneficiary of nuclear power, this generation has an ethical obligation to take care of its byproducts.

But the Yucca Mountain Project has not been without controversy, and this has been recognized in the oversight of the project.

"We live in a fishbowl of external review and scrutiny," Tito says. But the scrutiny is appropriate given the magnitude of the decision being made, he says.

Says Nuclear Energy Programs Line of Business Director Andrew Orrell (6800), who until July was Sandia's Yucca Mountain senior manager: "We recognized early on that the progress of the project is best served by credible and well-supported scientific work that is available for all to review and consider. This is why we have operated with such transparency, so all know we have worked through the science with the highest level of integrity."

## 30 years of study

Sandia has been involved in the Yucca Mountain Project since the late 1970s.

Initial work focused on gathering basic experimental data about the site, says Peter Swift (6780), Sandia's Lead Lab chief scientist. Researchers collected rock samples and tested them, described the site's geology, and sought to understand the site's hydrology and underground chemistry.

Field and lab tests helped describe how faults in the rock surrounding the repository offer potential pathways for movement of water and gases, and how temperature and humidity would vary inside the drifts once the tunnels were closed.

Teams of national lab, DOE, and commercial experts developed concepts for the barriers the repository would rely on: the soil and rock layers above the drifts, the engineered systems inside the drifts, and the rock layers between the drifts and water table through which groundwater may flow.

By the late 1990s, scientists were able to focus on the possible pathways along which radionuclides may be transported to the biosphere: routes to well water, crops, drinking water, and the air future humans would breathe. Along the way, they identified thousands of variables that could play a role in the dose a future human might receive.

## Managing variables

Kathryn Knowles (6781), Sandia's post-closure science integration manager for Yucca Mountain, explains that such dose estimates are derived from a variety of scenarios, ranging from the possible to the highly unlikely.

Volcanic activity, for example, might cause igneous matter to intrude into the drifts. Climate change could alter the amount of water reaching the repository. Waste containers might deteriorate faster or slower based on a number of factors.

Thus, any models of Yucca's performance would need to take into account variables inherent in climate, weather, hydrology, drift temperature and humidity, container degradation, and hundreds of other factors.

What's more, the team identified a number of "coupled nonlinear processes" — chicken-and-egg relationships where one factor, say drift temperature, affects another factor, such as drift humidity, which in turn affects seepage into drifts, which in turn affects drift temperature.

## Modeling likely outcomes

Because of these uncertainties, estimates of repository performance must involve probabilities.

Scientists ran computer codes describing various phenomena hundreds, sometimes thousands, of times, each time altering variables, to create a set of outcomes. Taken in total, this set of outputs describes which outcomes are more likely, which are less likely, and which variables most influence the outcomes.

In the end, tens of thousands of runs on some 250 computer codes were used to develop the annual dose estimates contained in DOE's license application — a "confederation of models," says Cliff Hansen (6787), one of several technical leads for the performance assessment.

Where the results of one model affected the inputs to another, assumptions were carefully examined to ensure that important uncertainties — those that affect outcome — were carried through the sequence of models

IN OCTOBER 1998, miners completed the 1.7-mile cross-drift tunnel built for scientific studies near the potential repository area.


SINGLE HEATER ASSEMBLY being installed in July 1996 to test repository conditions.

appropriately, he says.

"When working in a repository science environment, not only do you have to show you got the right answer, you have to show, step by step, how you got the right answer," he adds. "The documentation may at times seem burdensome, but its outcome is a product you can have confidence in when you meet the regulator to explain your results."

An umbrella code, GoldSim, brought all the simulations together in what's called the Total System Performance Assessment to generate the overall dose calculations, along with the accompanying probabilities and measures of confidence.

After running the models together, the researchers learned something: Some variables matter, but most don't affect the bottom line very much. In fact, only about seven variables, out of 329 used as input in the analysis, affect the estimated dose in a significant way.

## Estimate of risk

Peter is careful to explain that the goal is not to model only conservative "worst-case" scenarios — a common misperception of risk-based modeling.

Instead, scientists work to model probabilities of outcomes to produce an estimate of risk that can be used by decision makers to determine if the expected risk is acceptable. Doing a thorough job of characterizing risk given the uncertainties, Peter says, increases the complexity of the Yucca Mountain science work.

And, with changes in climate, vegetative cover, groundwater flow, and other unknowns, "we'd be stretching to say that we have precise predictions of what those are going to be like in a million years," Peter says. "What we do is offer a model that provides a reasonable estimate of uncertainty in possible conditions during that time."

