Helping Cities PREPARE for a Disaster

Researchers use advanced modeling and simulations to show how urban dwellers can survive both natural and human-caused events.

FOR several decades, Lawrence Livermore researchers have helped federal emergency officials and their state and local counterparts to better understand the science underlying a host of natural and human-caused disasters. More recently, the Laboratory has been working to formulate the most effective ways for responding to low-probability, high-consequence human-caused events involving nuclear, chemical, or biological materials. This task has become more urgent as the nation's population continues to move into dense urban centers, where large numbers of people gather in public areas such as arenas.

"The federal government wants communities to better prepare for the critical minutes and hours shortly following a disaster," says Livermore's Amy Waters, program leader for Explosives and Infrastructure Security. Toward that end, Livermore researchers use advanced modeling and simulations to show that many lives can be saved during incidents that once seemed impossible for which to prepare, in particular for events that can occur without warning. Livermore simulations, shared broadly with federal, state, and local agencies nationwide, serve as excellent training tools and can form the basis for community-specific emergency response plans. Waters says, "Emergency response personnel need plans in place that are technically informed."

In particular, the Laboratory is assisting the Federal Emergency Management Agency (FEMA) and other Department of Homeland Security (DHS) agencies to further the science-based understanding of what to expect from detonation of an improvised nuclear device (IND) or dispersal of a toxic chemical. Waters notes that historically a disconnect has existed between researchers working to resolve scientific questions about the likely effect of, for example, a detonated IND and the practical needs of emergency responders. During such an event, responders would be working with incomplete information, under severe time pressure, and, very likely, in the midst of mass panic and confusion. The Livermore simulations are showing officials—and the public—what to prepare for in the first critical minutes and hours. The simulations demonstrate, for example, how dense urban landscapes can mitigate the effects of an IND and provide valuable protection from fallout.

"The most important message," says Waters, "is that many lives can be saved with appropriate planning and preparedness." She notes, however, that the findings from science-based planning may at first seem counterintuitive. For example, denser-than-air clouds of toxic gases can remain concentrated close to the surface, disperse upwind, or persist longer than expected when trapped in urban areas. Likewise, immediate evacuation may not be wise following the detonation of an IND because of the high levels of initial fallout radiation. Evacuation may also be difficult because of the likelihood of car crashes caused by the initial burst of blinding light and street blockages caused by blast-generated rubble.

The Laboratory has a long history of developing models that track the transport and deposition of hazardous materials released into the atmosphere, thanks in large part to the National Atmospheric Release Advisory Center (NARAC). This federal facility, located at Livermore, serves as the Department of Energy's (DOE's) plume-modeling center for real-time assessments of the impacts of nuclear, radiological, chemical, biological, or natural emissions. NARAC has responded to numerous emergencies over more than three decades, beginning with the Three Mile Island nuclear power plant incident in 1979.

NARAC simulations couple meteorological, geographical, and material property data with computer models that account for the physical processes affecting the dispersion and deposition of radioactive and other toxic materials. For example, fallout simulations can show the trajectory of the plume and how much material is deposited onto buildings and streets. Maps of fallout plumes and ground

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concentrations inform disaster response plans and are valuable in training first responders on what to expect.

