Blowup at Yucca Mountain

A theory raising the possibility of atomic explosions in a nuclear waste dump is almost universally dismissed by researchers. But front-page newspaper coverage has turned it into a force in public debate

Scientists, not without a touch of sarcasm, call it publishing in *The New York Times*, as though the paper were an unofficial journal—the *JNYT*, perhaps. It is what happens when *Times* reporters hear of important research and write it up before a paper is published in a peer-reviewed journal or the work is aired at a scientific meeting. If the work is on a highly controversial subject or one of great social concern, its appearance in the *Times*—the most influential newspaper in the country—can give it an impact that may go far beyond the actual value of the research.

So it was when the front page of the 5 March *New York Times* featured a story headlined "Scientists Fear Atomic Explosion of Buried Waste," about a dispute at the Los Alamos National Laboratory over the long-term safety of a proposed and highly controversial nuclear waste repository planned for Nevada's Yucca Mountain. Two Los Alamos researchers, Charles Bowman and Francesco Venneri, had written a paper claiming that buried waste might, as the *Times* put it, "erupt in a nuclear explosion, scattering radioactivity to the winds or into ground water or both." The article noted that other Los Alamos staffers had extensively reviewed the work and judged it seriously flawed, but it quoted John Browne, head of energy research at the lab, saying that they had been unable to "put the stake through its heart." In what may have been a self-fulfilling prophecy, the article added: "The existence of so serious a dispute so late in the planning process [for the repository] might cripple the plan or even kill it."

The next day Senator Richard Bryan, a Democrat from Nevada, was on the floor of the Senate carrying an enlarged copy of the *Times* article and accusing the Department of Energy (DOE) of covering up the debate among its own scientists on the safety of the repository. The Nevada newspapers, meanwhile, were full of reports on the new doomsday scenario, including, as one National Academy of Sciences (NAS) administrator put it, "cartoons with huge mushroom clouds coming out of Yucca." The controversy now threatens to become a permanent feature of the debate over the Yucca Mountain project, and the whole episode provides an object lesson in the problematic relationship of science, politics, and the press.

Yucca Mountain was not new to controversy. In 1987, DOE selected Yucca Mountain as the only contender for a deep underground repository to hold for the foreseeable future and beyond the spent nuclear fuel from the nation's civilian nuclear power program. Since then, the end of the Cold War has posed the additional problem of disposing of surplus weapons-grade uranium and plutonium, a task for which Yucca has also been considered. Opponents of the project—who include much of the Nevada government as well as environmental groups critical of the nation's nuclear power program—have accused DOE of trying to bury any scientific opposition to the project. Meanwhile, the cost of the project has been prodigious—$1.7 billion and climbing fast. As a result, says DOE's Dan Dreyfus, head of the Office of Civilian Radioactive Waste Management, "virtually anything that happens on the Yucca Mountain program gets amplified well beyond rationality. It lends itself to sensationalism."

Ground zero? Yucca Mountain, Nevada, and headlines from the *New York Times* on a potential catastrophe within the high-level waste repository to be built there.

The motivating force behind the latest round of Yucca controversy is Bowman, an expert on neutron physics at Los Alamos who had spent the last 6 years working on a competing technology to dispose of nuclear waste. Known as accelerator transmutation of waste, or ATW, the nascent technology holds out the promise of using reactors to burn away spent nuclear fuel or weapons-grade uranium or plutonium. The reactors would be run at subcritical level, with no self-sustaining chain reactions that could lead to a meltdown. Instead, an accelerator would fire a beam of protons into a target in the reactor core, creating an intense neutron source that would keep the reaction going.

