RESEARCH SAFETY

Volcanologists Ponder a Spate Of Deaths in the Line of Duty

For most scientists, "life-or-death" situations mean things like applying for a grant or going up for tenure. For volcanologists, however, research can be a matter of life or death in a much more literal sense, a fact that has been all too graphically illustrated this year. On 12 March, two young researchers from the Geophysical Institute in Quito, Ecuador, were killed when the Ecuadoran volcano Guagua Pichincha exploded in their faces. And that tragedy followed barely 2 months on the heels of the deaths of six volcanologists in a similar blast at nearby Galeras volcano in Colombia (*Science*, 29 January, p. 599).

The deaths brought the toll during the past 2 years to 12, prompting the volcanology community to take a close look at whether they can devise a set of formal safety guidelines—the first ever—that could minimize the risks while allowing scientists to observe active volcanoes close up. "We need to think very seriously about safety, more than we have in the past," says William Rose of Michigan Technological University in Houghton, a veteran of 30 years of volcano watching. "I've taken groups to places with the same imponderable danger [as at Galeras]. Can I really justify that? You reflect on it when a bunch of good people are killed."

Obtaining scientific data that might save lives is worth taking some risks for. But at Ecuador's Guagua Pichincha, the potential value of the observation did not justify the risk, says Minard Hall, director of the National Polytechnic School's Geophysical Institute in Quito. On Tuesday 9 March an explosion had rocked the mountain, and early on the morning of Friday 12 March two young workers from the institute took it upon themselves to document the debris on film.

When Hall learned of the departure of the two workers, he sent a radio message to try to warn them of potential danger at 10:30 A.M. via an intermediary—transmission problems in the mountains making direct radio contact impossible. The message went through, but Hall is not sure the emphasis on "get out as soon as possible" remained clear. At 11:46 A.M., another minor explosion went off. Saturday morning Hall found the battered bodies of his colleagues near the crater's rim.

The story of the two inexperienced Ecuadorans might suggest that risks could be minimized by drawing on the experience of senior volcanologists, but in fact the researchers caught by the eruption at Galeras included some of the most experienced workers in the volcanological community. The 12 were knowingly exposing themselves to the uncertain hazards of an active volcano to collect volcanic gases and make other measurements that could tell them whether the newly invigorated Galeras was merely spouting the odd bit of steam or building toward a major eruption. Despite the victims' accumulated expertise, only one other volcano has taken a higher

Volcanologists' Accidental Death by Eruption

Year	Volcano	Total Killed	Volcanologists Killed
1951	Kelut (Indonesia)	7	3
1952	Myojin-sho (Japan)	31	9
1979	Karkar (New Guinea)	2	2
1980	Mt. St. Helens (U.S.)	57	1
1991	Unzen (Japan)	43	3
1991	Lokon-Umpong (Indonesia)	1	1
1993	Galeras (Colombia)	9	6
1993	Guagua Pichincha (Ecuador)	2	2

Source: H. Okada, Usu Volcano Observatory

A Clue to Small But Lethal Eruptions?

The recent surge in the number of volcanologists killed by erupting volcanoes has prompted a new effort by researchers to devise safety guidelines that might reduce the toll (see main story). But one development that everyone agrees could help is better methods of eruption prediction. While the successful prediction of Pinatubo's catastrophic outburst bodes well for prediction of large eruptions (*Science*, 2 August 1991, p. 514), the forecasting of small but still lethal eruptions has much further to go. Now, the latest behavior of the Colombian volcano Galeras, which killed six volcanologists last January, is offering a clue to recognizing when an apparently quiescent volcano is poised to explode.

In January, when the team of 12 volcanologists descended into the Galeras caldera, the volcano seemed reassuringly quiet. Seismic activity was low, little gas was venting from the crater, and swelling of the mountain was negligible. In other words, there were no signs that magma was pushing its way up into the volcano in preparation for an eruption.

But in the 20-20 clarity of hindsight, the mountain was sending out a signal of impending danger. While overall seismic activity remained low, 2 weeks before the eruption seismologists at the nearby volcano observatory had noted the appearance of a distinctive type of earthquake that produces seismic waves having longer periods than those produced by ordinary quakes. These long-period waves were also so regular that their tracings on a seismograph resembled a screw seen in profile. Such "screw-type," long-period quakes had preceded a Galeras eruption in July 1992. But because they had also struck beneath Galeras on two other occasions without an eruption immediately following, no one was particularly concerned as the field parties entered Galeras in January.

Now, there may be a pattern emerging at Galeras. Last month it erupted a third time, and for the third time the eruption was preceded by a substantial number of screw-type events. This time, local scientists warned visitors to the volcano away—and the eruption injured no one.

The immediate cause of these subtly foreshadowed eruptions appears to be magma that seeped up into Galeras during 1989 and 1990 and is now cooling and crystallizing in place, forcing magma gases into the pores of less permeable rock. Eventually, the rock ruptures, causing a small but potentially lethal eruption, says volcanologist John Stix of the University of Montreal. But just before the extreme gas pressurization causes the rock to fail, the pressure apparently creates cavities that resonate with long periods during an earthquake. "This strange type of seismic activity seems to be an indicator of an [impending] eruption," says Stix. No one knows yet whether that will continue or whether the screw-type events will also prove to be reliable eruption indicators at other volcanoes. But, says Stix, "we're definitely learning things."

–R.A.K.

toll: Myojin-sho killed nine researchers in 1952.

