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Dirty Bombs: The Threat Revisited

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Overview

Nuclear radiation, invisible and detectable only with special instruments, has the power to terrify—in part because of its association with nuclear weapons—and to become an instrument of terrorists. Radioactive isotopes can be spread widely with or without high explosives by a radiological dispersion device (RDD) or so-called *dirty bomb*. This paper provides a general overview of the nature of RDDs and sources of material for them and estimates the effects of an assault, including casualties and economic consequences. Many experts believe that an RDD is an economic weapon capable of inflicting devastating damage on the United States. This paper is in full agreement with that assessment and makes some quantitative estimates of the magnitude of economic disruption that can be produced by various levels of attack. It is also generally believed that even a very large RDD is unlikely to cause many human casualties, either immediately or over the long term. A careful examination of the consequences of the tragic accident in Goiânia, Brazil, however, shows that some forms of radiological attack could kill tens or hundreds of people and sicken hundreds or thousands. Nevertheless, contrary to popular belief, RDDs are not weapons of mass destruction.

The authors recommend several policies and actions to reduce the threat of RDD attack and increase the ability of the Federal Government to cope with the consequences of one. With improved public awareness and ability to respond, it should be possible to strip RDDs of their power to terrorize.

Many Americans first heard the term *dirty bomb* on June 10, 2002, when Attorney General John Ashcroft announced the arrest of Jose Padilla on the charge of plotting to detonate a device containing both high explosive and very radioactive material. In that announcement the attorney general used the following definition: "[A] radioactive 'dirty bomb' involves exploding a conventional bomb that not only kills victims in the immediate vicinity, but also spreads radioactive material that is highly toxic to humans and can cause mass death and injury."

On March 6 of the same year, the Senate Foreign Relations Committee held a hearing on the question of radiological dispersion devices (RDDs), the technical term for dirty bombs, and their ability to cause casualties and damage. At that hearing, experts from inside and outside government testified that, while an RDD could cause economic harm, it was unlikely to cause deaths or injuries beyond the area immediately destroyed by the high explosives used to spread the radioactive material.

Proper preparation for an incident of radiological terror requires an understanding of the real effects of an RDD attack, yet these two views of the effects are in direct conflict.

In the intervening months an intermediate possibility has emerged: prompt (roughly from one day to one month) deaths or acute radiation sickness from the radioactive material scattered by the RDD may be few in number, although a large (but as yet unpredictable) number of Americans could suffer quite high exposures if they ingest or inhale any of the particles. The authors propose that planning for an RDD attack be based on this assessment.

Radiation and Radioactivity

Three different kinds of radiation are emitted from radioactive materials: alpha (α) rays, which are helium nuclei; beta (β) rays, which are electrons; and gamma (γ) rays, which are very high energy, short wave length light.

α particles stop in a few inches of air, or a thin sheet of cloth or even paper. α-emitting isotopes pose serious health dangers if inhaled.

β particles are also easily stopped in, for example, aluminum foil or human skin. Unless they are ingested or inhaled, β-emitters pose little danger to people, although direct contact with a strong β source can cause deep and serious beta burns on skin. Some β-emitters also produce gamma rays through a process known as *Bremsstrahlung,* literally translated as braking radiation.

γ photons are very penetrating. They can go through many meters of air or many centimeters of lead shielding. Gamma rays are almost always emitted only after a nucleus decays by radiating either an α or β particle.

The strength of a radioactive source is determined by how many nuclei decay each second. The modern unit is the Becquerel, abbreviated Bq. One Bq is equal to one disintegration per second. The older and more convenient unit is the Curie, abbreviated Ci. One Ci is equal to 3.7×10^{10} disintegrations per second. A one-Ci source is considered large; a 100-Ci source extremely dangerous. The curie is equivalent to the radiation from one gram of pure radium.

The radioactivity of an isotope is proportional to its half-life, which is the amount of time it takes for 50 percent of the atoms in a sample to decay. With a one-year half-life of an initial sample of 1000 atoms, 500 will be left at the end of the first year, 250 after the second, and so on. The shorter the half-life, the more intense the radiation.

Specific activity is the number of curies contained in one gram of radioactive material. Heavy metals with long half-lives, such as uranium and plutonium-239 (^{239}Pu) have low specific activity.

From the long list of known radioactive isotopes only a few stand out as being highly suitable for radiological terror. These are cobalt-60 (^{60}Co), strontium-90 (^{90}Sr) (and its short-lived daughter, yttrium-90), cesium-137 (^{137}Cs), iridium-192 (^{192}Ir), radium-226 (^{226}Ra), plutonium-238 (^{238}Pu), americium-241 (^{241}Am), and californium-252 (^{252}Cf).

