The primary concern is that over thousands of years the "waste packages" that hold the radioactive material will corrode and radionuclides will leak out and be carried by moisture down into the water table. Once there, the radionuclides might flow out to a region where future generations could unknowingly tap into the contaminated water.

As problems with the mountain's geology have increased, DOE scientists have shifted toward engineered barriers. The current design calls for the waste to be placed in dual-metal containers consisting of two cylinders. The inner cylinder would be made of a special stainless steel two inches thick. The inch-thick outer cylinder, made of a nickel-based metal called Alloy 22, would protect the inner cylinder from corrosion. These containers would be lined up, end-to-end, on specially designed metal stands inside the repository's tunnels. Titanium drip shields would arch over all of the containers as an additional barrier against moisture.

The temperature created by the radioactive waste would be above the boiling point of water for at least 1800 years, keeping the surrounding rocks hot and dry and serving as yet another defense against moisture. DOE officials believe the engineered barriers alone, regardless of the surrounding geology, will keep the radionuclides contained for the required 10 millennia. Yet virtually every aspect of the DOE design is being challenged by government panels, independent scientists, and experts working with the state of Nevada.

Bob Loux, director of Nevada's agency for nuclear waste management and a strong opponent of the project, said he is troubled by DOE's increasing reliance on engineered barriers, when the whole point of Yucca Mountain was to create safe geologic disposal. "We're not sure it is geologic disposal anymore," he said. "It seems the site has become a liability, not an asset."

Loux said state scientists believe there could be groundwater contamination in as little as 300 to 500 years. His numbers are by far the most dire, and supporters of the project note that Nevada officials are opposed to the very idea of a Yucca Mountain repository. State officials are suing the EPA over standards that govern the site, have hired a Washington, DC, law firm to fight the project, and have vetoed in advance President Bush's possible approval of Yucca Mountain.

Congress can overturn the state's veto, so on Capitol Hill the entire Nevada delegation, led by Democratic Senator Harry Reid, is trying to corral enough votes to stop the project. Yet the nuclear power industry is insisting that the federal government meet its legal obligation to create a permanent repository for the waste, so the political pressure to approve Yucca Mountain is enormous.

One emerging area of concern at the mountain is the accuracy of the computer modeling being used to forecast what will happen in the distant future. The process, known as total system performance assessment (TSPA), consists of the "mathematical integration of everything we know, so it tends to be complicated," DOE's Van Luik said.

An international group recently completed a review, at DOE's request, of the TSPA process, "and they said that in some places we are being absurdly conservative," Van Luik said. The review panel said that so many of the assumptions were so conservative that the forecasts did not reflect reality. "We've compounded conservatism with conservatism," he said. The NWTRB, which has endorsed DOE's use of performance assessment techniques, shares some of the review group's concerns, noting that the strategy of using consistently conservative assumptions doesn't give reviewers anything to measure those assumptions against.

The international review group was also critical of the TSPA model of the all-important saturated zone, that area underneath the depository where water can carry radioactivity away from the mountain. "We thought we understood the saturated zone pretty well," Van Luik said. The peer review was so critical of that aspect of the model that he called it "mean spirited," although not necessarily wrong.

Irreducible uncertainties

All of the criticism and open questions do not necessarily reflect on the likelihood of Yucca Mountain getting its license and receiving its first shipments of waste around 2010, as DOE officials hope. "When you're doing something this complex, looking so far into the future, some uncertainties are irreducible," Van Luik said.

The recent terrorist attacks on the US added a new factor to the debate, said the NWTRB's Knopman. "For some it may make Yucca Mountain a no-brainer," she said. "The argument is you have to get the waste out of the 70 nuclear plant sites and get it to one location. Others may view the transportation to Yucca Mountain to be a bigger risk."

A range of possibilities exists for the political decision on the fate of Yucca Mountain. The repository could be approved as DOE proposes, or canceled based on Nevada's objections. There could be a commitment to the site, but not the design, with waste stored on the surface while a new design is developed. Or waste could be put in the mountain on a temporary basis while experts search for a better site. Like everything with Yucca Mountain, the political end game is expected to be unusually complex as it is played out over the next few years. **JIM DAWSON**

AIP Urges Documenting Big Physics for Posterity

Want your grandchildren to know how you built that satellite? Measured salinity and other properties of the world's oceans? Discovered the top quark or conducted some other major collaborative project? If so, start thinking now about saving records, says a new report by AIP's Center for History of Physics.