Models Point the Way

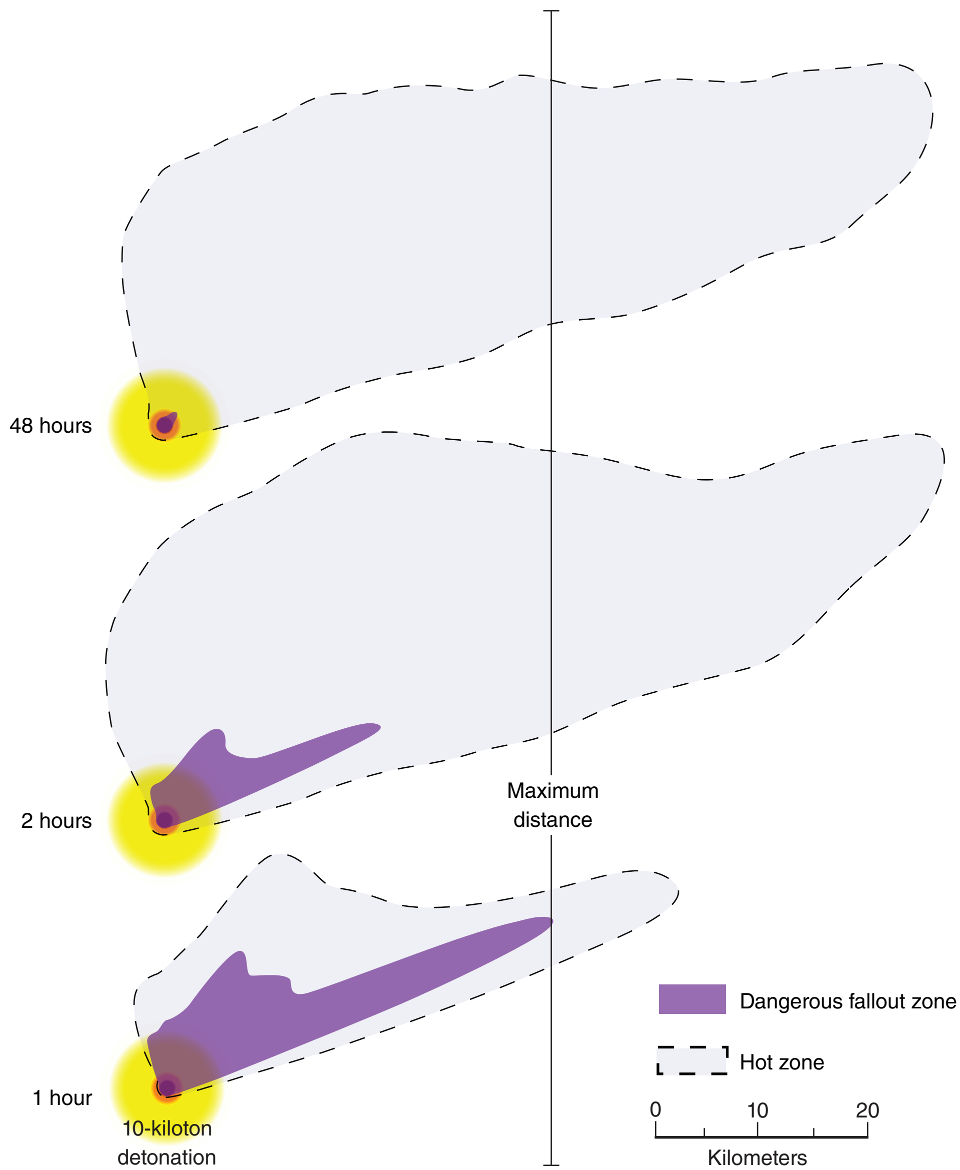
In 2008, DHS's Office of Health Affairs (OHA) launched a program to identify scientific consensus and recommend actions that local emergency responders should take to prepare for an IND detonation in their city. A 10-kiloton IND (equivalent to energy produced by 10,000 metric tons of TNT) could kill tens of thousands of people, particularly if it were set off in a dense U.S. urban setting that lacked sound response plans. The OHA program addressed a directive from Congress, whose members were concerned that cities had insufficient guidance to prepare for acts of nuclear terrorism.

For the OHA effort, Livermore health physicist Brooke Buddemeier chaired a working group composed of experts from several federal agencies and DOE national laboratories. At the time, minimal research had been done on the likely effects and best mitigation strategies specific to a low-yield, ground-level detonation of an IND in a modern U.S. city. Concurrently, as part of an integrated terrorism assessment for DHS's Science and Technology Directorate, Buddemeier and colleagues had begun a multiagency effort to develop detailed public health and medical impact assessments from the same type of event. Because of the large difference in destructive power between INDs and strategic thermonuclear weapons of the Cold War, much of the civil defense era guidance did not apply. Historic data from aboveground nuclear tests could be used for estimating the effects from an IND, but very few tests were conducted at ground level.