Types of Damage

Deterministic Injuries. Radiation is said to cause deterministic harm if an individual can be identified who received a known exposure to radiation and became ill as a result. Such illness or injury can include classic radiation sickness (hematological effects, loss of appetite, vomiting and other gastrointestinal damage, hair loss, death) or radiation burns on the skin. In general, the threshold dose for deterministic injury is quite high.[1] Loss of white blood cells is detectable at a whole body dose of 25 rem in some individuals and in most at whole body doses in excess of 50 rem[2]. It is unlikely that the victim will report illness. Vomiting sets in at whole body doses between 100 and 200 rem and hair loss at about 300 rem. A dose of 400-500 rem is generally considered lethal to half the exposed population. However, prompt doses—those coming directly from external radioactive material—above 25 rem are exceedingly unlikely for most RDD scenarios. Possible exceptions might be a lethal dose from contaminated shrapnel from an explosively driven RDD or from a large gamma source secretly emplaced to irradiate unwitting victims. Other, quite serious and potentially lethal, deterministic injuries from high doses of radiation will occur if the victim ingests or inhales significant amounts of radioactive material.

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Stochastic Injuries. Given common assumptions that any radiation dose, no matter how small, can cause harm and that the biological response increases with the size of the dose, it is conceivable that some individuals exposed to quite small doses of radiation might develop cancers. Their risk of developing the disease can increase with increased radiation exposure (this is certainly true for whole body doses in the several 10s of rem range). This is a statistical calculation that cannot identify a specific cancer victim, even one known to have been exposed to radiation, and assert that his or her cancer was caused by the exposure. Approximately 2,000 Americans in every 10,000 will die of cancer. It is impossible to identify a specific cancer victim exposed to radiation as the 2001st victim and to determine that the person would not have developed cancer had the exposure not occurred.

Economic and Psychosocial Damage. As we will see later in this paper, economic and psychosocial effects are likely to be the most serious damage mechanisms from any use of an RDD. The fear of ionizing radiation is a deep-seated and frequently irrational carryover from the Cold War. The threat of a radiological attack on the United States is real, and terrorists have a broad palette of isotopes to choose from. An RDD attack is unlikely to cause mass deaths, but it could cause tens to hundreds of fatalities under the right circumstances, and is almost certain to cause great panic and enormous economic losses.

Sources of Material

Radioactive material suitable for use in a radiological dispersion device may be found, stolen, or purchased legally. The radioactive materials most likely to cause great harm, based only on their physical properties, are also ones that have significant commercial applications and are widely available. They are employed in thousands of different medical, academic, agricultural, and industrial settings around the world, including medical therapy, food irradiation, smoke detectors, communication devices, navigation beacons, and oil well logging. This makes it extremely difficult not only to secure, but also to regulate these sources. The prevalence of these sources in the public domain, coupled with inadequate control and monitoring mechanisms, poses a significant threat to health and security, not only from the possible terrorist use of radioactive materials, but also from accidents.

The U.S. Nuclear Regulatory Commission has estimated that approximately one licensed U.S. source is lost every day of the year. These "orphan" sources have escaped proper control and their locations usually are unknown. An August 2003 United States General Accounting Office report states that from 1998 to 2002 there were over 1300 incidents in which sealed sources were lost, stolen, or abandoned in the United States.[3] Occasionally, one does turn up later. In early 2002, a two-curie cesium gauge source was recovered from the scrap metal conveyor belt leading to the NUCOR steel mill in North Carolina. Its label was intact, and it was traced to a chemical supply company located in or near Baltimore, Maryland. The company had gone out of business and its facility had been sold for scrap.

The producer of the source also had gone out of business under its original name, but had been acquired by another corporation, which had maintained the sales records of the first company. Those records indicated that the Baltimore concern had bought not one, but four sources—three of which were unaccounted for. Two of the remaining sources eventually turned up and were properly disposed of, as was the first. The location of the fourth source is still unknown.

Theft of sources meant for field radiography is not unknown. Gamma ray cameras used in the field to check the integrity of welds weigh about 50 pounds and are roughly the size of a lunch bucket. They are quite portable and relatively valuable (they cost upwards of several thousand dollars). Other small or well-shielded sources are also vulnerable to theft by comparatively untrained personnel and pose very low risk from radiation exposure unless the shielding has been removed.

The International Atomic Energy Agency (IAEA) reports that during the recent war in Croatia twenty-seven ^{137}Cs sources were lost. During the war in the Iraq, there were press reports that both cobalt and cesium sources were stolen from "Location C" at the Tuwaitha Nuclear Research Center south of Baghdad, Iraq. It is known that thieves and scavengers stole yellowcake (processed uranium ore), not for the uranium oxide, but rather for the barrels in which it was stored.

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Two of the worst radiation accidents, the Goiânia tragedy and the 1984 Juarez, Mexico melting of ^{60}Co as scrap steel (from an abandoned and stolen teletherapy source), were the direct result of the theft of the radioactive material from abandoned radiation therapy facilities.

Other potential candidates that might be vulnerable for theft by extremely well organized and well-financed terrorist groups include "megasources" such as Russian radioisotope thermal generators (RTGs) and *Gamma-Kolos* seed irradiators.