So far, however, the idea has not attracted enough funding for a proof-of-concept experiment, which Bowman estimates would cost $20 million each year for 6 to 7 years. What's more, the Los Alamos accelerator that could provide the neutrons for an ATW demonstration is scheduled to be shifted to DOE's defense research programs this September. Adding to ATW's troubles, JASON, an independent advisory panel to DOE and the Department of Defense, reviewed the technology's potential for disposing of weapons plutonium in January 1994, and the verdict was mixed. JASON said it was an interesting approach that the DOE should continue to study for the long-term disposal of spent reactor fuel, according to Matthew Bunn of the NAS, who is administering a study of options for plutonium disposal (*Science*, 4 February 1994, p. 629). But JASON thought the technology's time scale was too long to deal with the immediate problem of weapons plutonium.

Sizing up the competition

As ATW ran into difficulty, Bowman says he began considering the true viability of his "principal competition in this business," which was geologic storage of nuclear mate-

rial—i.e., Yucca Mountain. He says he had "nagging concern about criticality issues in underground storage." If those issues were properly taken into account, he thought that "they could have a major impact on the cost of storage and on the competitiveness of [geological storage versus ATW]."

Bowman began working on his theory with Venneri, a nuclear engineer on his ATW project. They set out to calculate what would happen if the plutonium "vitrified" in huge glass logs—the preferred method for safely burying weapons-grade plutonium—somehow leached out of the glass and then dispersed into the surrounding rock. "There's an enormous amount of fissile material going underground in a relatively small spot," Bowman explains, "so the idea of critical configurations coming about from rearrangements [of plutonium] did not seem impossible as a starting point."

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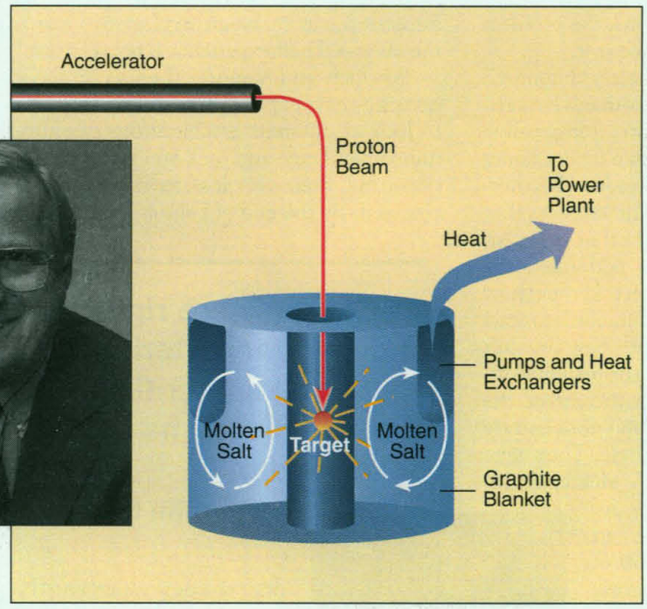
Previous researchers had studied such scenarios and concluded that even if a critical mass did form, any chain reaction would inevitably shut itself down with little consequence. As Bunn explains, water is crucial for a chain reaction to proceed in these systems, because it acts as a moderator, slowing the neutrons and making them more likely to trigger fission. And as the reaction gets going, it heats up the water, ultimately turning it to steam and driving it out. The reaction will then shut down.

Nature had even provided a precedent: uranium deposits in Gabon. Uranium extracted from mines there is unusually poor in fissionable uranium-235, indicating that a long-extinct natural fission process depleted that isotope. Nearly 20 such natural reactors have been found in Gabon, all of which burned some 2 billion years ago. "They fissioned on and off at low power," explains Rich Van Konynenburg, a nuclear engineer at the Lawrence Livermore National Laboratory. Each heating cycle "drove the water out, which turned them off. ... Then water would come back in, provide moderation, and the reactors would go critical again. The energy release was slow, not the rapid energy release you'd need for an explosion."

