Although the explosion and subsequent high-rise blaze are nasty, most building residents are away at work, so nobody is seriously hurt. A parade of police cars, ambulances and fire trucks pulls up to the curb, lights flaring and sirens blaring. Emergency crews dodge bits of smoking debris and prepare to enter the stricken structure.

Suddenly a sensor panel on a fire truck flashes a warning. **"The radiation detectors have gone off!" a stunned fire chief roars. "It looks like a dirty bomb!"** *Activity stops abruptly as alarm sweeps through the assembled crews. What appeared to be a standard fire emergency is actually a terrorist attack with a radiological weapon.*

Alerted by radio, disaster-control agencies dispatch specially trained radiation-mitigation teams to the site. Rescue workers slip into brightly colored hazmat suits. Police officers in gas masks start to evacuate bystanders, but most of the frightened onlookers are already running away in panic, handkerchiefs over their mouths.

The explosive device, spiked with radioactive cesium, has released a cloud of toxic dust. When it drifts downwind, fallout settles over nearly 60 city blocks. Buildings, sidewalks, streets and cars are quickly coated with radioactive debris. As the ventilation systems of buildings in the neighborhood suck in the dust, people inhale small amounts of carcinogenic particles.

After sitting abandoned and quarantined for a short period, the environs are swept by teams of workers who decontaminate surfaces with vacuums, water jets and other apparatus as part of a prolonged cleanup effort. In retrospect, the incident has caused relatively few injuries, most of which were the result of traffic accidents during the frenzied exodus. Still, fearful residents refuse to return. Business revenues and real-estate values plummet, and several buildings near ground zero have to be demolished. The final costs reach the tens of billions of dollars.

Weapons of Mass Disruption

Radiological terror weapons could blow radioactive dust through cities, causing panic, boosting cancer rates and forcing costly cleanups

BY MICHAEL A. LEVI AND HENRY C. KELLY

DREAD WIND: The greatest danger of a dirty bomb is not the explosive blast but the radioactive particles it projects into the air.

This kind of scenario could become a reality in the not too distant future.

Defending ourselves from the threat of radiological weapons has become a grim necessity. The components and know-how needed to build a dirty bomb are available, and there are fanatics out there who just might do the deed. The arrest earlier this year of Al Qaeda sympathizer José Padilla (Abdullah al Muhajir) on suspicion of plotting to construct and set off a dirty bomb gives an indication of the interest in building such a device.

A radiological weapon, or dirty bomb, is typically a crude device comprising conventional explosives, such as TNT or a fuel oil/fertilizer mixture, laced with highly radioactive materials. The explosives generate a pulse of heat that vaporizes or aerosolizes radioactive material and propels it across a wide area.

Weapons experts consider radiological bombs a messy but potentially effective technology that could cause tremendous psychological damage, exploiting the public's fears of invisible radiation. Not weapons of mass destruction but weapons of mass disruption, these devices could wreak economic havoc by making target areas off-limits for an extended period. Radiological bombs have never been used, mainly because they have long been considered inappropriate for military purposes: their effect is too delayed and unpredictable to sway a battle.

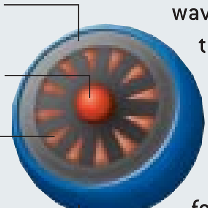
Although they are relatively simple in principle, constructing and deploying one of these mechanisms is difficult to do. It is more complicated than wrapping stolen materials around a stick of dynamite. Such a clumsy weapon might only scatter large chunks of material, limiting the area affected and making cleanup easy. An effective dirty bomb is, however, much easier to assemble than a nuclear weapon, although it would still require considerable skill. A major problem is that the builder could be fatally exposed to hot isotopes. But a deadly dose of radiation can take weeks to have an effect and so might not deter suicidal terrorists.

DIRTY VERSUS NUCLEAR BOMBS

People sometimes confuse radiological with nuclear weapons

A DIRTY BOMB is likely to be a primitive device in which TNT or fuel oil and fertilizer explosives are combined with highly radioactive materials. The detonated bomb vaporizes or aerosolizes the toxic isotopes, propelling them into the air.

