Summer 2010

NUCLEAR DANGERS

The BRIDGE

LINKING ENGINEERING AND SOCIETY

NATIONAL ACADEMY OF ENGINEERING
OF THE NATIONAL ACADEMIES

Promoting the technological welfare of the nation by marshalling the knowledge and insights of eminent members of the engineering profession.

The
BRIDGE

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Editor's Note

George Bugliarello

Nuclear Dangers

Perceptions and realities often diverge. This is certainly the case with nuclear dangers, which are virtually ignored by people in their twenties (the Y generation) and are all but suppressed in the minds of many older people, for whom a revival of the terrifying cold war threat of a nuclear holocaust is unthinkable. Nevertheless, nuclear dangers have not vanished.

Although a nuclear conflict among major powers is not likely for the foreseeable future, the possibilities of attacks with low-power nuclear explosives of a few kilotons, like the bombs at Hiroshima and Nagasaki, or of radiological dispersal devices, so-called "dirty bombs," by determined adversaries, rogue states, or non-state terrorists are increasing. Potential instabilities of some nuclear states add to the danger, as they could make it possible for people with bad intentions or irresponsible parties to get their hands on weapons of great power.

The damage caused by even a small portable weapon of a few kilotons, such as North Korea's weapons, the nuclear ambitions of Iran, the expansion of the nuclear arsenal in India or Pakistan all add to the uncertainties and grave risks—including the risk of serious miscalculations. Those risks are constantly increasing, as are the risks of further proliferation of nuclear technology and nuclear weapons. Add to these, the vulnerabilities of nuclear power plants and storage pools of spent nuclear fuel.

Advances in nuclear technology and the means of delivering nuclear weapons have created new opportunities for terrorists. Of the three major kinds of weapons of mass destruction that might be used—chemical, biological, and nuclear—nuclear weapons are the most difficult to develop because they require gathering nuclear materials. But the impact of nuclear weapons—physical destruction, radiation, heat, and psychological damage—can be catastrophic. Radiological bombs, although less lethal, also have potentially very high impacts, especially psychological impacts.

Most people are very frightened of the dangers of radiation, which, by and large, they do not understand well. For instance, in the event of a radiological attack or an attack with a small nuclear weapon, the most important question may be how to reduce exposure to radiation by defining the areas of contamination and the areas where people can be relatively safe, such as by taking refuge in a prearranged shelter or by sheltering in place. Although in the 1950s it was unrealistic to consider shelters against megaton bombs, this is not true today for kiloton bombs.

Low-power nuclear bombs and radiological bombs are easily transportable in small containers and can be dropped from unmanned aerial vehicles (UAVs). This expands the delivery scenario, particularly since many UAVs are now produced outside of the United States. However, weaponizing nuclear devices for delivery via missiles is a difficult proposition.

A great deal of nuclear material is not well protected, and a non-state entity could purchase or steal enough for a small kiloton bomb. Thus, we urgently need initiatives to stop the trafficking of nuclear materials and improve safeguards of existing stockpiles (e.g., the current Obama initiative). Materials for a radiological bomb can be gathered from a myriad of sources in most countries. Although the process is relatively easy, it does require time to accumulate enough radiological material.

Given the difficulties of assembling or acquiring a nuclear bomb and secretly assembling enough material for a radiological bomb, it is reasonable that, even if a terrorist organization decided to use them, attacks would be limited in number. However, even one attack with a few-kiloton bomb or an attack on a nuclear power plant would have devastating effects and would require major logistical arrangements for emergency management and ensuring there would be enough medical capacity to deal with the victims. The recent earthquake in Haiti has revealed how difficult it can be in a major disaster to make such capacity available.

People need accurate information and active guidance to prepare for nuclear events and to learn how to protect themselves. Response strategies to current nuclear and radiological threats, which are quite different from the doomsday scenarios of the cold war, include both physiological and psychological measures.

First, there must be changes in the way authorities communicate with the public, and first responders must be made aware of the nature of the new threats. Another urgent need is for an adequate number of well prepared, well trained forensic specialists who can make timely identifications of the sources of radioactive material.

This issue of *The Bridge* includes articles on some of the major aspects of current nuclear threats. It was assembled with the assistance of NAE members John Ahearne and Sigfried Hecker, who are also authors articles in this issue. The article by Siegfried Hecker, with Sean C. Lee and Chaim Braun, provides an overview and assessment of North Korea's decision to use its nuclear capacity to develop bombs rather than generate electricity. The authors also suggest how the United States might move forward in managing the greatest risks.

Brian Radzinsky and George Perkovich of the Carnegie Endowment for International Peace, review the status, risks, and consequences of Iran's nuclear program, another situation with a very high potential for miscalculation. NAE member Richard Garwin focuses on two nuclear terrorism scenarios, the detonation of an improvised nuclear device in a city and an attack on a nuclear reactor, spent-fuel storage pond, or reprocessing facility. He concludes that in a city the greatest damage and lethality would be caused by radioactive fallout.

In Brooke Buddemeier's discussion of recent research on the consequences of a nuclear detonation, he also concludes that in a modern U.S. city, the best way to reduce casualties is to reduce exposure to fallout. But, he says, until recently, there was no federal guidance on how to do this.

Georges C. Benjamin, head of the American Public Health Association, gives a realistic assessment of the loss of critical medical and response infrastructure that would follow a nuclear detonation in a city, which would be a disaster of national significance. The National Disaster Medical System, with its 1,500 hospitals, he says, can be expected to rebound quickly. But poor communities are less likely to do so.

John Ahearne stresses the importance of communicating risk, of ensuring that community and first responders have a thorough understanding of the dangers and protections against radiation exposure, and the usefulness of providing a primer on radioactivity. In a paper on the health effects of a nuclear or radiological incident, Thomas S. Tenforde and co-authors, of the National Council on Radiation Protection and Measurements, again stress the need for prompt diagnosis and treatment and call for a paradigm shift in the thinking of communities and organizations that support emergency responders.

The articles in this issue may not cover all essential aspects of the nuclear threats we face, but they do convey a sense of the urgency of preparing to respond to realistic potential dangers. No one can continue to ignore them.

George Bugliarello

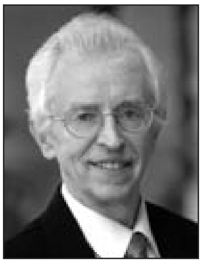
George Bugliarello
NAE Foreign Secretary

Although North Korea has the bomb, it has no nuclear arsenal to speak of and no nuclear-generated electricity.

North Korea's Choice

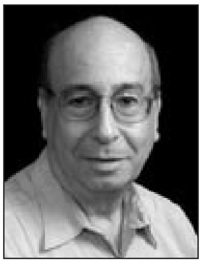
Bombs over Electricity

Siegfried S. Hecker, Sean C. Lee, and Chaim Braun



Siegfried S. Hecker

Sean C. Lee



Chaim Braun

Nuclear power and nuclear weapons have a common technological foundation. In pursuit of a civilian fuel cycle—making fuel, building reactors to burn the fuel, and dealing with nuclear waste, which might include extracting some valuable by-products of spent reactor fuel—a nation can develop the capability of producing the material necessary for a bomb, either highly enriched uranium or plutonium. Under civilian cover, North Korea developed a fuel cycle ideally suited to harboring a latent capability for weapons production. In fact, although the country now has the bomb, it does not have much of a nuclear arsenal or any nuclear-generated electricity (Hecker, 2010).

Siegfried S. Hecker is professor (research), Department of Management Science and Engineering, co-director of the Center for International Security and Cooperation (CISAC), Stanford University, and an NAE member. Sean C. Lee is a research assistant, and Chaim Braun is a consulting professor at CISAC.

In the 1970s, South Korea was also interested in the bomb, but it gave up those aspirations and, with international assistance, turned its nuclear focus to civilian energy. Today the South Korean nuclear power industry provides nearly 40 percent of the country's electricity, and South Korea is in a position to become a major international exporter of nuclear power plants. The factors that led North Korea to build the bomb and those that led South Korea to forsake it can be instructive for the United States in formulating a policy to restrain Iran's nuclear weapon ambitions, although the political situation there is dramatically different.

North Korea's gas-graphite reactor was ideal for producing plutonium fuel for a bomb.

Building a Dual-Use Nuclear Foundation

North Korea's nuclear story began about half a century ago. In the first phase of nuclear development, Kim Il-sung sent hundreds of students and researchers to Soviet-bloc universities and research centers to cultivate a base of technical expertise. Soviet material and technical assistance, under the umbrella of the Soviet Atoms for Peace program and the Soviet/North Korea 1959 nuclear cooperation treaty, led to the construction of a small research reactor (the IRT-2000) and, in the 1960s, many key nuclear facilities at the nuclear center in Yongbyon.

During the second phase, in the 1970s and 1980s, Pyongyang built an indigenous nuclear capability, driven partly by Kim Il-sung's interest in nuclear weapons and partly by his inability to obtain them from China or the Soviet Union. North Korea used its Soviet-supplied research facilities to train specialists and hone their skills by upgrading the research reactor to achieve higher performance.

Even though North Korea was then receiving minimal foreign assistance, it continued to rely on outside knowledge. Taking advantage of extensive declassified data on the design and operation of the first British reactor at Calder Hall (a dual-use reactor) and its larger progenies, such as Tokai-1 in Japan and Latina in Italy, North Korea was able to reverse engineer Western facilities. The country's first nuclear reactor, a 5-megawatt electric (MWe) gas-graphite reactor, became operational in 1986.

The gas-graphite reactor is well suited to industrializing countries with limited nuclear construction infrastructure and ideal for producing plutonium fuel for a bomb under the guise of generating civilian power.[1] With graphite moderation and carbon dioxide cooling, natural uranium can be used for reactor fuel, obviating the need for technologically demanding enrichment facilities. North Korea has abundant, indigenous supplies of uranium to fuel its reactors.

The gas-graphite reactor produces ample weapons-grade plutonium. And, because the natural uranium fuel is clad with a magnesium alloy that corrodes readily in contact with air and water, the discharged spent fuel rods are difficult to store. Thus North Korea was able to justify reprocessing the spent fuel to extract plutonium, which, in turn, can be used as bomb material.

Again relying on foreign designs, North Korea then copied the design of the Eurochemic reprocessing plant at the Mol-Dessel site in Belgium. Given Mol's international status, its many owners had published a plethora of information about its construction and operation. North Korean engineers used this information to construct the Yongbyon reprocessing plant.[2]

The 5-MWe reactor can produce roughly 6 kilograms (kg) of plutonium per year (about enough for one bomb), but the North Koreans were also building a 50-MWe reactor and a 200-MWe reactor, which together could have produced roughly 300 kg of plutonium per year when completed. The small reactor was well suited to quickly establishing a nuclear arsenal with little capacity for producing electricity; the medium-size reactor appears to be designed for dual use; and the large reactor appears to have been designed primarily for the production of electricity.

However, as the ambitious gas-graphite reactor program progressed in the 1980s, Pyongyang realized that modern light-water reactors (LWRs), which South Korea was acquiring from the West, were much better suited to producing electricity. Hence, in 1985, Kim

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[1] The Calder Hall design was code named PIPPA (pressurised pile producing power and plutonium) by the UK Atomic Energy Authority to denote the plant's dual commercial and military role. Early gas-graphite reactors built by various nations were used as plutonium production reactors, sometimes in concert with commercial nuclear power.

[2] The Mol reprocessing plant (60 metric tons/year capacity) was commissioned in 1966 and operated jointly by 12 OECD countries, which formed the Eurochemic Corporation—the first international reprocessing plant. North Korea extended this design to a capacity of 110 metric tons/year, with room for future expansion to 220 metric tons/year.

Il-sung asked the Soviets to build two LWRs to meet the North's growing demand for electricity.

Ready to Deal but Retaining a Hedge

With the demise of the Soviet Union, North Korea's hopes of getting Soviet-supplied reactors crashed, but by that time Pyongyang had expanded its gas-graphite program. By 1992, North Korea had overcome initial start-up problems with its 5-MWe reactor, built an extensive fuel-fabrication facility, and demonstrated its reprocessing plant. It had also made significant progress on the construction of the 50-MWe reactor and had broken ground on the 200-MWe reactor. Pyongyang was thus prepared to launch the next phase of its program, building an actual bomb. However, because of drastic changes in the country and in the outside world, it chose not to build a nuclear arsenal.

The sudden end of the cold war brought about an equally abrupt end to the billions in foreign aid, guaranteed markets, and "friendship prices" Pyongyang had enjoyed from the Soviet bloc. Concurrently, China was moving quickly to open its economy to the West in support of its own agenda. As North Korea watched, both Russia and China recognized and reached out to its archrival, South Korea.

In response, Pyongyang began to seriously explore accommodation with the West, especially the United States, to get much needed assistance to reverse its economic deterioration; industrial capacity had dropped to a mere fraction of what it had been a decade earlier. Pyongyang realized that better relations with the international community and economic improvement could diminish its need for the bomb and potentially provide nuclear-generated electricity to help power its economy.

In 1992, Pyongyang opened the window to its nuclear program and allowed inspectors from the International Atomic Energy Agency (IAEA) into Yongbyon. But the window was quickly closed when inspectors uncovered discrepancies between their nuclear measurements and Pyongyang's declarations. In early 1994, after a few tense years, intense negotiations in Geneva led to the Agreed Framework,[3] which changed North Korea's nuclear trajectory dramatically.

Pyongyang was ready to trade its gas-graphite reactor program for the promise of two 1,000 MWe LWRs to be supplied by the United States and constructed at the Sinpo site, originally dedicated to two similar-sized reactors that had been promised by the Soviets. Operation of the 5-MWe reactor, fuel-fabrication plant, and reprocessing facility were halted and monitored by IAEA inspectors, and construction of the two larger gas-graphite reactors came to a stop. The spent fuel rods, which contained an estimated 20 to 30 kg of plutonium from the 5-MWe reactor, were repackaged by an American technical team and stored temporarily in a cooling pool for eventual removal from North Korea.

However, actual reconciliation between Washington and Pyongyang proved to be difficult. Washington considered the Agreed Framework primarily a nonproliferation agreement, whereas North Korea placed greater value on its relationship-building aspects. Although the relationship between Pyongyang and Washington under the Agreed Framework was rocky almost from the start, it did result in considerable cooperation and dialogue. However, because of congressional opposition to the agreement, which led to a lack of funding, the United States quickly fell behind in its commitments. In addition, a complicated procurement process slowed the project further.

> *Because of drastic changes in the country and in the outside world, North Korea chose not to build a nuclear arsenal.*

Perhaps concerned about the prognosis for the Agreed Framework, but unwilling to completely abandon all hope, North Korea restarted a uranium enrichment program in the late 1990s; the program appears to have been shelved earlier in the decade when plutonium operations proved to be successful.[4] To secure badly needed revenue, and possibly

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[3] Under the Agreed Framework signed by the United States and North Korea on October 21, 1994, in Geneva, North Korea agreed to freeze its existing nuclear program. In addition to the United States supplying LWRs and delivering 500,000 metric tons of heavy fuel oil annually, the two sides agreed to move toward full normalization of political and economic relations and work together for peace and security on a nuclear-free Korean peninsula. See Arms Control Association link: *http://www.armscontrol.org/factsheets/agreedframework.*

[4] North Korea most likely experimented with uranium enrichment technologies in the 1980s in parallel with its plutonium program. For example, it attempted to purchase vacuum system components from Germany. In the late 1990s, Pyongyang is reported to have acquired centrifuge technology from Pakistan's A.Q. Khan (Musharraf, 2006). Additional evidence, including the purchase of aluminum tubes suitable for centrifuge rotors from Russia and attempted purchase from Germany, is discussed by Zhang (2009).

maintain the expertise of its idle nuclear workers, North Korea began to look into exporting nuclear technologies to Syria, Libya, and perhaps Iran, much as it had done with its missile technologies (Miller and Richter, 2008; Sanger and Broad, 2005).

The long-range missile test in April 2009 surprised the Obama administration.

Exercising the Hedge by Building the Bomb

Although beset by years of delays and almost derailed by the 1998 missile crisis that was saved by the Perry process,[5] the Agreed Framework was finally derailed by the change of U.S. administrations. Pyongyang suffered a major strategic setback when the Bush administration opposed both the terms of the Agreed Framework and efforts to achieve political accommodation. In late 2002, the United States accused North Korea of violating the agreement by pursuing the uranium enrichment path to the bomb.

Pyongyang used the occasion to exercise its hedge by building the bomb. It expelled IAEA inspectors, withdrew from the Nuclear Nonproliferation Treaty, reprocessed the spent fuel rods that had been previously packaged and stored, and restarted its reactor to make more plutonium. In 2003, for the first time, Pyongyang told the Americans it had manufactured nuclear weapons and that it would continue to strengthen its "deterrent."

The years 2003 to 2009 were characterized by intermittent disarmament discussions punctuated by provocative weapons-related actions. Pyongyang returned to the negotiating table under the Six-Party talks and signed the Joint Statement on the denuclearization of the Korean peninsula on September 19, 2005. However, the United States concurrently imposed financial sanctions, which convinced Pyongyang that its relationship with the United States had not fundamentally changed. Pyongyang then chose to demonstrate its nuclear capabilities with a nuclear test in October 2006.

Although the nuclear test was only partially successful, it changed Pyongyang's negotiating strategy, especially after the Bush administration relented and agreed to hold bilateral discussions. At this point, Pyongyang insisted that it be treated as a nuclear state and that the negotiations focus on mutual disarmament rather than on unilateral denuclearization.

After surprising the Obama administration with another long-range missile test in April 2009, North Korea responded to the predictable United Nations Security Council (UNSC) condemnation by once again walking away from all nuclear negotiations and conducting a second nuclear test in May. UNSC Resolution 1874 condemned the test and tightened sanctions.

Nevertheless, this test, which was much more successful than the first, appeared to embolden North Korea and strengthen its diplomatic hand. By the summer of 2009, Pyongyang signaled Washington that it was, once again, ready to talk; but since then it has skillfully dragged out its return to the Six-Party talks, trying to shape the conditions and the agenda under which it returns.

In retrospect, had the United States expeditiously implemented the terms of the Agreed Framework and built the LWRs as planned, Pyongyang would have traded a nuclear fuel cycle that was primarily geared to making weapons-grade plutonium for an LWR fuel cycle that is much less suitable for making bombs and much easier to monitor and control. Although we believe Pyongyang explored uranium enrichment as a potential alternative for making nuclear weapons in case the Agreed Framework fell apart,[6] the Bush administration's decision to confront Pyongyang in October 2002 proved to be disastrous.

Although the confrontation had the intended effect of killing the Agreed Framework negotiated by the Clinton administration, the United States was unprepared to deal with North Korea walking out, building the bomb, and then demonstrating it. In effect, the United States had traded the risk of North Korea developing a

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[5] As a result of a congressionally mandated commission headed by former Secretary of Defense William J. Perry, Pyongyang's second-ranking official, Vice Marshal Jo Myong-rok, visited the White House in October 2000. The two sides issued a Joint Communiqué that pledged "neither would have hostile intent toward the other and confirmed the commitment of both governments to make every effort in the future to build a new relationship free from past enmity." Combined with Secretary of State Madeline Albright's meeting with Kim Jong-il in Pyongyang a couple of weeks later, it dramatically changed the security relationship and nearly resolved both nuclear and political issues.

[6] In addition to the evidence presented above, traces of HEU contamination were found on items that North Korea turned over to the United States in an attempt to prove it had no such activities (Kessler, 2008).

highly enriched uranium bomb, which was many years away, for the risk of a plutonium bomb, which took only months to develop. Today, there is still no convincing evidence that North Korea has been able to advance beyond the exploratory stage of uranium enrichment.

Following the UN reprimand in April 2009, North Korea declared that it would pursue uranium enrichment to fuel LWRs that it would build itself. In September 2009, it declared success, although it is technically not possible to succeed in such a short time. The announcement appears to be politically motivated to allow Pyongyang to now justify enriching uranium. However, we believe that North Korea is not technically prepared to enrich uranium beyond the laboratory scale or to build its own LWR.

Ironically, while the United States and the international community were trying to keep North Korea from importing nuclear materials, Pyongyang was engaged in exporting nuclear technologies. It appears to have exported uranium hexafluoride, a precursor to highly enriched uranium, to Libya for Muammar Gaddafi's covert centrifuge program. From 2001 to 2007, it also built a plutonium production reactor for Syria; the facility was destroyed by an Israeli air attack before it became operational. What is most disturbing, however, is that North Korea was never taken to task for these egregious actions and today may be cooperating with Iran, with which it has had a robust exchange of missile technologies.

The Price of Keeping the Bomb

North Korea enters the next round of Six-Party negotiations with a handful of bombs, which we believe are of primitive design and have not been miniaturized to fit on top of a missile (Hecker, 2010). We estimate that, even though its plutonium-producing reactor became operational 24 years ago, North Korea has only 24 to 42 kg of plutonium, enough for four to eight bombs. That reactor is now shut down, and although the fuel-fabrication and reprocessing plants are functional, there is no new plutonium in the pipeline. North Korea appears ready to give up the Yongbyon plutonium-production complex, apparently believing that the political value of its few bombs is sufficient to keep the United States out and to provide negotiating leverage.

Pyongyang does not appear ready to give up its nuclear weapons, which it believes are necessary to secure the regime's survival domestically and internationally. In addition, the power and prestige of the bomb are believed to be diplomatic levers that strengthen North Korea's negotiating position. Pyongyang views the bomb as a diplomatic equalizer with South Korea and Japan, its much more prosperous and powerful, but non-nuclear rivals.

Without nuclear weapons, North Korea would receive scant attention from the international community. But what price did Pyongyang pay for getting the bomb, and how much more is it willing to pay to keep it?

Pyongyang's economic system and military-first policy, in which nuclear weapons are a key element, have resulted in a state of abject poverty in contrast to its free-market southern neighbor. Choosing to build the bomb cost North Korea the opportunity to produce much needed nuclear electricity for its energy-starved country. Unless it has much more electric power than it now has, North Korea cannot effectively rebuild its industries.

> *While the international community was trying to keep North Korea from importing nuclear materials, Pyongyang was exporting nuclear technologies.*

Construction of the two larger indigenous reactors, which could have delivered substantial electricity, was terminated by the Agreed Framework. Having lain dormant and unprotected since then, these larger reactors are now unsalvageable. Construction of the two LWRs promised as part of the Agreed Framework was terminated when the agreement collapsed, and there is not much to be salvaged. Although the Yongbyon reactor supplied small amounts of electricity and heat to the local town, the total amount of electricity it produced during its entire lifetime is equivalent to just 23 days of operation of one modern LWR.

The pursuit of nuclear weapons has cost North Korea much more than electricity. Its entire economy has suffered because of international sanctions and isolation following the missile launches and nuclear tests. North Korea has one of the highest political risk factors in the world, making it difficult to attract foreign capital and foreign aid. Moreover, recent cutbacks in economic support from South Korea have led to further isolation and economic impoverishment.

By building the bomb, North Korea also effectively terminated its production of medical isotopes. The county has not been able to acquire the fresh highly enriched uranium fuel necessary to operate the small Soviet-supplied research reactor that used to produce medical isotopes.[7] Yongbyon's technical specialists, although trained and competent, are now cut off completely from the global scientific community—including in areas such as nuclear safety and nuclear safeguards. University and civilian research facilities suffer from a chronic lack of electricity to run their equipment and train their people, thereby wasting the country's precious, limited human capital.

South Korea has realizable ambitions of becoming a leading exporter of nuclear power plants.

North Korea's nuclear choice and current economic status provide a stark contrast to the situation in South Korea, which seriously explored the development of nuclear weapons in the 1970s but gave up its pursuit because of heavy U.S. pressure and guarantees of increased U.S. security measures (Oberdorfer, 2001). As part of South Korea's drive to become an international economic powerhouse, it began to build a robust nuclear power program, initially with Western technology and assistance.

Eventually, however, the South developed an impressive indigenous capability in a transparent way in cooperation with Western suppliers, the Nuclear Suppliers Group, and the IAEA.[8] Today, South Korea has 20 modern LWRs that produce nearly 40 percent of its electricity. It has a strong nuclear research establishment in the Korean Atomic Energy Research Institute (KAERI) and its industrial nuclear-supply infrastructure.

South Korea has realizable ambitions of becoming one of the world's leading exporters of nuclear power plants. A recently awarded $20.4 billion contract to build the first four power plants in the United Arab Emirates is an example of its growing global role (Coker, 2009). In addition, in cooperation with the industrial giant Daewoo, KAERI just signed a contract to build a research reactor for Jordan. South Korea today has too much to lose economically to pursue the nuclear weapons option. In fact, it tries to be especially transparent and compliant so as not to jeopardize its export business.[9]

We draw the contrast between the North and the South not to suggest that North Korea could have done as well if it had simply pursued nuclear electricity and an expanded economy instead of bombs, but to demonstrate that North Korea could have much to gain by trading its military program for a civilian program. As it is, North Korea has gotten very little in return for its huge investments in its nuclear program. Even its remarkable technical accomplishments have been negated by international sanctions and isolation. Giving up the bomb and developing civilian nuclear power could help lift its economy and its people out of poverty.

Lessons Learned and a Path Forward

The North has paid a heavy price for choosing the military over the civilian route to nuclear power because its existential security concerns were never resolved by diplomatic means. Once the bomb had been built and demonstrated, it propped up the regime both internally and externally, and the country toughened its negotiating position. Ironically, today the regime may be protecting itself against imagined external enemies while the primary threats are internal and economic—a situation perhaps not unlike that of the Soviet Union in the 1980s.

The security concerns of the South, on the other hand, were taken care of by the U.S. alliance, which not only keeps U.S. troops on South Korean soil, but

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[7] During a visit to Yongbyon in February 2008, Ri Hong-sop, former director of the Yonbyon Nuclear Center, told Hecker that Russia refused to supply new fuel in the 1990s because North Korea could not afford to pay. Now international sanctions preclude all purchases of HEU.

[8] In 2004, South Korean scientists from the KAERI, however, conducted experiments in laser isotopic enrichment of various elements including uranium. These experiments were conducted without informing Korean Ministry officials or IAEA safeguards inspectors. This activity was stopped and fully reported to the IAEA later in 2005.

[9] South Korea is exploring a spent-fuel reprocessing option using pyroprocessing for its nascent breeder reactor program and for the reprocessing and volume reduction of their accumulated spent power-plant fuel. The effort is convincingly civilian this time because of the transparent manner in which South Korea is pursuing reprocessing.

Figure 1 Satellite image of the night sky over North and South Korea. Source: MailOnline, 2010.

for several decades also kept nuclear weapons stationed there. By moving toward a democratic government, gearing its economy for export, and providing 40 percent of its electricity from commercial nuclear power, South Korea has become an economic powerhouse.

The next Six-Party negotiations must balance the disincentives the parties can bring to bear on North Korea if it chooses to keep the bomb—namely further international sanctions and isolation—with incentives for greater security and economic development. To develop effective incentives, the United States should review its diplomatic record with North Korea. Instead of remaining fixated on denuclearization, Washington should realize that, in spite of its inconsistent and often contradictory policies during the past 20 years, diplomacy has left Pyongyang with only a handful of bombs, instead of the 100 or more it might have had by now, and essentially no significant nuclear-generated electricity (Figure 1).

Washington still considers the Six-Party talks and the September 19, 2005, Joint Statement primarily a denuclearization agreement, much as it considered the Agreed Framework. Pyongyang, however, views all of these agreements through the lens of resolving more than 60 years of hostilities on the Korean peninsula. Thus, although denuclearization must remain the final goal, we must approach it in combination with Pyongyang's need for security and economic recovery.

Trading in its weapons-oriented nuclear program for one that can deliver electricity and nuclear medicine would be an important step in that direction. Since this will take some time, however, Washington should focus now on managing the greatest risks—namely stopping all nuclear exports and keeping North Korea from building more and better bombs—as part of an overall understanding to ending all nuclear weapons activities.