Matters have only gotten messier since Richard Feynman said, in his Nobel lecture in 1965, "We have a habit in writing articles published in scientific journals to make the work as finished as possible, to cover all the tracks, to not worry about the blind alleys or to describe how you had the wrong idea first. . . ."

It's a problem that Joan Warnow-Blewett recognized years ago. And one that is exacerbated by the trend in recent decades toward large collaborations. "If you have an experiment spread among many institutions, and even countries, no one feels responsible for saving the documents," she says. Science historians ask questions like, "What is the economy of very large projects? How are they paid for? What structure do they have?" says Peter Galison, a historian and high-energy physicist at Harvard University. "There are a whole host of issues that surround the way knowledge is certified and enters circulation. Scientists don't write letters as they once did, but there is more documentation. From eight hours on a big collaboration, more data piles up than all the documentation we have on Galileo. Amidst a huge amount of data, what do you save?"

To see which documents to save and how to save them, Warnow-Blewett and colleagues at the American Institute of Physics's Center for History of Physics carried out a decade-long study of physics collaborations involving at least three institutions. They visited archives and interviewed more than 600 participants from nearly 60 experiments from the 1970s through the present, focusing first on high-energy physics at accelerators in the US and at CERN; then on space physics and geophysics (including projects involving both NASA and ESA, the European Space Agency); and wrapping up with a medley of subfields including ground-based astronomy, particle and nuclear physics, medical physics, materials science, and experiments controlled remotely via computer.

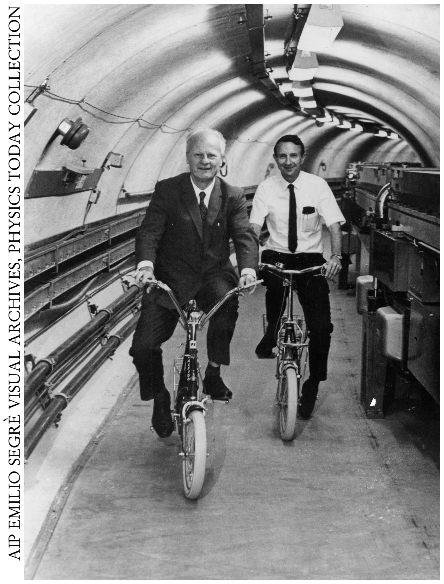
"When we compare the scope of the records needed to document collaborations against our assessment of current archival policies and practices, the urgency of our project recommendations is abundantly clear," the researchers write in *Documenting Multi-Institutional Collaborations*, which was completed earlier this year. "My particular job was to understand how the collaborations worked well enough to understand how to document them," says Warnow-Blewett. (The report is available free of charge from AIP, Center for History of Physics, One Physics Ellipse, College Park, MD 20740-3843; phone 301-209-3165; e-mail chp@aip.org; or on the Web at http://www.aip.org/history/pubslst.htm#collabs.)

Rank and record

Perhaps the report's most surprising finding is that project management and organizational structure—ranging from a pyramid hierarchy to a flat democracy—are not correlated with scientific specialty. "The only exception was high-energy physics, where decision-making is not hierarchical. They have reasons for getting their members involved in everything," says Warnow-Blewett.

Initial proposals and other core records should be kept for all big physics collaborations, and archivists should become involved early in a project's planning stages. In addition to such one-size-fits-all recommendations, the report sketches out by subfield the types of records that future historians are likely to want. "You have to find out, Where in the collaborations are the real decisions made? Which are the important committees?" says Warnow-Blewett. "That's how you find the crucial documents."

One of the report's key recommendations is that more records be kept for projects deemed most scientifically significant. Among the records to keep in particle and nuclear physics, for example, are proposals for beam time on accelerators, contracts between host labs and collaborations, and records of lab directors. For top-ranked projects, add intracollaboration mailings and other records from spokespeople, group leaders, project managers and engineers, and some technical records. The list for materials science collaborations starts with proposals and contracts for using synchrotron light sources and other major facilities, and, for the most important projects, includes newsletters plus records from external advisory committees, annual meetings, spokespeople, and staff directors.