A FISSION BOMB is a more sophisticated mechanism that relies on creating a runaway nuclear chain reaction in uranium 235 or plutonium 239. One type features tall, inward-pointing pyramids of plutonium surrounded by a shell of high explosives. When the bomb goes off, the explosives produce an imploding shock wave that drives the plutonium pieces together into a sphere containing a pellet of beryllium/polonium at the center, creating a critical mass. The resulting fission reaction causes the bomb to explode with tremendous force, sending high-energy electromagnetic waves and fallout into the air.



Radioactive Rebar

MATERIALS THAT ARE HIGHLY radioactive are employed in hundreds of medical, industrial and academic applications. There are about two million individual sources of ionizing radiation in the U.S. alone, thousands of which are of significant size. Their uses include destroying bacteria on food, sterilizing pharmaceutical products, killing cancer cells, inspecting welds, exploring for oil, and doing research in nuclear physics and engineering. The U.S. federal government encouraged the distribution of plutonium isotopes for research during the 1960s and 1970s, and much of the material is still out there because the government has not been willing to pay for its recovery.

Ionizing radiation sources, such as cobalt 60, cesium 137 and iridium 192, emit gamma rays; others, such as americium 241 and plutonium 238, produce alpha particles. These materials are often expensive, and authorities always assumed that there would be a clear economic incentive to protect them from thieves. Policymakers also expected that heavy protection of these substances would be unnecessary because no one would risk exposure to the life-threatening levels of radiation they produce.

Despite these assurances, significant quantities of materials suitable for dirty-bomb making have been found abandoned in scrap yards, vehicles and houses around the U.S. and Europe. A recent U.S. Nuclear Regulatory Commission (NRC) study reported that American business and research facilities had lost track of nearly 1,500 pieces of equipment with radioactive parts since 1996, scores of which would be big enough for a dirty bomb. Half were never recovered. Earlier this year a steel-recycling plant found a hot source mixed in with scrap metal. Several years ago radioactive cesium passed undetected through a recovery facility and was subsequently melted down and cast in steel reinforcing bars for concrete.

The International Atomic Energy Agency stated in late June that almost every nation in the world has the radioactive materials needed to build a dirty bomb. More than 100 countries lack adequate controls to prevent the theft of these materials. Late in 2001, for instance, two woodsmen in the former Soviet republic of Georgia were dosed after they found a portable radiothermal generator—a large radioactive strontium 90 source—abandoned in the woods. They used the generator as a heating device. Chechen rebels created a scare in 1995 when they placed a shielded container holding cesium 137 (taken from cancer-treatment equipment) in a Moscow park and then tipped off Russian news reporters to its location. Eight years previously, scrap scavengers broke into an abandoned cancer clinic in Goiânia, Brazil, and stole a medical device containing radioactive cesium. About 250 people were exposed to the source; eight developed radiation sickness, and four died. The incident produced 3,500 cubic meters of radioactive waste—enough to cover a football field to hip level—and left the local economy devastated.

Radiation Effects

IN ADDITION TO ACUTE HEALTH problems such as radiation sickness, radioactive materials can cause cancer. Quantifying dangerous radioactive dose levels is difficult, however, because specific health effects are uncertain.

Radiation doses are often measured in rems. Everyone receives about a quarter of a rem every year from exposure to natural sources, including cosmic rays and the uranium in granite bedrock. In general, people subjected to 100 rems or more develop radiation sickness and require immediate medical attention. Half the people exposed to 450 rems will die within 60 days. Even small doses can increase the risk of getting cancer. On average, if 2,500 people are exposed to a single rem of radiation, one will die of an induced cancer.

Scientists and regulators have long debated what level of radiation exposure is tolerable. Federal regulations prohibit radiation workers from receiving more than five rems annually. The U.S. Environmental Protection Agency recommends that a contaminated area be abandoned if decontamination efforts cannot reduce the extra risk of cancer death to about one in 10,000. This additional risk is equivalent to having 25 chest x-rays over one's lifetime or being exposed to cosmic radiation in Denver (as opposed to sea level) for three years. The NRC typically sets a looser threshold, equivalent to a one-in-500 increased cancer death risk over 50 years. But these assessments are controversial because there are no good statistics showing how much cancer increases as a result of low levels of radiation. Currently experts estimate the hazards of exposure by assuming that the chance of developing cancer decreases in proportion to the amount of radiation received. They also presuppose that there is no minimum level of exposure that is harmless.

