SHELTERING SCIENCE SAVES LIVES

AFTER a blinding flash, a tall mushroom cloud of radioactive particles is unleashed near a city. Prevailing winds carry the fallout through the densely populated downtown and into nearby neighborhoods. People are working in offices or at home, running errands, or exercising outdoors. Quick decisions by authorities and first responders about how to shelter mean the difference between life and death. How can decision makers maximize the number of lives saved in the initial moments of a catastrophe?

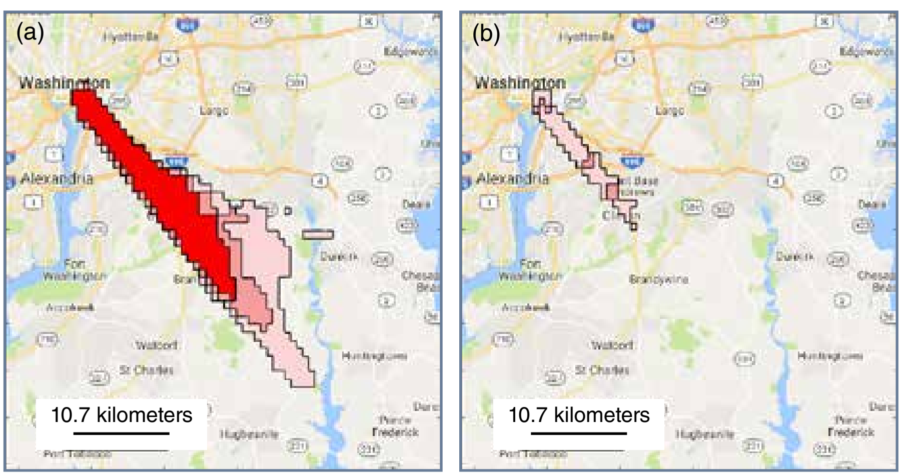
Lawrence Livermore researchers have worked for more than a decade to provide insights for a multifaceted emergency response, and in the process, they have advanced the science of sheltering and developed computer models to identify potentially life-saving strategies. Their efforts have provided actionable insights to protect people from many types of hazards, including radioactive hazards such as fallout from nuclear detonations, particles released from nuclear power plant accidents, and radiological dispersive devices (also called dirty bombs), in which radioactive particles are spread by an explosive device. Other hazards include industrial accidents discharging large clouds of hazardous chemicals, smoke from wildland or urban fires, and airborne-transmitted diseases such as COVID-19, Q-fever, Legionnaire's disease, and Valley fever.

Scientists must study many parameters to understand how sheltering can protect human life. "As an emergency response strategy, sheltering has not been studied as well as evacuation, but getting people into good shelters can save lives," says Livermore scientist Michael Dillon. "Most hazard assessments assume that everyone is outside. Being inside matters. Shelter can drastically change how many people are affected by outdoor hazards."

Sheltering studies conducted by a range of institutions over many decades have typically looked at protection provided by individual or a small number of buildings. Lawrence Livermore's research broadens earlier work by assessing the protection diversity provided by the current national building stock and considering options for improving response to specific threats. Livermore has provided advice to federal, state, and local agencies on how to use existing buildings to protect their populations from radioactive fallout, chemical, and biological hazards. "Sheltering can be used as a good response in so many different areas that a generalized approach may be the best strategy," says Dillon, "and a broad base of partners helps us get there. We are privileged to have great sponsors, collaborators, and end users." The list of partners includes Lawrence Berkeley, Oak Ridge, and Sandia national laboratories; private-sector partners; and agencies such as the Defense Threat Reduction Agency and the Department of Health and Human Services. Funding sources for the team's research and products include the Department of Energy—both the Office of Science and the National Nuclear Security Administration—the Department of Defense, the Department of Homeland Security (DHS), the Centers for Disease Control and Prevention, and the University of Texas.

