



Experiments in a tunnel at the Yucca Mountain nuclear-test site in Nevada aim to establish whether nuclear waste could safely be dumped here.

FORWARD PLANNING

The global future of nuclear power may rest in large part on local politics, reports **Geoff Brumfiel**.

Like 83% of the state of Nevada, the land to your right as you head up from Las Vegas towards Reno is owned by the federal government. A military airstrip for unmanned aerial vehicles and a nuclear-weapons test range stretch into the distance; enormous concrete tubes that once held MX missiles lie baking in the sun. The only signs of civilian life are a state prison, a brothel and a few small clusters of air-conditioned trailer homes.

It is here in Nye County — where 38,000 souls occupy 47,000 square kilometres — that the US Department of Energy would like to bury more than 70,000 tonnes of highly reactive nuclear waste. The federal government says that Yucca Mountain, a low peak on the western edge of its nuclear test site, some 100 kilometres northwest of Las Vegas, is one of the safest places in America for spent fuel to make its several-hundred-thousand-year journey to harmlessness.

Local residents want jobs, so they are not wholly opposed to the repository. But other citizenry of Nevada, many of whom remember the consequences of above-ground nuclear-weapons testing in the 1950s and 60s, are deeply sceptical. And so are their elected representatives. "The state of Nevada is committed to stopping this thing by any legal means possible," says Steve Frishman, a geologist and the technical

policy coordinator for the state government's Agency for Nuclear Projects.

Virtually every democratic nation that has embarked on a programme for the disposal of 'high-level' nuclear waste has run into similar trouble, and few have found a way forward. Bitter fights with concerned citizens have derailed plans in Germany, Canada and the United Kingdom. "All of the world's programmes now recognize that the non-technical problems are bigger than the technical ones," says Charles McCombie, a nuclear-waste consultant who has worked extensively on the Swiss, Canadian and Japanese disposal programmes.

Nations around the world with stocks of waste — including those anticipating rapid growth in such stocks (see 'Booming nations go nuclear', overleaf) — are realizing that to dispose of their nuclear waste, they need to build trust with local communities, and that it is on these efforts that much of the future of nuclear power depends. "If we don't solve the waste

problem, we're going to have major trouble continuing the revitalization of nuclear power," says Tom Isaacs, director for policy, planning and special studies at Lawrence Livermore National Laboratory in California.

A lasting legacy

The decay of the isotope uranium-235 in nuclear fuel rods creates atomic nuclei with a wide range of radioactivities and chemical properties. Some, such as neptunium-237, are present only in small quantities but can remain radioactive for millions of years. Others, including caesium-137 and strontium-90, make the waste a health hazard for decades or centuries, and raise its temperature to above 500 °C. The most problematic is plutonium-239, generated from uranium-238, which when purified can be fashioned into a nuclear weapon.

'Reprocessing', in which plutonium-239 and unused uranium-235 are reused as fuels or for weapons, reduces the amount of high-level waste produced. But as yet, it has never proved an economic way of making nuclear fuel. And even if reprocessing were to improve dramatically, or if the use of reactors or beams of particles to transmute some of the isotopes into less noxious ones were to prove practical, generating energy from nuclear fission would still produce

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Booming nations go nuclear

India and China have very little high-level nuclear waste today, but both countries are anticipating substantial nuclear growth spurts to feed their voracious energy needs.

In China, where the number of reactors is expected to go from 9 to 40 within 15 years, geologists are characterizing eight repository sites in remote Gansu province near the Mongolian border. Early work is now well under way, but it will be a while before a site is

constructed, according to Ju Wang of the Beijing Research Institute of Uranium Geology. Initial surveys will be completed in 2015, a site will be selected by 2030, and construction on a final repository could begin by 2050.

Meanwhile, Indian nuclear engineers are planning a massive nuclear complex that will include spent-fuel reprocessing and so-called breeder reactors. These use natural thorium deposits and

reprocessed nuclear fuel to create more uranium fuel. Such breeder reactor systems are technically complex but could dramatically cut down the waste stream coming from India's nuclear complex.

Nevertheless, the nation is still planning a repository, according to Srikumar Banerjee, director of the Bhabha Atomic Research Centre in Mumbai. Experiments have been carried out in a deep mine in the southern state of Karnataka, and further studies are

being carried out in an operating uranium-ore mine, Banerjee says.

Although the technical programmes are well in hand, both India and China have some work to do to resolve the societal issues surrounding a waste dump, notes Malcolm Gray, a nuclear engineer at the International Atomic Energy Agency in Vienna. "The Indians are looking carefully into the social problems," he says. "But, for now, the Chinese think they'll still be able to sidestep it." **G.B.**

some waste posing a hazard for millennia. And that waste will need to be put somewhere.