Finally, we hope that the stark contrast between North and South Korea in nuclear direction and the consequences of those choices will also give Iran pause as it pushes ahead with its nuclear ambitions; at the same time, that contrast could also inform U.S. policy toward Iran. Although Pyongyang has demonstrated that a handful of bombs can protect its regime from the United States, that protection has been bought at an enormous price.

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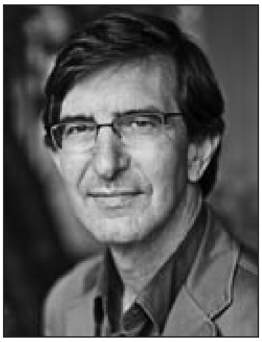
In the long run, a non-peaceful nuclear program will neither sustain nor secure the Iranian people.

Iran's Nuclear Program

Status, Risks, and Consequences

Brian Radzinsky



George Perkovich

Brian Radzinsky and George Perkovich

Whether or not Iran actually builds nuclear weapons, its nuclear activities pose an acute challenge to international order. By defying International Atomic Energy Agency (IAEA) demands and UN Security Council (UNSC) resolutions to cease its suspect activities and build international confidence in the peaceful nature of its nuclear program, Iran continues to mock the rule-based system for preventing nuclear proliferation. If the Islamic Republic goes further and weaponizes the nuclear capabilities it is accruing, the risks of war in the Middle East will increase as Iran and its neighbors adjust to the shifts in power.

The stakes are high, and nothing the United States, UNSC, or Israel could do has a high probability of resolving the situation happily. In the long term, a non-peaceful nuclear program will neither sustain nor secure the Iranian people, which can only exacerbate the structural weaknesses of the Iranian government. Increasing isolation from international investment and other cooperation will further weaken Iran, although it may not keep the country from building nuclear weapons.

Since the revelation in late 2002 that Iran was building facilities and acquiring other capabilities that could enable it to produce fuel for nuclear weapons,

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FIGURE 1 President Ahmadinejad visiting a centrifuge facility.

the United States, and later the UNSC, have demanded that Iran cease work related to the nuclear fuel cycle. Meanwhile, the collective Iranian leadership, headed by Supreme Guide Ayatollah Khamenei, has declared its bottom line from which it will not depart—Iran will not foreswear uranium enrichment formally or for any length of time that would seriously impede the technical development of this capability (Figure 1).

Tehran continues to reject the premise at the heart of the international community's bargaining position—that Iran's long history of noncompliance with safeguards requirements and the suspect nature of some of its activities require a suspension of further fuel-cycle development to build international confidence that Iran's nuclear intentions and actions are purely peaceful.

The Obama administration came into office hoping that engagement and negotiation would break the impasse with Iran. The revelation in late September 2009 that Iran was secretly building another enrichment facility once again put Iran on the defensive.

In October, Iran and the P5+1 (Britain, France, Germany [the EU-3], China, Russia, and the United States) met in Geneva for the first talks since Obama took office. The talks seemed to result in a deal to ship Iran's stockpile of low-enriched uranium (LEU) to Russia or France in return for fuel for the Tehran Research Reactor (TRR), which is used to produce medical isotopes. The deal was designed to build trust on both sides.

Iran's LEU stockpile contains enough uranium-235 to fuel at least one nuclear weapon if it were enriched further. Transferring this material to a third country would have pushed back the time when Iran could be expected to produce a nuclear weapon. Meanwhile, by following through with the deal to provide Iran with reactor fuel, the United States, France, Russia, and other counterparts could reinforce Iran's confidence that bargains would be kept.

Although Iran did not reject the deal outright, it proposed several modifications that the P5+1 have thus far dismissed as non-starters. After President Ahmadinejad's opponents in Tehran's ruling circles accused him of being willing to give away too much, he became wary of being tricked or of losing leverage. He then proposed sending only a fraction of Iran's stockpile out for enrichment and receiving fuel for the TRR at the same time.

Only a few facilities can produce the specific fuel required for the TRR, which takes at least several months to manufacture. Even though Iran's interlocutors were eager to remove uranium that had already been enriched (as it continues to enrich more), Tehran insisted on simultaneity.

The Obama administration reluctantly concluded in early 2010 that Iran's leadership is unwilling or unable to negotiate seriously on mutual confidence-building steps to calm and ultimately resolve the nuclear confrontation. Therefore, the United States, France, and the United Kingdom are pushing the UNSC to adopt another round of sanctions.

Although most officials admit privately that they do not believe sanctions will cause Iran to suspend enrichment and cooperate fully with the IAEA, they hope that strengthening sanctions will motivate Iran to negotiate seriously with the P5+1. If Iran were to agree that it must take serious steps to build international confidence in its intentions, the P5+1 privately appear ready to tolerate some level of ongoing uranium enrichment. Paris, London, and Washington would do so with great reluctance, but other Security Council members are inclined to concede this fundamental point.

The absence of viable military options for solving the problem is a major reason for the grudging (albeit private) recognition that Iran would be "allowed" to continue enrichment if it engaged in serious give-and-take. John McCain, Sarah Palin, and numerous others contend that it only requires the political will and bombing to end the Iranian nuclear challenge. In a Senate Armed Services Committee hearing on April 14, McCain said the U.S. "keeps pointing the gun, we haven't pulled a single trigger yet, and it's about time that we did."[1] However, U.S. defense officials who have studied military options for years conclude that "military options are not preferable."[2]

It is true that missiles and bombs could destroy most of the known targets (although it would take weeks of attacks according to most experts) (Albright et al., 2008). If the nuclear threat were only from known, targetable facilities, running the risks of war might not be imprudent. However, if attacks did not destroy enough capabilities to forestall progress toward nuclear weapons long enough (probably a number of years) for the political system to produce a friendly new government, war with Iran would make little sense. After being attacked, the current regime would almost certainly be more hostile, would kick out international inspectors, and would rush to build nuclear weapons.

American (or Israeli) bombing would also probably inspire sympathetic Muslim populations and political-terror organizations to support Iran politically and perhaps in other ways. Iran's Revolutionary Guard and other agencies would use proxies to escalate attacks on American interests and personnel in Iraq and Afghanistan.

Defense Secretary Robert Gates and Joint Chiefs Chairman Admiral Michael Mullen have downplayed the utility of military action and acknowledged that Iranian counteractions could gravely harm U.S. interests in Iraq, Afghanistan, and elsewhere. In February, Mullen voiced concern "about the unintended consequences of any sort of military action" and warned that "no strike, however effective, will be in and of itself decisive" (Agence France-Presse, 2010). More recently, the vice chairman of the Joint Chiefs of Staff, General Cartwright, told a Senate committee that "military activity alone is not likely to be decisive," and a war would affect U.S. military readiness and the economy.[3]

With no promising options, there is a natural tendency to bide time. Through diplomatic pressure, sanctions, covert action to disrupt the procurement and operation of nuclear equipment, and the mobilization of states in the region and conventional forces to contain Iran, the United States and its allies are attempting to delay Iran's ability to make nuclear weapons and deter its leaders from deciding to do so.

How much time is there is to "bide"? Would one weapon pose an operational threat, or would Iran need several weapons before it could take threatening action against Israel and the interests of the United States and Iran's neighbors with confidence that it could deter retaliation? Would the international community have adequate warning? How would other states react?

With no promising options for stopping Iran, there is a natural tendency to bide time.

Pathways to Proliferation

Iran can go down one of two pathways to a nuclear weapon. It can either divert declared nuclear material from safeguarded facilities and rush to produce one or more weapons with it, or it can build one or more clandestine enrichment plants. Either approach entails political risks and technical challenges.

Diversion of Nuclear Material

IAEA inspectors would most likely detect the diversion of nuclear material in time for the international community to muster a response. There is only a slight chance that Iran could bamboozle inspectors either by delaying their entry into facilities or by transferring nuclear material out during the window between inspections. If inspectors found that material had been diverted, the IAEA Board of Governors would be required to find Iran in noncompliance with its safeguards agreement and report the matter to the UNSC.

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[1] In an interview with Fox News in February, Palin said she would like Obama to declare war on Iran, or "decide[d] to really come out and do whatever he could to support Israel." She suggested that such actions would improve U.S. security while helping Obama's chances for reelection. "TRANSCRIPT: Fox News Sunday Interview With Sarah Palin," February 7, 2010, *www.foxnews.com/politics/2010/02/07/transcript-fox-news-sunday-interview-sarah-palin*.

[2] James Cartwright and Michelle Flournoy, "Prepared Joint Statement Before the Senate Armed Services Committee," April 14, 2010.

[3] James Cartwright, "U.S. Policy Towards the Islamic Republic of Iran," hearing of the Senate Armed Services Committee, April 14, 2010. Text from *Federal News Service*. Accessed April 19, 2010.

Similar steps were taken (slowly) in 2005 and 2006 in response to Iran's violations through late 2002.

Presented with evidence of diversion, the United States and others could seek tougher measures in the Security Council, including authorization to use military force. Alternatively, the United States or Israel could decide that Iran's actions posed an imminent threat that warranted a pre-emptive military attack. Iran has to weigh the likelihood and consequences of detection against the expected benefits of overtly pursuing a nuclear weapon.

Construction of Clandestine Enrichment Plants

Iran is more likely to produce fuel for a nuclear weapon at one or more clandestine enrichment facilities than to divert nuclear materials. The country has undertaken dozens of tunneling projects with ostensibly non-nuclear applications to mask its activities from foreign intelligence agencies (Broad, 2010). At the same time, the IAEA's authority to inspect suspicious activity has been limited because Iran has refused to implement an Additional Protocol to its safeguards agreement.

Other secret facilities would be necessary to sustain a secret enrichment program. At a minimum, a clandestine program would require a parallel plant to convert uranium ore into a form suitable for enrichment. At the moment, Iran's only operating conversion plant is under safeguards and would be easy to destroy. Iran would probably not risk diversion from that plant under the IAEA's gaze.

> *Iran has undertaken dozens of tunneling projects with ostensibly non-nuclear applications.*

Non-nuclear Components

While acquiring highly enriched uranium (HEU) and/or plutonium is the most important and difficult step in making nuclear weapons, the design, manufacture, and assembly of the non-nuclear components for a missile-deliverable weapon is more difficult than most people think. General Cartwright, the former head of the military command in charge of U.S. nuclear weapons, said recently that Iran could probably not assemble a nuclear explosive or a missile capable of delivering it for three to five years.[4] (Building a gun-type uranium-fueled nuclear bomb that could be transported by ship, truck, or large plane is much easier but is also more likely to be interdicted. Such a weapon would most likely be used against a large target whose destruction would be likely to invite massive retaliation against Iran).

Iran may already have the design of a nuclear weapon and may already have secretly manufactured and tested non-nuclear triggering mechanisms. If these capabilities and activities were not kept secret, the United States, Israel, and others would have a "smoking gun" to prove that Iran seeks nuclear weapons and is a clear and present threat to international peace and security. Iran must also keep secret any work still necessary to be able to manufacture a reliable nuclear weapon; the measures necessary to ensure secrecy would also add to the risk and time required for Iran to become a nuclear-armed state.

Building a Nuclear Arsenal

Another major variable for Iran (and the world) is whether decision makers in Tehran would insist on stockpiling enough HEU for multiple weapons, and if so, how many. One nuclear bomb would make it impossible for Iran to conduct a nuclear test explosion without consuming its deterrent at the same time. However, testing would demonstrate to Iranian leaders, the population, and neighbors that Iran had become a nuclear power.

Of course, testing would also invite international consequences that Tehran wishes to avoid. Without testing (or close consultations with friendly foreign nuclear-weapon experts), Iranian leaders might not be fully confident that they actually were in control of a workable nuclear weapon.

Even if Tehran chose not to conduct tests, it would probably try to produce several nuclear weapons without being detected. The more weapons, the greater the confidence that the United States, Israel, or other adversaries would not be able to destroy Iran's new deterrent before it was "launched," and the more difficult to would be to intercept Iranian weapons on the way to their targets.

Depending on how many weapons Iran wants before it acts in more assertive ways that would threaten Israel,

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[4] James Cartwright, "U.S. Policy Towards the Islamic Republic of Iran," hearing of the Senate Armed Services Committee, April 14, 2010. Text from *Federal News Service*. Accessed April 19, 2010.

the United States, and others, Iranian leaders are not likely to behave more belligerently until they have acquired this quantum. This, too, could mean that the United States and others have more time to prevent, dissuade, or deter Iran from posing such a threat. The question is how long it would take to produce the fuel for the desired number of weapons.

How Long Until Breakout?

Because the imperative of policy and politics is to keep Iran from acquiring the capability to produce even one nuclear weapon, breakout scenarios tend to focus on this minimum threshold. Thus the question is how long it would take Iran to produce 20 to 30 kilograms of 90 percent enriched uranium. Worst-case estimates are that Iran already has the know-how, equipment, and components to make a weapon as soon as it has enough fissile material. In that case, the production of fissile material becomes the key indicator.

Estimates vary for how long it would take Iran to produce enough HEU. Recently, the director of the Defense Intelligence Agency told a Senate committee that Iran could produce enough HEU for one nuclear weapon within a year.[5] Some experts estimate that Iran could break out with a nuclear weapon in less than two months. Others think Iran would need at least a year of uninterrupted time.

At the lower bound, Gregory Jones of the Nonproliferation Education Center estimates that if Iran recycled its LEU stockpile through a reconfigured centrifuge cascade of 3,000 machines, it could produce enough fuel for a nuclear weapon in 43 days (Jones, 2010). The number drops to 22 days if Iran uses 6,000 machines. Other experts, such as Albright, Brannan, and Shire (2008), however, calculate that with 3,000 centrifuges and Iran's existing stockpile of LEU, weapons-usable uranium could be produced in two to five months (Albright et al., 2008). At the upper bound, Kemp and Glaser (2009) estimate that, under various scenarios, Iran could produce weapons fuel in one to three years.

The Centrifuge Program

In the near term, the primary impediments to Iran's nuclear-weapons capability are the small size of its uranium stockpile and the quality and quantity of its centrifuges. Several factors will affect when Iran might produce a sufficient quantity of weapons-usable uranium: the average efficiency of Iran's centrifuges; the amount of stockpiled nuclear material; the centrifuge production and installation rate; the number of centrifuges running at any given time; centrifuge reliability; and Iran's willingness to trade off a higher rate of centrifuge malfunction for a higher enrichment rate.

Estimates of breakout time fall along three main axes: (1) separative capacity; (2) the number of centrifuges used; and (3) whether Iran will "batch recycle" LEU to produce weapons fuel. We consider each of these in turn, and then discuss their advantages for Iran.

Technical problems are likely to frustrate Iran's plans to attain higher enrichment levels.

Separative Capacity

Centrifuges separate fissile uranium by rotating at high velocities. Because an individual centrifuge can only separate a small quantity of fissile material, it takes large cascades of interconnected machines to produce significant quantities of nuclear fuel. One reason for the differences in estimates is that experts disagree about the efficiency, or separative capacity, of Iran's centrifuges. Because the number of centrifuges being used for enrichment is not known, experts have had to make rough calculations of separative power based on the total number of centrifuges and the amount of material produced thus far, as measured by the IAEA.

Separative capacity affects the economic viability of the enrichment program as well as the timeframe for producing a nuclear weapon. The separative power of Iran's centrifuges, measured in separative work units (SWUs) per year, provides a basis for making rough calculations about how much nuclear material Iran could produce in a given time for various centrifuge configurations. Thus, doubling the SWU/year of a centrifuge roughly doubles the amount of material it can enrich in a given timeframe.

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[5] Ronald Burgess, "U.S. Policy Towards the Islamic Republic of Iran," hearing of the Senate Armed Services Committee, April 14, 2010. Text from *Federal News Service*. Accessed April 19, 2010.

Technical problems are likely to frustrate Iran's plans to attain higher enrichment levels. Centrifuges are delicate machines, and minor flaws in construction, assembly, or calibration can cause them to break down. Iranian scientists have made steady progress, but they continue to face a number of problems that might force cutbacks in enrichment. Rumors abound of clandestine foreign-instigated sabotage of Iran's machines, which rely on imported components.

Number of Centrifuges

Recent reports indicate that Iran is feeding roughly 4,000 centrifuges with nuclear material; another 3,000 have been installed but are not yet enriching nuclear material. However, because of technical problems, only a fraction of the 4,000 to 7,000 machines may be enriching uranium at any given time.

Because Iran has not implemented the Additional Protocol, IAEA inspectors are not allowed into the centrifuge manufacturing facilities. Therefore, we do not know the rate at which Iran is assembling new centrifuges or whether Iran has begun to manufacture more advanced models in significant numbers. Experts assume that the workhorse of Iran's program for the foreseeable future will remain the IR-1 centrifuge, but in a recent announcement Iran boasted that a third-generation centrifuge had been completed. Whether this new centrifuge will be produced in large numbers and will meet high expectations is not clear as of this writing (Global Security Newswire, 2010).

Batch Recycling

The plants that Iran has acknowledged enrich natural uranium into LEU under 5 percent. However, the cascades could be reconfigured to "batch recycle" fuel multiple times until it attains a sufficiently high enrichment level. This would significantly reduce the time it takes to produce weapons-usable fuel, because gains in enrichment grade are not linear. As higher enrichment levels are fed through the cascades, the amount of time it takes to attain even higher concentrations decreases (given a certain separative capacity).[6]

The Plutonium Pathway

So far, Iran's program has focused almost exclusively on producing enriched uranium. However, in the future, Iran might develop plutonium production capabilities as well. Iran's experience with plutonium has been limited to producing small quantities in the laboratory. However, the country is constructing a heavy water reactor in Arak capable of producing enough plutonium for about two bombs per year.[7] Because Iran has not fully cooperated with IAEA requests to inspect the facility, ongoing work at Arak is cause for concern.

If Iran were to produce plutonium indigenously, it would also have to build specialized facilities known as "hot cells" to extract plutonium from the spent fuel. In 2004, Iran announced that it was scrapping plans to build hot cells capable of reprocessing plutonium because of difficulties procuring the necessary equipment (IAEA, 2004). If Iran eventually chose to build plutonium-friendly hot cells at Arak, it would have to submit updated design information to the IAEA.

Conclusion

If Iran decided to build nuclear weapons and was interrupted in the process by a military attack, it is extremely difficult to predict the consequences. Much would depend on the ensuing actions and reactions. We do know that there would be serious consequences in Iran itself, in the broader Middle East, and in the overall international system.

It is slightly less difficult to predict what would happen if the Islamic Republic of Iran succeeded in acquiring a small nuclear arsenal. The primary threat would then be that the government of Iran, including the agencies that support subversive or terrorist organizations outside Iran, would be emboldened to challenge the interests of Israel, moderate Arab states, and the United States.

For example, groups such as Hezbollah, Islamic Jihad, Hamas, and the states or other actors that support them could be provided with more potent means of violence and subversion and encouraged to pursue causes they share with Iran's ascendant Revolutionary Guard. These actors and Iran could believe that Iran's nuclear capability would deter Israel and the United States from pursuing counterforce tactics against them.

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[6] Iran has recently taken steps toward a batch recycling capability. On February 9, Iran informed the IAEA that it would be feeding the centrifuges at its pilot enrichment plant with a small quantity of LEU to produce 20 percent enriched uranium fuel for the Tehran Research Reactor, even though Iran lacks the capacity to manufacture such materials into fuel assemblies, and international offers have been made to supply the fuel (IAEA, 2010).

[7] According to ISIS (see *www.isisnucleariran.org/sites/facilities/arak-ir-40*).

Fearful, smaller Arab states in the Persian Gulf, as well as Egypt, might try to accommodate Iran in hopes of inducing it to refrain from actively threatening their interests. In return, Iran could demand that these states distance themselves from the United States and pursue more radical policies toward Israel. The United States would try to counter Iranian gains by intensifying military aid and other assistance to induce Iran's neighbors to work more closely with the United States to contain Iran's projection of power.

The risks of acute crises and military conflicts would increase as Iran tried to project power and influence while being countered by the United States, Israel, and others. The ominous shadow of Iranian and Israeli nuclear weapons would hang over the political-security environment, resulting in the daunting prospect of managing crises that could go nuclear without significant warning.

The ongoing need for the United States to project power in the Persian Gulf (including Iraq) and Afghanistan would be significantly complicated by Iran's potential to use nuclear weapons against U.S. forces and the countries that host them. In short, the region—from the Levant through the Persian Gulf and Afghanistan—would become even more volatile than it is now.

By rough analogy, India and Pakistan have engaged in one armed conflict and two military crises in the 12 years since they conducted nuclear tests. However, unlike Iran, both India and Pakistan maintain relatively good relations with the United States, which has enabled Washington to intervene diplomatically to help end the Kargil conflict in 1999 and the 2001–2002 and 2008 post-Mumbai crises. But the strategic relationship between India and Pakistan has still not been stabilized.

Thus, it is clear why the United States and other governments that seek to preserve and enforce 21st century norms of international security, economics, and human rights are so alarmed by Iran's apparent unwillingness to negotiate an equitable resolution of the crisis it initiated by violating the rules regulating the peaceful use of atomic energy. Diplomatic options for resolving the crisis are dwindling, and military alternatives are fraught with dangerous consequences. It's no wonder that biding time looks like the least-bad policy.

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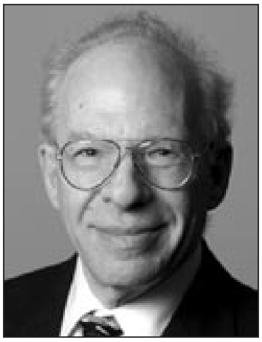
A surface detonation of a 10-kiloton nuclear bomb would be far more deadly than either of the bombs dropped on Hiroshima and Nagasaki.

A Nuclear Explosion in a City or an Attack on a Nuclear Reactor



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Richard L. Garwin

In this article, I discuss two types of nuclear terrorism: (1) the detonation of a nuclear weapon or improvised nuclear device (IND, also called an improvised nuclear explosive) in a city; and (2) an attack on a nuclear reactor, spent-fuel pond, or reprocessing facility with the intent of releasing the vast amount of radioactivity they contain.

Explosion of an Improvised Nuclear Device

Nuclear terrorists are likely to use an IND rather than a weapon from the inventory of a nuclear state. An IND is an explosive device created by a sub-national group that contains weapons-usable material, such as highly enriched uranium metal or plutonium, combined with a means of rapidly assembling fissionable material that exceeds a critical mass and causes a nuclear explosion (for a detailed description, see Garwin, 2010).

For the purposes of this article, I assume that terrorists or criminals have managed to assemble a gun-type device of highly enriched uranium and to detonate it with a yield of 10 kilotons at a location and time of peak population density in a major city. This scenario was the focus of President Obama's Nuclear Security Summit in Washington on April 12–13, 2010 (White House, 2010).

A photo of Hiroshima in October 1945 (Figure 1), taken two months after the city was destroyed by a 13-kiloton nuclear explosion at an altitude of about 570 meters (m), can give an impression of the destruction. The blast knocked down buildings, and the radiant heat from the explosions ignited fires and burned or incinerated people. Because the fireball did not touch the ground, there was essentially no radioactive material ("fallout") on the city. "Prompt radiation" (i.e., radiation emitted within a few seconds of the explosion) added relatively little to the death toll, but it was a new and frightening phenomenon.

FIGURE 1 Hiroshima in October 1945. Iconic photo taken by U.S. Navy personnel and signed by the captain of the B-29 bomber that released the bomb.

A surface burst of a nominal 10-kiloton explosive in a densely populated modern city would be even more devastating. Because of the heavy local fallout of radioactive material associated with a ground burst, a ground-level detonation would greatly increase the number of deaths and injuries from radiation. In addition, there would be a fallout spot, or plume, delayed by, perhaps, 30 minutes, at a distance of 5 to 20 kilometers (km) from the ground burst. Another new phenomenon would be a crater, which, on dry soil or dry soft rock, would have a diameter of about 75 m and a depth of about 17 m (Glasstone and Dolan, 1977).

A blast of invisible nuclear radiation would be released within microseconds, followed within milliseconds by thermal radiation from the surface of the expanding fireball. Winds and destructive overpressure would follow, knocking down buildings in the destroyed area, breaking windows out to a radius of 5.3 km (at 0.5 psi = 0.03 bar overpressure from a surface burst of 10 kiloton yield), and converting people and objects into lethal missiles (Glasstone and Dolan, 1977).

About six seconds later, the nearest potential survivors would feel an enormous blast and wind. The intensely bright fireball would be long gone by then and some fires would be burning, but more would later be ignited by broken gas mains and the ignition of combustible materials from buildings.

The crater material would give off intense, but unfelt, radiation in the immediate area; a total dose of 4 Sieverts (4 Sv or 400 rem)[1] would be lethal to at least 50 percent of the people exposed. The bomb debris, mixed with hundreds of thousands of tons of material from the crater, would rise in the prototypical mushroom cloud into the stratosphere from which coarse debris particles, along with much of the radioactive material, would fall out over a period of 30 minutes or so. With a nominal wind speed, there would be a fallout plume about 2 kilometers (km) wide to a downwind distance of about 20 km. The area affected by lethal fallout might be on the order of 20 km^2. An example of such a plume with boundaries at the dose rate of 10 rem/hr is shown in Figure 2.

Not much could be done to help people in the area of the 50-percent blast-casualty distance of 590 m. People within the 1.8 km radius, where there would be 50 percent mortality from thermal burns, would be lucky if they had been indoors and not in the direct line-of-sight of a window. But the realization that there had been a nuclear explosion would raise concerns about family members and others, and many people would be on the streets trying to gather their families or to

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[1] Sievert: A measure of dose (technically, dose equivalent) deposited in body tissue, averaged over the body. Such a dose would be caused by an exposure imparted by ionizing x-ray or gamma radiation undergoing an energy loss of 1 joule per kilogram of body tissue (l gray). One sievert is equivalent to 100 rem. Rem: A unit of absorbed dose that accounts for the relative biological effectiveness of ionizing radiation in tissue (also called equivalent dose).

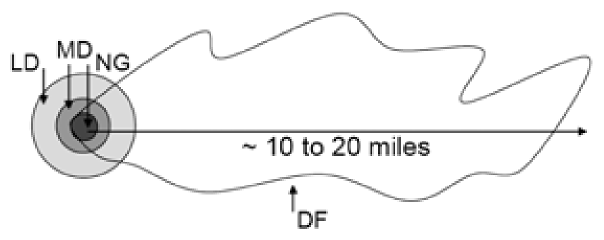

FIGURE 2 Nominal fallout plume bounded by 10 rem/hr initial dose rate. DF = dangerous fallout zone; LD = light damage; MD = moderate damage; and NG = "no go." Source: Homeland Security Council, 2009.

leave the area. In tens of minutes a firestorm could develop, accompanied by strong in-rushing winds from the unaffected area, and evacuation by vehicle would be impossible except, perhaps, in areas where streets were not blocked by rubble.

Beyond the blast-damage area, the power and communications infrastructure would be largely intact, but the instantaneous loss of load on the electrical system would be likely to cause a blackout of uncertain duration; in principle, it need not last for more than a few seconds. The electromagnetic pulse from a ground-burst explosion would cause little damage outside the blast area, so cell towers in the suburbs and beyond should be capable of carrying traffic.

Roads would be clogged and emergency equipment almost absent. In 1946, Philip Morrison, a scientist with the Manhattan Project, described the effects of such an explosion in a U.S. city (Morrison, 1946). A more modern description appeared in a 2006 RAND paper for the U.S. Department of Homeland Security (DHS), which posited a 10-kiloton nuclear explosion in a cargo container in Long Beach harbor. Because the harbor region has relatively low population density, only about 60,000 deaths were predicted. Nevertheless, about 6 million people would be evacuated, and losses would amount to $1 trillion. The paper included graphics showing the range-to-effect for blast effects, burns, and prompt radiation, as well as the contours of the lethal fallout area (Meade and Molander, 2006). The area exposed to near-lethal fallout levels of 300 rem would be about 30 km^2, with the orientation of the fallout pattern dependent on the winds aloft.