Hot Cloud in the City

TO UNDERSTAND THE POTENTIAL impact of a dirty bomb, we examined a range of plausible attacks. We studied hypothetical dispersal scenarios and estimated the sizes of the areas that would be contaminated above various dose thresholds. To do this, we used the HOTSPOT computer code, developed at Lawrence Livermore National Laboratory, which simulates the movement of radioactive particles. The model's results were then combined with experimental and theoretical data on the effects of radiation to produce estimates of health risks and contamination.

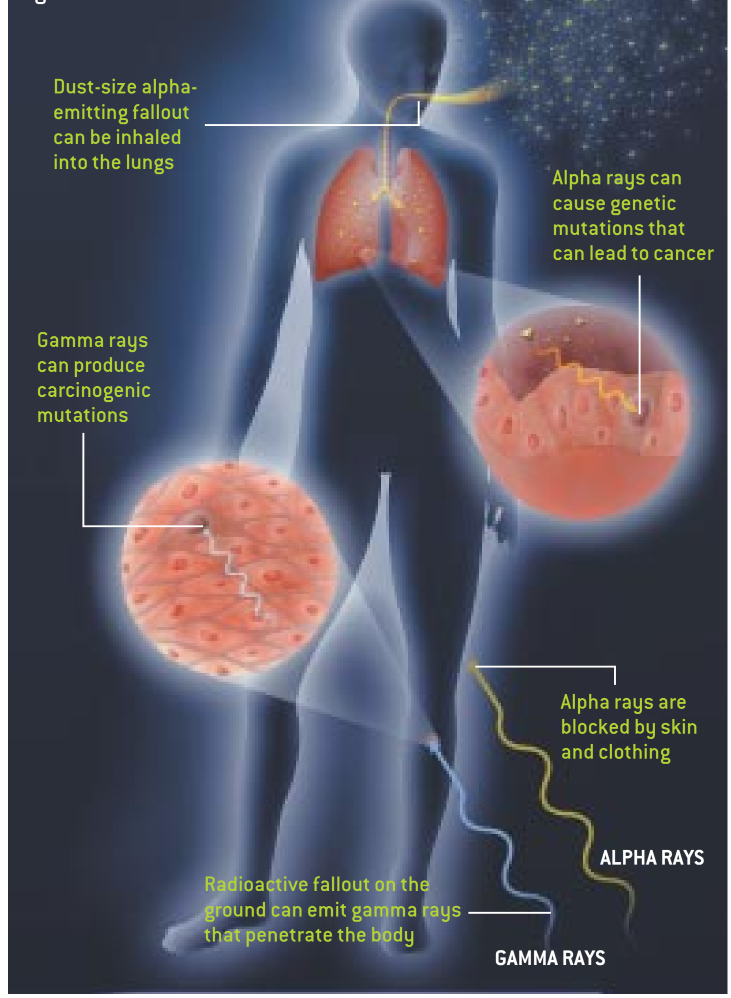
A simulated dispersal depends on a range of inputs, including time of day, weather, wind speed, and scattering methods. Higher winds, for example, spread materials over a greater area, reducing the amount of contamination in any one place. To ensure that our outputs were not simply the result of specific initial conditions, we ran more than 100 dispersal scenarios. For a given radioactive source, variations in ambient conditions produced changes in our estimates by at most a factor of 10. Such an error range does not affect our basic conclusions, if only because the various factors tend to offset one another. For every factor with the potential to make a bomb's impact half as bad, there is another to make it two times worse.

If people in the vicinity of an explosion are unable to leave the area before the dust cloud arrives, they will inhale small par-

RADIATION EFFECTS ON THE BODY

ALPHA RAYS can produce genetic mutations, causing cells to divide rapidly and become cancerous. Suspended alpha-emitting particles can lodge in the lungs, where they can damage internal tissues and form tumors.