Since the late 1950s, the scientific community has more-or-less agreed that the best way to deal with this waste is to put it deep underground, says Malcolm Gray, a nuclear engineer with the waste-technology section of the International Atomic Energy Agency in Vienna, Austria. Providing safety and security for surface facilities, such as the spent-fuel ponds used at nuclear power plants, is costly, especially in the long term. Properly chosen and engineered sites can remain stable for millennia and would not require the modification of international treaties on dumping. "Geological disposal is the only practical solution," Gray says. Sites for such disposal are under

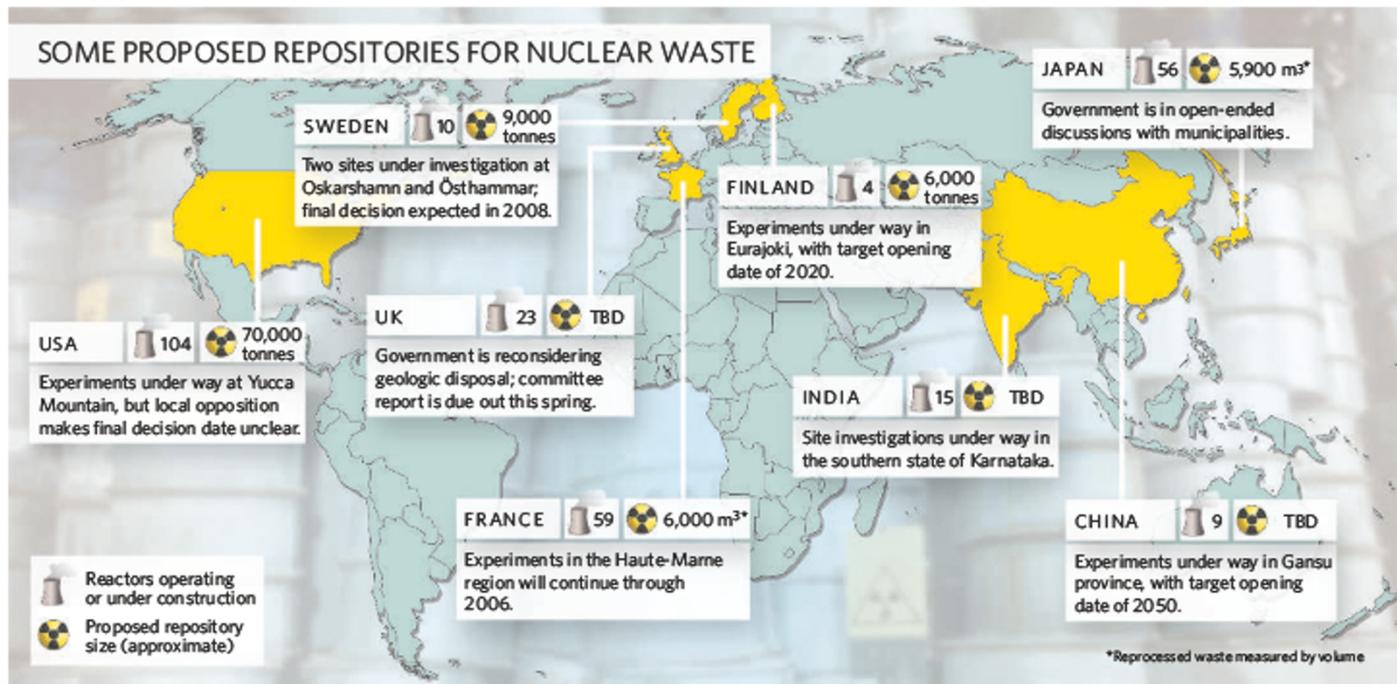
consideration around the world (see graphic).

Yucca Mountain should serve as a cautionary tale, for such efforts, on two grounds. One is that despite years of research it is still not clear how well this particular site would meet the stringent regulations called for by the National Academies of Science (NAS). The NAS recommends a regulatory period of several hundred thousand years, which could mean keeping the waste safe all the way through the next two ice ages. The other is that the local people have never been more united in their rejection of the plans.

Yucca Mountain has been studied as a possible site for nuclear-waste disposal since 1978. A bevy of experiments in an eight-kilometre tunnel built in the side of the mountain have

looked at how water, heat and stray radioactive material might move through the rock. The data are used to estimate exposure rates for humans who might stumble across the site centuries or millennia into the future.