The reaction among volcanologists to the recent tragedies varies greatly, according to Tom Casadevall of the U.S. Geological Survey (USGS) in Denver, who is involved with international efforts to address the safety issue following Galeras. Those whose chosen line of work takes them into craters recognize the risks, and in fact, says Casadevall, they see the hazard as precisely the reason why scientists wish to monitor volcanoes. But he adds, "Folks whose work doesn't take them into craters have been very critical." One such volcanologist, who insisted on anonymity, told *Science*: "I don't think it was surprising; volcanoes explode. It's plain those guys didn't take the hazard seriously." As examples of their lack of seriousness, he cites the large size of the party in harm's way and the fact that only three of the 12 were wearing hard hats.

Others agree that hard hats might help. They're among the pieces of safety equipment recommended in a set of "Lessons Learned at Galeras Volcano" being circulated by Michael Conway of Florida International University, a Galeras survivor. Other recommended safety measures include flame-retardant clothing, powerful two-way radios for links to those outside who are monitoring the volcano, and a research plan that minimizes the number of field party members and the time they spend near open volcanic vents. The initial reaction to the suggested guidelines has been positive, says Conway, and they will probably figure in discussions on safety guidelines at a volcanological congress next September in Australia.

But while veteran volcano visitors don't object to such guidelines, many see a limited payoff. Stanley Williams of Arizona State University, who led the gas sampling group at Galeras and suffered a fractured skull, a crushed leg, and third-degree burns, is of this school. "I've seen drafts about safety rules, and so far I haven't seen any great new insights." While he wasn't wearing a hardhat that day, he adds, "it wouldn't have done me much good."

As to the larger question of whether some higher authority should be telling volcanologists when they can enter particular volcanoes, the answer so far is no. "I'm concerned there will be an overreaction" to Galeras, says Donald Swanson of the USGS at the University of Washington, a frequent visitor to Mount St. Helens. "We certainly want to minimize the risk, but we have to stop short of keeping people out of situations that would allow them to do some good." Casadevall adds: "The overwhelming consensus seems to be to not legislate behavior." Volcanologists' behavior may not be legislated, but recent losses have had a sobering effect. "I feel guilty having led groups into dangerous places when the payoff was marginal," says Rose. "I don't want to do that again."

–Richard A. Kerr

COMPUTER SCIENCE

Researchers Defy the Physical Limits to Computation

Each year's new computing technology, it seems, leaves the last year's in the dust. But physicists are now beginning to tell computer scientists that it can't go on this way. Sooner or later, as computers get smaller, faster, and more complex, the laws of physics will throw up roadblocks to further progress. There's only one way out of this bind: radically new strategies. And some of those strategies are starting to emerge.

Rolling Back the Costs of Computing

Strange as it may seem to computer users who have seen their machines effortlessly wipe out files, it takes energy to destroy information. And in current computer designs, the machines are destroying information every step of the way, even when they're working properly. Computer scientist William Athas and his group at the University of Southern California (USC) are working to end some of that waste—and thereby tremendously improve the efficiency of computers. Athas' group has realized a theoretical possibility proposed some 20 years ago and built a computer switch that, by preserving the information that goes into each computation, may ultimately lead to a new generation of energy-sparing computers.

For the moment, the switches designed by the Athas group are too cumbersome to make a dent in the real-world computer market, but there's a strong practical impetus for refining the idea further, says Xerox Corp. physicist Ralph Merkle. If computer circuits go on getting smaller and more powerful, by the year 2000 it will be possible to pack about 10^{17} logic gates into a cubic centimeter. And no matter how efficient those circuits are made, says Merkle, they will still have to dissipate megawatts of energy—enough to dry a thousand hairdos—simply to destroy information as the computation proceeds. If the information could somehow be spared, computers could be made as efficient—and as cool—as you like.

The idea that the destruction of information would place a fundamental limit on the efficiency of computing was proposed by theorists, including IBM's Rolf Landauer and Charles Bennett, in the 1970s. Bennett describes the problem this way: Imagine two memory elements in your computer. One (call it A) is set to 0; the other (B) is set to 3. If A is made equal to B during a computation, you've thrown away the information that A was equal to 0. Destroying that information consumes energy, explains Los Alamos researcher Wojciech Zurek, because by turning two values into one, it decreases entropy, which is a measure of the number of possible configurations of a system.

The theorists who identified this stumbling block thought they saw a way around it—at least in theory: Make every process in the computer reversible, so the information that goes into a computation can be recovered. Instead of setting A to equal B, for example, describe A's new value in terms of its old one—as A+B. Then you have enough information to retrieve the original A, by taking the new A and reversing the operation. Though performing such a reversible operation will still dissipate some energy, as electrons course through the circuits, the amount can be arbitrarily small. The slower you run the device, the less energy you use, says Landauer.

But this possibility remained speculative until recently because in conventional computers both the logic circuits and other components are set up to run in one direction only. Late last year, however, Merkle, Athas and his USC colleague Jeffrey Kollar, and several other groups realized that there was a way out of that bind. What they did was to take energy-efficient CMOS transistors, arrange them into reversible switches, and intersperse among them elements known as inductors, which harvest electrical energy that would have been lost as heat and feed it back into the power supply. The reversible circuits, the researchers say, are 7.7 times more efficient than conventional ones.

Yet, as always when researchers are approaching limits of computation, there's a catch: achieving those gains in efficiency requires slowing the computations by a thousand-fold. Even if the system could be sped up, Athas says he doesn't see his work leading to a completely reversible computer. The ideas are still too new. "I'm skeptical of whether anyone will use this in the near future," he says. Eventually, though, he thinks computers will use some reversible parts and some irreversible ones. "We will end up with a hybrid solution—that's what I see when I look into the crystal ball." Merkle is less cautious. As computer scientists push back the limits of miniaturization and efficiency, he thinks the attractions of these thrifty circuits