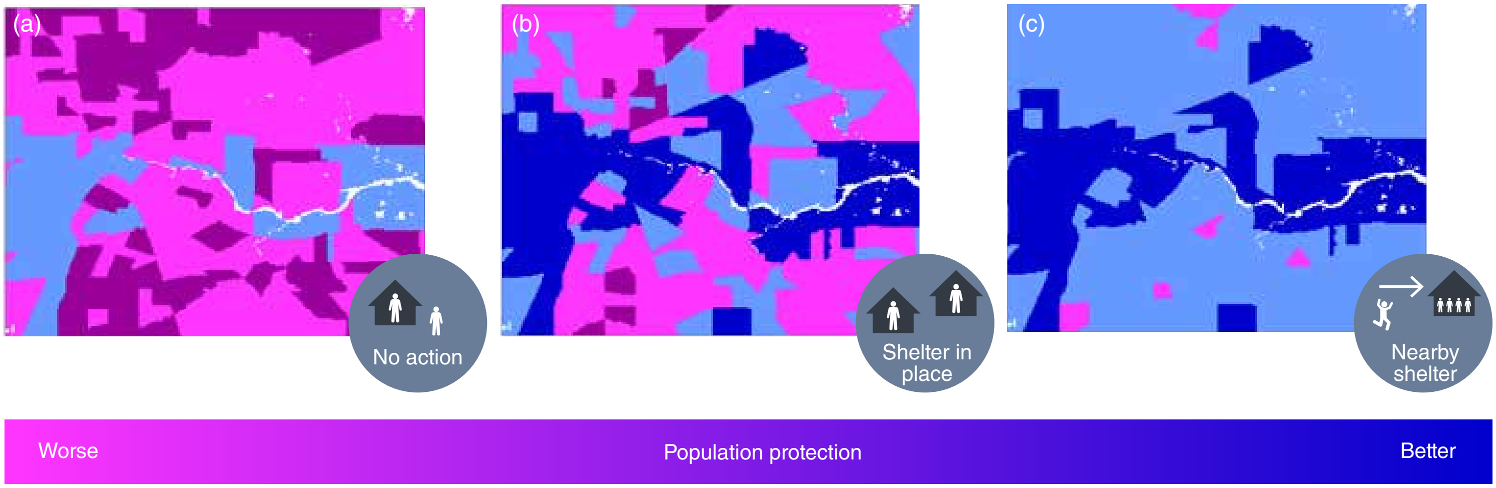
Building Details Matter

Specific properties of a building's design, construction, and operation affect how well it protects people from particular



Risk of Death	Probability
Near certain	90% or more
Likely	50% to 90%
Possible	10% to 50%

Regional Shelter Analysis products present the risk of dying due to fallout radiation exposure. Planning and real-time response visualization and analysis are designed to help officials understand outcomes of possible response strategies for their region. Figures a and b present two outcomes for the same region in a fallout incident. (a) More people remain outdoors and face a higher risk of death (dark red). (b) People shelter in place, and expected risk of death is reduced across the region.



Regional Shelter Analysis incorporates shelter quality into hazard assessments. In Figure a, for example, most people have relatively poor shelter (magenta). In Figure b, people choose to shelter in the closest buildings and have mixed levels of protection (magenta, light blue, dark blue), while in Figure c, people take shelter in nearby buildings such as churches or supermarkets that can offer better protection (light and dark blue).

hazards. For example, protection against nuclear fallout depends on the building size; the weight of the exterior and interior walls, ceiling, and floors; the presence or absence of a basement; as well as aperture (window and door) characteristics. Inhalation hazard protection requires an understanding of how air enters and leaves the building—moving through openings such as windows, doors, ventilation fans, and microscopic cracks in walls as well as, if present, the heating, ventilation, and air conditioning (HVAC) system. In addition, inhalation hazard protection also requires knowing how indoor airborne material may be deposited onto interior surfaces, how it can be filtered by HVAC or air cleaning equipment, and other ways the material will be removed from the air.

After identifying the key building properties, Livermore researchers and their collaborators estimated the protection that current U.S. buildings provide. First, they developed accurate, fast-running, physics-based models that estimate the protection for a single building and hazard. Specifically, Livermore researchers built the PFscreen model for nuclear fallout assessments while a separate, joint effort between Livermore and Lawrence Berkeley researchers developed novel inhalation hazard models. Next, the teams studied how buildings are built and operated in the United States, assembling key information on the range of modern building attributes needed to assess nuclear fallout and inhalation protection. They evaluated the protection for common building types—single family homes, supermarkets, and office buildings—by modeling the protection of more than 10,000 buildings. This approach enabled researchers to understand the average protection for each hazard that each building type provides as well as the variation of protection within a given building and among different buildings of the same type. Now, Livermore researchers and partners understand which building types, and locations within those building types, are best for sheltering for specific hazards—and which may leave people more exposed.