In recent years, some of those experiments have shown that waste could migrate to the water table more quickly than expected. And studies of young volcanoes around the mountain have raised concerns about a breach occurring at the site (see *Nature* 412, 850–852; 2001). A big problem is that no models can be expected to precisely predict exposure over such vast time periods. As Michael Voegele, a geological engineer with more than 25 years of experience at the site, puts it: "It's impossible to know exactly how water is going to move through the moun-





Keep out: storing radioactive waste in surface facilities such as spent-fuel ponds is expensive and risky.

tain when Chicago's under 5,000 feet of ice."

These uncertainties fuel the doubts of Las Vegas, says Peggy Maze Johnson, executive director of Citizen Alert, an environmental group that is trying to block the project. Local people think Yucca Mountain was picked because Nevada is thinly populated and has little political representation in Washington. "I am not an expert," Johnson says. "All I know is that when something is based on politics, it doesn't make it sound science."

Looking to the leaders

Repositories cannot be built without addressing this blend of political and scientific concerns, says Tero Varjoranta, director of nuclear waste and materials regulation at Säteilyturvakeskus (STUK), a nuclear research centre and regulatory authority in Helsinki, Finland. Varjoranta says it is critical that government agencies be, and be seen to be, impartial and authoritative. "We're not selling the repository," Varjoranta says of his own office. "We try to convince people that if it is built, it will be safe."

In neighbouring Sweden, such impartiality has been vital because of the strength of local municipalities, says Saida Engström, a member of the board of directors at Svensk Kärnbränslehantering AB (SKB). Based in Stockholm, SKB is a company formed by the government that is charged with developing Sweden's waste repository. When Engström was in charge of assessing the environmental impact of a repository in the village of Tierp, 67% of the population supported her work, she says. But the city

council vetoed the project by one vote.

"I'd be lying if I told you I wasn't bothered by it — I was," she says. "But for the credibility of the project it is vital that you involve local people in the process." Ultimately, the veto at Tierp showed that SKB was serious about respecting local wishes and strengthened the programme's reputation in other parts of the country, she argues. The company is continuing investigations at Oskarshamn and Östhammar, where public support for the project continues to be strong.

Attempts to gain public trust have put the two Scandinavian nations far ahead in their efforts to build a repository, and other countries are now looking to them for inspiration. In the United Kingdom, a government committee was established in 2003, to tackle radioactive-waste management. The committee, which includes

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environmentalists and social scientists as well as physicists and engineers, will determine whether a deeply buried repository is the best way to dispose of waste. Lessons have been learnt after plans to build a repository at Sellafield were thrown out by a public inquiry in 1997. "That was the end of an old tradition where scientists, industry and government got together behind closed doors, thought up the right option, thought up the right site and then

announced it," says Gordon MacKerron, an economist from the University of Sussex who chairs the committee.

Yet others worry that the pendulum has swung too far in the direction of public opinion. "There's a view out there, which basically says that science is not reliable anymore," says David Ball, a professor of risk management at Middlesex University in London. Ball resigned last spring from Britain's committee on radioactive-waste management, in protest of what he saw as an over-reliance on public opinion. "They didn't see science as holding any objective truth and replaced it with the good old common sense of the man on the Clapham omnibus," he says.

Winning trust

Keith Baverstock, a radiation health expert at the University of Kuopio in Finland (see page 993), adds that the Finnish and Swedish success is not due to national public acceptance. "The Finns have never had more than about 40% of the general population agree that this form of disposal was the correct way to do it," he says. The key, he says, is to find a local community willing to accept the project.

The views of local communities will not be determined only by local issues, such as jobs or worries about contamination. "Many groups began opposing Yucca Mountain because they didn't want new nuclear power and they didn't want it seen as the solution that allows for the construction of new nuclear plants," says Judy Treichel, executive director of the Nevada Nuclear Waste Task Force, which opposes the Yucca Mountain project. And in Sweden, there might be more local resistance to the country's waste-repository project if the government wasn't already committed to phasing out nuclear power across the country. At least, that's the view of Johan Swahn, director of the Swedish Office for Nuclear Waste Review — an environmental group that uses government funding to monitor the repository project. "People are more willing to participate in the process with the understanding that nuclear waste is a finite problem," he says.

Regardless of what scientists and engineers believe is technically possible, they must be prepared to address these sorts of cultural concerns, says nuclear-waste consultant McCombie. More broadly, governments eager to see a nuclear repository built must work harder to win their citizens' respect. That's no mean feat and can only be achieved through time and transparency, McCombie says: "You can't just build it like you would a filling station; it has to be a long process with buy-in and the potential for reversal at each stage."

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