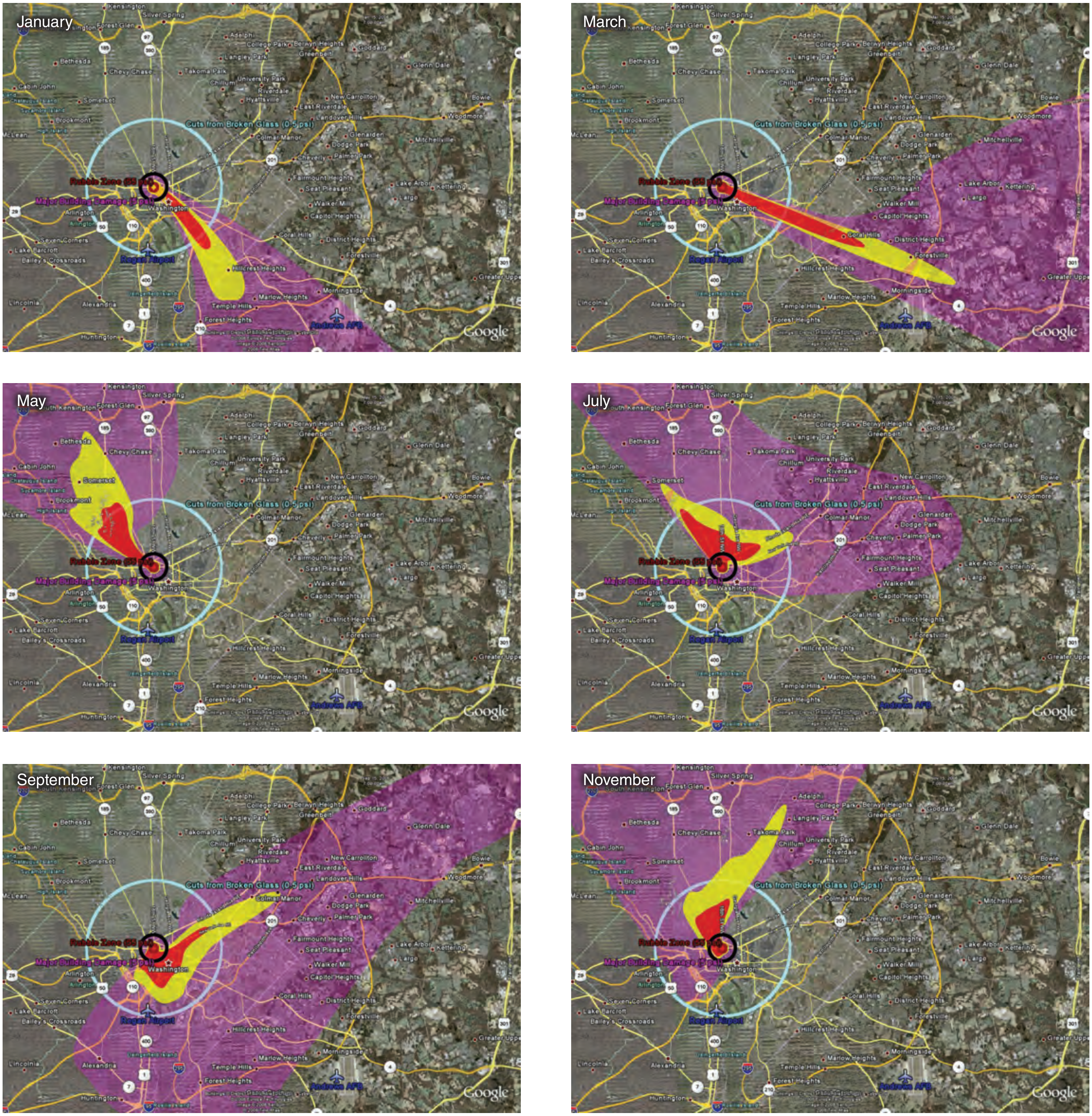
According to Buddemeier, perceptions among city planners have been shaped by Cold War thermonuclear attack scenarios. As a result, planning for an IND event has seemed overwhelming to agencies charged with public health and safety. Says Buddemeier, “Some people assume nothing can be done because ‘we will all be dead,’ or that a detonation response is ‘a federal problem.’ Unfortunately, such inattention in local planning could lead to tens of thousands of preventable casualties. When this effort began, a lack of scientific consensus existed regarding key protective measures such as shelter and evacuation.”

Buddemeier and colleagues reviewed a number of nuclear weapon effects studies. They also performed detailed modeling of the effects of a nuclear detonation in a number of U.S. cities, drawing on data from more than 1,000 Cold War nuclear tests and the experiences of Hiroshima and Nagasaki. The outcome of this effort was the 2009 Lawrence Livermore report, *Key Response Planning Factors for the Aftermath of Nuclear Terrorism*. The document recommends practical ways to plan for an IND and potentially prevent many fatalities and casualties. The Executive Office of the President also used this research to support the 2009 interagency document, *Planning Guidance for Response to a Nuclear Detonation*. This report, updated in 2010, continues to support preparedness documents and training materials for major U.S. cities. “Our most important responsibility is translating science into actionable information for responders and the public that will save lives,” Buddemeier says. The OHA initiative continues today primarily under FEMA, which is working to strengthen regional IND response planning in all FEMA regions.