Gamma rays, which can penetrate the body, can also cause genetic mutations and cancer.



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NOXIOUS PLUME of hot fallout spreads over New York City's Manhattan Island after the simulated detonation of a radioactive cesium-based dirty bomb (assuming a wind from the southwest). The highlighted zones would be expected to have radiation levels comparable to those that caused the closing of contaminated regions around the damaged Chernobyl nuclear power plant.

ticles. From past incidents, we know that if the material is an alpha emitter, such as plutonium or americium, it could become lodged in victims' lungs for years and lead to long-term radiation exposure. But if evacuees are decontaminated quickly, thoroughly washing their skin and disposing of contaminated clothing, the total exposure will be minimal.

Dust from a radiological weapon would remain trapped for extended periods in cracks and crevices on the surfaces of buildings, sidewalks and streets, and some would have been swept into the interiors of buildings. Certain materials that could be used in a radiological attack, such as cesium 137, chemically bind to glass, concrete and asphalt. More than 15 years after the 1986 Chernobyl disaster, in which a Soviet nuclear power plant underwent a meltdown, cesium is still affixed to the sidewalks of many Scandinavian cities that were downwind of the disaster. Fortunately, the radiation exposure from underfoot is fairly low, increasing the cancer death risk by less than one in 10,000.

If the material contains alpha emitters, the long-term health risk comes from breathing radioactive dust suspended in the air by wind, the action of tires or pedestrian traffic. In Kiev, more than 100 kilometers from Chernobyl, dust in the streets still contains low levels of plutonium. Should the material remaining in the area contain cesium 137 or other gamma emitters, anyone entering a contaminated area would be exposed to low-level radiation because, unlike alpha rays, gamma rays penetrate clothing and skin.

Consider the dispersal of 3,500 curies of cesium 137 by an explosion at the lower tip of Manhattan Island. Sources capable of delivering this much radiation have been "orphaned" in the former Soviet Union; the U.S. recently committed $25 million, in partnership with Russia, to track these materials down. Such a source, if acquired by terrorists, would be difficult to handle, requiring some shielding to prevent a builder from receiving an incapacitating radiation dose. But the cesium would already be in powder form, making dispersion relatively easy.

If this source were prepared and then exploded, about 800 square kilometers would be contaminated above the strict EPA decontamination guidelines. The disaster would not be of Chernobyl's magnitude; it would release less radiation overall, and none in the form of potent short-lived isotopes such as iodine 131. But its strategic placement would wreak havoc. Over an area of about 20 city blocks, there would be a one-in-10 increased risk of death from cancer for residents living in the area (without decontamination) for 30 years, a 50 percent increase over the background rate. A broader area of 15 square kilometers—varying from four to 20 square kilometers, depending on the weather—would be contaminated above the relocation threshold recommended by the International Commission on Radiological Protection and accepted by the NRC. If these standards were relaxed and the relocation threshold were the same as that used around Chernobyl, the area affected would still be roughly 100 city blocks. The property value of this area is estimated in the hundreds of billions of dollars.

Decontamination Procedures

REMOVAL OF URBAN RADIOACTIVE contamination has never been performed on a large scale because no one has ever had to deal with the consequences of a radiological attack. Our current knowledge of how to cleanse an urban area is based on experience from smaller-scale industrial operations and from cold war–era studies on the aftermath of nuclear war.

The cleanup effort would initially involve removing loose contamination—radioactive dust particles settled on surfaces or lodged in interstices. Relatively low cost mechanical techniques such as vacuuming or pressure washing should be effective. More invasive, higher-cost surface-removal techniques, such as sandblasting, would be necessary where hot dust has penetrated deep into more porous materials. In some cases, sidewalks and asphalt may have to be removed. The top layer

SARA CHEN (*top*); YUN JAI-HYOUNG *AP Photo* (*bottom*)

COSTLY CLEANUP EFFORTS will follow any use of a dirty bomb. Hazmat-suited workers will have to scrub fallout from surfaces with water jets, vacuums and sandblasters, as well as remove contaminated plants and soil.

of soil might have to be carted off-site and disposed of. Much vegetation might have to be cut down. Chemical agents such as acids might have to be used to dissolve rust and mineral deposits in which contaminants are trapped.