A further useful report was prepared for the Homeland Security Council. This report included information about how much protection could be provided by buildings. As Figures 3a and 3b show, taking shelter in the basement of an ordinary, one-story wooden house would reduce exposure to radiation by a factor of 10. A high-rise office building, even with windows, would

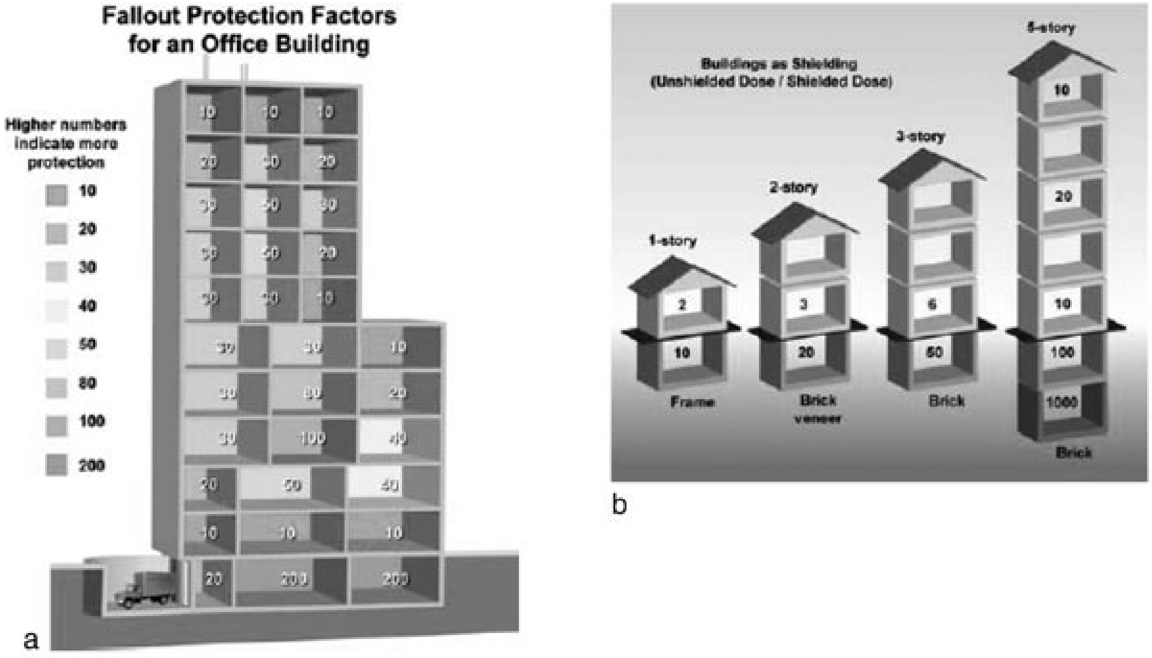

FIGURE 3 Fallout protection factors for occupants of high-rise and low-rise buildings. (3a) Fallout protection factors: numbers represent a dose reduction factor. A dose reduction factor of 10 indicates that a person in that area would receive 1/10 the dose of a person in the open. (3b) Building as shielding: numbers represent a dose reduction factor. A dose reduction factor of 200 indicates that a person in the area would receive 1/200 the dose of a person out in the open. Source: Homeland Security Council, 2009.

reduce exposure by a factor of 50, even as low as the third floor (Homeland Security Council, 2009).

Responding to a Nuclear Attack

During the early stages of the cold war, a Soviet attack was much on the minds of national leaders, and understanding the effects of nuclear weapons on U.S. cities was considered essential. In a nuclear exchange with the Soviet Union, *all* significant U.S. cities would have been attacked and destroyed. Thus there would have been no possibility of bringing in resources from undamaged areas to help the one or two affected areas.

Indeed, it is impossible for each municipality to organize and put aside resources to respond to such an explosion. Nevertheless, it is important that the public be educated on how to protect themselves, especially from exposure to lethal fallout. But a thorough understanding of the variations in destruction and the training and mobilization of resources to provide water and food to the surviving population in little-damaged regions of the city, must be a federal responsibility.

A nuclear explosion would be fundamentally different from a disaster like the earthquake in Haiti, or even the Katrina-induced flooding of New Orleans. Because the United States has a developed economy, roads and railroads will be able to provide necessary transport capacity, and within a few days, it should be possible to obtain adequate water from suburban areas to supply the interior of the city. The federal government would take the lead in planning and creating capabilities for mapping (probably by drone aircraft or helicopters operating at an altitude of about 150 m) the distribution of radioactive fallout within 100 km or so of ground zero.

On April 19, 2007, the Preventive Defense Project, co-chaired by Ashton B. Carter of Harvard University and William J. Perry of Stanford University, convened The Day After Workshop, the purpose of which was “to address the actions that can and should be taken in the 24 hours following a nuclear blast in a U.S. city.” The insightful published report of that workshop is consistent with the estimates presented here and with my own comments at the workshop (Carter et al., 2007a,b):

> Although there are some unknowns and variations, the broad outlines of the grisly effects of a 10-kiloton groundburst are clear. The downtown area, about one mile in radius, would be obliterated. Just outside the area leveled by blast, people wounded by flying debris, fires, and intense radiation would stand little chance of survival. Emergency workers would not get to them because of the intense radiation, and in any event, their burns and acute radiation exposure would require sophisticated and intensive medical care to offer any chance of survival. Further downwind from the detonation point, a plume of radioactive debris would spread. Its shape and size would depend on wind and rain conditions, but within one day, people within five to 10 square miles who did not find shelter or flee within hours would receive lethal radiation doses. This area, for example, could include Brooklyn, New York; northwest Washington, D.C.; or the upper peninsula of San Francisco.

The city center would remain too radioactive to rebuild for a year or more.

> People who were relatively close to the detonation point or who did not shelter themselves from the radiation, which would be most intense on the day of the blast and [would] subside with time, would receive large but varying doses of radiation. If the dose was intense (more than 400 rem), they would get sick and die; if strong but moderate (50–400 rem), they would get sick but probably recover; if moderate (less than 50 rem), they would not notice the effect[s] immediately but would have a greater chance of contracting cancer over their lifetime than if they had received no dose. [At 50 rem, an additional lifetime mortality from cancer of about 2.5 percent.] Because there is little that could be done for those in the area in and around the blast zone, responders would concentrate on minimizing the radiation dose to the population further downwind and preventing chaos among the rest of the population, which would be physically unaffected but traumatized and deprived of whatever utilities and services were located in the affected area.
>
> In the months and years following the attack, policymakers would face a trade-off in the large downwind plume area. If they allowed residents to return early, those residents would experience a higher average cancer rate later in their lives, resulting in many additional deaths when averaged over a large population. If not, or if those people were unwilling to accept a larger lifetime cancer rate, their homes would have to be abandoned. The city center itself would remain too radioactive to rebuild for a year or longer.

The Importance of Planning on the National Level

According to a recommendation by the authors of the report cited above, planning by the federal government is the key to reducing potential losses from an IND explosion (Carter et al., 2007a,b):

> The federal government should stop pretending that state and local officials will be able to control the situation on the Day After. The pretense persists in Washington planning for the Day After that its role is to "support" governors and mayors, who will retain authority and responsibility in the affected area. While this is a reasonable application of our federal system to small and medium-sized emergencies, it is not appropriate for large disasters like a nuclear detonation.

Effective planning will require realistic modeling of the specific potential local impact of an explosion, as outlined above, but also of the effects on the larger society. For example, the loss of 300,000 people in an IND attack on Manhattan would be a large, but not unprecedented death toll from a natural disaster, such as a tsunami, an earthquake, or a pandemic. Sophisticated modeling can be used *now* to determine if the concentration of talent, data, or capability among those 300,000, just 0.1 percent of the total population of 300 million Americans, could imperil the functioning of the entire society.

The federal government should stop pretending that state and local officials will be able to control the situation on the Day After.

If there is a significant potential of the collapse of the whole society, modifications and expenditures must be made immediately to ensure that the federal government can meet its first responsibility—to protect the people against unnecessary harm. This will require a change in our thinking and a realistic recognition of the magnitude of the problem.

Prevention of a Nuclear Detonation in a City

Prevention will be imperfect, so it makes sense to consider the consequences of failure and how to mitigate the harm. First of all, reducing the numbers of nuclear weapons in the world, particularly weapons that are not essential to a nation's security, will reduce their availability for theft and terrorist use.

To prevent the detonation of an IND, it will also be helpful to reduce the amount of weapon-usable highly enriched uranium (HEU) and plutonium in the world. The Obama administration proposes to lock up all such HEU within four years, except for HEU in nuclear weapons or, perhaps, fuel for naval reactors on ships and submarines. A particular focus of this effort is to convert research reactors to use low-enriched uranium instead of HEU, and quickly. The four-year goal was unanimously adopted by the April 2010 Nuclear Security Summit.

Vast numbers of radiation detectors are being deployed in the United States and elsewhere to attempt to detect the transport of HEU or plutonium to a location where it might be fabricated into a bomb or smuggled to the chosen site for an IND. Unfortunately, HEU produces very few gamma rays, and gamma rays from plutonium can be easily shielded, so prospects are not bright for intercepting these materials with high probability.

Reducing the Damage from Exposure to Radiation

The best way to reduce damage from exposure to radiation is to reduce the exposure—and preventing a successful attack is by far the best approach. Despite everyone's best efforts, however, an attack may succeed, and then exposure may still be reduced with sufficient knowledge and training. The distribution of radioactive material in an attack will not be uniform.

Given the location and magnitude of the release of radioactivity, the National Atmospheric Release Advisory Center (NARAC) at Lawrence Livermore National Laboratory is capable of predicting, within a few minutes, the distribution of radioactive material on the ground as determined by the wind profile of the moment. Therefore, it should be a high priority to provide NARAC with data on the location and yield of the nuclear explosion. These data would be available from sensors operated by the U.S. government for that purpose.

Attack on a Nuclear Reactor

Nuclear reactors are purposely sited in areas with low population density. Thus an attack on a nuclear reactor would cause no physical damage to an urban area. The nuclear-reactor scenario might involve a team of 20 or 30 dedicated terrorists on a suicide mission—probably a "beyond-design-basis threat" as defined by the U.S. Nuclear Regulatory Commission (USNRC). A few members of the team would have expert knowledge of the plan and of the reactor technology, at least to the point of having gathered information about locations and vulnerabilities.

The team would probably approach the area in several vehicles, would be armed with explosives, and would have undergone military-type engineering training, so it would be prepared to make its way through obstacles and to use rocket-propelled grenades and other shoulder-fired munitions to overcome the guards. The objective might be not only to cause a meltdown of the reactor by intentionally attacking the multiple safety systems that are designed to function independently in case of an accident (as they did in the 1979 Three Mile Island [TMI] incident), but also to blow a hole in the containment structure, which at TMI kept the large amount of radioactive material that escaped from the reactor pressure vessel from entering the environment as the reactor core melted.

There would be adequate warning that an attack on the reactor was in progress, not only through emergency communications from the reactor security force but, one hopes, also from a constant "all is well" communication among the USNRC, U.S. Department of Homeland Security (DHS), local security forces, and the reactor protective force.

A meltdown provoked by disabling the emergency core cooling system would mean the heat produced by radioactive decay within the reactor pressure vessel would no longer be removed (as it was at TMI) by water circulating through the pressure vessel. (At TMI, a gas bubble at the top of the pressure vessel prevented cooling of the upper part of the core, which melted.)

In the event of a complete meltdown, the radioactive contents of the core, on average two tons of fission products resulting from two years of full-power operation, would enter the containment building and would escape to the atmosphere through the hole that might have been blown in the containment structure. The USNRC-DHS could have organized and trained emergency response teams with the equipment necessary to close such a hole (e.g., an external crane to insert a gasketed steel umbrella-like device through the hole, just as one plugs a hole in a water heater or mounts a heavy-duty support on a hollow-core door).

If the reactor emergency systems have been overcome, the residual "decay heat" of the reactor core must be dissipated to the environment. Immediately after shutdown, the decay heat would be 7 percent of the normal 3,000 megawatts-thermal (MWt) output of the reactor—about 220 MWt. After one day, radioactive decay would reduce the heat generation to about 0.6 percent of the operating thermal output—about 20 MWt, corresponding to the evaporation (at 2.3 megajoule per kg of water) of about 9 kg/s or 0.5 tons per minute or 700 tons per day. However, this amount of water could not simply be allowed to boil freely to the atmosphere, because admixed debris from the reactor core would be intensely radioactive. One possible solution would be to create an emergency heat exchanger by allowing river water or pond water to remove heat by boiling.

There would be adequate warning that an attack on a reactor was in progress.

Attack on a Spent-Fuel Storage Pool

An attack on an at-reactor storage pool for spent-fuel elements would be much like an attack on the reactor, in that it would be carried out by a suicide team armed with explosives. Again, it seems feasible to have stockpiled protective equipment at the site to prevent the rapid escape of water from the storage pool through a fissure or hole in the pool wall created by the attackers.

Because attackers might also cause a breach in the pool wall that would allow the release of thousands of tons of water that serve to shield and cool the spent-fuel elements, gasketed steel sheets might be put in place by a mobile crane provided for that contingency. Indeed, if one took seriously the prospect of an attack on a storage pool, analysis might show that such plates might be stored inside the pool along the wall, ready to be moved into place when necessary.

The Importance of Preparedness

Although it would be good to develop (even in secret) ways of responding to attacks on reactors and storage pools, it would be much better to make it publicly known that the consequences of an attack would be minimized or nullified, thus reducing the likelihood of such an attack.

Unlike a nuclear explosion in a city, the hazards created by an attack on a reactor or spent-fuel storage pool would be strictly radiological, and all physical systems would function normally, although fleeing staff could be a problem. There would be much less short-term radioactivity in the reactor core than in a nuclear explosion (i.e., primary fission products with half lives of less than a few hours), although a typical core of average operating age of two years contains long-lived fission products (e.g., 30-year strontium-90 and cesium-137) from 2,000 kg of uranium fissioned, equivalent (at 17 kilotons of energy release per kg of fission) to 34 megatons of explosive yield (i.e., 3,400 times the long-lived radioactivity of a 10-kiloton explosion).

Prevention of an Attack on a Reactor or Storage Pool

Attackers would not need nuclear materials to attack a reactor or spent-fuel pool. The essential factor in protecting those facilities is to recognize the harm that could be done either by an external team or by collusion among internal personnel. In a sense, protection against an external team is more likely to be effective, if the attack is detected early and the use of lethal force, in the form of land mines, automatic guns, and so on, has been properly planned and authorized. But the first requirement is to acknowledge the damage that might be done and to build flexible systems to counter an attack.

In the event of an attack on a reactor or storage pool, the communication infrastructure would be untouched and would retain the capability of broadcasting contamination maps to cell phones and on the web to guide individual decisions as to where to stay and where to seek safety from what might be a narrow plume of radioactivity. Similarly, with information on the nature of the release of radioactive material from a failed reactor or spent-fuel storage pool, NARAC could estimate the rate of cumulative dose to an individual.

Conclusion

The greatest damage and lethality from a nuclear explosion in a city would result from radioactive fallout that might expose people in a 20 km^2 area to radiation levels that would cause 50 percent mortality. People outside (not shielded) during the time of maximum fallout would be subject to extremely high exposure levels because of the “beta” (electron-decay) radioactivity in contact with clothing or skin. Shielding from buildings can greatly reduce those levels (by a factor of 2 or 3 from light-frame buildings and a factor of 50 for even the lower stories of high-rise buildings). Without those protections, there would be 160,000 deaths in New York City (density 8,000 per km^2) and 80,000 deaths in Los Angeles (density 4,000 per km^2) from fallout.

Preventing an attack by securing nuclear weapons and nuclear materials is highly desirable. Preventing it by reducing the number of people with evil intent would also be beneficial. However, if such an attack does take place, an adaptable, rapid communication system could inform people after the first hour or so where the fallout hazard was greatest, so they could move one or two kilometers, on foot, away from that area and reduce their exposure to radiation. A communication system through cell phones or smart phones could save many lives.

Unfortunately, little has been done to create and test such a system, and the received wisdom is that no federal help will be available for the first 24 hours, when it would be most useful. The “push technology” that has been implemented in some tsunami-prone areas would be a starting point for such a system, although more detailed information would be necessary to characterize fallout patterns and to automatically provide specific advice about which way to go (e.g., a “Fallout App” for the smart phone).

Although not everyone in such an attack can be saved, it is the federal government’s responsibility to do the analysis, planning, simulation, and communication that might be needed for an attack on any one of 20 or more target cities. It would fall to local governments to prepare regulations that would facilitate the temporary sheltering of people, within tens of minutes, in office space to which they do not normally have access.

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Until very recently, there was no scientific consensus on measures to be taken after a nuclear detonation.

Reducing the Consequences of a Nuclear Detonation

Recent Research

Brooke Buddemeier is a health physicist, Radiological and Nuclear Countermeasures Division, Lawrence Livermore National Laboratory.

Brooke Buddemeier

Nuclear terrorism has been an essential part of national preparedness since the formation of the U.S. Department of Homeland Security (DHS),[1] but until recently little research had been done on the potential effects and mitigation strategies specific to a low-yield, ground-level nuclear detonation in a modern U.S. city. An effective response will involve large-scale measures, mass casualty management, mass evacuations, and mass decontamination. Preparedness planning for this scenario presents especially difficult challenges in time-critical decision making and the management of a large number of casualties in the hazard area. Perhaps even more challenging will be coordinating a large-scale response that involves multiple jurisdictions with limited infrastructure and limited resources.

In 2007, Congress, concerned that cities had little guidance to help them prepare their populations to react in the critical minutes after a nuclear terrorism event, directed the DHS Office of Health Affairs (OHA) to work with the National Academies Institute of Medicine, the Homeland Security Institute, the national laboratories, and state and local response organizations to address this issue (U.S. Congress, 2007). The OHA initiative is currently managed by the Federal Emergency Management Agency (FEMA) as

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[1] Scenario #1 of the 15 Department of Homeland Security national planning scenarios is an improvised nuclear detonation in the national capital region.

part of a coordinated federal effort to improve response planning for a nuclear detonation.

At the start of OHA's efforts, there appeared to be no scientific consensus on actions that should be taken after a nuclear detonation. For example, the recommendations on the DHS website, *Ready.gov*, are consistent with the recommendations of the National Academies (2005) but were criticized by the Federation of American Scientists (2006) based on conflicting recommendations in a RAND study (Davis et al., 2003; Orient, 2005).

Moreover, the existing federal guidance was focused on avoiding relatively low-level exposures to reduce the risks of cancer from an accidental release of radiation from transportation or a nuclear power plant and was not applicable for making the life-or-death decisions that would be necessary in the immediate aftermath of a nuclear detonation (DHS, 2008).

The cold war-era civil defense program can provide some insights, but many of the paradigms no longer apply. For example, community fallout shelters might have worked for people who had a few minutes warning of incoming missiles, but they would be much less effective for an attack that occurs without notice.

Through workshops with state and local stakeholders, OHA found that few, if any, communities had developed coordinated regional response plans for the aftermath of a low-yield (10 kiloton or less) nuclear detonation. The workshops revealed a general lack of understanding of the response requirements and many uncertainties about federal, state, and local roles and responsibilities. At an Institute of Medicine workshop on medical response planning for an improvised nuclear device (IND), a responder from Chicago, Joseph Newton (2006) commented, "We don't know what perfect looks like."

Recent Research

To resolve conflicts in the technical community and create a coordination point for research, DHS formed the IND Modeling and Analysis Coordination Working Group (MACWG), comprised of national laboratories, technical organizations, and federal agencies, to coordinate research on the effects of an IND and develop response strategies. The purpose of MACWG was: (1) to establish scientific consensus (where possible) on the effects of, and issues related to, INDs; (2) to bound uncertainties and identify unknowns; and (3) to resolve conflicts about recommended response actions.

As directed by Congress, OHA has coordinated an extensive effort to model the effects of 0.1-, 1.0-, and 10-kiloton nuclear yields in New York City, Washington, D.C., Chicago, Houston, San Francisco, and Los

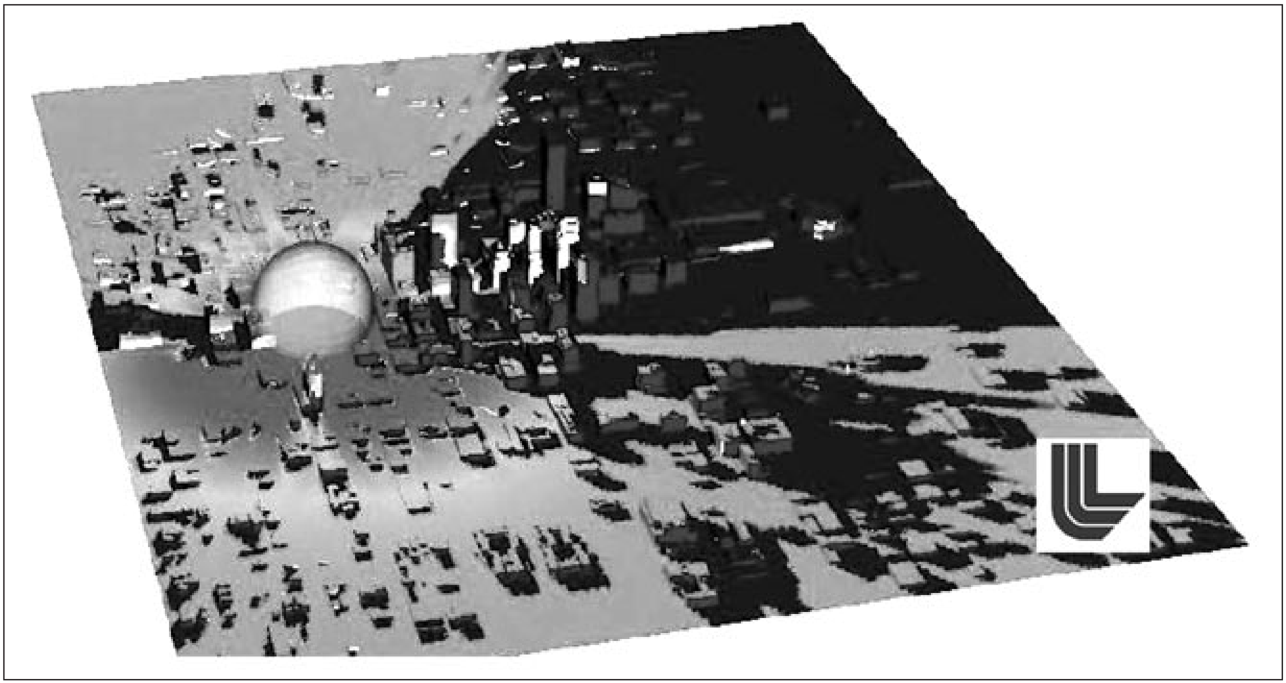

FIGURE 1 Integrated thermal flux from a 10-kiloton ground-level nuclear detonation in a small U.S. city. SOURCE: Lawrence Livermore National Laboratory. For more information contact *brooke2@llnl.gov*.

Angeles; sponsored workshops in state and local communities across the nation, as well as with the National Academies; conducted testing with focus groups on public messaging; and coordinated its efforts with key federal agencies, national laboratories, and technical organizations that have unique capabilities and knowledge about nuclear effects and emergency response.

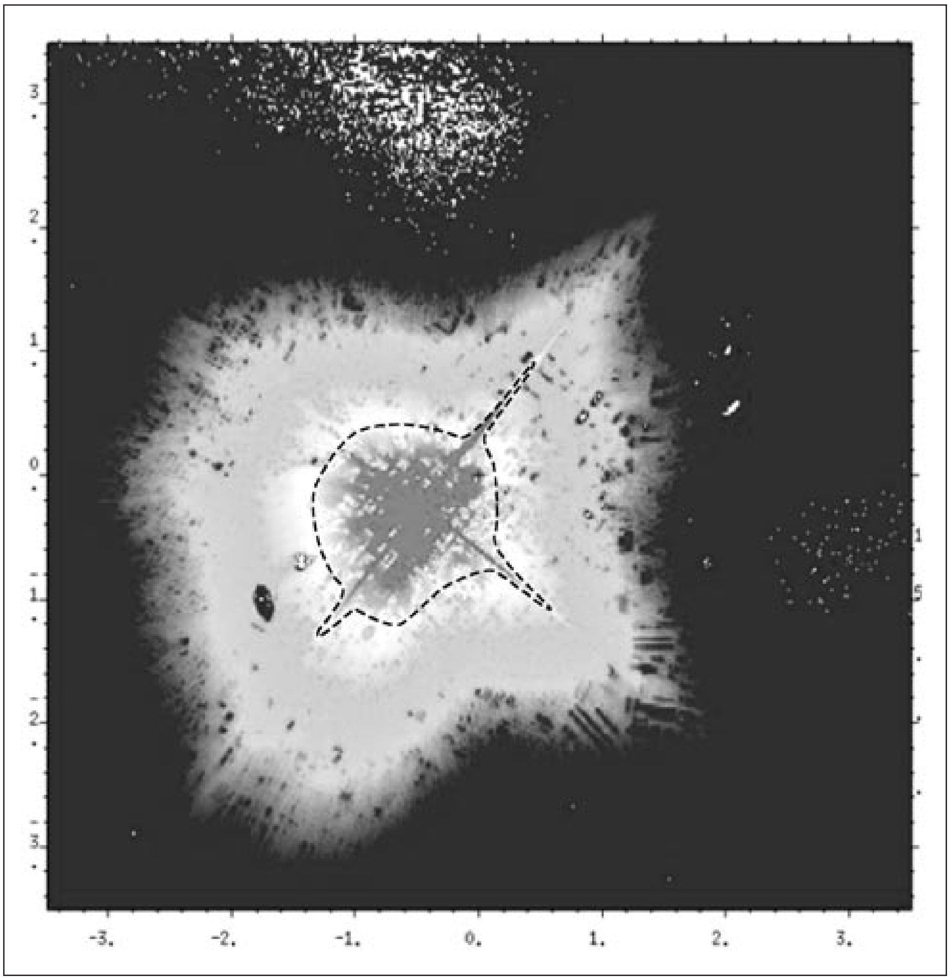

FIGURE 2 Initial gamma radiation from a nuclear detonation in an urban environment. SOURCE: Image courtesy of J.T. Goorley, the ASC's Nuclear Weapon Effects for Urban Consequences, Los Alamos National Laboratory, LA-UR 09-00703 and LA-UR-10-01029. For more information contact Tim Goorley at *jgoorley@lanl.gov*.

Thermal Exposure

The results of recent modeling indicate that a modern urban environment can greatly mitigate some of the effects of a low-yield nuclear detonation. For example, thermal burns from the heat of the initial explosion, primarily a line-of-sight phenomenon, can be greatly reduced in an urban environment where structures can block the thermal radiation. Figure 1, from a model developed at Lawrence Livermore National Laboratory, shows how building shadows can protect the outdoor population from significant thermal exposure (Marrs et al., 2007).

Models developed at Applied Research Associates (ARA) and Los Alamos National Laboratory have shown similar reductions in injuries from the initial radiation produced in the first minute of a nuclear explosion. The Los Alamos graphic (Figure 2) shows the nonsymetrical nature of urban exposure. In the areas beyond the dotted line on the image, even outdoor exposures levels would be low, survivable levels from prompt gamma radiation. Like the thermal analysis, these studies indicate that the ambient radiation levels from a low-yield, ground-level nuclear detonation in an urban environment could be significantly reduced. For example, the unobstructed range for a potentially lethal radiation exposure of 400 rads (cGy)[2] is about 1,200 yards. Initial results by ARA indicate that the range might be reduced by one-third or more, down to 600 to 800 yards, from the detonation point in built-up areas.