Mitigating the impacts of an IND requires understanding both prompt effects and delayed fallout. Prompt effects radiate through an area immediately following a detonation and could cause hundreds of thousands of casualties within a few



Prompt effects from a simulated 10-kiloton improvised nuclear device (IND) radiate immediately following a detonation. These effects include an intense flash of light, a shockwave, heat, and both ionizing and electromagnetic radiation. The dangerous fallout zone (radiation levels greater than 10 rems per hour) in purple shrinks quickly, while the much less dangerous hot zone (radiation level greater than 0.01 rems per hour) continues to grow for about 24 hours postdetonation as radioactive material is transported and deposited further downwind. (A rem is a unit of absorbed ionizing radiation. Doses greater than several hundred rem can be fatal.)



Simulations from the National Atmospheric Release Advisory Center reveal how changing weather over the greater Washington, DC, area can cause complex and variable fallout patterns. The weather data used for the simulations were obtained at noon on the 15th of each month in 2006 (six months are shown here). The inner black circle denotes major building damage, and the outer blue circle is the range where glass is broken with enough force to cause injury. The colors of the fallout areas represent 300 rems (red), 100 rems (yellow), and 1 rem (magenta) for a two-hour exposure period. (Images courtesy of Google.)

kilometers. These effects include an intense flash of light, a shockwave, heat, and both ionizing and electromagnetic radiation. The flash of light would likely temporarily blind anyone within 10 kilometers. As a result, most roads within this range would likely be clogged with accidents, which is an important planning factor.

Many previous modeling studies have overpredicted prompt effects in the urban environment because the models did not consider how urban buildings would mitigate some effects on the population. However, advanced radiation transport models show a significant reduction in the range of thermal and prompt radiation effects in urban areas.

Radioactive fallout is generated when the dust and debris excavated by the initial explosion combine with radioactive fission products produced in the nuclear detonation and then are drawn upward several kilometers. The highly radioactive particles can then drop to earth. Unlike prompt effects, which occur too rapidly to be easily avoided, exposure to fallout radiation can be minimized by proper action. Advanced Livermore shelter modeling has helped evaluate the extent to which typical urban buildings can protect citizens if people are provided with a few simple guidelines.

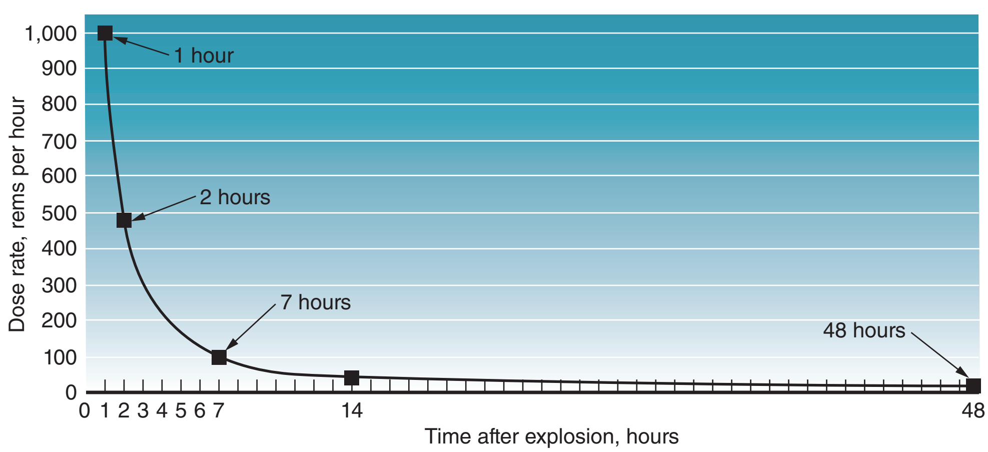
To inform FEMA regional response planning, Livermore researchers have made computer simulations showing prompt effects and fallout patterns from hypothetical INDs for a number of U.S. cities. Fallout modeling is performed with a suite of dispersion and meteorological computer codes, many of which have been developed at NARAC. The models incorporate real-world weather conditions, including wind speeds and direction at different locations and altitudes that are critical when calculating the transport and deposition of fallout. By incorporating advanced geospatial analysis and overlays generated in Google Earth, the simulations allow block-by-block analyses of prompt blast, thermal, and radiation effects, as well as fallout arrival and decay over time.

Block-by-Block Analyses

"We've moved away from simple circles and cigar-shaped contour plots of prompt and integrated fallout exposures," says Buddemeier. "Now we divide a city into individual blocks and buildings and view events unfolding minute by minute based on an observed weather pattern for a chosen day and hour."