AIP EMILIO SEGRÈ VISUAL ARCHIVES, PHYSICS TODAY COLLECTION

HANS BETHE (left) and Boyce McDaniel cycle around the Cornell Electron Storage Ring in 1968. CESR was one of the sites included in AIP's study of multi-institutional collaborations.

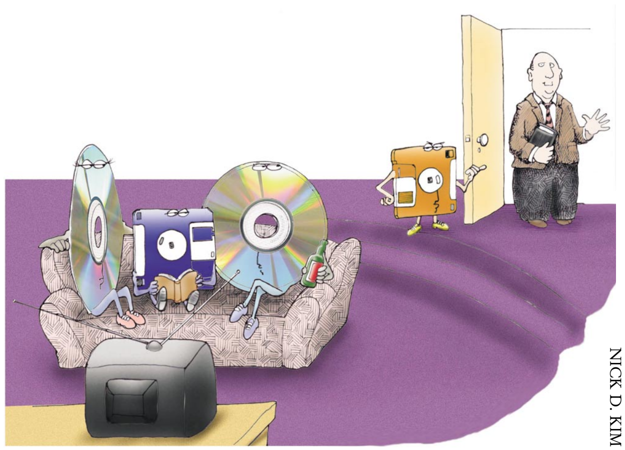
The report also recommends a small increase in overhead rates at universities to pay for documenting experiments. The cost would be less than 1% of grants, Warnow-Blewett says. The records that should be saved represent about 5% of the total generated, she adds. "[What's saved has] got to be small in volume but dense in information."

"Understanding and documenting large-scale science is a problem we will have for the foreseeable future," says Galison, who served as an adviser to the AIP study. "The genome, Sloan Digital Sky Survey, CERN, Fermilab, are important examples. The science is not captured by one person's work, by biography, or by a Nobel Prize. The AIP project focuses attention on the need to preserve documents in order to grasp the way knowledge is produced."

DOE does it best

Take the Deep Sea Drilling Project, an international collaboration that was run mainly out of the Scripps Institution of Oceanography in La Jolla, California, and one of the projects studied by AIP. "It yielded results important to understanding the structure of Earth and confirming plate tectonics," says Scripps archivist Deborah Day. "There would have been a chief scientist for each leg of the ship's tracks. Those leg files are where the scientific meat of the expedition was—they gave information, photographs, reports of scientists. They are what people now come to study. [At first] people didn't realize that the leg files would be permanently valuable. There was no person in charge of the records."

What AIP has told archivists, says Day, "is that we need to be proactive. Find out what projects are going on, and select them for retention. We have to go to the principal investigators, and tell them, 'I am here to work with you.' If archivists don't get involved while the project is still alive, Web pages



NICK D. KIM

"The guy at the door wants to know if we've all been saved...?"

disappear, scientists leave, and paper records get lost. At that point there is no history except memory."

"It's not an exaggeration to say that I have my job because of the AIP study," says SLAC archivist Jean Deken. The study grew out of Warnow-Blewett's earlier look at DOE national labs, and that's where it's had the most impact so far. Not only does SLAC now have a full-time archivist—and Lawrence Livermore National Laboratory is seeking one—but DOE's new rules for identifying and saving R&D documents were influenced by AIP's findings, including requiring that projects be ranked. "This shouldn't be radical, but it was. Before, nobody ever took the project-by-project approach," says Deken. "A Level 1 project is groundbreaking, it has international significance or alters the direction of research—all significant documents are kept permanently for these projects. Level 2 is important, it increases the scope of knowledge, but is not earth shattering—records are kept for 25 years. Everything else goes into Level 3, and records are kept for 10 years." The BaBar detector and PEP-II storage ring at SLAC, and the National Ignition Facility at Lawrence Livermore, for example, are Level 1 projects. "The beauty of ranking," says Deken, "is that scientists respect and understand it immediately."

DOE keeps the best records, says Warnow-Blewett. "It could be used as a model for other federal agencies—which haven't come to terms with the importance of documenting the science they're in the business to do."