To make the process manageable, we may need to reevaluate contamination guidelines. The strict EPA regulations are appropriate for peacetime purposes—they were developed (with public consultation) to force limits on corporate polluters. Faced with the alternative of abandoning swaths of a city, we might have to accept an increased risk. We might choose, for example, to adopt the NRC guidelines, which require cleanup of all areas where contamination would deliver a dose greater than five rems over 50 years, increasing the risk of cancer death by more than one in 500 (equivalent to a reduction of each person's life expectancy by roughly 15 days). An alternative would be to require cleanup of all areas where contamination would more than double the background radiation rate.

Protective Measures

MANY RELATIVELY LOW COST, practical steps can be taken to reduce the risks from radiological weapons and minimize the effects if an attack should occur. The first step is to ensure that the materials themselves are secure. The NRC and other federal agencies are tightening the licensing process governing access to radioactive materials and the security standards for all dangerous materials. Inspections must be frequent and thorough. Programs to collect and safeguard unused materials, building on efforts such as the successful Los Alamos Offsite Source Recovery Project, need to be expanded.

Research should also be funded to identify less dangerous technologies—ion beams, for example—that can provide the food sterilization, medical and other services now supplied by radioactive materials. Increased security will raise the cost of using radioactive materials and create economic incentives for nonradioactive alternatives.

The next step would be to improve our ability to detect materials in the event that they are stolen. The U.S. ought to install an extensive array of radiation-detection systems at key points such as airports, harbors, rail stations, tunnels, highways and borders. This effort has already begun: radiation detectors from the Department of Energy's Nuclear Emergency Search Teams are being installed along the Boston–New York–Washington corridor and on the perimeter of the nation's capital. Routine checks of scrap-metal yards and landfill sites would also protect against illegal or accidental disposal of dangerous materials. In applications such as these, highly sensitive detectors are unnecessary because materials could all be checked at the entrance to a facility and would be unlikely to be shielded. Simple, inexpensive Geiger counters would suffice.

We must also ensure that the government is prepared to mitigate the impact of any radiological weapon that is actually used. An effective response to an attack requires a system capable of quickly gauging the extent of the damage, identifying appropriate responders, developing a coherent response plan, and getting the necessary personnel and equipment to the site rapidly. To help assuage fear, federal authorities should designate a single scientifically credible official who could provide consistent information about the attack.

All of this requires extensive training. Emergency and hospital personnel need to understand how to protect themselves and affected citizens during a radiological attack and be able to determine rapidly if individuals have been exposed to radiation. Although generous funding has been made available for instruction, the program needs a clear management strategy.

Finally, we need to learn how to decontaminate large urban areas and determine the steps necessary to minimize contamination. This could mean the difference between abandoning or demolishing a city and getting it back in operation after a few months of cleanup.

Although the effects of a radiological attack are minor compared with those of even a small nuclear weapon, a dirty bomb could have drastic economic and psychological consequences. Fortunately, studying the nature of the risk gives us the chance to take actions that could reduce the likelihood of an event and minimize the damage. We should begin immediately. SA

What to Do if Attacked

In the event of a radiological weapons incident, take these basic steps:

If you're inside, close your windows and turn off any external ventilation. This will stop radioactive particles from getting inside. Although filter masks are useful outside, they do not offer any added protection indoors.

If you're outside, get inside, wash up and discard your clothes. This will remove any radioactive particles. You might track in some radioactive fallout, but this danger is offset by the benefits of being indoors. You should stay inside until you're told to do otherwise by law-enforcement officials or emergency personnel. If people start fleeing the scene, it will be harder to contain contamination and to move emergency workers and equipment efficiently.

In all cases, listen for instructions from the authorities. The nature of the required response will depend on the size and type of the dirty bomb.

Iodine tablets are ineffective, because dirty bombs (unlike reactor meltdowns) would be unlikely to release radioactive iodine.

MORE TO EXPLORE

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