Livermore simulations reveal that the most important action following an IND detonation is to reduce fallout exposure with early adequate sheltering followed by delayed, informed evacuation. Fallout decays rapidly, releasing more than half its energy in the first hour because of the short half-lives of many radionuclides. The primary hazard from fallout is not from breathing in radioactive particles but from exposure to the particles that have settled on the ground and on roofs. Because people who are outdoors or inside vehicles will have little protection from fallout, they should move quickly into the nearest robust (concrete or brick) building—ideally, either below ground, such as in a basement or parking garage, or into the middle floors of a multistory building. "Our simulations show that nearly all fallout casualties can be eliminated by taking proper steps in the first few minutes and hours of the event," says Buddemeier.

As a participant in FEMA-sponsored regional preparedness activities, Buddemeier has presented to local officials and emergency response personnel advanced simulations that compare the relative degrees of protection afforded by different types of buildings. His message is that science-based response plans can "save many lives in the first few hours." Common misconceptions about fallout are dispelled when people watch the simulated fallout cloud from an IND detonation moving across an urban area with radiation readings first growing and then shrinking. The simulations also show many nuances to sheltering in place followed by informed evacuation. For example, it is counterproductive for someone to evacuate when they do not have the information needed to avoid fallout areas. The advanced multimedia simulations produced by this effort help responders and planners understand "what they will see, what they will know, and the impact of their decisions," says Buddemeier.



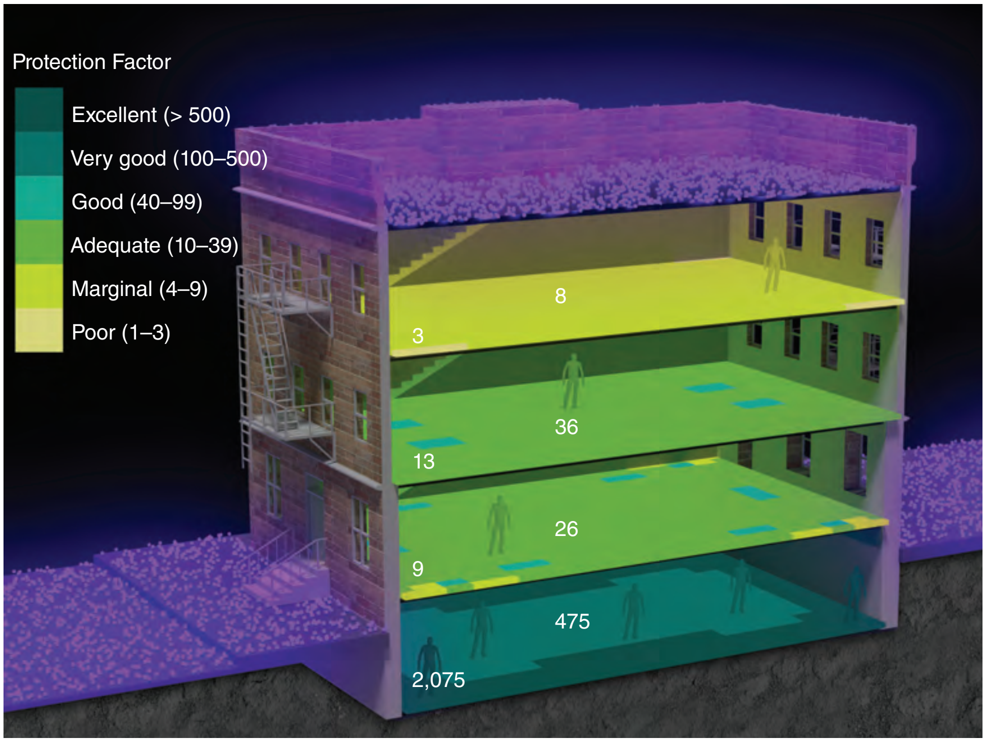
Following an IND detonation, sheltering for the first few hours, when the radiation levels are highest, can help avoid significant evacuation exposures.

