erators that make up DARHT won't be ready until 2008, 5 years late. Of seven shots originally planned for the fiscal year that just ended, the lab conducted only three.

DOE officials say an 8-month shutdown of the lab last year, ordered by former director George "Pete" Nanos after computer disks with classified data were reported missing (*Science*, 23 July 2004, p. 462), forced them to alter their original plans. But they insist the facility remains on schedule. However, even the plan for six firings next year suggests that the lab could have trouble reaching the level of 11 per year called for by 2009. Last year, the lab conducted seven of 10 scheduled hydrotests, but only by relying on an older facility called PHERMEX, which provides much less data than DARHT does. PHERMEX was closed last year after officials decided it was redundant with a similar facility at Livermore.

Another major hurdle for the lab is containing debris from DARHT's open-air shots. The lab had hoped to have hard containers in place by 1999, DOE auditors say. But researchers are still developing a rigid, mobile container that doesn't disrupt x-rays. Meanwhile, foam-filled tents catch debris. Los Alamos officials acknowledged to the IG that the foam system extends the time needed to clean up after each test and prepare for the next one. But David Crandall, an official with DOE's National Nuclear Security Administration (NNSA), which oversees Los Alamos, says preparing the experiments, not the cleanup, is the limiting factor.

Planning and management challenges also loom large at DARHT. A 2003 report criticized the program for $58 million in cost overruns that other programs had to absorb. And the new report complains that administrators have "often dispersed responsibility for completing the work among several organizations, … lessening control and accountability for completing specific tasks." NNSA officials say they've implemented management changes that address these problems.

Shelving PHERMEX was another sign of poor planning, says Los Alamos experimentalist John Horne. It "should never have been closed," he says, arguing that the data, although not as rich as those from DARHT, would still have been very useful. "If you don't collect [hydrodynamics] data, you can't make changes if necessary." NNSA adviser Jeremiah Sullivan of the University of Illinois, Urbana-Champaign, said the problems with the program are not serious. But he agrees that "deadlines should be met" to maintain credibility.

Hydrotesting isn't the only element in the lab's effort to certify weapons. A prime distraction, says Raymond Jeanloz, a UC Berkeley physicist and member of an LANL oversight committee, is the Robust Reliable Warhead (RRW) program, a nascent effort by the weapons labs to redesign components of currently deployed weapons—or whole new bombs—instead of simply copying existing ones. Created by Congress last year, the RRW program is seen by lab managers as a way to mend what in May they declared was an "increasingly unstable" stockpile stewardship program.

Critics worry that designing new weapons would give foreign powers an excuse to build their own new weapons or lead to calls for nuclear testing to ensure the new designs actually work. The failure to perform routine tasks such as hydrotests is "going to add arrows to the quiver of proponents of the RRW," says John Pike, director of GlobalSecurity.org in Alexandria, Virginia.

NNSA officials say the IG report fails to account for routine adjustments to the DARHT program. Some of the shots originally planned for this year have turned out to be unnecessary, they say, and the two shots the lab fired provided "critical" hydrotest data for the W76 refurbishment. Los Alamos has cut the turnaround time between shots while using the foam, Crandall says, and a lab spokesperson says RRW work has not diverted resources from other missions, which are on schedule.

Spending panel staff from the House and Senate who oversee the lab say they are confident the program is heading in the right direction. But as U.S. policymakers debate the need for new weapons, they will also be wondering how well the nation is preserving existing ones.

–ELI KINTISCH

Building Safety

Directing the Herd: Crowds and The Science of Evacuation

No skyscrapers are designed to be able to disgorge all their occupants in a dire emergency like the attack on the World Trade Center towers. Can they be made safer?

VIENNA, AUSTRIA—In the hour and 42 minutes that elapsed between the first airplane strike on the World Trade Center (WTC) on 11 September 2001 and the collapse of both towers, more than 2000 people failed to escape. Roughly 500 occupants are believed to have died immediately upon impact, and more than 1500 trapped in upper floors died in the aftermath. The toll might have been far worse, according to studies presented here at the International Conference on Pedestrian and Evacuation Dynamics on 28 to 30 September. Had the same attack come when the towers were at their full capacity of 20,000 people each, says Jason Averill, a fire safety engineer at the National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland, the staircases would have quickly gridlocked, resulting in some 14,000 deaths.