Blast Effects

The primary prompt effect[3] of a nuclear explosion is blast damage. A 10-kiloton explosion is equivalent to ~5,000 truck bombs like the one that destroyed the

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[2] Rad (radiation absorbed dose): a unit of measurement of the absorbed dose of ionizing radiation, corresponding to an energy transfer of 100 ergs per gram of any absorbing material. cGy (centigray): a unit of absorbed radiation dose equal to one hundredth (10^{-2}) of a gray, or 1 rad. Gray (Gy): The SI special name for the unit of absorbed dose. 1 Gy = 1 J kg^{-1}.

[3] Prompt effects are effects that radiate outward from the detonation location, referred to as ground zero. These effects include blast effects, electromagnetic pulse, light, thermal radiation, and the ionizing radiation produced in the first minute.

Murrah building in the 1995 Oklahoma City bombing (Mlakar et al., 1998). Blast effects from such an explosion can severely damage or destroy most buildings within half a mile of the detonation point, and people in this area would probably not survive. From one-half mile to about a mile out, survival would most likely depend on the type of structure a person was in when the blast occurred. Even at a distance of one mile, the blast wave would have enough energy to overturn some cars and severely damage some light structures.

Updating our cold war understanding of blast damage in a modern city is another important area of research. The bombings of Hiroshima and Nagasaki demonstrated that the area of glass breakage is nearly 16 times greater than the area of significant structural damage (Glasstone and Dolan, 1977). Injury from broken glass has not previously been well modeled, however, because cold war planners generally considered it "not of military significance."

Although improved building codes since the cold war may contribute to better building survival, there would be a higher likelihood of breakage and potential injury for people near windows because many modern buildings have larger windows. The American Academy of Ophthalmology has noted, "Most injuries among survivors of bombings have been shown to result from secondary effects of the blast by flying and falling glass, building material, and other debris. Despite the relative small surface area exposed, ocular injury is a frequent cause of morbidity in terrorist blast victims" (Mines et al., 2000).

Nuclear Fallout

In addition to prompt effects that radiate outward from the detonation site, a nuclear detonation can also produce nuclear "fallout," which is generated when the dust and debris excavated by the explosion combine with radioactive fission products produced in the nuclear detonation and are drawn upward by the heat of the event. This cloud rapidly climbs through the atmosphere, and a 10 kiloton explosion could potentially rise to a height of 5 miles.[4] Under ideal weather conditions, it would form a "mushroom cloud" from which highly radioactive particles would drop back to earth as the cloud cools. At Hiroshima and Nagasaki, there was no significant fallout because the detonations occurred at altitudes of 1,900 and 1,500 feet, respectively, so fission products did not have an opportunity to mix with excavated earth.

In the absence of complex, accurate weather information, fallout modeling has typically relied on the cigar-shaped Gaussian fallout pattern. Although this pattern could occur under ideal weather conditions, it is not a good planning assumption because fallout patterns would most likely be irregular or differently shaped in real-world atmospheric conditions. Even in nuclear tests at the Nevada Test Site, where the detonation could be conducted under favorable weather conditions, fallout patterns (Figure 3) were very different from the cigar-shaped Gaussian plots commonly used for response planning.

Basing community or regional response plans on the expectation of a Gaussian fallout pattern would create a false impression that fallout would be limited to a symmetrical, easily defined area that could be quickly and easily traversed and that the population in the fallout area would have perfect situational awareness of which areas had been contaminated. These false expectations may have contributed to "evacuate immediately" guidance, which can actually result in higher exposures because it would put people outdoors and in harm's way when the radiation levels would be highest (Davis et al., 2003; Federation of American Scientists, 2006).

An artist's rendition of the combined prompt effects and fallout (Figure 4) provides an example of a complex fallout pattern. The image also shows thermal exposure ranges for someone with an unobstructed view of

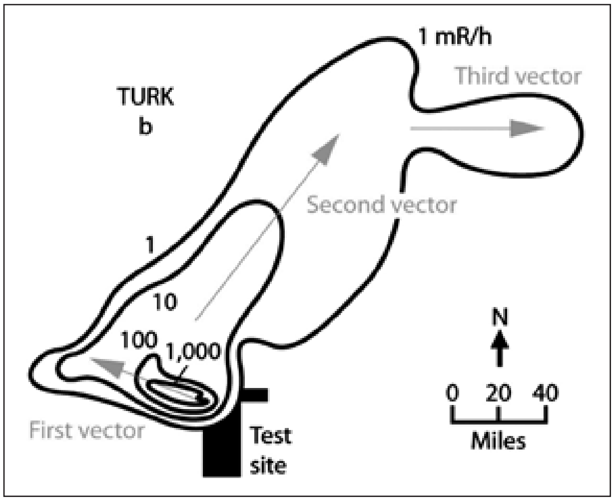

FIGURE 3 Early fallout dose-rate contours from the TURK test at the Nevada Test Site. SOURCE: Lawrence Livermore National Laboratory.

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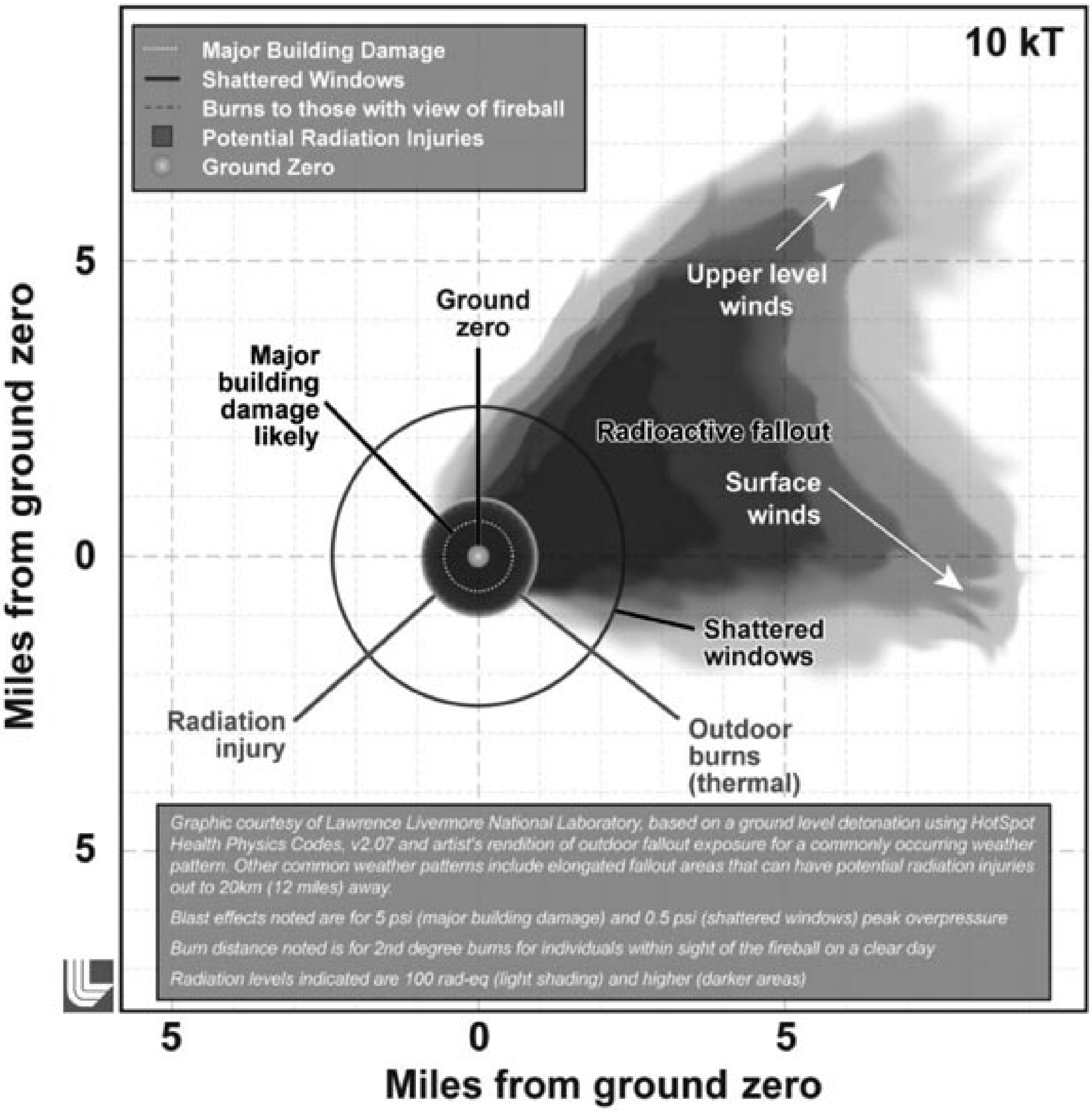
[4] The estimated cloud height is based on an extrapolation from nuclear test data for desert detonations, but more research will be necessary to determine how an urban environment would affect cloud rise.



Graphic courtesy of Lawrence Livermore National Laboratory, based on a ground level detonation using HotSpot Health Physics Codes, v2.07 and artist's rendition of outdoor fallout exposure for a commonly occuring weather pattern. Other common weather patterns include elongated fallout areas that can have potential radiation injuries out to 20km (12 miles) away.

Blast effects noted are for 5 psi (major building damage) and 0.5 psi (shattered windows) peak overpressure

Burn distance noted is for 2nd degree burns for individuals within sight of the fireball on a clear day

Radiation levels indicated are 100 rad-eq (light shading) and higher (darker areas)

FIGURE 4 Artist's rendition of detonation effects. Source: Lawrence Livermore National Laboratory. For more information contact *brooke2@llnl.gov*.

the fireball; the circles should be considered the likely maximum range, although actual effects could be significantly attenuated by intervening buildings. The fallout pattern in this figure (the shaded areas northeast and east of ground zero), is just one possible ground contamination pattern and potential exposure pattern. Actual exposures would depend on how long an individual spends in the fallout area and on the quality of the shelter.

Unlike prompt effects, which occur too rapidly to avoid,[5] health effects from fallout can be mitigated by leaving the area before the fallout arrives or by taking shelter from it. Although some fraction of ionizing radiation can penetrate buildings, shielding by walls and distance from outdoor fallout particles can easily reduce exposures by a factor of 10 or more, even in common urban buildings.

The quality of shelter is defined by a protection factor (PF), which is equal to the ratio of outside dose rate divided by inside dose rate. Like sunscreen SPF, the

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[5] Note that the Civil Defense program "Duck and Cover" strategy can provide protection from prompt effects of flying glass and the thermal pulse; however it requires reacting properly to the bright flash within the first few seconds.

higher the PF value, the lower the exposure compared to the exposure of an unsheltered person in the same area. Figure 5 shows sample PF estimates based on evaluations conducted circa 1960 for typical structures during that era.

Efforts are under way at several national laboratories and at ARA to use advanced modeling capabilities to update our understanding of the level of protection modern buildings could provide. Figure 6 shows an analysis of a modern, three-story office building (left), in which most of the first floor locations had PFs of 10 (shown as light colored areas near the border of the building [right]); PF 10 is considered adequate according to federal Planning Guidance for Response to a Nuclear Detonation (Homeland Security Council, 2009). Most other areas in the building provided even better protection with PFs higher than 100 (darkest areas inside the building) (Johnson et al., 2010).

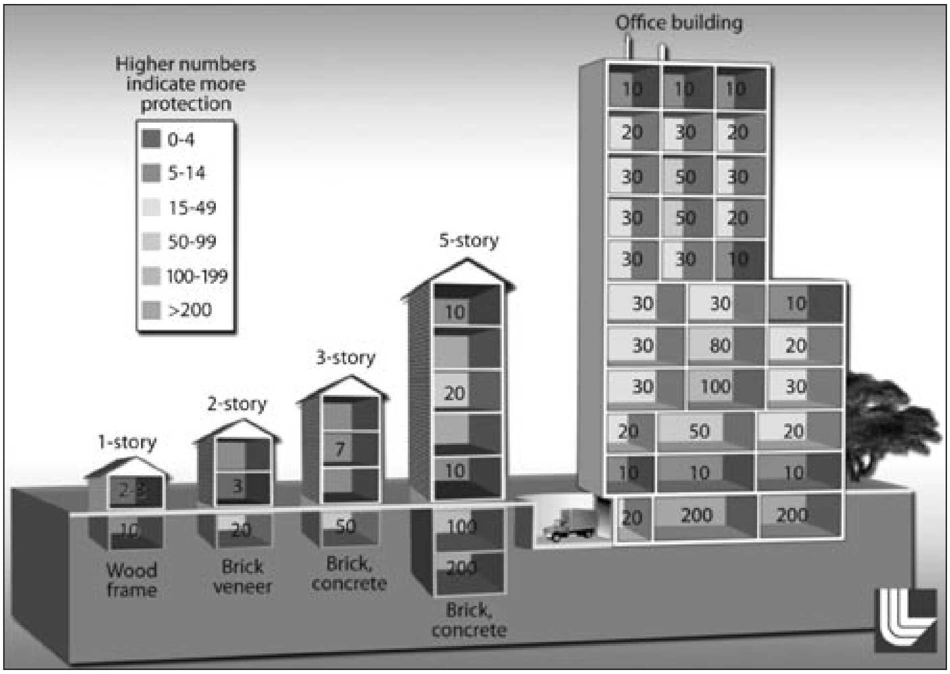

FIGURE 5 Typical protection factors (PFs) estimated during the cold war. SOURCE: Lawrence Livermore National Laboratory. For more information contact *brooke2@llnl.gov*.

Studies by Sandia National Laboratories evaluated the effectiveness of various shelter/evacuation strategies (Brandt, 2009; Brandt and Yoshimura, 2009a,b). In the Los Angeles scenario, even a moderate shelter with a PF of 10 reduced the number of people who received significant exposures of 100 rem or more from ~285,000 to ~45,000. Higher PF shelters, which are common in the urban environment, can reduce the number of significant exposures even further.

Evacuation Strategies

The Sandia studies also analyzed various evacuation strategies (Figure 7). The exposure dose received by an evacuee leaving reference point #1 would

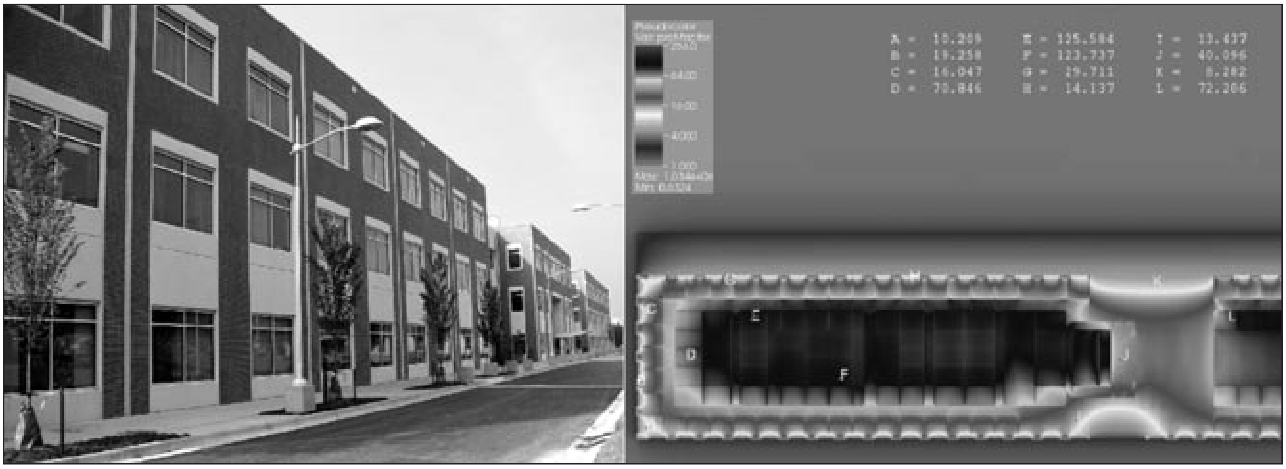

FIGURE 6 Protection provided by a typical modern building. Source: Images courtesy of Oak Ridge National Laboratory.

depend on the evacuation route. The heights of the path in the image represent radiation levels (or dose rates) to which the evacuee would be exposed during the journey.

Unfortunately, unless evacuees had information on where the hazard zones are, they would not know which route would have the lowest exposure. Within a few miles of the detonation, dust and debris created by the blast wave would probably cloud the air and limit visibility. Once the dust settled and the fallout cloud had passed downwind, there would be little visual evidence to indicate fallout hazard areas when sheltered populations emerged.

The hazard from fallout is not from breathing in the particles, but from exposure to the ionizing radiation given off after particles have settled on the ground and on the roofs of buildings (Crocker et al., 1966; Lacy and Stangler, 1962; Levanon and Pernick, 1988; Mamuro et al., 1967; Peterson and Shapiro, 1992). Radiation levels from these particles drop off quickly, however, with most (~55 percent) of the potential exposure occurring within the first hour after detonation and ~80 percent occurring within the first day.

The graph in Figure 8 shows the rapid decay of outdoor radiation levels at one point downwind of a 10-kiloton explosion (Buddemeier and Dillon, 2009). Depending on weather conditions, the most dangerous concentrations of fallout particles (i.e., potentially fatal to people outside) occur within 20 miles downwind of the event and are expected to be clearly visible as they fall, possibly as particles resembling sand, table salt, ash, or rain (Lessard et al., 1954; NCRP, 1982).

Although the lowest possible exposure can be achieved through delayed departure, the delay also means that individuals would be receiving exposure from fallout while waiting in their shelters. To evaluate the total radiation exposure for various shelter/evacuation strategies, the cumulative dose received within the shelter was added to the dose received during evacuation for a continuum of shelter departure times. Figure 9 is a graph showing total exposures (shelter dose + evacuation dose) for various shelter departure times for a given shelter located a little more than a mile downwind and a shelter PF of 100, which can be found in the core of most office buildings.

In this example, departure after one hour results in a cumulative shelter dose of 8 rem and an evacuation dose of 62 rem, with a total exposure of 70 rem. Notice that the longer the sheltering time, the lower the total dose. A 24-hour departure can result in a total dose of 17 rem, significantly lower than the one-hour departure dose.

This analysis reveals the hazards of early or immediate evacuation, when initial fallout radiation levels are extremely high. More detail on the methodology of this analysis can be found in *Key Response Planning Factors for the Aftermath of Nuclear Terrorism* (Buddemeier and Dillon, 2009).

Community Outreach

If a nuclear detonation were to occur in a modern

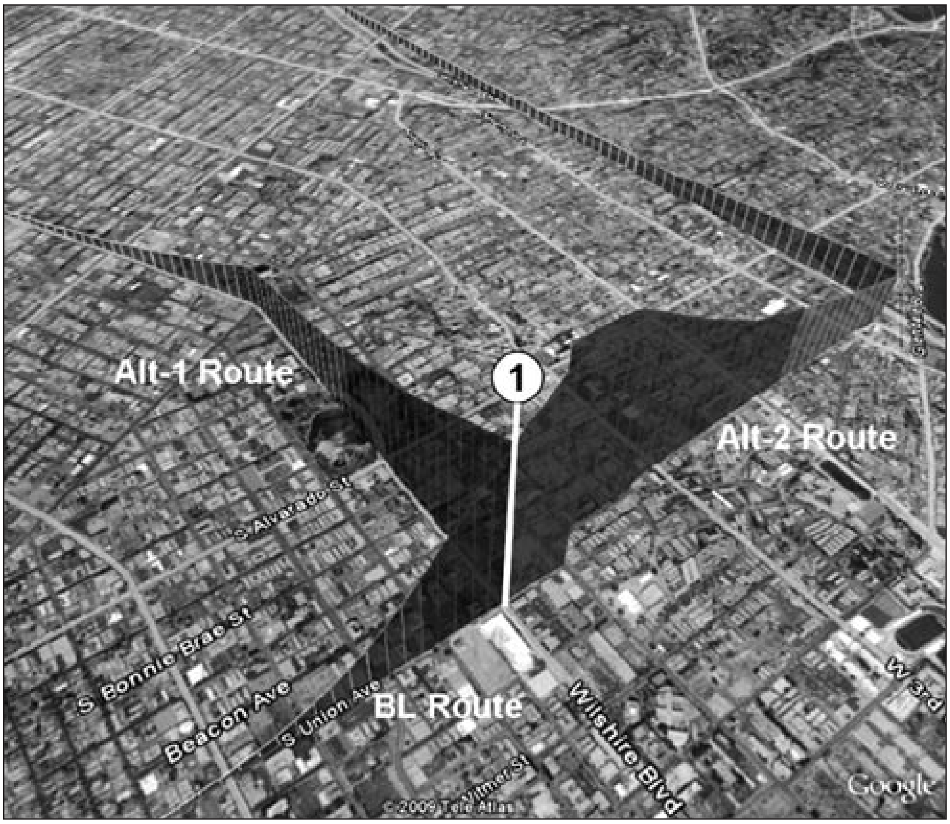

FIGURE 7 Analysis of evacuation strategies. Source: Image courtesy of Sandia National Laboratories.

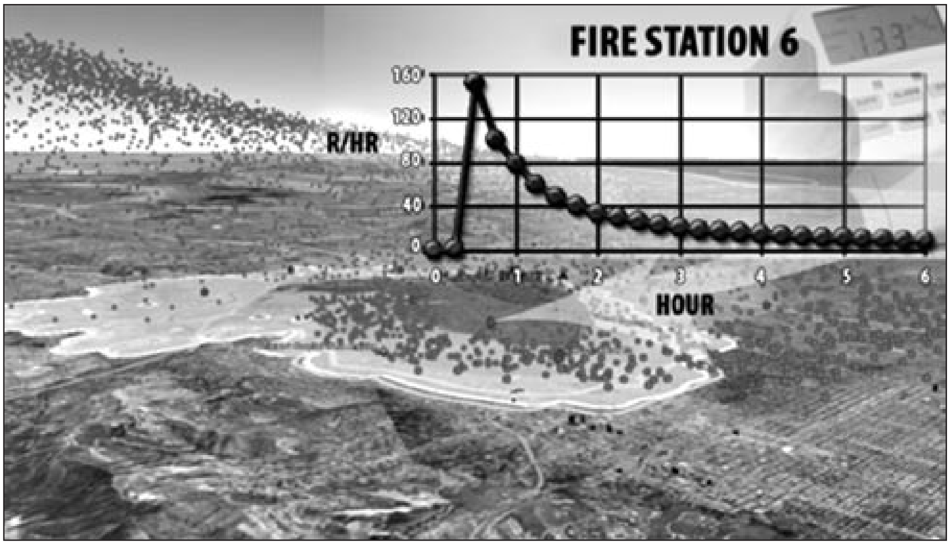

FIGURE 8 Illustration of radiation levels over time downwind of a 10-kiloton detonation (weather dependent). Source: Lawrence Livermore National Laboratory. For more information contact *brooke2@llnl.gov*.

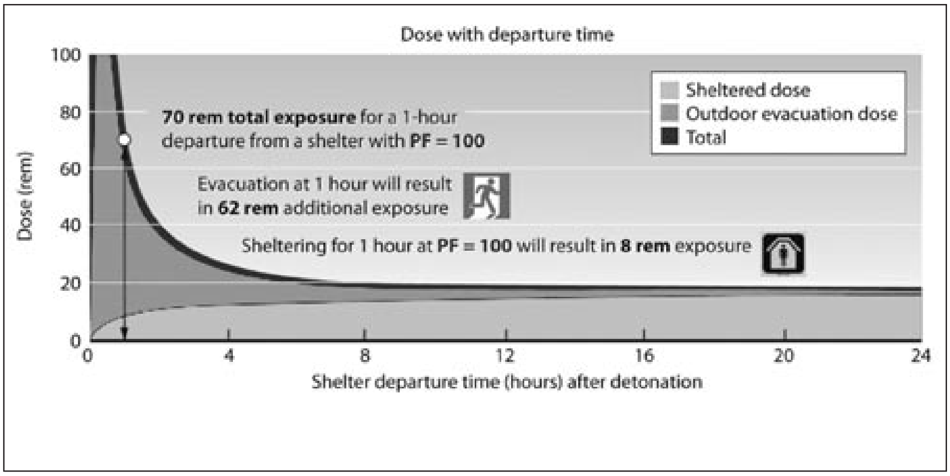

FIGURE 9 Cumulative doses for various departure times from shelter. SOURCE: Lawrence Livermore National Laboratory. For more information contact *brooke2@llnl.gov*.

U.S. city, the best way to reduce casualties[6] during the response phase (post detonation) would be by reducing exposure to fallout radiation. This can be accomplished through early, adequate sheltering followed by informed, delayed evacuation.[7] However, the most critical decisions must be made in the first few minutes. Unfortunately, many people incorrectly believe that response efforts are futile. Thus responses to a nuclear detonation must include public information, planning, and rapid response. Because a successful response will require extensive coordination by a large number of organizations supplemented by appropriate responses by local responders and the general population in the hazard zones, regional planning will also be essential.

By the nature of their work, response organizations are distributed throughout a community, and the vast majority of them would survive. However, unless there has been a basic level of large-scale emergency planning, response organizations will not know how to apply their skills safely and effectively. Although there are considerable federal capabilities, it is unlikely that comprehensive assets would arrive in the first few days, and they could be further delayed by actions taken nationally to prevent or mitigate further attacks.

The convergence of detailed, three-dimensional prompt and atmospheric modeling capabilities, day and night time population distribution information, and building type and distribution information in the DHS HAZUS[8] database provides an unprecedented basis for community-specific, science-informed response planning. FEMA is working on integrating this information to support community response planning.

The results of initial DHS modeling and analyses were

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[6] Casualties are defined in this document as both injuries and fatalities.

[7] This article focuses primarily on protection from fallout. Other issues, including planning actions that would reduce injuries/fatalities arising from prompt effects (e.g., "duck and cover" to reduce injuries from broken glass) are discussed only briefly.

[8] HAZUS (abbreviation for HAZards United States) is a geographic information system-based natural hazard loss estimation software package developed and freely distributed by FEMA.

presented to federal, state, and local working groups in New York City, the national capital region, Charlotte, Houston, Portland, and Los Angeles to obtain broad-based reviews and feedback on strategies and messaging. In addition to some of the technical information presented above, advanced modeling, animation, and graphics were used to illustrate how a nuclear detonation event in the city of the community of interest might unfold. Emergency responders, emergency managers, and public health officials were shown animations of cloud movements (from the perspective of a person on the ground), visualizations of rapidly changing affected areas as fallout accumulates and then decays (Figure 8), and the efficacy of various shelter/evacuation strategies.

The updated information and methods of communication were well received by the response-planning community and have helped correct misunderstandings about the crucial importance of local response planning. Regional planning for response to nuclear terrorism are also being initiated in several communities.

National Guidance

Until recently, there was no scientific consensus on the correct actions to take, and response planners had no federal guidance. The *Federal Register Notice* published by DHS (2005), which clarified how existing guidance for protective action applies to response to radiological or nuclear terrorism, did not specifically address guidance for dealing with the acute effects of a nuclear explosion (MacKinney, 2006).

Now, in addition to the technical reports cited above, a number of federal agencies have worked together to develop *National Planning Guidance for Response to a Nuclear Detonation* (Homeland Security Council, 2009; a 2010 update is currently under review). In addition, the National Council on Radiation Protection and Measurements will soon publish *Responding to Radiological and Nuclear Terrorism: A Guide for Decision Makers*.

In addition to guidance specific to nuclear terrorism, DHS has undertaken extensive preparedness activities, including providing billions of dollars in preparedness grants to states and urban areas. DHS preparedness programs and strategies favor a capability-development approach that stresses mitigating the effects of adverse events. Thus preparedness for a low-yield nuclear detonation would create important capabilities that would also be crucial in responding to other catastrophic events that require coordinated regional response, time-critical decision making, caring for mass casualties, crisis communication, and the prioritization of resources.