Tracking Toxic Chemical Releases

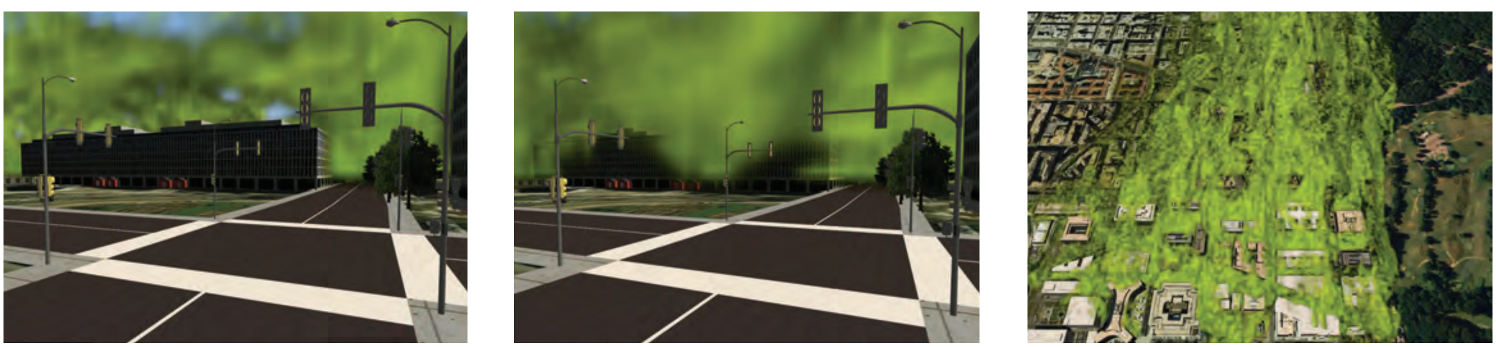
Livermore scientists are also supporting disaster response planning for the release of a toxic chemical, whether by terrorists or by accident. They consider a range of scenarios, based on examples ranging from the 2005 freight train derailment that released 60 tons of chlorine gas in Graniteville, South Carolina, to the 1995 Japanese cult's release of sarin nerve gas in the Tokyo subway system. Each city is unique, with its own set of factors that shape disaster response. For example, a city may have large venues where people gather, or a large concentration of chemical processing plants, or freight trains that regularly travel through carrying toxic chemicals.

Livermore scientist Akshay Gowardhan is developing a NARAC code named Aeolus that simulates flow and dispersion in urban areas. Aeolus explicitly resolves individual buildings and can simulate the atmospheric dispersion of toxic gases and particles, including denser-than-air gases. The model has been validated against experimental data from urban field experiments with tracer gas releases.

Gowardhan explains that buildings influence the movement of gases, creating complicated and at times nonintuitive flow patterns. His code simulates complex airflow phenomena such as eddies that occur at street intersections and vertical drafts caused by skyscrapers. The code can be run in either a high-fidelity or fast-running model. While other building-resolving codes require a supercomputer, Aeolus runs on a laptop. Although it is currently being used for planning and



Adequate shelters such as this brick apartment building can shield occupants from the penetrating radiation of radioactive fallout. The most protection is afforded in a basement away from exterior walls. The top floor offers the least protection because it is close to fallout accumulation on the roof. (Rendering by Ryan Chen.)



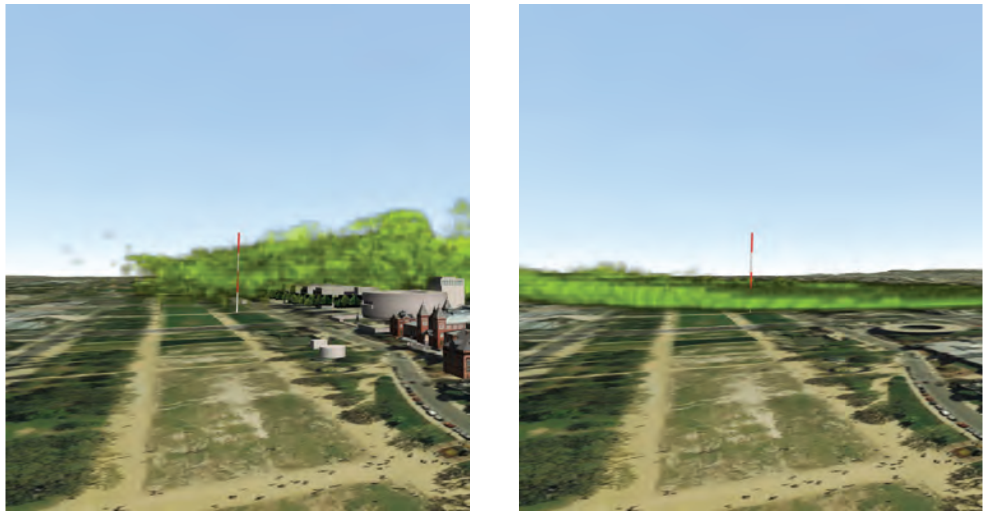
These visualizations of an Aeolus simulation, created using Livermore's SceneWorks software, depict the aftermath from a ruptured chlorine tank car in a hypothetical urban setting. (left, center) Two snapshots, taken just a few seconds apart, show chlorine gas spreading quickly at street level. (right) An overhead perspective, taken 18 minutes postrelease, shows the gas flowing between and over buildings.

training, the code is fast enough for eventual use in NARAC real-time operations.