Bowman, however, thought that an underground reactor could experience a positive feedback mechanism that other researchers hadn't considered. Bowman argued that if the plutonium from the glass logs were to disperse into the surrounding rock, the rock itself would act as a moderator. As the system went critical, it would get hotter, the plutonium would disperse through a greater volume of rock, which would moderate even more neutrons, and the reaction would take off. He then suggested that if the rock were strong enough, it could keep the system compressed so that it would remain "supercritical," at which point it could begin to double its energy "on order of a millisecond or so, and in much less than a second a very large amount of energy can be generated." In the case of Yucca Mountain, as the *Times* put it, the denouement could be "a nuclear blast equal in force to about a thousand tons of high explosives, setting off other blasts throughout the vast repository."

Because those calculations related almost exclusively to pure plutonium, it took Bowman and Venneri some extra steps to link them directly to Yucca Mountain, which for now is intended only as a repository for spent nuclear fuel. According to Bowman, the various fissile materials in the spent fuel might "rearrange themselves in a way such that one could reach criticality." Because Bowman and Venneri were unable to provide a full scenario to describe how this might happen, several Los Alamos researchers later described the speculation as scientifically equivalent to the statement "and then a miracle occurs." Bowman, however, characterizes it as "a simple scenario, [chosen] so the calculations and concepts would be simple to understand."



SOURCE: CHARLES BOWMAN

A competing strategy. Accelerator transmutation of waste, developed by Charles Bowman of Los Alamos, relies on a beam of protons from an accelerator to generate an intense neutron flux that sustains nuclear reactions within high-level waste, circulating in a bath of molten salt. The process burns off the long-lived isotopes and generates electric power into the bargain.

An unprecedented review

Bowman first broached his findings to the Los Alamos administration last September. Browne, who was overseeing a program studying accelerator-based disposal of weapons-grade plutonium, says Bowman told him, "It looks like this stuff could go supercritical." Although Browne had serious doubts about Bowman's hypothesis, he knew it was a potential bombshell, right or wrong, and suggested that Bowman write up a paper, which Bowman did by the beginning of November.

Bowman sent his paper to a handful of physicists whose input he wanted, among them IBM's Richard Garwin, who was taking part in the NAS plutonium disposal study. The two met at IBM and discussed the work. Garwin later said that he found Bowman's explosion hypothesis technically deficient and "not a full theory," and he warned Bowman about the possible repercussions if his work were to be made public before its merit—if any—could be established. "I told him," says Garwin, "that it was really irresponsible for him to imperil an ongoing program before he had thought this thing through. [The Yucca Mountain project] had been in the works for years; they'd spent billions of dollars; and it is the one solution people have to problems of spent fuel and high-level waste. It has to be carefully thought out, but politically, if you let out an analysis that might be half-baked, then it might result in people picking it up and killing the program."

With so much at stake, Los Alamos administrators decided to give the idea a thorough review. "Even without looking at [the analysis]," says Browne, "some people felt it had to be wrong. I felt it would be important to get a broad cross section of people from the laboratory who could take a look at this from all angles. It was such an important topic. And if Charlie were really right and nuclear material could go supercritical, it didn't mean it was not a solvable problem, but it would clearly have to be dealt with."

The review Browne organized was unprecedented at Los Alamos: a three-sided examination involving a red team, more commonly known at Los Alamos as a "murder board," whose job would be to tear apart the paper and find everything wrong with it; a blue team, which would try to duplicate Bowman's results "by making as many positive assumptions as they could," says Browne, and then defend the work; and a white team,

composed of senior members of the lab, to serve as neutral referees and make a recommendation to the administration. All three teams had experts covering the range from nuclear waste disposal to nuclear weapons, geology, and geochemistry.

The teams met to hash out their conclusions on the afternoon of 21 December, with Bowman present to hear the results. Browne describes the atmosphere as less than caustic but certainly tense. "There were some people who were very vocal and very strongly opposed and stated remarks in that way," he says. "Other people were trying to maintain more objectivity and deal with the problem rather than get emotional about it."