Further, researchers understand how practical actions can improve building protection and indoor air quality. For example, in many U.S. homes, the furnace can offer protection against hazardous smoke if the existing filter is replaced with a readily available, higher quality home furnace filter—rated at minimum efficiency reporting value 13 or better—and the home furnace fan is activated.

Considering the Hazard and Scenario

Livermore and Berkeley researchers also studied how building protection factors vary with specific hazards and scenarios. For example, inhalation hazard protection strongly depends on particle size, with buildings providing orders of magnitude more protection against larger (10-micrometers in diameter) particles than smaller ones (0.1-micrometers in diameter).

For all inhalation hazards, building protection increases with faster indoor airborne material removal rates. In addition, the short-term hazard (acute toxicity) of some chemicals, including many common industrial chemicals such as chlorine, ammonia, and hydrofluoric acid, depends strongly on the peak exposure. For these chemicals, buildings are particularly good at providing protection since they act as low-pass filters, smoothing out the chemical concentration time series and significantly reducing peak exposures. For these hazards, ensuring the toxic outdoor cloud has passed before occupants leave a shelter is more important than prescribing a particular length of time to remain inside.

For nuclear fallout, building protection depends on the radiation spectra. The gamma radiation emitted from fallout particles will change over the first few days as the short-lived isotopes decay away forming new isotopes. Livermore researchers are investigating how the changing fallout spectra affects the corresponding building protection. This information assists researchers in determining the optimal time to evacuate sheltered populations based on the indoor radiation exposure rate for different building types.

Locating People is Key

Understanding which U.S. buildings offer the best protection provides only part of the puzzle. Knowing where people are located is also important when using sheltering as an emergency response tool. Prior approaches that simultaneously considered both building protection and population location have been computationally expensive, posing a challenge for emergency planning and response activities.

People in this building are well protected and so are least at risk.

People in these buildings are not well protected and so are most at risk.

In many regions, nonresidential buildings, such as offices, churches, and supermarkets (represented by a blue dot), provide much better fallout protection than the surrounding housing (magenta dots).

To meet this challenge, Livermore researchers have developed the Regional Shelter Analysis. This approach combines variations in both building protection and population location to create a set of shelter quality factors for a region or neighborhood. These factors can be used to rapidly scale the results of traditional, outdoor-only assessments, such as those produced by Livermore's National Atmospheric Release Advisory Center, to account for building protection and shelter posture. Resulting maps can indicate regions in which building protection is insufficient to avoid acute radiation injury if dangerous fallout was present. Emergency planners and responders can, therefore, focus efforts on these regions to prevent potentially life-threatening exposure. Fortunately, many regions have a few buildings nearby—such as a church, supermarket, or school—that provide much better protection than the surrounding buildings.

Livermore has extended the Regional Shelter Analysis approach to also account for variations in population demographics and individual sensitivity to the hazard. A recent paper extended the original Regional Shelter Analysis method to show that the spatial distributions of many natural airborne disease outbreaks were well predicted by the Regional Shelter Analysis method combined with physics-based modeling.

Dillon and colleagues are developing planning and real-time response visualization and analysis. Their results will help officials better manage emergencies by identifying which regions could be affected and indicating expected benefits of possible response strategies. Dillon and his team aim to provide useful and technically defensible products to help planners should outdoor hazards occur. "We strive to meet this ongoing challenge," he says. "Sheltering can save lives, and the Laboratory's attention to basic science and computer modeling will show the way."

—Allan Chen

Key Words: Airborne disease; Centers for Disease Control and Prevention; Defense Threat Reduction Agency; Department of Health and Human Services; Department of Homeland Security; heating, ventilation, and air conditioning (HVAC) system; National Nuclear Security Administration; nuclear fallout; PFscreen model; sheltering.

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