Watching Chlorine Gas Disperse

Livermore researchers use Aeolus and other NARAC codes to help strengthen existing local government plans for responding to the release of a toxic chemical such as chlorine. A train transporting liquefied chlorine typically pulls tank cars that individually hold 90 tons of gas. A single ruptured chlorine tank car could cause thousands of casualties from gas inhalation.

In an effort led by Livermore chemist Sarah Chinn, Laboratory chemists and engineers use simulations to understand how buildings affect the dispersion of gas from



SceneWorks-generated visualizations of Aeolus simulations show chlorine gas rises much higher (left) in an urban environment than (right) in an open field. The red and white pole measures 100 meters tall.

An Aeolus-simulated chlorine gas release (red) near downtown Houston, Texas, spreads quickly following a train derailment.

a ruptured chlorine tank car in a downtown urban location. As liquid chlorine pours out from the car, it quickly turns into a toxic cloud carried downwind through city streets. Simulations show that in 5 minutes the gas cloud travels several blocks. However, along the way, it is also trapped inside courtyards, forming “hot zones.”

The Aeolus simulations show that although chlorine is a heavy gas, the cloud can be swept upward to the tops of multistory buildings. Within about an hour, most of the toxic cloud is blown downwind and dispersed. However, some of the cloud lingers in high concentrations in alleys and behind buildings. Chinn says that the simulations give emergency planners a more realistic idea of such an incident’s consequences, both in terms of immediate and long-term health effects and of cleanup. Team member Maureen Alai explains, “Not every responder would necessarily consider how buildings affect dispersion. Yet a responder could encounter pockets of high concentrations after the cloud appears to have dispersed. Other models that do not resolve individual buildings show the gas remaining closer to the ground.” Ultimately, local planners can incorporate this knowledge into their own emergency response planning efforts and tailor the plans to the specifics of their own community.

As part of an OHA project to assess disaster response capabilities, Livermore engineers Robert Greenwalt and Wilthea Hibbard use advanced simulations to investigate the effects of a large toxic chemical release, examine the capabilities of local response systems, and determine best practices to maximize the lives saved. OHA managers asked the researchers to study two locales: Houston, Texas, with one of the biggest concentrations of chemical plants in the world, and an indoor sports and entertainment arena in Boise, Idaho, with virtually no nearby chemical industries.

The scientists are assessing Houston’s and Boise’s emergency response plans in the context of five separate chemical incidents, including a hypothetical large chlorine gas release from a train derailment. Model simulations and experimental measurements are used to estimate changing chlorine gas concentrations and determine the locations and number of people that would be affected under typical weather patterns. “OHA’s focus is on saving lives,” explains Greenwalt. “We are examining the entire response system, from initial exposure until the last casualty is released from the hospital. We use the gas plume for estimating the number of people who will be exposed to determine how local emergency rooms will be affected.”

Looking for Planning Gaps

“We are looking for any gaps in a city’s emergency response capabilities,” says Greenwalt. “Our aim is to suggest improvements.” The long-range goal is to produce a generic document showing any city how to evaluate its emergency response system with respect to a chemical release.

The two engineers made several trips to both Houston and Boise, where they met with local emergency responders. At the arena, Greenwalt and Hibbard measured the indoor airflow to determine how quickly the release of a toxic gas would spread through the structure. They also measured how quickly an external plume of gas would flow into the building. Finally, they studied the methods firefighters would use to conduct large-scale decontamination of arena spectators.

Hibbard found that the proper response to a toxic gas release such as chlorine depends on a citizen’s location. People in an arena should leave at once if a toxic gas release occurs inside the facility. However, in the case of an outdoor toxic gas release, buildings can provide considerable protection. In this instance, the people should shelter in place, close windows and doors, turn off air-conditioning and heating systems, move to interior rooms, and remain in those rooms until further notice.

Livermore researchers are also developing toxic chemical release scenarios for Georgetown University’s Emergency and Disaster Management master’s program, a collaboration between the university and Livermore. “The

Photograph courtesy of Brooke Buddemeier program is designed to prepare students for careers in emergency and disaster management and to become thought leaders in the field," says Livermore's Nancy Suski, deputy program director for academic partnerships, who serves as the disaster management program's executive director. As part of the students' training, they visit Lawrence Livermore to learn how researchers predict the effects of potential hazardous threats. Suski says that scenario-based learning founded on simulations places students in the center of a disaster so that they can "see," for example, how a gas might be blown through a cityscape. Graduates of the program often go on to help cities respond to human-caused and natural disasters.