Faulty tower? Experts say the proposed Freedom Tower would be as hard to evacuate as its destroyed predecessors.

CREDIT: SKIDMORE, OWINGS & MERRILL LLP

No tall building is designed to be fully evacuated. Instead, regulations typically require that a few floors be emptied, assuming nothing worse than a localized fire. "This has to change," says Shyam Sunder, deputy director of NIST's Building and Fire Research Laboratory, "because in the lifetime of a building, there will be situations where you've got to get everyone out."

But getting everyone out of harm's way will require a deeper understanding of the collective behavior of crowds, says Jake Pauls, a veteran building safety consultant now based in Silver Spring, Maryland. Researchers are "just scratching the surface," says Averill, although they have made leaps and bounds over the past few years. Studies presented at the meeting offered a glimpse of how evacuations could be conducted more safely.

Modeling mobs

Until recently, there was little science in emergency planning, says Ed Galea, a fire safety engineer at the University of Greenwich, U.K. That is changing as scientists try to capture the behavior of crowds using computer simulations. A diverse effort is under way to refine these models with real-world

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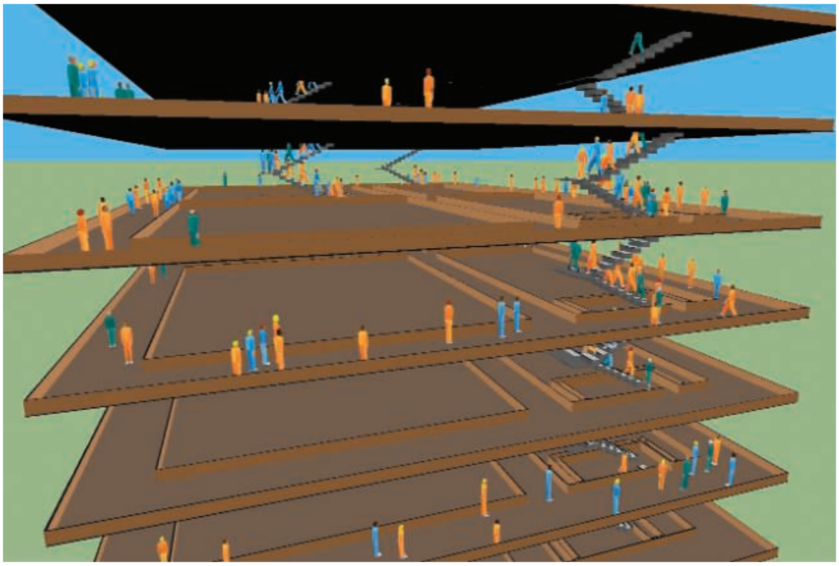
data. For example, a team led by Jean Berrou, a computer scientist at the Maia Institute in Monaco, has been secretly filming pedestrians in 10 different cities around the world, analyzing nearly 1000 hours of video to measure different cultural patterns of walking. For example, he says, "pedestrians in London are faster than those in New York."

The goal is to find rules that individual pedestrians unconsciously follow to navigate crowded spaces. "What's amazing is that people don't collide with each other more often on a typical city sidewalk," says Jon Kerridge, a computer scientist at Napier University in Edinburgh, U.K. On a scale of microseconds, people negotiate priority with cues transmitted through body language. "If we can understand how that works," he says, we might learn why certain geometries of corridors and portals work better than others.



Built-in catastrophe? Computer modeling of the World Trade Center reveals the inherent risks of today's tall buildings when the entire structure must be evacuated.

CREDIT: FSEG/UNIVERSITY OF GREENWICH

The next step is to understand how an emergency changes everything. Researchers use a parameter called drive to define the level of motivation people have to go from A to B. "This is where things get very difficult to model," says Kerridge, "because we're talking about innate, personal factors."