Because many, many lives depend on actions taken by citizens and responders in the first few hours after a catastrophe, the capability of making those decisions and disseminating information and guidance quickly is essential during rapidly unfolding catastrophic events.

Conclusion

Recent research indicates than many potentially lethal effects of a nuclear detonation can be greatly mitigated by the urban environment. Urban shadowing and shielding can significantly reduce the range of prompt thermal and ionizing radiation, and, although fallout continues to be a significant issue, adequate shelter can easily be found in the urban environment.

If a nuclear detonation were to occur in a modern U.S. city, the greatest reduction in the number of casualties would be achieved through rapid actions taken by citizens supported by accurate, timely information and prompt actions by state and local officials. Unfortunately, most response organizations (and the general public) currently lack a fundamental awareness and have not developed plans to make informed decisions in the event of a nuclear explosion.

Given the daytime population density of a large modern city, the number of people who could be hurt by prompt effects or threatened by fallout could easily be in the hundreds of thousands. Fortunately, the number of casualties could be significantly reduced by taking appropriate action and by community pre-event planning at the local level.

Reducing exposure to fallout radiation, which can be accomplished through early, adequate sheltering followed by informed, delayed evacuation, would result in the largest potential reduction in casualties. A well organized response would enable sheltered populations to make informed evacuations and support timely medical interventions, which would greatly improve the prognosis for the injured (Einav et al., 2004; Ellidokuz et al., 2005; Macleod et al., 2007; Noland and Quddus, 2004; Sampalis et al., 1993; Teague, 2004; Trunkey, 1983; Wightman and Gladish, 2001; Wyatt et al., 1995).

Recent advances in scientific understanding, federal guidance, and preparedness tools have provided a foundation for state and local planning. Resources are now available for state, local, and regional response planning that can help bring a region together to address a number of difficult challenges presented by the nuclear terrorism scenario. The capabilities gained through response planning can also facilitate effective responses to a variety of natural and other man-made catastrophic events that require large-scale coordination to handle mass casualties and mass evacuations.

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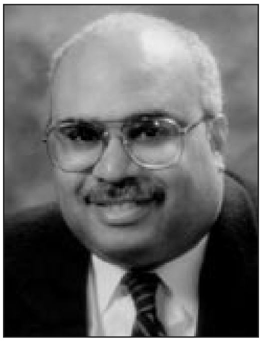
The medical and public health community is still in its infancy in terms of preparedness for the detonation of a nuclear device.

Medical Preparedness and Response to Nuclear Terrorism



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The atomic age began in the 1900s and brought with it the promise of using nuclear technologies for peaceful purposes. It also brought with it the reality of nuclear weapons and a potential catastrophic public health threat.

Early nuclear weapons were large, heavy, and complicated to make and use. Most important, only nation states had them. As technology advanced, nuclear weapons have become smaller, lighter, and more potent. In addition, terrorists are now working diligently to get their hands on them.

Today, detonation of a compact, portable nuclear device by a small group of terrorists is a real threat. These devices, known by a variety of names—suitcase nukes, mini-nukes, or improvised nuclear devices (INDs)—are small enough to put in a backpack or suitcase and can yield an explosion of up to 20 kilotons.

Challenges to Emergency Medical Response

All nuclear detonations result in significant structural and environmental destruction from the blast, heat, and radiation. The level of physical destruction in and beyond the response area and the potential loss of critical medical infrastructure in surrounding areas at relatively remote distances will create significant barriers to normal emergency medical responses. In addition, dangerous levels of radiation in the immediate response area and downwind from the radiation plume will make it difficult to respond rapidly to victims of the blast. Operational and logistical problems with the delivery of supplies, patient transport, and emergency communication will further complicate emergency medical response.

The medical effects will be catastrophic, both for people in the immediate area and for people within a radius of several miles. Survivability in the short and intermediate term will depend on the degree and type of physical injury combined with the degree of exposure to radiation (Waselenko et al., 2004). The radiation effects will have immediate, delayed, and long-term health consequences for both victims and emergency response personnel.

Under any scenario that includes the release of a nuclear weapon, there will be thousands, possibly tens of thousands, of casualties. In the immediate aftermath, there will be an urgent need for a large number of specialized beds for patients with burns, blunt and penetrating trauma, eye injuries, and other injuries that would quickly overwhelm the existing overtaxed health system. The number and variety of casualties, the lack of adequate emergent health care infrastructure (e.g., burn and trauma beds, respirators, supplies, and trained staff) in many areas, and the expectation of long-term disruptions of routine emergent and urgent health care services represent significant challenges to planners.

Preparing for the Worst

With these challenges in mind, how does one address the need for public health preparedness? First, achieving preparedness is a process, not a point in time. Preparedness requires training, practice, and an organized approach to the development of an emergency medical system. The investment in emergency preparedness must be persistent and sustained in a way that creates dual-use systems that will serve the needs of the public on a daily basis but can also be scaled up quickly to address a surge of patients in case of an overwhelming event.

Since the horrific events of September 11, 2001, the nation has been working toward improving preparedness to threats to public health ranging from infectious diseases to weapons of mass destruction. Preparing for any emergency begins with asking "what if" security officials fail to prevent the release of a biological or chemical weapon or the detonation of an IND in an urban area or a highly populated American city. The medical and public health community is still in its infancy in preparing to respond to such an unthinkable event (IOM, 2009).

Public health preparedness activities have been undertaken to address unintentional outbreaks of infectious disease, such as pandemic influenza (H1N1) and severe acute respiratory syndrome (SARS); large outbreaks of food-borne illnesses from pathogenic bacteria, such as E-Coli 0157:H7 and Salmonella; and intentional threats from potential bioweapons, such as smallpox and anthrax. These measures have improved the nation's capacity to respond to infectious outbreaks and a variety of other basic health emergencies.

However, they are not sufficient to address a disaster with the range and scope of destruction that would be caused by the detonation of an IND. The profound loss of critical medical and response infrastructure would profoundly diminish the effectiveness of the emergency response. The only recent experiences that approach the scope of an IND event are Hurricanes Katrina and Rita and, possibly, the earthquake in Haiti, which also caused the acute loss of significant critical infrastructure.

The detonation of an IND would cause a level of destruction and risk to health that would be a megadisaster of national significance (Figure 1). In such an attack, federal authorities would have to be immediately engaged in the emergency response and not wait for requests from state or local officials, as they would in a typical scenario. Medical preparedness for a nuclear detonation will require using all of the measures taken for many types of natural and manmade disasters. It will also require a radical change in thinking about how we provide emergency medical care.

In addition to planning a response to the effects of a large explosion, preparation will require addressing the problems faced in a radiologic hazards material (Hazmat)

FIGURE 1 Mushroom cloud following a ground-level nuclear explosion. Source: FEMA News Photo.

spill. Because of the radioactive cloud, the contaminated area would include not only the blast area, but also communities that may be many miles from the site. Planners must also be prepared to mount an emergency response in conditions that mimic an earthquake or tornado, such as the loss of physical infrastructure and widespread physical blockages of ingress and egress routes.

Finally, because this would be an intentional attack, planners must include preparations to respond to multiple detonations or the release of biological or chemical weapons. These challenges will require an all-hazards approach to emergency medical preparedness, which will be only one component in the general emergency response plan for a major disaster.

Response Plans for Weapons of Mass Destruction

Metropolitan Medical Response System Program

One of the earliest efforts to plan for responding to weapons of mass destruction was the Metropolitan Medical Response System Program (MMRS), which was started in 1995. This federal program was an early attempt to encourage integrated planning for large-scale disasters in several urban cities. The intent was to link first responders (e.g., police, fire, and emergency medical services) with public health and emergency management officials.

The MMRS program depended on local control and decision making. Although it was a good effort, because of the magnitude of planning and program needs, MMRS has remained generally undeveloped for responding to an event of the size and scope of an IND detonation.

Urban Area Security Initiative

Many other public and nonpublic efforts have been undertaken by a variety of federal, state, and local agencies to prevent, mitigate, or respond to the threat of a nuclear weapon. The Urban Area Security Initiative (UASI), for example, provided funds to multiple urban areas to address preparedness specifically for detonation of a nuclear weapon. The program was designed to improve capabilities and preparedness planning in response to improvised explosive devices in high-density, high-threat urban areas.

Like MMRS, this program is also still in its infancy in terms of planning. Although some progress has been made, it has not yet developed the kind of preparedness plans necessary to respond to a catastrophic event, such as the detonation of an IND in one of these cities.

Other Government Programs

The U.S. Department of Health and Human Services (DHHS) has a range of programs to support preparedness, including the Public Health Emergency Preparedness Program and the Hospital Preparedness Program. Both are designed to achieve all-hazard preparedness for public health emergencies. Additional programs that support emergency medical planning and response are run by the Federal Emergency Management Agency.

Training Health Professionals

Unlike health professionals trained to respond to bioterrorism or Hazmat spills, very few health professionals have received training in the management of nuclear emergencies. This is a major gap in our medical preparedness. The anthrax release in October 2001, followed by concerns about smallpox and an influenza pandemic, resulted in intensive efforts to educate people in a large number of health disciplines in medical responses to these emerging threats.

Very few health professionals have received training in the management of a nuclear emergency.

We need similar efforts for the emergency management of radiation and nuclear threats. But it will take federal leadership to jump start the process through public health and professional associations and educational institutions. Examples of such training include programs supported by the National Disaster Life Support Foundation (*www.ndlsf.org*) and others, which provide a variety of courses on the management and treatment of mass casualties. We will also need specialized training for leaders in emergency medical services, lay emergency managers, and public health directors to manage the unique aspects of nuclear emergencies.

Health Effects of a 10-Kiloton Nuclear Device

Our understanding of the full health effects of an IND detonation in an urban setting is still evolving. Real-life scenarios of nuclear and radiation events are limited to the military airbursts at Nagasaki and Hiroshima, nuclear weapons tests, the civilian tragedy of Chernobyl, the Three Mile Island accident, and occasional laboratory accidents.

Because there have been few experimental ground-level detonations, most of what we know comes from sophisticated models estimating the effects of an IND. Based on these models, current estimates for a 10-kiloton release (a small suitcase bomb) are about 40,000 to 50,000 people killed within the first 24 hours from blast effects and burns and more than 130,000 injured from radioactive fallout (Marrs, 2007). Factors that modelers use to estimate human casualties include population density, time of day, geographic location, wind speed, and so on.

Thus, even with conservative estimates, the health care system would quickly be overwhelmed (Bell and Dallas, 2007). The immediate types of injuries sustained from an explosion of this type would include a combination of blast, burn, and penetrating traumas. For initial survivors, acute and chronic radiation illness would be another problem, which, when combined with traumatic injuries, is known to increase mortality (Flynn, 2006). There are therapies for radiation exposure, but survival depends on the dose of radiation received.

The management goal in a disaster is to move from chaos to controlled disorder as quickly as possible.

The First 72 Hours

The management goal in a typical disaster is to move from chaos to controlled disorder as quickly as possible. In a disaster like an IND, the period of chaos would be magnified because of fear, the size of the affected area, and the loss of local response capacity, that is, responders who are used to working together. Traditional preparedness planning is based on the assumption that local communities will be the responders for the first 48 to 72 hours. Thus planning focuses on optimizing the response until outside assistance arrives, as needed. The mobilization of meaningful federal assistance is expected to take from 48 to 72 hours.

The explosion of an IND or other weapon of mass destruction, however, would be immediately understood as an event of national importance, and local, state, and federal planners must harmonize their plans in a way that immediately nationalizes the response. Although the local community may be on its own for some period of time for logistical reasons, it is clear that, without immediate nationalization, there cannot be a reasonable emergency medical response.

Because of the loss of a significant amount of the local critical infrastructure (e.g., ambulances, hospitals and clinics, and associated personnel), the response plan should be designed to use regional and national health resources for the most severely affected patients. Medical standards of care may also change dramatically, under appropriate medical supervision and ethical guidelines, in disaster situations. For example, critically ill patients might have to be treated in a school gymnasium instead of a hospital because of the volume of patients, and non-physician caregivers might be authorized to give injections and perform other procedures, even minor surgical procedures (IOM, 2010).

First responders will have to address the early loss of command and control and operational communications (mostly because of blast or burn effects, less so from the electromagnetic pulse). Situational threat awareness, accurate weather information, and the status of the medical system infrastructure are critical pieces of information essential for effective control and command of the medical response.

Risk communication to the public will be a major challenge; messages must be clear, consistent, and as accurate as possible. Maintaining public trust will be of great importance for health officials, who will have to make difficult decisions based on incomplete information. Managing fear, post traumatic stress disorders, as well as traditional mental health concerns (e.g., depression) will also be critical (Koenig et al., 2005).

In an emergency, immediate care (first aid) is often provided by bystanders and others in the general area of the event. In the case of an IND explosion, however, the area will be contaminated with radiation, and even able-bodied survivors may be unable or unwilling to assist because of concerns about the risk of lethal exposure. Significant search and rescue may also be delayed because of contamination of the site.

The decontamination of victims will be an essential medical procedure, not only to protect patients, but also to protect care providers from continued radiation exposure. In general, however, most experts recommend that emergency care not be delayed because of fear of a contaminated patient. Removing a patient's clothing will usually reduce the amount of contamination by 90 percent.

Historically, emergency providers have recognized that the first few hours in a mass causality situation require sorting patients into priority groups, ranging from people who require care first to those who are not expected to survive and are, therefore, made comfortable and treated last. The biggest barrier to providing immediate care will be ensuring that it is safe for first responders to enter the affected area.

Planners must be clear about the level of radiation exposure a rescue worker will be allowed to receive and must maintain a system so that they know when a worker is approaching that limit. The level of personal protective equipment will depend on the level of risk and should also be predetermined as part of the operations plan.

Making decisions that limit exposure to ground radiation, airborne particles, and gases will be crucial for survivors in the affected area. Evidence clearly shows that sheltering in place is an effective strategy for limiting exposure and improving the chances of survival. Thus, finding shelter, or remaining sheltered, should be strongly emphasized in event planning and in the dissemination of plans and information. The science behind sheltering in place and when to evacuate a shelter to minimize exposure is clear, but communicating this to populations on a wide scale to achieve an orderly evacuation will be difficult.

The Federal Response

Early activation and prepositioning of national response assets upon notification of a threat warning will be critical. Rapid mobilization of medical response assets, such as the strategic national stockpile, military airborne patient transport, the National Disaster Medical System (about 1,500 hospitals and 34,000 beds), blood collection and delivery systems, and radiation detection devices will also be essential (Coleman et al., 2009).

Regulatory action by DHHS to authorize the emergency use of pharmaceuticals and emergency hospital transfer rules to optimize medical care should be taken soon. Medical transportation systems for large-scale evacuations should be activated and implemented immediately.

Beyond the First 72 Hours

The mapping of contaminated areas, continued search-and-rescue operations, and later recovery operations of remains will last long past the first 72 hours. These may seem like almost routine activities until one understands the complexity of mapping a contaminated area in a blast zone and that changes in the prevailing winds can make predicting the path of the fallout plume extremely difficult, except with computer models and on-the-ground radiation detectors. Simply put, relying on the traditional unidirectional plume model will not be adequate for determining which areas to avoid.

> *Early activation and prepositioning of national response assets upon notification of a threat warning will be critical to rapid response.*

Medium- and long-term health effects of radiation exposure, combined with disabilities from trauma, will mean that the direct health effects will persist for several years or more. Long-term planning should address these issues.

Cleaning the environment of contaminants, radioactive materials, and other toxic debris will create significant health hazards. Safe removal and disposal methods must be included in the remediation plan.

Building Community Resilience

A great deal of work has been done in the last several years to help communities become more resilient in the face of emergencies. Resilient communities are characterized by the ability to mitigate the effects of a significant disaster and return to normal or near normal quickly. However, resilience in the face of a disaster means adding an element of human capital to planned systems that promote a rapid return to normalcy once the disaster is over. Communities where poverty levels are high, the built environment is dilapidated or not kept up, and the underlying health status is poor are less likely to rebound quickly. In the case of the recent earthquake in Haiti, for example, even a return to a baseline level of profound poverty is going slowly.

A community with significant resources, good underlying health, and a solid, practiced emergency plan will have the capacity to recover more quickly (NRC, 2006). However, after an attack with an IND, even a resilient community will face many challenges, depending on the extent of the loss of infrastructure, the degree of community disruption, and the forced migration of residents out of the affected and surrounding areas, probably for a significant period of time.

Conclusion

Ensuring that an emergency medical system can respond to a nuclear emergency requires a proactive, nontraditional approach to disaster planning and response. This can be accomplished within the traditional framework of all-hazard planning, but it will require immediate recognition of the national nature of the emergency, an "all in" response from the beginning, and complex decisions in response to an emergency that has elements of different types of disasters.

The prospect of responding under continued threat of multiple intentional detonations or the use of conventional or unconventional weapons could further complicate the situation. Moving successfully from chaos to controlled disorder will require that emergency planners effectively integrate response to the unique challenges of a particular event with the medical response scenario. In the event of the unthinkable, even a resilient community will be slow to recover.

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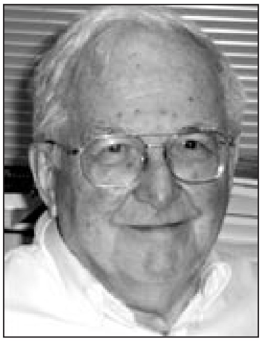
Effective communication is essential to informed decision making about radiological risks.

Radiological Terrorism
First Responders and Communicating Risk



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During the cold war, school children were taught what to do in case of a nuclear attack, and some people built underground shelters to enable them to outlast the long-term effects of such an attack. When the cold war ended, so did the exercises and the digging. However, since 2001, the public has again heard a great deal about the dangers of nuclear and radiological terrorism. In 2008, the National Academy of Engineering published *Grand Challenges for Engineering* in which 14 grand challenges were identified, including nuclear terror (NAE, 2008). That report states:

> Long before 2001, defenders of national security worried about the possible immediate death[s] of 300,000 people and the loss of thousands of square miles of land to productive use through an act of terror. From the beginning of the nuclear age, the materials suitable for making a weapon have been accumulating around the world. Even some actual bombs may not be adequately secure against theft or sale in certain countries. Nuclear reactors for research or power are scattered about the globe, capable of producing the raw material for nuclear devices. And the instructions for building explosive devices have been widely published, suggesting that access to the ingredients would make a bomb a realistic possibility.

In the event of such an attack, responders will be called upon to go into areas where they may be exposed to radiation. In addressing potential exposures of soldiers on the battlefield, an Institute of Medicine report cautioned that although "there is a general ethical principle that one should not put individuals at risk of harm, . . . [c]ertain roles . . . carry with them an obligation to bear risk for the benefit of others." In those cases, there "must be an analysis that supports . . . that no more risk than . . . necessary is . . . imposed or placed on the individual. . . . This includes *disclosure* of the risks to the person both before and after the exposure . . . ." (IOM, 1999).

Responders must be aware of public fears and misconceptions about the dangers of radiation.

The same applies to responders to a radioactive event, who should be trained to explain radiation, measure exposures, and understand the risk of entering contaminated areas following a radiological attack. Responders must also be aware of public fears of chemicals and radiation. Studies have shown that as many as 60 to 75 percent of people believe that if an individual is exposed to a chemical that can cause cancer, that person will someday develop cancer. A similar number believe that exposure to radiation will probably lead to cancer (e.g., Slovic, 1996).

Communicating Risk

The definition of "risk" depends on culture and context. Risk in the financial world is different from risk in bridge construction and from risk in the world of religion. According to a recent definition, the factors that determine risk in the context of radiological terrorism include "(1) the hazardousness of the material, (2) its quantity, (3) the probability of release, (4) the dispersion of the hazard, (5) the population exposed, (6) organism uptake, and (7) [the] response of officials to the hazard before, during, and after release" (Greenberg et al., 2009). That description, although probably too complex to be of use for the average person, can serve as a framework for educating responders.

In addition to learning the framework for risk analysis, effective risk communication requires understanding the audience. Officials often believe the public does not and cannot understand complex situations. While the general public may not have an understanding when a crisis arises, according to Professor Baruch Fischhoff of Carnegie Mellon University, "...lay risk perceptions may be judged unfairly, leading professionals to be unduly critical of lay-people's decision-making capabilities" (Fischhoff, 2009). He notes that "Citizens can, typically, acquire the understanding to reach reasonable conclusions, given well-prepared communications, presented at appropriate times" (personal communication). The key is having well prepared communications ready when needed.

More than two decades ago, the National Research Council recognized the necessity of taking special care when communicating risk during a crisis (NRC, 1989):

> Risk managers should ensure that (1) where there is a foreseeable potential for emergency, advance plans for communication are drafted, and (2) there is provision for coordination among the various authorities that might be involved and, to the extent feasible, a single place where the public and the media can obtain authoritative and current information.

In the aftermath of the Three Mile Island accident, it became apparent that these principles should be incorporated into regulations for all nuclear power reactors, and the U.S. Nuclear Regulatory Commission has since done so.

The likelihood of panic following a radiological terrorist attack should be a strong motivator for federal, state, and local authorities to develop and practice using a communication hub. The National Council on Radiation Protection and Measurements advises that: "In preparing for or responding to terrorist incidents involving radioactive releases, it is crucial to recognize the centrality of social and psychological issues" (NCRP, 2001).

There are many other sources of information on addressing stressed individuals in a radiation incident. The International Radiation Protection Association, for example, has identified the most important issues that should be addressed in planning with responders (IRPA, 2008):

- initiation of the process as early as possible
- seeking out and involving relevant stakeholders and experts
- ensuring that the roles and responsibilities of all participants are well understood and that the rules for cooperation are clearly defined

Effective risk communication is central to informed decision making about radiological risks because it establishes public confidence in the ability of individuals and organizations to deal with a radiological emergency. The keys to successful risk communication are anticipation, preparation, and practice.

High-concern situations change the rules of communication. At a recent conference the director of the Center for Risk Communication provided 12 templates for crafting messages, such as, "When responding to any high stress or emotionally charged question: provide information at four or more grade levels below the average grade level of the audience [and] be brief and concise in your first response: no more than 27 words, 9 seconds, and 3 messages" (Covello, 2010).

For examples of what not to do, we need only look back to the weeks and months following the 1986 Chernobyl accident in the Ukraine. Communication after the event was summed up by Slovic (1996): "Communication about Chernobyl was dreadful in Europe. Information messages were peppered with different terms (roentgens, curies, bequerels, rads, rems, sieverts, grays) which were explained poorly or not at all."

A recent review of research on public understanding of issues important in a radiological emergency reported that only about 50 percent know the difference between a nuclear bomb and a "dirty" bomb and that common terms for protective action, such as "shelter in place," are not always understood (Becker, 2010). Among responders, the review found low levels of technical knowledge and a low comfort level with radiation, which raises "serious concerns about individual and organizational preparedness for a terrorist event involving radioactive materials." "Top Hat" exercises have been conducted to test the ability of responders.

Understanding Radiation and Hazards

Radiological terrorism is not just a theory. Attacks have been carried out in Russia and have been defined in a study by the Nuclear Safety Institute of the Russian Academy of Sciences (2005): "Radiological terrorism is carrying out technological terrorism where ionizing sources are used as defeating agents." The Russian study describes a broad range of possible methods and devices for dispersing radioactive substances over a city or infrastructure, including placing sources of ionizing radiation in the public transport system, in subway stations or stadiums, in air flow intakes in buildings, in water supply systems, and so on.

In the same study, some possible scenarios (which could be realized in the United States as well) were analyzed:

- the planting of a cobalt-60 gamma radiation source under a seat in a subway car
- the detonation of a strontium-90-based dirty bomb in a subway station during rush hour (This high, but not nuclear, explosive was used in the two subway attacks in the Moscow metro in late March 2010, demonstrating terrorists' ability to carry out such attacks.)
- contamination of an asphalt roadway, before it enters a highway, with a liquid solution of cesium-137

The fear and stigma associated with radiation and the term "nuclear" underlies opposition to nuclear power plants. The same fears have led to the well known

BOX 1

The International System (SI), using Grays and Sieverts, is now the common usage worldwide. Some people still prefer the old system which uses rads and rems.

The following is a simplified version of the glossary maintained by NCRP (2008):

Becquerel (Bq): The SI special name for the unit of radioactivity. 1 Bq equals one disintegration per second. 37 MBq (megabecquerels) = 1 mCi (millicurie).

Curie (Ci): The conventional special name for the unit of radioactivity equal to 3.70×10^{10} becquerels (or disintegrations per second).

Gray (Gy): The SI special name for the unit of absorbed dose. 1 Gy = 1 J kg^{-1}.

Dose: The amount of energy deposited per unit of mass.

Radiation: Energy propagated through space in the form of electromagnetic waves or particles.

Radioactivity: Property or characteristic of an unstable atomic nucleus to spontaneously transform with emission of energy in the form of ionizing radiation.

Rem: The special unit previously used for dose. 100 rem = 1 Sv. Often given in millirem, 10^{-3} rem.

Roentgen (R): The special name for the unit of exposure. Exposure is a specific quantity of ionization (charge) produced by the absorption of x- or gamma-radiation energy in a specified mass of air under standard conditions. 1 R = 2.58×10^{-4} coulomb per kilogram (C kg^{-1}).

Sievert (Sv): The special name (in the SI system) for the unit of dose. 1 Sv = 1 J kg^{-1} or 1 Sv = 100 rem.

public-relations name change from “nuclear magnetic resonance,” an accurate description, to the more palatable “magnetic resonance imaging” (MRI); the closing of a Brookhaven research reactor after very small amounts of tritium were detected in groundwater; and opposition to the proposed Yucca Mountain nuclear spent fuel repository (Slovic, 1996). The fear of tritium, which has a 13.7 year half-life, also led the Vermont senate to vote overwhelmingly to shut down the Vermont Yankee nuclear plant after tritium leaks were found in ground measurements. The utility compounded the problem by issuing inaccurate and misleading statements.

Radiation Exposure

In a radiological event, first responders and later responders will face a serious obstacle. Although the average American is exposed to radiation every day, half of which is unavoidable, most people, including some responders, fear radioactivity and do not understand it. Table 1 shows the effective dose per individual in the United States in 2006.

The total for an individual is 6.2 milliSieverts (mSv). As a reference point, a typical dental x-ray gives a patient about 0.005 mSv per image, or about 0.02 mSv—or 2 mR—for a four-image examination (NCRP, 2010). Not every individual is subject to medical exposures, but everyone is subject to background exposures. Nevertheless, as anyone who has tried to argue the insignificance of an extra milliSievert of exposure knows, routine exposures do not seem to make the general public more understanding of, or more willing to tolerate radiation.

TABLE 1 Radiation Exposure per Individual in the United States, 2006

Source	Typical radiation dose in milliSieverts (mSv)[1]
Background Radiation This includes external radiation from space, radon from the ground, and internal from material in the human body (e.g., potassium). Radon accounts for more than 70 percent of this dose.	3.11
Medical Radiation Includes cat scans, nuclear medicine, fluoroscopy, and radiography. Cat scans account for nearly half.	3.00
Consumer Products Radiation The largest contributors are cigarette smoking, building materials, and commercial air travel.	0.13

Source: NCRP, 2010.

[1] 1 milliSievert equals 100 millirem.

“Dirty Bombs”

Constructing a nuclear weapon requires well trained personnel and careful construction, of course, but, most of all, it requires either plutonium or highly enriched uranium (special nuclear materials [SNMs]), which are quite difficult to obtain. Plutonium must be chemically separated from nuclear fuel that has been used in a nuclear reactor. Highly enriched uranium (HEU) can be obtained by enriching natural uranium. (The enriching process, in which Iran is currently engaged, is the reason for international concern.)