The conclusions, nonetheless, amounted to a complete rejection of Bowman's hypothesis. Even the blue team found it impossible to defend the work. Blue team leader James Mercer-Smith, who then headed the thermonuclear design group at the lab, says that his team was able to confirm that Bowman and Venneri had correctly performed the criticality calculations, which told them how much plutonium had to accumulate to start and sustain a reaction. But they couldn't validate or even rationalize the assumptions the two had come up with to extract the plutonium from spent fuel and concentrate it, let alone cause it to explode. They were "just wrong ... nonsense," Mercer-Smith says, adding, "I'm a weapons designer. The idea that nature can randomly make a bomb is sort of offensive to me; we go to great efforts to do that."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The red team's conclusions, too, were unequivocal. Art Forster, a former head of the lab's radiation transport group who led the team, says, "There were just too many things [in the hypothesis] that were not physically possible." In the lingo of the laboratory, the Bowman and Venneri work was full of "upper-limit oversimplifications and omissions." Time scales for geologic processes, for instance, were overestimated by orders of magnitude—in one case, by a factor of at least a million, according to Forster. The key effect determining whether an explosion could occur, the rate at which energy is released, was neither calculated nor estimated, but just assumed somehow to be fast enough.

"The bottom line," says Forster, "was even if all of these 'miracle steps' could occur, the energy generated would be quite small, like [that of the Gabon reactors]. This would be a reactor; it would not be a bomb." To the possibility that one waste pile could explode, sparking a chain reaction of explosions elsewhere in the repository, Forster answers, "goodness gracious, no." The white team's report echoed that skepticism, saying the probability of Bowman and Venneri's explosion hypothesis being realized was "essentially zero."

Publication anxiety

In February, Browne asked Bowman to respond to that conclusion and the white team report. Later Bowman would say, in the *Times*' words, that the internal debate left his work "honed and strengthened." Speaking to *Science*, he simply rejected the criticisms. The whole weapons program at Los Alamos, he said, is "devoted to concentrating nuclear material to make it explode. We show that dispersion can make an explosion. Ours is the inverse. Their experience is not relevant."

Bowman and Venneri then went about revising their paper by expanding its scope to look at different combinations of plutonium abundance and rock and water conditions, but their conclusions remained unchanged. By the end of February they had a draft of a new paper, and the laboratory was wrestling with the question of what to do next. Says Los Alamos Director Sig Hecker, "If one of our scientists has some idea that has potentially large political implications, and quite clearly this one did, we've got to stick to science, and we've got to allow him to go ahead and develop the idea and then really subject it to the scientific process of peer review and publication."

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—John Browne

On the other hand, Hecker says, he was wary of seeming to give a Los Alamos National Laboratory imprimatur to such a tenuous hypothesis. Hecker says he and Browne decided the solution was to have the white team write up its review as a scientific paper, so that both it and the Bowman-Venneri paper could be submitted to journals simultaneously. "I thought this was a good game plan," says Hecker. But it soon became moot.

By the time Bowman and Venneri had finished their revised draft, news of the work had already leaked out, although how is still unclear. Bowman had distributed copies of the paper to a few physicists, who had been sworn to secrecy, and last December Bowman and Browne had briefed a few DOE administrators on the work. Somehow the news reached *New York Times* reporter William Broad. "Like my mother said," says Bowman, "if you're not willing to keep a secret, don't fuss at your friends when they give your secret away. If you send it out, it's eventually going to get out."

What is clear is that after learning about Bowman and Venneri's theory, Broad called Massachusetts Institute of Technology physicist and Nobel laureate Henry Kendall, chair of the Union of Concerned Scientists and a longtime critic of the U.S. nuclear power program. Kendall had received a copy of the paper from Bowman, with whom he had discussed it at some length. Although Kendall knew he was no expert on the subject, he thought Bowman's work was important, demonstrating, he says, that the DOE's Yucca Mountain program "had failed to analyze a very obvious potential weakness in the planning of it." Kendall says he expressed that view to Broad.