Strange things happen when fear is added to the mix. Take the paradox that the more urgently people want to leave a crowded room with a narrow exit, the longer it takes to get out. That occurs in part because of a breakdown in normal communications. Daniel Parisi and Claudio Dorso, computer scientists at the University of Buenos Aires, Argentina, have found that the optimum exit speed is a fast walk of about 1.38 meters per second.

Such studies reveal that "the fundamental unit of a crowd is not the individual but the cluster," says Kerridge. This is because "the first thing we do in an emergency situation is look to each other for support and information." But that response slows movement dramatically. On a larger scale, people form groups similar to animal herds in which individuals let the crowd do the navigating, often passing right by exits within clear view.

Learning to predict and control these behaviors may save lives—and not just in big buildings. The main killer when people mass is not trampling, as is commonly thought, but "crowd crush." When two large groups merge or file into a dead end, the density makes it impossible to fall down, says Pauls. But the accumulated pushing creates forces that can bend steel barriers. "The situation is horrible," he says: "Suddenly everything goes quiet as peoples' lungs are compressed. No one realizes what's happening as people die silently." Dangers like these make designing architecture and procedures for evacuation like a tightrope walk, says Pauls: "You have to get people out fast, but safely."

Revisiting 9/11

Armed with these insights, two separate groups have been trying to model the WTC evacuation to see what lessons can be learned. In 2002, the U.S. Congress ordered NIST to investigate the WTC safety and emergency response, and the U.K. government commissioned a team led by Galea, which has paved the way for a larger study called HEED. "This was one of the largest full-scale evacuations of people in modern times," says Galea.

To build a minute-by-minute chronology of the event, the NIST team has conducted more than 1000 interviews with survivors by telephone, and Galea's team is set to do up to 2000 face-to-face interviews next year. One of the most surprising discoveries, says Galea, is the long lag time between the first attack and the start of evacuation. Galea's team found that although 77% of survivors began the egress within 5 minutes of the impact, it took another hour for the next 19% to get going, and 4% stayed in their offices for over an hour. "In some cases people were more worried about saving their computers," he says.

Both teams have incorporated these data into a model called EXODUS, designed by Galea. When the NIST team used the model to play out the WTC disaster with full occupancy, it estimated roughly 14,000 deaths, most among those stuck on the stairs. This didn't surprise Pauls.

"Those stairs were not designed to handle a full evacuation," he says. "In fact, no tall building is prepared for it." Sunder says NIST is pushing to include full evacuation for many tall buildings in the next review of U.S. building codes in 2008. "There is a lot of resistance" to requiring full evacuation capability even after the WTC attacks because people "believe that was a one-time-only event," he says. But he notes that a building's typical lifetime is a century; designers should be preparing for other "extreme events" like multifloor fires, earthquakes, and hurricanes.

Until the existing tall buildings are replaced with a new generation, experts say, improvements will have to come through better emergency procedures and retrofitting. For one, elevators should be made usable during emergencies, says Sunder. WTC tower number 2 emptied far more efficiently than tower 1 because its elevators were available before it was hit by the second plane, the studies found. New elevator systems that include independent power supplies and computers that prevent them from opening on a burning floor will be available within a few years, says Averill. Galea suggests another possible innovation: adding sky bridges to create new escape routes linked to other buildings. His simulation of a WTC evacuation with the towers linked by a bridge was far more efficient.

Evacuation experts say they are continuing to look at all kinds of evacuation backups, even far-out ones. For example, a pole system that can be attached to the outside of buildings is being tested. By strapping into a vest attached to the pole, people could slide down safely using electromagnetic brakes. Another option: People could jump into fabric tubes and bounce their way down to the bottom—although this would likely cause friction burns. Even parachutes have been proposed as a last chance resource.

"But really, the best thing we can do to make these buildings safer," says Pauls, "is to focus on the basics." That means better stairs, elevators, and fire drills.

–JOHN BOHANNON

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