As mined, uranium is less than 1 percent U235, the fissionable isotope. The uranium used in most reactors has been enriched to 3 to 5 percent U235. The uranium most useful for a nuclear weapon (weapon-grade uranium) requires more than 90 percent U235.

Whereas SNMs to make a nuclear weapon are extremely difficult to obtain, radioactive material for a dirty bomb is not. The capability of packaging conventional explosives with radioactive material and detonating a radiological dispersal device to kill and terrorize people—the “dirty bomb” scenario—is, unfortunately, within the means of some terrorist groups (NRC, 2007). Strong ionizing radiation sources (IRSs), such as cobalt used in medical devices and cesium used to power remote devices (e.g., navigation beacons in isolated locations), are but a few of the sources of radiological materials.

According to a 2007 report by the National Research Council, “Hundreds and perhaps thousands of inadequately protected IRSs . . . are present in many countries. Some are in use, some are in storage, and some are awaiting permanent disposal . . . [S]ome IRSs have simply been abandoned . . . because there were no financially affordable disposal pathways for those that had exceeded their useful lifetimes or were no longer needed.”

Radiological material could also be obtained because of lax security. For example, at one facility in Russia two installations contain 27 sources of cobalt-60 and 15 sources of cesium-137. These materials are not being used, only stored, and there are no restrictions on approaching the facility. Another facility in Russia has 42 sources that have not been used for years and are located "in a tumbledown building . . . ." with no closed fence around it. The same report reveals that in the United States, "hundreds of unwanted IRSs have not been under adequate control, but DOE [U.S. Department of Energy], with the assistance of other federal and state agencies, has mounted an aggressive program to find, collect and secure these orphan sources . . . ." (NRC, 2007).

A "dirty bomb" used by terrorists would cause great alarm, even though the physical damage from such a device, caused by the high explosive, might be limited. Placing a radioactive source, such as Cs137, around or on the outside of a high explosive does not make a nuclear weapon, but the message that such a device has exploded may lead to public panic and understandable fear in responders. For these reasons, it is important that police and fire organizations be trained in responding to radiation-laden attacks.

Conclusions

Radiation remains a topic of fear to much of the public, including first responders. While a nuclear weapon detonated in a U.S. city would be catastrophic, a dirty bomb would not be. But unless the public and responders are educated in radioactivity, a dirty bomb could cause havoc.

Planning exercises for responders should include a short course on radioactivity and the use of measurement equipment. Giving responders opportunities to question experts can alleviate understandable concerns. Establishing rules of communication and periodically rehearsing these in table-top exercises can give responders the knowledge and some experience on which they can rely in times of emergency. These exercises should be repeated at least every three years.

Providing a primer on radioactivity would be a useful contribution to public education. A first step would be to provide the primer and a short course for public school teachers. Perhaps one of the National Science Foundation or U.S. Department of Education programs could be adapted for that purpose.

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Preparedness for responding to a radiological or nuclear attack requires dedicated resources, a sustained vision, and measurable performance requirements.

Health Aspects of a Nuclear or Radiological Attack

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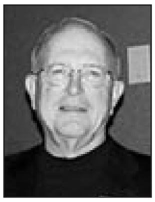
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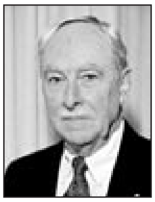
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Since September 11, 2001, the National Council on Radiation Protection and Measurements (NCRP) has produced several publications related to: the detection and interdiction of nuclear and radiological materials and weapons (NCRP, 2003a,b, 2007, 2010a,b); preparation, training, and countermeasures to acts of nuclear or radiological terrorism (NCRP, 2001, 2005a,b, 2009, 2010c,d); and cleanup and restoration of contaminated sites (NCRP, 2010e). Information on these publications is available at *http://NCRPpublications.org*.

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This brief paper provides a summary of key issues facing local, state, and national responders in preparing for and counteracting acts of nuclear or radiological terrorism, including medical management and follow-up care for victims. We also provide a brief look at important issues that remain to be addressed.

A Radiological Attack

As part of the government's preparations for responding to radiological or nuclear attacks by terrorists, National Planning Scenarios have been developed for two types of attack: (1) a radiological-dispersal device (RDD)—a so-called "dirty bomb"; and (2) an improvised nuclear device (IND) (NPS, 2005).

An attack with an RDD is considered the more likely of the two because explosives and radioactive materials from waste, hospitals, and test sources are widely available (Hamilton and Poston, 2004; Medalia, 2002; NPS, 2005; Zimmerman and Loeb, 2004). Radiation exposure from an RDD can be either from an external source (i.e., radioactive contamination) or from internalized radioactive materials inhaled as aerosolized particles or embedded fragments. Pedestrians and vehicles moving through contaminated areas can resuspend and redistribute radioactivity for hours after an explosion thus greatly expanding the contaminated area (NPS, 2005). In addition to radiation exposure, many people would suffer burns and wounds from the explosion.

Because of the large variety of radioactive materials and possible dispersal mechanisms, the specifics of radiation exposure can vary greatly. For example, there could be a non-explosive dispersion of radioactive materials, such as the introduction of radionuclides into a municipal water supply or as contaminants in food. The resulting radiation exposure doses would likely be low, but many people could be affected because recognition of a radiological threat would be delayed until responders arrived with detectors or public health officials noticed radiation-induced symptoms in affected individuals (NCRP, 2001).

An alternative to active dispersal would be a radiological exposure device (RED), that is, a radiation-emitting source hidden in a public space (DHHS, 2010). For example, an RED placed in a heavily frequented area would surreptitiously expose the civilian population to radiation. A carefully disguised RED on a train or in a shopping mall could expose large numbers of people before the source was discovered.

A Nuclear Attack

Although detonation of an IND is considered less likely than an attack using an RDD or RED, it would be the most devastating scenario. A nuclear weapon in terrorist hands might range from a 1-kiloton (kT) device the size of a large backpack to a 10- to 20-kT device analogous in power to the nuclear weapons used in World War II.

Detonation of a nuclear device would lead to prompt exposures to both gamma and neutron radiation. The ratio of neutron to gamma radiation would vary with weapon yield, distance from the blast, and shielding.

> *Radioactive materials for a "dirty bomb" are widely available.*

With a surface-level burst, soil and water would be vaporized by the heat of the explosion, activated by neutrons, and dispersed as fallout. The distribution of the fallout would depend on the height of the burst and the specific meteorological conditions. External radiation from fallout is predominantly from gamma and beta radiation. Doses from fallout would likely be lower than prompt doses and could be delayed because of the time required for the radiation to reach downwind locations (NCRP, 2001). There are also hazards from internalized radioactive material. A 10-kT nuclear device would also cause moderate to severe blast damage to structures within a mile of the detonation.

Responding to Terrorist Incidents

The ability of federal, state, and local response authorities to plan and prepare for managing terrorist incidents is complicated by limited resources (e.g., funding, personnel, and equipment). In addition, these organizations are already called upon to respond to a great many incidents and crises, and terrorist incidents are generally agreed to be low-probability, though high-consequence, events.

On the one hand, not planning a response to terrorist incidents would leave communities vulnerable and totally unprepared. On the other hand, adequate planning without dedicated resources and a sustained vision can have an adverse effect on the quality of response.

The easiest way to ensure preparedness for a terrorist incident is for government authorities to make it a high priority, which would entail dedicated budgets and measurable performance requirements. Response planners would then be able to staff and gather resources at appropriate levels.

Without government support, even if an organization has dedicated program requirements for terrorism preparedness, the funding would have to be taken from another part of its asset base. Thus preparation would be a zero sum game for them; they would be faced with meeting extra job requirements using the same resource base.

Response communities must have ongoing, dedicated funding to build sustainable competence and resources.

Because the recent financial crisis has forced cutbacks in response personnel and critical programs, the situation today is even worse than it was several years ago. With no guidance available, response organizations must manage as best they can with whatever resources they can muster.

Clearly, for preparation and training for terrorist incidents to become a reality, we must have a paradigm shift in the thinking of communities and organizations that support emergency responders. These organizations, which include local, state, and federal offices with preparedness assets, such as the U.S. Department of Homeland Security and professional organizations (e.g., NCRP) and societies (e.g., Health Physics Society), must help response communities articulate a sustained vision of terrorism response preparedness.

Even if the state of preparedness is not ideal, the vision should be translated into specific requirements. For example, a requirement should be established that first-on-scene responder vehicles be equipped with specialized chemical, biological, radiological, and nuclear (CBRN) detection equipment so that suspected threat agents can be detected within a specified number of minutes after they arrive. CRBN requirements should also be established for medical triage and treatment capabilities, population monitoring, decontamination, and so on.

The requirements should be developed by a process that engages stakeholders at all levels and should be tailored to meet the needs of individual communities. The requirements should include: the number of personnel required to perform necessary functions; training requirements; equipment needs; desired end states; and other detailed information. Planners should leverage multi-use job functions, equipment, and training whenever possible.

Preparation and training do not have to be the same for every community. The Urban Area Security Initiative (UASI) has identified cities at risk to encourage regional preparedness. The UASI model could also be used to prioritize regions at greatest risk, and those communities should then insist that terrorism preparedness and training be made a priority.

The federal government provides grants to response communities through competitive processes to bolster preparedness for terrorism response. As a result, there are storage rooms filled with necessary equipment, but many responders are not adequately trained to use or maintain it. Response communities do not benefit much from grants that provide one-time funding to build competence that is not sustainable. The responder's mantra, "You lose what you don't use," applies to every aspect of response preparedness. Therefore, future grant programs must provide measurable, sustainable approaches to preparedness.

Unfortunately, a well organized government program that provides an ideal pathway to response preparedness is not likely to emerge soon. Nevertheless, numerous local and state communities around the nation have shown tremendous ingenuity when it comes to terrorism response preparedness. These communities have realized that building competency through job function would be ideal, but given the low-probability, high-consequence nature of a terrorist attack, training and routine exercises will be necessary to refine and maintain the skills necessary for an effective response.

To advance preparedness and training programs, communities should first assess their ideal end states according to the threats they face. They should then seek support from all levels of government and from all available funding sources. If requirements have not been developed or are not available, they must establish them and develop a strategic plan to describe how and when the requirements will be met and how they will work.

The community will then have to implement the strategic plan step by step. Training, exercises, and equipment maintenance should be integrated into a comprehensive plan for sustaining the state of preparedness. The community must regularly assess its progress and ensure that the resources for supporting preparedness remain available.

Potential Health Effects of a Nuclear Incident

Health effects are most likely to result from localized or whole-body exposures to radiation rather than from the internal or external deposition of radionuclides (contamination). Localized, deep exposure to radiation caused by handling highly radioactive sources may result in a localized radiation burn manifested initially by reddening of the skin (erythema) and later by desquamation, blistering, and, potentially, necrosis.

Because the dose rate drops rapidly with distance from the source, systemic manifestations are not as severe as local injuries. Erythema in the first hours or days indicates an acute skin dose of > 2 gray[1] (Gy). Dry or moist desquamation occurs at doses of more than 10 Gy; doses of more than 15 Gy can result in permanent injury, including atrophy, telangiectasia (dilated superficial blood vessels), and ulceration.

Large acute doses (more than about 2 Gy) of whole-body penetrating radiation can result in various forms of acute radiation syndrome (ARS), which becomes manifest over a period of hours to weeks. In the first few hours, the prodromal phase of ARS may include nausea, vomiting, fever, and diarrhea. In the following weeks, at doses of > 2 Gy, there may be mild bone marrow depression; with doses of 10 to 30 Gy, there will be severe bone marrow depression and damage to the gastrointestinal mucosa resulting in infection, sepsis, and bleeding.

At acute doses of more than 30 Gy, changes will be apparent sooner (hours to days) related to injury to the cardiovascular and central nervous systems. Patients exposed to acute doses of > 5 Gy to the lens of the eye are likely to develop some degree of cataract within a few years.

Internal contamination can occur transdermally or through inhalation, ingestion, or wounds. For the most part, acute health effects will be minimal, although an IND or reactor accident would release radioiodine that could result in hypothyroidism or late thyroid nodules or cancer. External contamination, particularly from intense high-energy, beta-emitting radionuclides, can result in significant widespread skin injuries, which then become portals for infection. If present with ARS, widespread skin injury significantly increases mortality.

In the event of a ground-level detonation of an IND, exposure to fallout in the first few hours could cause beta burns but also enough penetrating radiation to cause ARS and lethality. Any combination of thermal or traumatic injuries with radiation increases complications and mortality.

Late health effects are predominantly radiation-induced carcinogenesis. Radiation can induce many (but not all) types of cancer and leukemia, which often take years, even decades to develop. The risk of fatal cancer in acutely exposed populations is on the order of 5 percent per sievert.[2] There is little evidence of hereditary effects in humans.

Any combination of radiation with thermal or traumatic injuries increases the likelihood of complications and mortality.

Prompt Treatment and Long-Term Monitoring

Victims of acute radiation-related events will require prompt diagnosis and treatment of emergency medical and surgical conditions, as well as of conditions related to possible radiation exposure. Traditional medical and trauma criteria should be used for triage. Radiation doses to patients can be estimated by rapid automated biodosimetry and clinical parameters, such as the history and timing of symptom complexes, the time to emesis, lymphocyte depletion kinetics, chromosomal damage, and multi-parameter biochemical tests.

Acute high-level radiation exposure should generally be treated medically as involving multi-organ failure (MOF). Radiation-induced multi-organ dysfunction

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[1] Gray (Gy) is the special name for the SI unit of absorbed dose (1 Gy = 1 J kg⁻).

[2] Sievert (Sv) is the special name for the SI unit of equivalent dose and effective dose (1 Sv = 1 J kg⁻).

(MOD) and MOF are defined as progressive dysfunction of two or more organ systems as a result of radiation damage to cells and tissues over time. Radiation-associated MOD appears to develop partly as a consequence of systemic inflammatory response syndrome and partly as a consequence of radiation-induced loss of functional cell mass in vital organs (for more detail see Fliedner et al., 2009). The Strategic National Stockpile Radiation Working Group recently issued recommendations for medical management of ARS (Waselenko et. al., 2004), and a website on medical management (*http://www.remm.nlm.gov/*) provides guidelines for the management of acute radiation injury (Bader et al., 2008).

An IND incident would result in victims with both radiation injury and conventional trauma. In a recent report on the scientific aspects of combined injuries (radiation + burns or trauma), the authors concluded that two (or more) injuries that are sublethal or minimally lethal when they occur individually act synergistically with radiation injury, resulting in higher mortality (DiCarlo et al., 2008).

Proper supportive care of ARS can significantly prolong survival. The lethal dose for survival of 50 percent of contaminated persons for 60 days ($LD_{50/60}$) is approximately 3 to 4 Gy in persons managed without supportive care. The $LD_{50/60}$ can be increased to 6 to 7 Gy with antibiotics and transfusion support. The lethal dose appears to be even higher with early administration of hematopoietic colony stimulating factors.

Only about half of the general public understands the differences between a nuclear device and a "dirty bomb."

Patients most amenable to treatment will have received doses of 2 to 6 Gy. If there are people who have been subject to doses of more than 6 to 8 Gy, and they also have significant blast or thermal injuries, the combined injuries will preclude survival. For patients with few or no other injuries, however, many authorities would consider stem cell transplants (peripheral or cord-blood) for victims irradiated in this dose range.

It is common practice to distinguish late physiological effects from early effects of radiation exposure. Deterministic effects are acute and typically show a sigmoid dose-response curve; the severity of harm from the radiation exposure increases with dose. Effects are non-neoplastic and are rather promptly expressed in exposed individuals. In contrast, late stochastic effects (i.e., non-threshold effects) represent a probabilistic tissue response to radiation exposure. Stochastic effects are generally expressed later.

Follow-up medical care of an irradiated individual will, therefore, focus on late effects, most significantly the detection of cancer. In addition, late psychological effects from radiation exposure should always be considered in continuing medical surveillance. For patients with relatively low-dose exposures, the long-term psychological trauma may be more medically significant than radiation-induced organ damage.

Issues to be Addressed

The number of key issues remaining to be resolved is much greater than the number of issues considered to date by NCRP or other expert groups. Several important issues have received little or no consideration:

- retaining proficiencies in responder communities; gaps in the training of these individuals; and training new responders
- maintaining equipment and supplies in a state of readiness over long periods of time
- training for responding to attacks with weapons of mass destruction (WMD) as opposed to "dirty bombs"
- ensuring the coordination of all responder organizations at the local, state, and national levels
- addressing late-phase issues after a nuclear or radiological incident, such as reentry, reoccupancy, and recovery of the affected area
- communications with the public before, during, and after an incident
- dealing with psychological impacts and restoring public trust.

Communications

Effective communication prior to an incident, during an incident, and after an incident has been brought under control will be extremely important. Decision makers must issue directives to the public with recommendations for certain areas based on the size and dimensions of the incident. This will require that the general public be able to understand the information and respond appropriately.

For example, many people still to do not understand the term "shelter-in-place," and only about half of the general public understands the difference between a WMD (e.g., an IND) and a "dirty bomb." Thus significant efforts, beginning now, should be made to "educate" the public. These challenges have been addressed by nuclear utilities in the United States as part of their emergency planning, and local, state, and federal officials could learn a great deal from their efforts. So far, however, useful, readily understandable information has not been widely distributed on a national scale.

Late-Phase Activities

To date, efforts have focused mostly on early-phase responses to a terrorist incident. Few have considered the reentry, reoccupancy, or recovery issues. Sullivan et al. (2008), who have considered dose assessments to guide decisions in the event of an RDD incident, emphasize the need for a consensus approach to cleanup and recovery efforts. NCRP agrees that there must be total stakeholder "buy-in" for late-phase recovery efforts (NCRP, 2001). Chen and Tenforde (2010) have discussed the involvement of stakeholders in planning for the cleanup and restoration of contaminated sites.

If a WMD is detonated in an urban environment, the recovery phase will be just as important as the immediate response phase. To plan for late-phase recovery, careful studies of actions taken in Hiroshima and Nagasaki will be essential. Today, both cities are once again thriving, and their recovery represents a "real-world laboratory" from which lessons can be learned for developing response plans for nuclear or radiological terrorist incidents.

Summary and Conclusions

The goals of radiation protection are to *prevent* the occurrence of clinically significant radiation-induced deterministic effects (e.g., ARS) and to *limit* the risk of stochastic effects (e.g., cancer) to a reasonable level in relation to societal needs, values, benefits gained, and economic factors (NCRP, 1993). However, achieving

TABLE 1 Approximate Acute Death, Acute Symptoms, and Lifetime Fatal Cancer Risk as a Function of Whole-Body Absorbed Doses of Radiation (for Adults)

Short-Term[a] Whole-Body Dose [rad (Gy)]	Acute Death[b] from Radiation without Medical Treatment (%)	Acute Death from Radiation with Medical Treatment (%)	Acute Symptoms (nausea and vomiting within 4 h) (%)	Lifetime Risk of Fatal Cancer without Radiation Exposure (%)	Excess Lifetime Risk of Fatal Cancer Due to Short-Term Radiation Exposure[c] (%)
1 (0.01)	0	0	0	24	0.08
10 (0.1)	0	0	0	24	0.8
50 (0.5)	0	0	0	24	4
100 (1)	<5	0	5 – 30	24	8
150 (1.5)	<5	<5	40	24	12
200 (2)	5	<5	60	24	16
300 (3)	30 – 50	15 – 30	75	24	24[d]
600 (6)	95 – 100	50	100	24	>40[d]
1,000 (10)	100	>90	100	24	>50[d]

[a] Short-term exposure = radiation exposure during the initial response to the incident. The acute effects listed are likely to be reduced by about one-half if radiation exposure occurs over a period of weeks.

[b] Acute deaths are likely to occur 30 to 180 days after exposure; there will be few if any after that time. Estimates are for healthy adults. Individuals with other injuries, and children, will be at greater risk.

[c] Most cancers are not likely to occur until several decades after exposure, although leukemia has a shorter latency period (<10 years).

Source: NCRP, 2005b.

these goals may not be possible in the event of radiological or nuclear terrorism.

Table 1 shows two types of health risks that may result from short-term, high-level, whole-body radiation exposure that could occur as a result of a terrorist incident involving an IND: (1) acute deaths from injury to organs and tissues (e.g., bone marrow); and (2) increased risk of solid cancers (typically 10 to 40 years after exposure) and leukemia (less than 10 years after exposure).

Immediate and sustained investments by the U.S. government in infrastructure development (e.g., radiation detectors), education, training, communication, and medical countermeasures will be essential to ensuring the nation's ability to address the immediate and long-term health effects of a radiological or nuclear incident.

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NAE News and Notes

NAE Newsmakers

On April 27, six NAE members were elected **members of the National Academy of Sciences**: **Frances E. Allen**, IBM Fellow Emerita, Thomas J. Watson Research Center, Croton-on-Hudson, N.Y.; **Alexis T. Bell**, professor, Department of Chemical Engineering, University of California, Berkeley; **Michael I. Jordan**, Pehong Chen Distinguished Professor, EECS Department, University of California, Berkeley; **Chad A. Mirkin**, George B. Rathmann Professor of Chemistry, Northwestern University; **Ignacio Rodriguez-Iturbe**, James S. McDonnell Distinguished University Professor and professor of engineering, Department of Civil and Environmental Engineering, Princeton University; and **Jack Keil Wolf**, Stephen O. Rice Professor, Center for Magnetic Recording, University of California, San Diego, La Jolla.

Rakesh Agrawal, Winthrop E. Stone Distinguished Professor, School of Chemical Engineering, Purdue University, and **Klavs F. Jensen**, department head and Warren K. Lewis Professor of Chemical Engineering and professor of materials science and engineering, Massachusetts Institute of Technology, have been named **"Fellows" of the American Institute of Chemical Engineers** (AIChE). Candidates are nominated by peers in AIChE and must have been chemical engineers for at least 25 years and members of AIChE for at least 10 years.

The Association for Computing Machinery (ACM) has named **Eric A. Brewer**, professor, Computer Science Division, University of California, Berkeley, recipient of the **2009 ACM-Infosys Foundation Award in the Computing Sciences** for his contributions to the design and development of highly scalable internet services. The award is given in recognition of "personal contributions by young scientists and system developers of a contemporary innovation that exemplifies the greatest recent achievements in the computing field." The Award includes a $150,000 cash prize.

James M. Coleman, Boyd Professor, Coastal Studies Institute, Louisiana State University and Agricultural and Mechanical College, has been **inducted into The College of Basic Sciences Hall of Distinction**. Members of the college are individuals who have significantly contributed to their disciplines, the community and the college and university by demonstrating sustained excellence in scientific, business, educational and community service activities.

Joseph M. Colucci, retired executive director, materials research, General Motors Research and Development, and president, Automotive Fuels Consulting Inc., was presented with the **2010 SAE International Medal of Honor** at the SAE 2010 World Congress. The Medal of Honor, established in 1986 and presented annually, is SAE International's most prestigious award. The recipient is a member of SAE International who has made significant and unique contributions to the organization.

Lynn A. Conway and **Jean E. Sammet** have been named the 2009 recipients of the **Institute of Electrical and Electronics Engineers (IEEE) Computer Society Computer Pioneer Award**. Lynn Conway, professor of electrical engineering and computer science, University of Michigan, was chosen "for contributions to superscalar architecture, including multiple-issue dynamic instruction scheduling, and for the innovation and widespread teaching of simplified VLSI design methods." Jean Sammet was cited "for pioneering work and lifetime achievement as one of the first developers and researchers in programming languages."

David E. Daniel, president, University of Texas, has been honored by the American Society of Civil Engineers (ASCE) with a **Lifetime Achievement Award in Education**. Dr. Daniel was also presented with the **2010 Outstanding Projects and Leaders (OPAL) Award** for lifetime achievement in engineering education at the annual OPAL gala, on March 25, 2010, in Washington, D.C.

Mary Jane Irwin, Evan Pugh Professor, Department of Computer Science and Engineering, Pennsylvania State University, has been named the **2010–2011 Athena Lecturer** by the Association for Computing Machinery Council on Women in Computing. The award celebrates women who have made fundamental research contributions in computer science and includes a $10,000 honorarium. Dr. Irwin was awarded the lectureship for designing novel computer structures for laptops that have vastly improved image and speech applications and for developing techniques "to automate computer-aided design (CAD) activities."

Thomas Kailath, Hitachi America Professor of Engineering, Emeritus, Stanford University, was elected in December 2009 to the National Academy of Sciences, India—the country's first science academy, founded in 1930. Professor Kailath has also been awarded the **2009 BBVA Foundation Frontiers of Knowledge Award** in the Information and Communication Technologies category for "creating knowledge with transformative impact on the information and communication technologies that permeate everyday life. These pioneering developments laid the mathematical foundations enabling solutions to some of the challenging problems in this area and have also served to break through the barrier of chip miniaturization." The award, which includes a prize of 400,000 Euros, will be presented at a ceremony in Madrid on June 30, 2010.

Kuo-Nan Liou, director, Joint Institute for Regional Earth System Science and Engineering, University of California, Los Angeles, is the recipient of the Committee on Space Research (COSPAR) **William Nordberg Medal** for his "outstanding contribution to the application of space science." The award will be presented to Dr. Liou at the 38th COSPAR Scientific Assembly on July 19, 2010.

Subhash Mahajan, Regents' Professor and Fulton Fellow, Ira A. Fulton School of Engineering, Arizona State University, has been selected a **Fellow of the Materials Research Society** (MRS). Fellow status is conferred in recognition of engineers and scientists "for their distinguished research accomplishments and their outstanding contributions to the advancement of materials research worldwide." MRS specifically cited Dr. Mahajan for "pioneering research on defects in solids, structure-property correlations in semiconductors, magnetic materials, and materials for light-wave communications, and for the successful mentoring of students and faculty members."

W.F. "Bill" Marcuson, Director Emeritus, Geotechnical and Structures Laboratory, U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi, is a recipient of the **Civil and Environmental Engineering Distinguished Alumni Award** from Michigan State University. The Distinguished Alumni Award is given for career accomplishments, as well as for "the pride brought to the department and the College of Engineering" by the recipient. The award will be presented on May 8 at a black-tie ceremony in conjunction with the 2010 spring commencement ceremony.

Jerald L. Schnoor, Allen S. Henry Chair Professor of Engineering, University of Iowa College of Engineering, is the 2010 recipient of the **Athalie Richardson Irvine Clarke Prize** presented by the National Water Research Institute. The prize, a medallion and a $50,000 award, is conferred upon active researchers and practitioners who demonstrate excellence through their continuous contributions to the body of knowledge relating to protecting, maintaining, treating and reclaiming water resources. Dr. Schnoor was cited for dedicating his career to the sustainable use of water.

Kumares C. Sinha, Olson Distinguished Professor of Civil Engineering, Purdue University, received the **2009 Roy W. Crum Distinguished Service Award** of the Transportation Research Board (TRB) of the National Research Council, in recognition of his outstanding achievement in transportation research. The award was presented at a luncheon at TRB's 2010 annual meeting in January 2010.

Ponisseril Somasundaran, director, NSF/IUCR Center for Surfactants, and La Von Duddleson Krumb Professor, School of Engineering and Applied Science, Columbia University, has been awarded the **Padma Shri** by the Indian government, the highest civilian award given to Indian citizens in recognition of distinguished contributions in the arts, education, industry, literature, science, sports, medicine, social service, and public life.

The Association for Computing Machinery (ACM) has named **Charles P. Thacker**, Technical Fellow, Microsoft Corporation, the winner of the **2009 ACM A.M. Turing Award** "for his pioneering design and realization of the Alto, the first modern personal computer and the prototype for networked personal computers." The Turing Award, widely considered the "Nobel Prize in Computing," includes a $250,000 prize.

NAE President **Charles M. Vest** has been named **Drexel University 2010 Engineer of the Year** for his contributions to engineering. Dr. Vest was recognized at a ceremony on February 19, 2010, at the conclusion of Drexel's celebration of National Engineer Week.