Kendall also called Bowman at Los Alamos and suggested he send his paper to Broad, arguing that Broad seemed committed to doing the story and might as well have the latest draft of the paper so that he could get it right. Bowman says he rejected the idea, but on 2 March, Broad contacted the laboratory and officially requested an interview with Bowman and a copy of the paper. Jim Danieskold of the lab's public relations staff says his office recommended that Bowman agree to the request, which he did.

Broad had considerably less luck obtaining a copy of the white team report, although he certainly tried. The report, explains Greg Canavan, the physicist who led the white team, was for internal use only and had not been cleared for external distribution. Or, as Bowman puts it, "part of it was so vituperative that the lab did not want that to get out."

The refusal of Los Alamos to release the report may have been a misstep, says NAS's Bunn; after all, "they knew that Broad already had the Bowman paper." Still, Hecker and Browne, who was at Livermore at the time, agreed that Browne could give a summary of the white team report to Broad. Says Browne, "I gave him all the major results on which [the white team's] summary conclusion was based." That wasn't the only caution Broad received. For example, Garwin says he also tried to steer Broad away from doing the story. In an exchange of e-mail, Garwin wrote that it would be "very irresponsible to raise [Bowman's] technical conjectures as if they were established fact." Bunn, who had a copy of the white team report, says he called up Broad and "even read him the sentence about the probability of events described being essentially zero."

Nonetheless, Broad's article appeared on Sunday, 5 March, prominently placed on the

upper left-hand corner of the front page. While the article stressed the internal dispute at Los Alamos, researchers there felt it had an obvious slant, embodied, for instance, in the phrase "questions about a nuclear explosion may be wrong but are important." It went on to give equal weight to what most scientists saw as two unequal camps. On the positive side were Bowman and Venneri and maybe Kendall; on the negative side were the 40 or so researchers involved in the red, blue, and white teams, as well as the lab administration, Garwin, and others.

A theory goes critical

Those who doubted Bowman and Venneri's work were, not surprisingly, upset by the *Times* story. Garwin called it "very destructive"; Forster, who headed the red team at Los Alamos, was harsher still. "I am just so angry," he says, calling the article "a sensationalistic story ... the sole purpose of which is not to inform but to inflame and sell papers." Hecker says dryly, "It did not add positively to the debate on the Yucca Mountain project."

Nicholas Wade, the *Times*' science editor, defended the decision to publish the story. "Newspapers have different criteria than scientific journals," he told *Science*, "and it's right that they should be different. We perform different functions. It's often enough for us to write a story if there's simple disagreement between various experts in the field and the issue is sufficiently important. ... It would be wrong for a newspaper to wait until a scientific issue is completely resolved if it [is already] an important dispute among experts."

The repercussions quickly followed. On Monday, 6 March, the day after the *Times* article appeared, Bryan, the Nevada senator, was in Congress calling for an independent review of Yucca Mountain. It didn't help the situation that in a session before the Senate Energy Committee 4 days earlier, where both DOE Secretary Hazel O'Leary and Dreyfus had appeared, witnesses testified that no scientific issues were holding back progress at Yucca Mountain. Bryan declared that the *Times* article "reveals nothing could be further from the truth."

The Los Alamos administration immediately sent the white team review to Bryan and Bennett Johnston, the Louisiana senator who had been the original architect of the Yucca Mountain legislation. Johnston then officially entered the review into the Congressional record. "It had escalated to the point that they needed documentation," says Browne by way of explanation. That same week Browne flew to Washington to brief congressional staffers and key committee members on the situation, and the Los Alamos administration suggested to Bowman that he complete his paper and submit it to a journal. Los Alamos also decided that there would be no more interviews with the press, says Browne, so as to "let the situation play itself out in the scientific community and not have people passing judgment in the press about the correctness or incorrectness of Charlie's ideas." By early April, Bowman had finished his paper and submitted it to *Nature*.