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DAVE BRONOWSKI (6315) tests fracture behavior of Yucca Mountain rocks. (Photo by Randy Montoya)

RON PRICE (6785) checks fracturing in Yucca Mountain rocks following experiments in Albuquerque. (Photo by Randy Montoya)

LIGHT AT THE END OF THE TUNNEL — the tunnel boring machine reaches daylight in April 1997.

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## What's next?

Docketing of the license application by the NRC marked the end of 25 years of scientific study and the beginning of a three-to-four-year regulatory phase during which Sandia's Yucca Mountain Project team will engage, side by side with DOE and other project participants, in a formalized public licensing proceeding.

Team members are likely to be asked to provide additional information supporting their scientific conclusions in the license application, Tito says.

"We will have staff asked to serve as expert witnesses," he says. "We will get challenged."

After three to four years of review and public hearings, the NRC could grant a license application for construction of the Yucca Mountain Repository, which would be followed by five to 10 years of construction, dependent on funding, after which DOE would request a license to receive nuclear waste at the repository.

## The bottom line

So what dose would the hypothetical person near the repository (formally defined as the Reasonably Maximally Exposed Individual, or RMEI, and known to project workers as "Remmy"), receive one million years from now?

According to Sandia's estimates, average peak doses will be about 0.24 millirems per year in 10,000 years and 2.0 millirems per year in one million years. For comparison, the regulatory limits established by the EPA are 15 millirem per year at 10,000 years, and 100 millirem per year at one million years, respectively.

Furthermore, the license application demonstrates that no significant releases should occur for many tens of thousands of years if the repository site is undisturbed. Over hundreds of thousands of years, the estimated annual doses are well below those from natural background radiation sources. All estimated doses are within regulatory limits.

Kathryn's conclusion: "Yucca Mountain is a good site," she says. "If you wanted to find a better site, you might be able to, but you could spend $10 billion doing it."

"Now our job is to show everyone during the review of the application that, through sound science, we can dispose of nuclear waste safely at Yucca Mountain," says Tito.

WORKERS DELIVER the Yucca Mountain License Application to the Nuclear Regulatory Commission office in White Flint, MD, on June 3, 2008. Inset: The Yucca Mountain License Application.

A SCIENTIST CONDUCTS a hydrology experiment in niche #3 of the Exploratory Studies Facility (the underground laboratory inside Yucca Mountain).

A rail cask

## The waste

A typical high-level waste package for Yucca Mountain would contain spent fuel rods encased in a protective matrix designed to keep the rods away from each other to minimize heat buildup.

The rods and matrix are encased in stainless steel inner canisters. An outer canister is made of one-inch-thick nickel chromium alloy. Typical waste packages are approximately two meters in diameter and five meters long and weigh as much as 80 tons when full.

The packages rest on specially designed nickel chromium alloy pallets. Following emplacement the packages are protected from above by titanium drip shields.

## Yucca Mountain timeline

1957 — National Academy of Science study concludes deep geologic disposal is the "preferred alternative"

1970s — Evaluation of multiple repository sites begins

1982 — Nuclear Waste Policy Act provides a legal structure, specifies NRC as regulator, and requires DOE to receive waste at unspecified future date

1987 — Congress amends NWPA to focus on one site (versus three previously): Yucca Mountain

1998 — DOE reports to Congress that the Yucca Mountain site is viable

2002 — Site recommendation submitted by Secretary of Energy, approved by president, and ratified by Congress

2006 — Sandia named OCRWM Lead Lab for Repository Systems

2008 — (June) License application submitted to NRC

2008 — (September) NRC dockets license application

## The Sandians of Yucca Mountain

Since 2006, more than 100 Sandians have been involved in the Yucca Mountain program at any given time, supported by nearly 300 contractors. In all some 350 Sandians contributed over the years, estimates Andrew Orrell (6800), who has been with Yucca Mountain since 1997 and was Sandia's Yucca Mountain senior manager from 2002 until July 2008.

"It takes a special kind of person to perform at a standard of excellence in the environment of budgetary pressure, political concerns, and scientific complexity that has often characterized the history of the Yucca Mountain Project," he says. "You can spend years doing the science, work that doesn't have an analog outside the national labs, and then you have to be prepared to support that work during a licensing proceeding that will last for several years. You sign up for a career here. These are special people."