The Chemical Heritage Foundation (CHF) announced that **George M. Whitesides** will receive the **2010**

Othmer Gold Medal. The medal was established in 1997 "to honor outstanding individuals who have made multifaceted contributions to our chemical and scientific heritage through outstanding activity in such areas as innovation, entrepreneurship, research, education, public understanding, legislation, or philanthropy."

NAE Chair, Vice President, and Councillors Elected

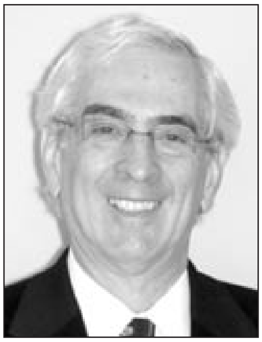

Irwin M. Jacobs

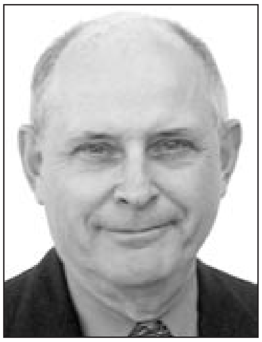

Maxine L. Savitz


Linda M. Abriola


Ruth A. David


Charles Elachi


Paul Citron


Lawrence T. Papay

This spring, NAE reelected the incumbent chair and vice president, reelected three incumbent councillors, and elected one new councillor. All terms begin July 1, 2010.

NAE chair **Irwin M. Jacobs**, co-founder, current board member, and retired CEO and chairman of QUALCOMM Incorporated, was re-elected to a two-year term. NAE vice president **Maxine L. Savitz**, retired general manager for technology partnership, Honeywell Inc. (previously AlliedSignal), was re-elected to a four-year term. **Linda M. Abriola**, dean of engineering at Tufts University, **Ruth A. David**, president and chief executive officer of Analytic Services Inc., and **Charles Elachi**, director of the Jet Propulsion Laboratory and vice president of the California Institute of Technology, were re-elected to three-year terms as councillors.

The newly elected councillor, who will serve a three-year term, is **Paul Citron,** retired vice president of technology policy and academic relations, Medtronic Inc.

On June 30, 2010, **Lawrence T. Papay**, chief executive officer and principal of PQR LLC, and retired sector vice president of Science Applications International Corporation, completed six continuous years of service as councillor, the maximum allowed under the NAE bylaws. Dr. Papay was recognized for his distinguished service and other contributions to NAE at a luncheon in May attended by NAE Council members and staff.

Third Indo-American Frontiers of Engineering Symposium

Attendees at the third Indo-American Frontiers of Engineering Symposium.

On March 11–13, the third Indo-American Frontiers of Engineering Symposium (IAFOE) was held at the Jaypee Palace Hotel in Agra, India. This biennial symposium—one of five international FOE meetings—was inaugurated in 2006. The 2010 symposium was sponsored by the Indo-U.S. Science and Technology Forum (IUSSTF) and jointly organized by NAE and the Indian Institute of Technology, Kharagpur. NAE member **Athanassios Panagiotopoulos**, Susan Dod Brown Professor of Chemical Engineering at Princeton University, and Partha Chakrabarti, professor of computer science and engineering and dean at the Indian Institute of Technology, Kharagpur, co-chaired the symposium.

Typical of bilateral FOE symposia, this meeting brought together approximately 60 engineers, ages 30 to 45, from U.S. and Indian universities, companies, and government laboratories for a two and one-half day meeting, where leading-edge developments in four engineering fields were discussed. The topics health diagnostics and disease monitoring technologies, high-performance computing, advanced engineering materials, and technologies for a clean environment and environmental cleanup were selected for their relevance to both countries. In addition to the technical sessions, the entire group toured the Taj Mahal on the last morning of the symposium.

In the Health Diagnostics and Disease Monitoring Technologies session, speakers emphasized that early, accurate diagnoses and timely monitoring of diseases are crucial for the efficient delivery of health care services. They also noted that technologies for monitoring geographical distributions of disease prevalence, including outbreaks and epidemics, would help health care workers and logistics planners ensure the equitable distribution of specialized services in remote and rural areas. Talks in this session focused on telemedicine (the use of information technology for remote medical examinations, procedures, and consulting); expert medical systems (software that reproduces the knowledge of health experts); advanced sensors and systems for diagnosing diseases; and medical imaging for diagnosis and monitoring.

High Performance Computing (HPC), the topic of the second session, has become a ubiquitous component of engineering design, modeling, simulation, and verification. The talks focused on domains for which HPC is necessary to advance technology and research, such as innovative uses of new architectures and strategies for performance and power efficiency in the molecular simulation of materials and biochemical systems; information and knowledge extraction from vast unstructured sources of data, such as the worldwide web; and design challenges in handling complex, software-controlled systems, such as flight control.

Speakers in the Advanced Engineering Materials session described how the discovery and investigation of new materials affects medicine, space exploration, transportation systems, and quantum computing. Examples include smart materials that can monitor and react to their surroundings and even self-heal; biomaterials and biocompatible soft materials that are revolutionizing medicine; cellular materials being used in the transportation sector and thermo-mechanical systems; multiferroic materials with magnetic and ferroelectric capabilities that are revolutionizing data storage capabilities; and new synthesis techniques and analysis/characterization tools being used to develop materials with fundamental properties at length scales in the nanometer range and smaller. Speakers provided an overview of mechanical properties of new materials, such as bulk metallic glasses, shape memory alloys, and nanocomposites; the tailoring of properties in polymers for particular applications; design paradigms and research findings on new polymeric compositions and architectures; and biological exoskeletons that could provide wear and scratch resistance, protection against blunt trauma, damage detection and sensing, self-repair and regeneration, and flexibility and mobility.

The fourth session, Technologies for a Clean Environment and Environmental Cleanup, featured two distinct technical areas. The first presenter focused on technologies for controlling the release of pollutants, the development of fuel cells to reduce greenhouse gas emissions, and the impact of combustion technologies on climate change on a global scale. The second talk was on identifying sustainable sources of transportation fuel, particularly technologies that can enable the production of biofuels. The first speaker in the second half of the session addressed the concept of "eco-imagination," and the reliability and economic feasibility of advanced technologies for treating wastewater. The last speaker described challenges arising from aging water and wastewater treatment systems in urban environments, the potential for using treated wastewater as a water resource in water-stressed cities, and the quantification of risks associated with exposure to contaminants in reused water.

Dinner addresses were given by A.S. Kiran Kumar, associate director of the Space Application Center, Indian Space Research Organization (ISRO), on future ISRO space missions; and Praveen Vishakantaiah, president of Intel-India, on the impact of current technology trends.

IUSSTF, the symposium sponsor, is an autonomous, nonprofit society that promotes and serves as a catalyst for Indo-U.S. bilateral collaborations in science, technology, engineering, and biomedical research. IAFOE, established in 2000 under an agreement between the governments of India and the United States, receives funding from both governments. Additional funding sources were: the Asian Office of Aerospace Research and Development, Tokyo; Army Research Center; Office of Naval Research Global, Tokyo; and The Grainger Foundation. The next IAFOE symposium will be held in February or March 2012 in the United States.

NAE has hosted Frontiers of Engineering symposia since 1995. For more information about the symposium series or to nominate an outstanding engineer to participate in an FOE meeting, contact Janet Hunziker at the NAE Program Office at (202) 334-1571 or *jhunziker@nae.edu*.

2010 German-American Frontiers of Engineering Symposium

GAFOE participants at Oak Ridge National Laboratory.

Poster session.

On April 22–25, the thirteenth German-American Frontiers of Engineering (GAFOE) Symposium was hosted by Oak Ridge National Laboratory (ORNL) in Oak Ridge, Tennessee. NAE member **Dennis Assanis**, Jon R. and Beverly S. Holt Professor of Engineering at the University of Michigan, and Kai Sundmacher, professor at the Max Planck Institute for Dynamics of Complex Technical Systems, co-chaired the organizing committee and the symposium.

Modeled on the U.S. Frontiers of Engineering Symposium (USFOE), this bilateral meeting brought together engineers ages 30 to 45 from German and U.S. companies, universities, and government agencies. Like the USFOE symposium, the goal is to bring together emerging engineering leaders in a venue where they can learn about new developments in a variety of engineering fields, thereby facilitating interdisciplinary transfers of knowledge and methodology. In addition, bilateral meetings build cooperative networks across national boundaries. NAE works with the Alexander von Humboldt Foundation to organize GAFOE symposia.

The four topics covered at the meeting were: Lasers, the Final Frontier; Rapid Vaccine Manufacturing; Modern Power System Grid Control; and Novel Concepts for Automobiles. The symposium took place just as air travel was returning to normal following the eruption of the volcano in Iceland that had disrupted air traffic all over Europe. As a result, about one-third of the German participants, including six of the eight German speakers, were unable to attend. Nevertheless, through a combination of substitute speakers from among the general participants, narrated presentations, and audio-conferencing, all speaker slots were filled. Presentations covered specific topics, such as random lasers, new technologies in vaccine manufacturing, information technologies for smart grid operation, and sensor-equipped and communicating vehicles. Poster sessions on the first afternoon provided an opportunity for all participants to talk about their research or technical work and to share ideas.

ORNL is the largest U.S. Department of Energy science and energy laboratory. With its state-of-the-art conference facility, gracious staff, and careful arrangements, ORNL was an outstanding venue for the meeting. On the first evening, Dr. Thomas E. Mason, director of ORNL, gave an informative presentation on the history of the lab and its current portfolio of research activities. On the second evening, Dr. David Greene, a corporate fellow at ORNL, gave an interesting talk on timely issues related to U.S. oil independence, which generated a spirited question and answer session and group discussion.

GAFOE participants were given tours of two facilities—the Spallation Neutron Source, the world's most intense pulsed, accelerator-based neutron source; and the National Center for Computational Sciences Computer Laboratory, which provides the most powerful computing resources in the world for open scientific research.

Funding for the meeting was provided by ORNL, The Grainger Foundation, the Alexander von Humboldt Foundation, and the National Science Foundation. The next GAFOE meeting will be held in 2012 in Germany.

For more information about GAFOE, contact Janet Hunziker in the NAE Program Office at 202/334-1571 or by e-mail at *jhunziker@nae.edu*.

NAE/IOM Joint Regional Meeting on Engineering Innovations in Health Care

On February 25, 2010, NAE and the Institute of Medicine (IOM) held a joint regional meeting, Engineering Innovations in Healthcare. The meeting was hosted by the University of Miami at Coral Gables, Florida. Participants were welcomed by Donna E. Shalala (IOM), university president; **James M. Tien**, Distinguished Professor and dean, College of Engineering; and **Daniel Berg**, Distinguished Research Professor, University of Miami. **Charles M. Vest**, president of NAE, and Harvey V. Fineberg, president of IOM, also delivered some opening remarks.

The first presentation, by Pascal Goldschmidt, senior vice president for medical affairs and dean, University of Miami Miller School of Medicine, and CEO of the University of Miami Health System (UHealth), was entitled "Autonomous Innovations in Healthcare." He proposed a new model of health care—the autonomic care system (ACS)—a concept based on a combination of management techniques for an intensive care unit (ICU) and autonomic computing. This approach to health care, he said, would meet the needs of the growing number of mostly elderly, often frail people who are living longer with co-morbidities. The current system is not well suited to improving outcomes for these patients, Goldschmidt said, because no one person on the medical team is likely to have the information necessary to manage all of their health needs.

The sheer volume of co-morbid patients today necessitates the prioritization of patients and separate optimization teams for each medical condition and for each patient. ACS would be an electronic information-technology (IT) system designed to automatically prioritize a patient's clinical conditions, with the highest priority on the most unstable condition.

The development of ACS presents two major challenges. First, designing and engineering a co-morbidity algorithm will be difficult. Second, the question of who the coordinating operator should be must be answered. ACS would be similar to an autonomic computing system in which the human operator does not directly control the system but defines the general policies and rules that govern the self-management process. The human operator steps in only when a conflict in prioritization arises.

Ideally, human operators (ACSists) would be specially trained, just as "intensivists" are trained to staff ICUs. Training for ACS operators would include systems management, trend identification, conflict resolution, negotiation, and leadership in addition to medical care. Dr. Goldschmidt noted that developing and implementing ACS would be done in stages. In the first phase, for example, specialized types of ACS would be developed (e.g., pediatric, surgical, neurological, and myocardial) analogous to specialized ICUs.

In the long term, ACS might provide a road map, he said, for revamping the health care system, bringing down barriers between specialties, and improving the quality of care for all hospitalized patients. He envisages that ACS will ultimately bring about the convergence of all fields of medicine in a way that would result in all of a patient's medical conditions, and all patients, being managed systematically and autonomically.

William Stead, the second speaker, is a member of IOM, and associate vice chancellor for health affairs, chief strategy and information officer, and McKesson Foundation Professor of Medicine, at Vanderbilt University. He spoke on "Biomedical Informatics: The Scientific Basis for the Use of IT in Biomedicine and Healthcare." Dr. Stead described the characteristics of biomedicine and health care that make it difficult to apply IT and the overarching challenge—"decision support"—to the computer science community in health care informatics. Some of the most challenging aspects of health care are: the variability of biological systems, the lack of precision in clinical measurements, the lack of detail in diagnoses, the chaotic and opaque quality of the clinical care system, and the absence of a common vocabulary among health care providers and computer researchers.

A National Research Council study committee concluded that current health care information technology (HIT), which provides transaction data and raw data, will not meet the goals of IOM's vision for 21st century health care (IOM, 2001). Meeting those goals will require closing the gap between current HIT and biomedical informatics, which would provide information that enables health providers to manage the complexity of the medical knowledge base.

Stead went on to describe the science of biomedical informatics, which deals with the structure, acquisition, and use of biomedical information, and he explained how informatics techniques work in conjunction with other techniques to address a problem. The important components of biomedical informatics are: techniques for structuring, discovering, visualizing, and reasoning with information content; approaches that link people, process, and technologies to create a system; methods of evaluating systems and their technical components; and processes for managing large-scale change. Dr. Stead closed with examples of how Vanderbilt has used biomedical informatics to improve the care of patients.

Van C. Mow, the third speaker, is a member of NAE, IOM, the Taiwan Academia Sinica, the Academy of Science of the Developing World, and UNESCO; he is also Stanley Dicker Professor of Biomedical Engineering and chair, Department of Biomedical Engineering, Columbia University. In his talk, "Engineering Models in Healthcare," he described recent advances in the understanding of normal and pathological human physiological systems and subsystems, which could provide a basis for improving clinical treatment. He also described successful engineering models for treating problems related to osteoarthritis, osteoporosis, and functional tissue engineering, as well as how cells perceive and transduce signals (biological and/or biophysical) in situ to control the production of proteins and glycoprotein and orchestrate their micro and molecular structures into functional body tissues.

Dr. Mow described how recent advances in our understanding of the role of biomechanics in normal physiology and pathophysiology are being used to develop regenerative strategies to restore damaged or diseased tissues in vivo and create living tissue replacements in vitro. Dr. Mow predicted that these advances will have an enormous impact on the future of health care.

The last speaker, **William Rouse**, is an NAE member, executive director of the Tennenbaum Institute, and professor in the College of Computing and School of Industrial and Systems Engineering, Georgia Institute of Technology. He summarized the major ideas in *Engineering the System of Healthcare Delivery* (Rouse and Cortese, forthcoming), a new publication that focuses on how the complex health care delivery system, which evolved over time but has never been rationalized, can be engineered to improve quality, increase safety and reduce errors, improve chronic and geriatric care, deal with palliative and end-of-life issues, and rationalize, and ultimately reduce costs. The keys to the engineering approach would be to change the structure and uses of information and incentives. Each chapter is written by a different author(s).

Chapters on applicable engineering methods focus on systems engineering and management, operations research, service systems, process engineering, modeling of pandemics, and the delivery of dental care. Chapters on information focus on IT for actionable information, electronic health records, evidence-based medicine, and patient empowerment. Chapters on changing incentives focus on health economics, pay for value, and changing the way health care providers are paid.

A third section identifies and describes barriers to change. The last section, the summary, reviews characteristics of the current "system" and describes prospects for transforming the business of health care.

References

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Rouse, W.B., and D.A. Cortese, eds. Forthcoming. Engineering the System of Healthcare Delivery. Studies in Health Technology and Informatics, Vol. 153. Fairfax, Va.: IOS Press.

NAE Regional Meeting and UCSD Research Expo Focus on Renewables and Energy Efficiency

Marye-Ann Fox, chancellor, UC San Diego; Irwin Jacobs, NAE chairman; and Lawrence Papay, CEO, PQR.

Renewable energy took center stage during the southern California NAE regional meeting at the University of California-San Diego Jacobs School of Engineering on April 15, 2010. NAE members attended a full day of events, as the Jacobs School combined its annual exhibition of graduate student work, known as "Research Expo," with the regional meeting. The theme of the 2010 Expo—now in its 29th year—"Renewables and America's Energy Future"—featured research projects on breakthroughs in energy storage and efficiency. During a related event called "EUReKa" (engineering undergraduate research konference), 35 undergraduates presented research posters showing the highlights of their work. More than 450 students, faculty, industry partners, and NAE representatives attended the events of the day.

The day-long program was hosted by Dr. **Frieder Seible**, NAE member and dean of the Jacobs School. Dr. Seible joined UC San Diego Chancellor Marye-Ann Fox, NAE Chairman **Irwin Jacobs**, and NAE President **Charles M. Vest**, in welcoming NAE members and guests. Event sponsors included ViaSat, Qualcomm, Northrop Grumman, and BD.

In addition to nearly 300 poster presentations led by Jacobs School faculty, the event featured a keynote address by NAE Council member **Larry Papay**, CEO, PQR. In his talk, he noted that renewable sources could generate 20 percent of the nation's electricity by 2020 and 30 percent by 2035. The major impediments, he said, are deployment and integration into the power system. Papay, who has chaired the National Academies Panel on Electricity from Renewables, also co-chairs a joint committee on renewables with the Chinese Academy of Science.

Jacobs School NAE members and visiting NAE members then had an opportunity to view the work of more than 250 graduate students and attend technical breakout sessions led by faculty from all six departments of the Jacobs School. In Paul Yu's (Electrical and Computer Engineering) report about work on quantum structures for photovoltaic applications, he explained that the successful capture and conversion of solar energy will require realizing the promise of quantum wells, quantum dots, and nanowires to improve the conversion efficiencies of future solar cells. Renkun Chen (Mechanical and Aerospace Engineering) focused on solar thermal energy conversion using thermophotovoltaics, thermoelectric, and thermodynamic heat engines. Tajana Simunic-Rosing (Computer Science and Engineering) described her work on designing and implementing new energy-management strategies to conserve energy in computing systems. Yuri Bazilevs (Structural Engineering) described an advanced-geometry modeling and simulation framework for large-scale computational analysis of wind turbines.

Each department, along with its industry partners and alumni, then selected a winning graduate student poster. The winner of the overall Best Poster Award for 2010 was Jason Harris Karp, a Ph.D. student in electrical and computer engineering, whose poster, "Planar Micro-Optic Solar Concentration," showed a new design for a solar concentrator that would reduce the number of required photovoltaic cells and lead to less expensive, more environmentally friendly solar installations. Existing high-efficiency solar cells, he explained, incorporate optics to focus sunlight hundreds of times and can deliver twice the power of conventional solar panels. Karp's new solar concentrator would use thousands of small lenses imprinted on a single sheet to collect sunlight. These lenses would direct sunlight into a flat "waveguide" that would then deliver it to a single photovoltaic cell.

That evening, more than 50 NAE members attended a business meeting, where NAE President Charles Vest updated them on NAE news and recent developments. He also shared his ideas for increasing the visibility and prominence of the engineering profession in the United States. The dinner and reception that followed were attended by members of the Jacobs School Council of Advisors, 28 C-level executives representing local, national, and international businesses; members of the Corporate Affiliate Program (CAP), a consortium of 46 Jacobs School industry partners; and NAE members—about 80 people in all. The evening festivities were held in the new Qualcomm Conference Center in Jacobs Hall, the main building of the Jacobs School of Engineering. Highlights of the dinner and reception were remarks by UCSD Chancellor Marye-Ann Fox, Jacobs School Dean Frieder Seible, NAE Chairman Irwin Jacobs, and NAE President Charles Vest.

For information about the Jacobs School of Engineering and the 2010 Research Expo, please visit *http://www.jacobsschool.ucsd.edu/re/*.

Report of the Foreign Secretary

George Bugliarello

Since my last report, two bilateral Frontiers of Engineering symposia have taken place: the Indo-American Frontiers of Engineering Symposium (IAFOE) and the German-American Frontiers of Engineering (GAFOE) Symposium.

IAFOE , held in Agra, India, from March 10 to March 13, was arranged by Professor Damodar Acharya, director of the Indian Institute of Technology, Kharagpur. The participants were welcomed by Dr. Arabinda Mitra, executive director, Indo-U.S. Science and Technology Forum, and me on behalf of NAE. **Lance Davis,** NAE executive officer, also attended. The co-chairs of the symposium, Professor Partha Chakrabarti of the Indian Institute of Technology, Kharagpur, and NAE member Professor **Athanassios Panagiotopoulos** of Princeton University, selected the speakers and session chairs. Janet Hunziker, senior program officer, Frontiers of Engineering, and program assistant Elizabeth Weitzmann managed the process from the NAE side.

The symposium dealt with four themes: health diagnostics and disease monitoring technologies, high-performance computing, advanced engineering materials, and technologies for a clean environment and environmental cleanup. The 60 participants, outstanding young researchers (30 to 45 years of age) in their counties, were equally divided between U.S. and Indian engineers. All participants had an opportunity to visit the Taj Mahal, the great monument of Muslim architecture. The next IAFOE symposium will be held in approximately 18 months in the United States.

The 2010 GAFOE Symposium, sponsored by the Alexander von Humboldt Foundation and NAE, was held from April 22 through April 25 at Oak Ridge National Laboratory (ORNL), which generously hosted the event. The participants were welcomed by NAE President **Charles M. Vest** and Dr. Thom Mason, director ORNL. Unfortunately, Dr. Helmut Schwarz, president of the Alexander von Humboldt Foundation, and several other participants from Germany were unable to attend because ash from the volcanic eruption in Iceland had grounded flights from Europe. The co-chairs of the symposium, NAE member Professor **Dennis Assanis** from the University of Michigan and Professor Kai Sundmacher of the Max Planck Institute for Dynamics of Complex Technical Systems, selected the session chairs and speakers.

The symposium encompassed four themes: Lasers, The Final Frontier; Rapid Vaccine Manufacturing; Modern Power System Grid Control; and Novel Concepts for Automobiles. A highlight of the symposium was a visit to three unique science facilities, the Spallation Neutron Source, the National Center for Computational Science Computer Laboratory, and the ORNL Exploratory Visualization Environment for Research in Science and Technology.

A dinner talk by Dr. Mason, director of ORNL, was entitled "Science and Technology for the Energy Challenge at Oak Ridge National Laboratory." Dr. David Greene, Corporate Fellow at ORNL, delivered a provocative talk entitled "Can the U.S. Achieve Oil Independence?"

The first European Union-U.S. Frontiers of Engineering Symposium will be held in September 2010 in Cambridge, England. Several European countries will be participating. The long-established GAFOE Symposium series, the first bilateral FOE symposium series, will continue to be held separately.

In June, the International Council of Academies of Engineering and Technological Sciences (CAETS) will hold its biennial convocation in Copenhagen. One of the events will be a symposium, "Sustainable Food Systems—Food for All Forever."

Respectfully submitted,

George Bugliarello

George Bugliarello

2010 NAE Annual Meeting

The 2010 NAE Annual Meeting will be held October 3 and 4 at the JW Marriott Hotel and the Keck Center of the National Academies in Washington, D.C. Prior to the meeting, members of the NAE Class of 2010 will meet on Saturday, October 2, for an orientation. That evening the new members and foreign associates will attend a black-tie dinner in their honor hosted by the NAE Council.

The induction ceremony for the Class of 2010 will be held at noon on Sunday, October 3. An awards presentation featuring the winners of the 2010 Founders Award and Arthur M. Bueche Award will follow. The program will continue with the Armstrong Endowment for Young Engineers-Gilbreth Lectures.

The Business Session will be held on Monday, October 4, for members and foreign associates. The meeting will be followed by the Forum. Section meetings will be held in the afternoon at the Keck Center. The Annual Meeting will conclude with an optional dinner dance at the JW Marriott.

The flyer for the NAE 2010 Annual Meeting and online registration form will be available on the NAE website in mid-June.

Inaugural Kavli Prize Science Forum

The Norwegian Academy of Science and Letters, the Kavli Foundation, and the Norwegian Ministry of Education have announced the inaugural Kavli Science Prize Forum, which will feature NAE President **Charles Vest** as moderator of a panel discussing science policy in the United States, Europe, and China. NAS President Ralph Cicerone will be a member of the panel.

NAE member **John Holdren**, Science Advisor to President Barack Obama and director of the Office of Science and Technology Policy, will give a keynote speech on "International Cooperation in the Advancement of Science."

The event, scheduled for September 6, 2010, in Oslo, Norway, will address the promise and impediments to conducting scientific research across international borders and will provide a venue for a roundtable discussion of current and potential opportunities for advancing science. The purpose of the Kavli Prize is to recognize outstanding scientific research, honor highly creative scientists, promote public understanding of scientists and their work, and encourage international cooperation among scientists. The Forum will be held every two years in conjunction with the presentation of the prize.

NAE maintains a library of publications by members and foreign associates. If you recently published a book, please send a copy to the NAE Membership Office, 500 Fifth Street, NW, Washington, DC 20001, and we will add it to the library.

News from the Center for Engineering, Ethics, and Society

The Center for Engineering, Ethics, and Society's (CEES) ethics column (*http://www.nae.edu/17098.aspx*) has a new entry featuring the work of NAE member **Harry Bovay Jr.**, founder of Bovay Engineers and president of Mid-South Telecommunications. Mr. Bovay has funded philanthropic endeavors around the country and has been deeply involved in engineering ethics initiatives. His support underwrites CEES and the Online Ethics Center at NAE.

NAE recently released *Engineering, Social Justice, and Sustainable Community Development*. This summary of a workshop covers engineering ethics at home and abroad, focusing on the importance of protecting human welfare, ensuring social justice, and striving for environmental sustainability along with the more explicit goal of economic development. Workshop participants identified options for engineers, students, and professional societies to promote these goals. The report can be found online at *http://www.nap.edu/catalog.php?record_id=12887*.

Calendar of Events

June 15–16	Center for Engineering, Ethics, and Society Advisory Group Meeting
June 28–29	Engineering Ethics and Synthetic Biology Meeting
June 29	CAETS/ATV Symposium on Sustainable Food Systems Copenhagen, Denmark
June 30	CAETS Council Meeting Copenhagen, Denmark
July 6	Committee on Changing the Conversation Meeting
August 3–4	NRC Governing Board Meeting Woods Hole, Massachusetts
August 5–6	NAE Council Meeting Woods Hole, Massachusetts
September 1–3	EU-U.S. Frontiers of Engineering Symposium Cambridge, United Kingdom
September 23–25	U.S. Frontiers of Engineering Symposium Armonk, New York

All meetings are held at the National Academies in Washington, D.C., unless otherwise noted.

In Memoriam

FRANCIS W. BOULGER, 96, retired technical advisor, Battelle Columbus Laboratory, died on February 24, 2010. Mr. Boulger was elected to NAE in 1978 "for research into the properties, machinability, and deformation of metals and contributions in development of new and better production methods."

PRAVEEN CHAUDHARI, 72, Brookhaven National Laboratory, retired, died on January 13, 2010. Dr. Chaudhari was elected to NAE in 1988 "for contributions to the field of materials science and engineering and to the advancement of electronic materials."