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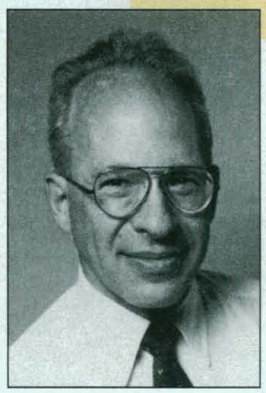
—Richard Garwin



The laboratory had also begun sending out copies of the Bowman-Venneri paper to researchers interested in testing its assumptions and had already arranged for two more reviews, by groups of scientists and engineers at Livermore and the nuclear engineering department at the University of California, Berkeley. "We thought these [reviews] would help to bring this back into the scientific arena," says Hecker.

That meant leaving out the press, which would not be easy. On 23 March, Broad reported that three researchers at the DOE's Savannah River facility had managed to confirm the Bowman-Venneri theory, although that was not quite the case. The *Times* ran the story under the headline, "Theory on Threat of Blast at Nuclear Waste Site Gains Support." But as a Savannah River spokesperson later explained, the paper, which was leaked from the laboratory, "really only looks at one part of what takes place in the Bowman-Venneri situation, and that's the criticality part"—the calculations of what constitutes a critical mass. As Browne points out, even the Los Alamos blue team had confirmed that part of Bowman and Venneri's work; the real question about this particular work was whether the scenarios leading up to explosive criticality were in any way realistic.

On that issue, the Livermore report, released on 5 May, was strongly negative. The review, says Van Konynenburg, who directed it, was a compilation of the input of dozens of researchers at Livermore. It cited six significant errors and shortcomings in the Bowman-Venneri paper: for instance, assuming little difference between weapons-grade plutonium and spent fuel, making assumptions inconsistent with the known properties and behaviors of real waste and rock, and ignoring "the disparity between the slow rates of geologic processes and the rapid speeds of assembly needed" to achieve a bomb. The bottom line of the Livermore report: "We do not believe [the Bowman-Venneri paper] would make a useful contribution to the literature in the field of criticality safety in geologic disposal of fissile materials."

But that isn't the end of it. The Berkeley review is still to come, and the American Nuclear Society has planned a session on the topic for a meeting this week. While Bowman agrees that further reviews are warranted, he takes them as evidence that the original review at Los Alamos and the follow-up Livermore review were lacking in "scientific backup or argument." Only publication and the full discussion of his work by the scientific community will bring a resolution, he says. "I want to see the scientific process be allowed to operate unencumbered with these pseudoscientific evaluations."

Meanwhile, Yucca Mountain has come under new attacks. At the end of May, Representatives John Kasich, chair of the House Budget Committee, and Robert Walker, chair of the House Science Committee, outlined a proposal that the government scrap the idea of a permanent nuclear waste repository in Nevada and instead look for interim storage solutions—facilities that would store the waste for 100 years rather than 10,000. Kasich and Walker explained that the House Budget Committee had concluded that the Yucca Mountain project was "poorly conceived and nearly impossible to carry out." The problem, says a staffer, is that DOE is studying the problem to death rather than pushing ahead with construction. In Nevada, however, the state commission overseeing the project argues that DOE needs to do more study of possibilities like Bowman and Venneri's scenario rather than less.

One way or the other, says Bunn, even if Yucca Mountain survives the latest attack in Congress, and even if Bowman and Venneri are as wrong as the preliminary reviews strongly suggest, "this is going to come up in every public hearing that happens in Nevada from here through the indefinite future. Some people will say it's been discredited, and others will say some scientists say it has and some say it hasn't, and are you going to take the chance of causing a nuclear explosion in your own back yard. And since science is complicated, you'll never be able to convince people who live next door to Yucca that this was wrong. That doubt will always be there."

–Gary Taubes