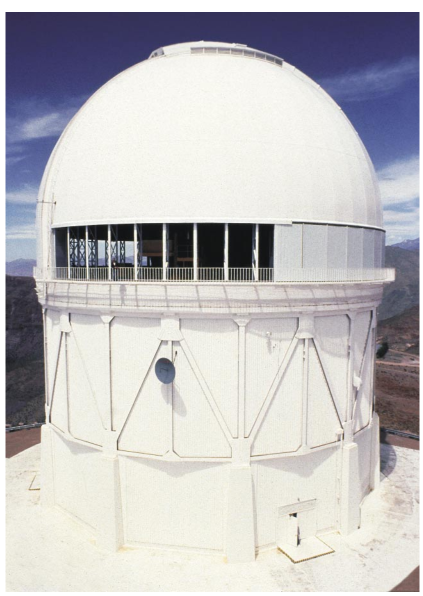
Toni Feder

US Panel Nixes Astronomy Move

Astronomers in the US gave a collective sigh of relief when a National Academy of Sciences (NAS) panel rejected a proposal outlined in President Bush's 2002 budget to move ground-based telescopes from NSF's to NASA's auspices. Nor were NASA officials disappointed by the outcome: "The proposal came as a total surprise," says Edward Weiler, the agency's associate administrator for space science. The NAS panel did, however, shine the spotlight on some weaknesses of NSF's stewardship, and recommended in a report that the foundation create its own long-term strategy for astronomy, improve the management of existing projects, and consider competitive bidding for building new facilities.

Both financial pressure and concerns about the future of US astronomy spurred the White House Office of Management and Budget (OMB) to discreetly arrange for NSF and NASA to call for the NAS study this past spring. But the 11-member panel, headed by Norman R. Augustine, a former CEO for Lockheed Martin now at Princeton University, nixed the proposed move to NASA. The panel, dominated by university astronomers, concluded that giving NASA oversight of US ground-based observatories would cause so much upheaval that it would "seriously weaken the intellectual roots of the discipline." The panel cited the advantages of having astronomy in an agency closely tied to the academic research community. But it also pointed out that NSF will have to negotiate with private institutions and form more international partnerships to afford the next generation of large instruments.

Ground-based astronomy at NSF faces many problems: a stagnant budget, a lack of political support for future projects, NASA's growing influence over astronomy, and demands by independent facilities such as the Keck Observatory for new NSF-funded instruments. These problems are all intertwined in a complex relationship, explains William Smith, president of the Association of Universities for Research in Astronomy, which manages the national optical observatories for NSF. NASA and NSF together fund about 90% of all US astronomical research, but NSF's share has dropped from 60% to 30% over the past decade. The rest of the funding is from private sources and universities. And NASA now funds nearly three-quarters of individual research grants in astronomy.



NOAO

Ground-based observatories such as the Blanco 4-meter telescope in Chile will stay with NSF, not be moved to NASA.

In evaluating whether ground-based astronomy should remain at NSF or be clumped with NASA, the NAS panel solicited comments from hundreds of astronomers. In addition to providing opinions on the NSF move, astronomers complained about the lack of support for research areas that overlap the two agencies, such as balloon-based observations. Many cited a slow erosion of the US lead in astronomy. "For the last 30 to 40 years, the US has dominated optical astronomy," says Riccardo Giacconi, president of Associated Universities Inc in Washington, DC (which operates the National Radio Astronomy Observatory) and former director-general of the European Southern Observatory. "Now there is strong competition from Europe and Japan."

"Several staff members in the executive branch and in Congress conveyed to the [panel] their perception that NSF does not manage large projects well," says the NAS panel, but "we did not find evidence" that NSF had "significantly more" management problems than other federal agencies. Their report suggests that NSF develop a more comprehensive accounting system for each project and improve its communication with Congress, the White House, and the public. "NSF can do a better job of bringing science to the public," agrees Weiler. "NASA has, and I am quite proud of that. If you don't get that science translated into a form that real Americans can understand, you are not doing the job of a federal agency."

But astronomy's biggest problem is funding. "By a substantial margin, the NSF does not have the resources to keep US ground-based optical and infrared astronomy at the world level," the panel's report says. The only solution, it continues, is to develop "systematic, comprehensive, and coordinated planning" between the agencies and private facilities through a high-level joint advisory committee run by the OMB and the White House Office of Science and Technology Policy.

This suggestion is controversial and many astronomers doubt that the new advisory committee would be successful. "The National Academy does an outstanding job in setting priorities for