AARON COHEN, 79, Professor Emeritus of Engineering, Texas A&M University, died February 25, 2010. Professor Cohen was elected to NAE in 1988 "for technical leadership and engineering achievements in manned space flight systems."

IAIN FINNIE, 81, James Fife Professor Emeritus, Department of Mechanical Engineering, University of California, Berkeley, died on December 19, 2009. Dr. Finnie was elected to NAE in 1979 "for contributions in high temperature design, erosion, and brittle fracture of materials."

DONALD N. FREY, 86, professor, McCormick School of Engineering, Northwestern University, died on March 5, 2010. Dr. Frey was elected to NAE in 1967 "for development of gas turbine engines."

E. MONTFORD FUCIK, 96, Chairman Emeritus, Harza Engineering Company, died on April 6, 2010. Mr. Fucik was elected to NAE in 1974 "for leadership in the development of soil mechanics, water resources, and hydroelectric engineering."

ROBERT A. FUHRMAN, 84, retired vice chairman, president, and chief operating officer, Lockheed Corp., died on November 21, 2009. Mr. Fuhrman was elected to NAE in 1976 "for contributions to the design and development of the Polaris and Poseidon underwater launch ballistic missile systems."

HAREN S. GANDHI, 68, Ford Technical Fellow and manager, Chemical Department, Ford Motor Company, died on January 23, 2010. Dr. Gandhi was elected to NAE in 1999 "for contributions to the research and development of automotive catalysts."

WILLIAM E. GORDON, 92, consulting engineer, died on February 16, 2010. Dr. Gordon was elected to NAE in 1975 "for pioneering in radar telescope design, and development of tropospheric and ionospheric wave-scattering concepts leading to improved radio communications."

THOMAS R. KUESEL, 83, Chairman Emeritus, Parsons Brinckerhoff Quade & Douglas, Inc., and consulting engineer, died on February 17, 2010. Mr. Kuesel was elected to NAE in 1977 "for innovations in the design of long-span bridges, immersed tunnel-tubes, and other special transit structures, and contributions to seismic design of underground structures."

FREDERICK F. LANGE, 70, professor of materials engineering and professor of chemical engineering, Materials Department, College of Engineering, University of California, Santa Barbara, died on April 2, 2010. Dr. Lange was elected to NAE in 1992 "for innovative contributions to the understanding of ceramic processing."

BRAMLETTE MCCLELLAND, 89, retired chairman and CEO, McClelland Engineers, Inc., died on April 14, 2010. Mr. McClelland was elected to NAE in 1979 "for pioneering efforts in the practice of geotechnical engineering, and contributions to improvements in the design of ocean structures."

KENNETH G. MCKAY, 92, former executive vice president, AT&T Bell Laboratories, died on March 5, 2010. Dr. McKay was elected to NAE in 1968 "for developments in communications, especially in systems engineering and management of technical advances."

THOMAS H. PIGFORD, 87, Professor Emeritus of Nuclear Engineering, University of California, Berkeley, died on February 28, 2010. Dr. Pigford was elected to NAE in 1976 "for contributions in nuclear power utilization and in nuclear engineering education."

WILLIAM F. SCHREIBER, 84, Professor Emeritus of Electrical Engineering, Massachusetts Institute of Technology, died on September 21, 2009. Dr. Schreiber was elected to NAE in 1995 "for contributions to image-processing, television technology, video compression, and color graphics."

MANFRED R. SCHROEDER, 83, University Professor Emeritus, University of Gottingen, died on December 28, 2009. Dr. Schroeder was elected to NAE in 1979 "for founding the statistical theory of wave propagation in multi-mode media and contributions to speech coding and acoustics."

JOANNE SIMPSON, 86, Goddard Senior Fellow and Chief Scientist for Meteorology, Emeritus, Earth-Sun Exploration Division, NASA Goddard Space Flight Center, died on March 4, 2010. Dr. Simpson was elected to NAE in 1988 "for far-reaching advances in the mechanisms of atmospheric convection, clouds, and precipitation and their application to weather prediction and modification."

H. GUYFORD STEVER, 93, retired trustee and advisor, died on April 9, 2010. Dr. Stever was elected to NAE in 1965 "for outstanding contributions to the nation's space engineering effort."

M. GORDON WOLMAN, 85, professor, Department of Geography and Environmental Engineering, Johns Hopkins University, died on February 24, 2010. Dr. Wolman was elected to NAE in 2002 "for outstanding contributions in fluvial processes, water resources management and policy, and environmental education."

Publications of Interest

The following reports have been published recently by the National Academy of Engineering or the National Research Council. Unless otherwise noted, all publications are for sale (prepaid) from the National Academies Press (NAP), 500 Fifth Street, N.W., Lockbox 285, Washington, DC 20055. For more information or to place an order, contact NAP online at <*http://www.nap.edu*> or by phone at (888) 624-8373. *(Note: Prices quoted are subject to change without notice. Online orders receive a 20 percent discount. Please add $4.50 for shipping and handling for the first book and $0.95 for each additional book. Add applicable sales tax or GST if you live in CA, DC, FL, MD, MO, TX, or Canada.)*

Electricity from Renewable Resources: Status, Prospects, and Impediments. In this volume in the America's Energy Future Series, a committee of experts reviews the technical potential of alternative, renewable energy sources, such as wind, solar-photovoltaic, geothermal, solar-thermal, hydroelectric, and others, then focuses on the most promising in terms of impact on the electricity system and readiness for commercial deployment in the next 10 years. The committee provides quantitative characterizations of these technologies; estimates of costs, performance, and impacts for each; and identifies barriers and areas for further research and development. The report also addresses the challenges to incorporating these new technologies into the power grid and suggests changes in the current grid to facilitate the incorporation of renewables.

NAE members on the study committee were **Lawrence T. Papay** (chair), chief executive officer and principal, PQR LLC, and **Rakesh Agrawal**, Winthrop E. Stone Distinguished Professor, School of Chemical Engineering, Purdue University. Paper, $49.95.

Research at the Intersection of the Physical and Life Sciences. The natural sciences have traditionally been divided into biological and physical sciences, but an increasing number of scientists today are addressing problems at the interfaces between the two. Most problems are biological in nature, but examining them through the lens of the physical sciences can yield exciting results. For example, studies may focus on the dynamics of systems, equilibrium, multistability, and stochastic behavior—concepts familiar to physicists and chemists—to study adaptation, feedback, and emergent behavior in living systems. In this report, a committee of experts describes how tools and techniques developed in the physical sciences are being used to solve mysteries in the biological world. The committee presents five major challenges that must be addressed to advance our understanding of fundamental questions that will impact public health, technology, and the environment. The committee then recommends what academic administrators of research universities and institutions can do to accelerate progress.

NAE members on the study committee were **Shirley Ann Jackson**, president, Rensselaer Polytechnic Institute; **Charles V. Shank**, senior fellow, Howard Hughes Medical Institute; and **George M. Whitesides**, Woodford L. and Ann A. Flowers University Professor, Harvard University. Paper, $32.00.

Lifelong Learning Imperative in Engineering: Summary of a Workshop. In the first years of the 21st century, there has been a rapid increase in the pace of knowledge creation in science and engineering. Competing in the global economy requires a workforce that is consistently at the technological forefront. As Dr. Charles Vest, president of the National Academy of Engineering, expressed it, "Prospering in the knowledge age requires people with knowledge." The purpose of the workshop summarized in this volume was to consider learning opportunities for engineering professionals. Topics addressed included the necessity of lifelong learning, the history of continuing education, possible delivery systems, systems used by other professions, and the current status of technological learning in a time of rapid change.

NAE members on the study committee were **Linda P.B. Katehi** (chair), chancellor, University of California, Davis; **James J. Duderstadt**, President Emeritus and University Professor of Science and Engineering, University of Michigan; and **Wm. A. Wulf**, University Professor and AT&T Professor of Engineering and Applied Sciences, University of Virginia, and

President Emeritus, National Academy of Engineering. Paper, $15.00.

Rebuilding a Real Economy: Unleashing Engineering Innovation: Summary of a Forum. Technological innovation will be essential for addressing the difficult challenges that lie ahead, such as feeding a growing population, meeting the demand for energy without destroying the environment, and countering chronic and emerging infectious diseases. At a public forum at the 2009 Annual Meeting of the National Academy of Engineering, "Rebuilding a Real Economy: Unleashing Engineering Innovation," seven prominent leaders of the innovation system discussed the challenges facing the United States. The panelists agreed that reenergizing our innovation system will require a portfolio of interconnected, interdependent initiatives to generate new knowledge and technology and move that knowledge into a competitive world marketplace. The panelists discussed the roles of key players, such as research universities, entrepreneurs, national laboratories, and the manufacturing sector, and initiatives that could encourage and support innovation, including enlightened energy policy, incentive prizes, and creative educational programs. The experience of Singapore was cited as an example of how innovation could support an economy.

NAE members who participated in the panel discussion were **Jean-Lou A. Chameau**, president, California Institute of Technology, and **Charles (Chad) O. Holliday Jr.**, retired chairman of the board and CEO, DuPont. Paper, $15.00.

Science and Technology for DOE Site Cleanup: Workshop Summary. The U.S. Department of Energy Office of Environmental Management (OEM) is developing a technology road map to guide congressional appropriations for its technology development programs. OEM asked the National Research Council (NRC) of the National Academies to provide technical and strategic advice for the development and implementation of this road map, specifically by identifying principal science and technology gaps and prioritizing cleanup programs based on previous NRC reports. The study committee updated and extended the scope of its review to reflect current site conditions and OEM priorities based on input from the U.S. Nuclear Regulatory Commission, Defense Nuclear Facilities Safety Board, Environmental Protection Agency, and state regulatory agencies. This volume provides both a high-level synthesis of principal science and technology gaps identified in previous reports and a summary of a workshop that brought together representatives of external groups to discuss current site conditions and science and technology needs.

NAE member **Edwin P. Przybylowicz**, retired senior vice president, Eastman Kodak Company, chaired the study committee. Paper, $21.00.

Letter Report for the Committee on Deterring Cyberattacks: Informing Strategies and Developing Options for U.S. Policy. This letter report, the first phase of a multidisciplinary study of deterrence strategies for preventing cyberattacks, identifies key issues that merit study. The committee provides basic information that reveals the nature of the problem and lists important questions that can drive research on preventing, discouraging, and inhibiting hostile activity against U.S. information systems and networks. In the next phase, experts will prepare papers on key issues and questions, including the ones identified here.

NAE member **Steven M. Bellovin**, professor, Department of Computer Science, Columbia University, was a member of the study committee. Free PDF.

The Dragon and the Elephant: Understanding the Development of Innovation Capacity in China and India: Summary of a Conference. China and India are home to nearly 40 percent of the world's population, but until recently neither had played an influential role in the contemporary global economy. In the past two decades, they have liberalized internal economic policies, opened up foreign investment and trade, and experienced economic growth at sustained high rates. However, from the point of view of the United States, the most important change for the long term may be the development of domestic innovation capacities in both countries, which are committed to growing their science and education systems to support research and further economic expansion. The National Academies organized a conference in Washington, D.C., summarized in this volume, to discuss recent changes on the macroeconomic level and in selected industries and to explore the causes and implications of those changes. This conference summary written by a committee of experts, describes developments in both countries in relation to each other and to the rest of the world.

NAE members **Nicholas M. Donofrio**, IBM Fellow Emeritus and retired executive vice president, Innovation and Technology, IBM Corporation, and **Mary L. Good**, Donaghey University Professor and dean, Donaghey College of Engineering and Information Technology, University of Arkansas, Little Rock, and former under secretary for technology, U.S. Department of Commerce, were members of the study committee. Paper, $21.00.

An Enabling Foundation for NASA's Space and Earth Science Missions. NASA's space and Earth science program has two principal components: spaceflight projects and mission-enabling activities. Most of NASA's Science Mission Directorate budget is used for spaceflight missions, but nearly one-quarter of it is identified as "mission enabling." Principal mission-enabling activities traditionally include research and analysis (R&A) programs, which are essential to the development of space and Earth science missions; also included are support for basic research, theory, modeling, and data analysis; suborbital payloads and flights and complementary ground-based programs; advanced technology development; and advanced concept studies for missions and instrumentation. Throughout NASA's history, defining an appropriate scale for mission-enabling activities has posed a challenge. In this report, the study committee identifies appropriate roles for mission-enabling activities and metrics for assessing their effectiveness. In addition, the committee evaluates, from a strategic perspective, how to balance mission-related and mission-enabling components, as well as various elements in the mission-enabling component per se. The hope is that this will make a good program even better.

NAE member **Yvonne C. Brill**, aerospace consultant, Skillman, N.J., was a member of the study committee. Paper, $21.00.

Report of a Workshop on the Scope and Nature of Computational Thinking. This report presents a number of perspectives on the definition and applicability of computational thinking. For example, computational thinking can be understood as a fundamental analytical skill that everyone can use to solve problems, design systems, and understand human behavior. Supporters of this perspective believe that computational thinking is comparable to the linguistic, mathematical, and logical reasoning taught to all children. Many efforts have been made to introduce K–12 students to basic computational concepts, and college curricula have tried to provide a basis for life-long learning of new and advanced computational concepts and technologies. Neither end of the spectrum, however, has focused on fundamental concepts, which are the focus of this report. The study committee explores the idea that the increasing use of computational devices must be supported by the widespread promulgation of computational thinking skills. This volume is an excellent resource for educators, scientists, and other professionals in a wide range of fields.

NAE member **Alfred V. Aho**, Lawrence Gussman Professor of Computer Science, Columbia University, was a member of the study committee. Paper, $30.00.

Strategic Planning for the Florida Citrus Industry: Addressing Citrus Greening. Citrus greening, a disease caused by an insect-borne bacterial infection, decreases yield, compromises the flavor, color, and size of fruit, and eventually kills the tree. Greening is now present in all 34 citrus-producing counties in Florida. In 2008, citrus yield was down several percent, and the disease continues to spread, threatening Florida's $9.3 billion citrus industry. A response will require (1) earlier detection of diseased trees so they can be removed quickly to stop the spread of greening; and (2) new methods of controlling the insects that carry the bacteria. In the long term, technologies such as genomics might be used to develop new citrus strains that are resistant to both the bacteria and the insect.

NAE member **Paul Citron**, retired vice president, technology policy and academic relations, Medtronic Inc., was a member of the study committee. Paper, $66.50.

Continuing Assistance to the National Institutes of Health on Preparation of Additional Risk Assessments for the Boston University NEIDL, Phase 1. In 2003, the Boston University Medical Center was awarded a $128 million grant from the National Institutes of Health to build one of two high- and maximum-containment laboratory facilities for research on biological pathogens. The purpose of these laboratories is to support the research agenda of the National Institute of Allergy and Infectious Diseases and biodefense agencies to develop new approaches to treating, preventing, and diagnosing a variety of viral diseases. The diseases and agents to be studied include viruses and bacteria that occur naturally and cause infections or that could be used in deliberate attacks. In this report, a study committee reviews the proposed risk assessment plans associated with operating NEIDL facilities and provides discussions on key milestones in the development of supplementary risk assessment.

NAE member **John F. Ahearne**, Executive Director Emeritus, Sigma Xi, The Scientific Research Society, chaired the study committee. Free PDF.

NAKFI Synthetic Biology: Building a Nation's Inspiration: Interdisciplinary Research Team Summaries. Synthetic biology is an innovative new field that unites engineering and biology based on research that resulted from recombinant DNA technology and genome sequencing. By definition, synthetic biology is interdisciplinary. It involves biologists in many specialties, as well as engineers, physicists, computer scientists, and others and promises (1) a deeper understanding of how living systems work and (2) a capacity to recreate living systems for medicine, public health, and the environment, including renewable energy. This report provides discussions of (1) new foundational technologies and tools that would make biological systems easier to engineer, (2) ethical issues unique to synthetic biology, (3) how synthetic biology can reveal the underlying principles of natural genetic circuits, and (4) how synthetic biology can help answer fundamental biological questions.

NAE members on the study committee were **Frances H. Arnold**, Dick and Barbara Dickinson Professor of Chemical Engineering, Bioengineering and Biochemistry, California Institute of Technology; **Chaitan Khosla**, professor, Department of Chemistry and Chemical Engineering, Stanford University; and **David A. Tirrell**, professor, California Institute of Technology. Paper, $31.00.

Technical Capabilities Necessary for Systemic Risk Regulation: Summary of a Workshop. Current discussions about financial reform include the need for monitoring and regulating systemic risk in the financial sector. To inform those discussions, the National Research Council held a workshop on November 3, 2009, summarized in this volume, to identify major technical challenges to developing such a capability. More than 40 experts, with a variety of perspectives, participated. Although every systemic event has a unique pathology, there are some common elements. The workshop participants focused on these elements, such as triggers and propagation of effects, for systemic risk in general rather than for specific scenarios. Thus, by design, neither the causes of the current crisis nor policy options for reducing risk were discussed. In addition, the participants attempted to steer clear of some policy issues altogether (such as how to allocate new supervisory responsibilities).

NAE members on the study board were Philip A. Bernstein, principal researcher, Microsoft Corporation; **Gerald G. Brown**, Distinguished Professor of Operations Research, U.S. Naval Postgraduate School; and **J. Tinsley Oden**, associate vice chancellor for research and director, Institute for Computational Engineering and Science, and Cockrell Family Regents Chair in Engineering #2, University of Texas, Austin. Paper, $15.00.

Transitions to Alternative Transportation Technologies—Plug-In Hybrid Electric Vehicles. Plug-in hybrid electric vehicles (PHEVs), which can travel some distance powered by electricity drawn from the grid, also have an internal combustion engine that kicks in when the batteries are discharged. Thus PHEVs can reduce both oil consumption and greenhouse gas emissions. Despite many advances in battery technology in recent years, however, batteries are still very expensive. This report, which builds on a 2008 National Research Council report on hydrogen fuel cell vehicles, includes: reviews of the current and projected technology status of PHEVs; a discussion of the factors (e.g., the interface with the electric transmission and distributions system) that affect how rapidly PHEVs could enter the marketplace; estimates of the maximum penetration rate for PHEVs consistent with the time frame and factors identified in the 2008 hydrogen report; and the incorporation of PHEVs into the models used in the hydrogen study to estimate costs and impacts on petroleum consumption and carbon dioxide emissions.

NAE members on the study committee were **Michael P. Ramage** (chair), executive vice president, ExxonMobil Research and Engineering Co. (retired); **Rakesh Agrawal**, Winthrop E. Stone Distinguished Professor, Purdue University; **James R. Katzer**, manager of strategic planning and program analysis, ExxonMobil Research and Engineering Co. (retired); **Lawrence T. Papay**, senior vice president for Integrated Solutions Sector, Science Applications International Corp. (retired); and **William F. Powers**, vice president of research, Ford Motor Co. (retired). Paper, $30.00.

National Security Implications of Climate Change for U.S. Naval Forces: Letter Report. In recognition of the potential impacts of climate change on U.S. naval forces, leaders of the Navy, Coast Guard, and Marine Corps are preparing their organizations to adapt to changes as necessary. This letter report, the first component of a study to assess the implications of climate change for U.S. Naval services, argues for heightened awareness of changes that could have near-term impacts and near-term planning to ensure that naval capabilities are protected. The final report will address all of the issues raised in this report, as well as the larger, long-term implications of climate change.

NAE members on the study committee were **Frank L. Bowman** (co-chair), president, Strategic Decisions LLC, and U.S. Navy, Retired; **Arthur B. Baggeroer**, Ford Professor of Engineering, Secretary of the Navy/Chief of Naval Operations Chair in Oceanographic Science, Massachusetts Institute of Technology; **David J. Nash**, president, Dave Nash & Associates LLC; **David A. Whelan**, vice president, deputy-GM Phantom Works and chief scientist, Boeing Defense, Space, and Security, Boeing Company. Free PDF.

Capabilities for the Future: An Assessment of NASA Laboratories for Basic Research. Over the past five years, severe budget cuts for new equipment, maintenance, and facility upgrades for NASA's laboratories have steadily undercut support for NASA scientists and the agency's ability to make basic scientific and technical advances in support of programs of national importance. As a result of the downgrading of NASA's laboratory capabilities, its ability to support its own goals is now in serious jeopardy.

NAE members on the study committee were **Joseph B. Reagan** (co-chair), vice president and general manager, Lockheed Martin Missiles and Space Co. (retired); **William F. Ballhaus Jr**., president and CEO, Aerospace Corporation (retired); **Peter M. Banks**, partner and chair of the Scientific Advisory Board, Astrolabe Ventures Partners; **Wesley L. Harris**, Charles Stark Draper Professor of Aeronautics and Astronautics, and associate provost for faculty equity, Massachusetts Institute of Technology; **Eli Reshotko**, Kent H. Smith Professor Emeritus of Engineering, Case Western Reserve University; and **James M. Tien**, Distinguished Professor and dean, College of Engineering, University of Miami. Paper, $29.75.

Informing Decisions in a Changing Climate. Government agencies, private organizations, and individuals are all facing an environment in which it is no longer prudent to follow routines based on past climatic averages. State and local agencies, as well as the federal government, must consider what they will do differently if a 100-year flood arrives every decade or so, if protected areas for threatened species are no longer habitable, or if severe wildfires, hurricanes, droughts, water shortages, or other extreme environmental events become more frequent. Both conceptually and practically, people and organizations will have to adjust long-held assumptions in response to the consequences of climate change. This report argues for climate-related decision support—that is, organized efforts to produce, disseminate, and facilitate the use of data and information to improve the quality and effectiveness of climate-related decisions—in response to a growing need. Drawing on evidence of past efforts to organize scientific information to improve decision making, the authoring committee provides guidance for government agencies and other institutions responsible for providing or using information to cope with climate change. The critical analyses in this volume will be of interest to government agencies at every level, as well as to private organizations.

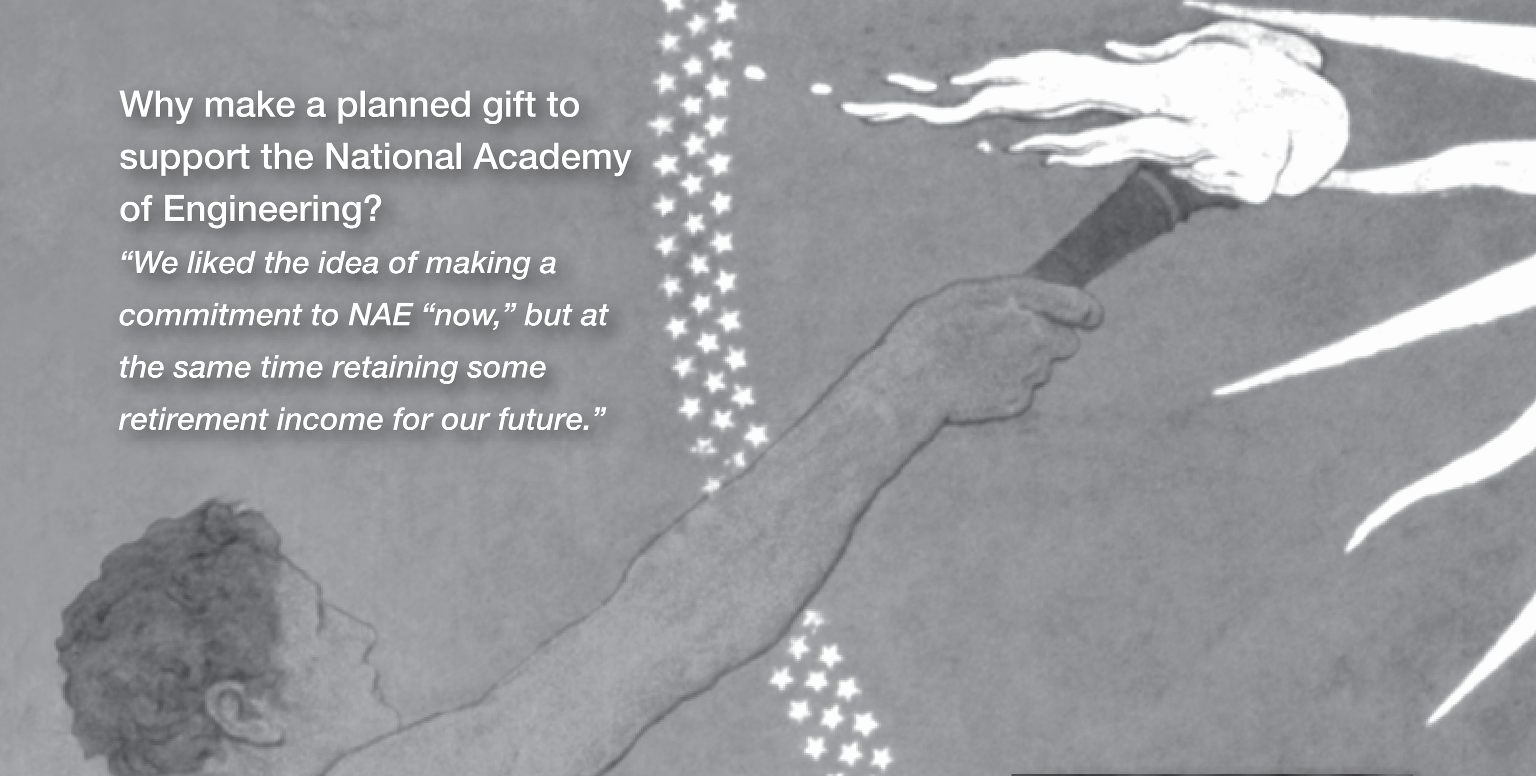
NAE member **Soroosh Sorooshian**, UCI Distinguished Professor and director, Center for Hydrometeorology and Remote Sensing, University of California, Irvine, was a member of the study committee. Paper, $39.00.

Sustainable Critical Infrastructure Systems: A Framework for Meeting 21st Century Imperatives. To meet the challenges of the 21st century, we will need a new paradigm for the renewal of critical infrastructure—water, wastewater, power, transportation, and telecommunications. Built in the 20th century, these systems have become so much a part of modern life that they are taken for granted. But by 2030, 60 million more Americans will depend on them to deliver essential services, even though large segments and components are already 50 to 100 years old and their performance and condition are deteriorating. Although improvements are clearly necessary, relying on the processes, practices, technologies, and materials that were developed in the 20th century is unlikely to yield the same results. The study committee that produced this report discusses the essential components of a new paradigm and outlines a framework to ensure that ongoing activities, knowledge, and technologies can be aligned and leveraged to meet 21st century national objectives.

NAE members on the study committee were **David J. Nash** (chair), president, Dave Nash & Associates LLC; **Henry J. Hatch**, U.S. Army, retired, and former chief of engineers, U.S. Army; and **Garret P. Westerhoff**, Chairman Emeritus, Malcolm Pirnie, Inc. Paper, $21.00.

The New Orleans Hurricane Protection System: Assessing Pre-Katrina Vulnerability and Improving Mitigation and Preparedness. Hurricane Katrina, which struck New Orleans and surrounding areas in August 2005, ranks as one of the nation's most devastating natural disasters. Shortly after the storm, the U.S. Army Corps of Engineers established a task force to assess the performance of the levees, floodwalls, and other structures comprising the area's hurricane protection system. This volume provides an independent review of the final draft report by the task force, in which the group identifies key lessons from the Katrina experience and describes their implications for future hurricane preparedness and planning in the region.

NAE members on the study committee were **G. Wayne Clough** (*chair*), secretary, Smithsonian Institution; **Rafael L. Bras**, dean and Distinguished Professor, Henry Samueli School of Engineering, University of California, Irvine; **John T. Christian**, consulting engineer, Waban, Mass.; **Delon Hampton**, chairman of the board, Delon Hampton & Associates Chartered; and **Thomas D. O'Rourke**, Thomas R. Briggs Professor of Engineering, Cornell University. Paper, $21.00.



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