Livermore modeling expertise is used in other types of potential disaster scenarios including the natural contamination or deliberate poisoning of a city's food supply. Such events could occur, for example, from radioactive fallout settling on fields outside of an urban area or inadvertent contamination of food at a processing plant. The accidental or deliberate contamination of food has been named one of the major global public health threats in the 21st century. Experts contend that strengthening surveillance and response plans constitutes the most efficient and effective way of countering food terrorism.

In an effort to improve response planning for food bioterrorism, Livermore engineer Tom Edmunds and colleagues have investigated potential scenarios involving the deliberate poisoning of a city's food supply. His research uses systems analysis to examine how an attack might be perpetrated, how quickly symptoms would appear, the extent of casualties, and potential mitigation measures. In one scenario, the researchers developed a model that simulates all the steps involved in a milk-poisoning event, including distribution through the supply chain and response to the incident.

With the help of experts from the California Department of Public Health, Edmunds' team developed a human dose response model to estimate when symptoms first appear and hospital emergency personnel begin seeing their first patients. The model also calculates when hospitals would need to order additional doses of antitoxin. One important attribute of the model is that it allows authorities to test the effectiveness of new countermeasures against food bioterrorism.

Realistic Training Is Key

Livermore researchers are also developing methods to make disaster scenarios and response training more realistic. Steve Kreek, who leads Livermore's Nuclear Detection and Countermeasures Research Program, and colleagues have been working with the Neptune Coalition, a northern California consortium of more than 50 federal, state, and local agencies from the State of California, U.S. Coast Guard, and nine Bay Area counties. The Neptune Coalition is developing a regional response for maritime operations, and local police marine units are deploying pilot-scale radiation detection systems developed at Livermore.

The Neptune Coalition executive board includes Livermore scientists who provide technical advice on exercise planning and concepts of operation. "Thorough plans are essential," says Kreek, "and realistic training of local responders is critical."

Students from Georgetown University's Emergency and Disaster Management master's program learn about special hazardous material operations during a visit to a Livermore–Alameda Country Fire Station located at Lawrence Livermore. (Photo by George A. Kitrinos.)

The Livermore representatives help improve training for responding to a nuclear incident, such as determining the extent of radioactive fallout.

However, training first responders to locate and identify radiation sources is limited by the materials that can be deployed. Actual nuclear materials cannot be deployed for safety, security, and cost reasons. Rather, surrogate radiation sources must be used, but they typically do not represent an actual radiation threat. "At this time," says Kreek, "training is hampered by its artificiality. We want robust training scenarios for a postdetonation radiological or nuclear event, but we can't distribute radioactivity around a city."

A Livermore-designed device called the Spectroscopic Injection Pulser (SIP) aims to create far more realistic training. The device injects a simulated radiation signal (statistically valid energy spectra) into a commercial gamma-ray detector. The signal is injected pulse by pulse, as would be the case using a real radiation source. With SIP, the simulated signals appear the same to the users as a real radiation source. However, because SIP produces a synthetic signal, one can represent far more realistic scenarios such as wide-area contamination and complex compositions that vary with time and location. The prototype device can be attached to the exterior of a detector or later could be integrated into the instrument.

The Livermore team is currently working with a number of detector manufacturers, encouraging them to include the equivalent of a standard interface port (analogous to a USB port) with their next-generation detection equipment to accommodate SIP. The system was recently demonstrated as a "plug and play" with a commercial high-resolution gamma detector commonly used by responders. The team plans to miniaturize the Laboratory prototype as well as expand the capability of the device to simulate electronic signals for detectors used in releases of toxic chemicals and explosives. "The approach lends itself to just about any instrument that makes a physical measurement," says Kreek.

Sound Science Is Cornerstone

Livermore continues to provide advanced modeling, technical assessments, briefings, and reports to inform federal, state, and local response and recovery planning activities. "Every community is different," says Waters. "Sound science is the cornerstone of good response planning, but it must be tempered with city-unique operational realities and strategies."

Planning for a potential terrorist event is not a pleasant task. However, Livermore researchers are showing that when planning is based on science and advanced modeling, the payoff could be tens of thousands of lives saved.

—*Arnie Heller*

Key Words: Aeolus code, chlorine gas, Department of Homeland Security (DHS), Federal Emergency Management Agency (FEMA), improvised nuclear device (IND), National Atmospheric Release Advisory Center (NARAC), Office of Health Affairs (OHA), Spectroscopic Injection Pulser (SIP).

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