By far the most likely route for terrorist acquisition of intermediate quantities of radioactive material (100–10,000 curies) is open and legal purchase from a legitimate supplier. Until some time after the World Trade Center and Pentagon terrorist attacks, regulation of radioactive sources was geared towards ensuring the safe use of the material by people and organizations presumed to be acting without malice.[4] In that earlier and less fearful era, inspections of facilities designed to hold moderate to large sources, such as those used in industrial radiography or teletherapy, rarely took place until at least six months after a license was issued and the source shipped. Little information was required beyond a facility layout and a radiation safety plan aimed at preventing accidents and ensuring safety. Not until after the 2001 attacks did protection against deliberate attempts to steal or divert radioactive material for malevolent uses play a significant role in radiation safety programs except for safeguarded nuclear material.

Nuclear Regulatory Commission (NRC) officials report that they have begun the process of revising licensing regulations for acquisition of radioactive sources and that they have taken interim steps to determine that license applicants are unlikely to divert material to illicit uses. These steps have not yet been publicly described.[5]

There is no absolute requirement that a foreign supplier selling radioactive material to a U.S. end user verify the validity of any license submitted by the American purchaser. Most reputable foreign suppliers try to be scrupulous about checking for valid licenses, but there are limitations to the process. In addition, U.S. exporters of radioactive material are not required to notify the competent authorities in the destination country that radioactive material has been shipped to their country or verify that a foreign purchaser is authorized to receive the material. The only exceptions to these regulatory loopholes are for special nuclear material (plutonium or uranium that is usable in nuclear weapons), which is already safeguarded.[6]

Radioactive material also may transit the United States en route from a foreign supplier to a foreign consignee. Generally, no special record of such shipments is kept. It is required, however, that the packages be marked. Since no customs entry will be made (because the material will not legally enter the country), usually neither Customs nor the NRC is notified.

The United States system of licensing of users of radioactive sources is fragmented between so-called Agreement States, which have been delegated by the Nuclear Regulatory Commission to regulate sources within their boundaries, and Non-Agreement States, which are regulated only by the NRC. Many observers contend that local regulatory authorities are better able to track users than is the more distant NRC. In the region surrounding the Nation's Capital, Maryland and both Carolinas are Agreement States, while Virginia, West Virginia, Delaware, New Jersey, and the District of Columbia are not.[7]

In summary, given the relatively weak and lax laws and regulations surrounding the storage, sale, and shipment of radiological source material, coupled with the vast number of orphaned and unprotected sources located throughout Russia and former Soviet states, a determined and well financed group feasibly could obtain even quite large sources openly. Additionally, many smaller sources are vulnerable to loss or theft. Finally, because very large and vulnerable sources exist in the former Soviet Union, a rigorous system of accounting for existing sources and detailed laws regarding the safe storage, sale, and shipment of these sources must be supported to ensure that accidental and intentional radiological incidents do not threaten American interests or security.

Goiânia, Brazil 1987

The tragic radiological accident that occurred in Brazil between 13 September 1987 and March 1988 is the closest event to a true RDD attack. While the parallels are not exact, study of the incident provides some insight into the possible progress of a case of radiological terrorism.

On 13 September 1987, two scrap metal scavengers broke into an abandoned radiotherapy clinic and removed a source capsule from the protective housing of a teletherapy machine. The International Atomic Energy Agency (IAEA) estimates that the source capsule contained 1375 Ci of cesium-137 chloride ($^{137}CsCl$) in soluble form. The capsule had been abandoned when the Instituto Goiâno de Radioterapia (Goiânia Institute of Radiotherapy) moved to a new location in the city two years earlier. The two thieves took it by wheelbarrow to the home of one of the men, a distance of half a kilometer. The same day both men were vomiting because, they assumed, of bad food they had eaten. The next day one of the men had diarrhea and a swollen hand.[8]

On 18 September the crucial event that precipitated the radiological incident occurred; one of the thieves punctured the 1-mm thick window of the source capsule, allowing the powder to leak out. That same day the assembly was sold to a junkyard owner, who had an employee take the apparatus to the junkyard by wheelbarrow and leave it in a garage. That night the junkyard operator, D.F.[9], saw that the powder glowed blue. Intrigued by the glowing blue material, he took the capsule into his house to show it off to his family and friends.

The contamination spread further on 21 September when E.F.1, a friend of D.F., removed source powder from the capsule and distributed some to his brother (E.F.2) before taking much of the rest home. D.F. also passed out fragments to his family. At this point several people sprinkled or rubbed the material on their bodies as they might have done with Carnival glitter.

M.F.1, the wife of D.F., became ill with symptoms of acute radiation sickness on 21–23 September. Her mother, M.A.1, nursed M.F.1 for two days, and then returned to her home outside Goiânia, taking "a significant amount of contamination" with her. M.A. 1 ingested 270 μCi of ^{137}Cs and received a dose of 430 rad. Although this is close to the lethal dose for half the population (LD_{50}), she survived. Over the next few days the rotating assembly of the source was disassembled by two of D.F.'s employees; both died having received estimated doses of 450 rad and 530 rad. W.P., one of the thieves, was admitted to the Santa Maria Hospital for 4 days and then transferred to the Tropical Diseases Hospital.

The saddest incident occurred on 24 September. Six-year-old Leide das Neves Ferreira (L.F.2 in the IAEA report) played with the colorful source powder, painted it on her body, and ate a sandwich while her hands were contaminated. She was massively internally contaminated (27 mCi) and received a 600 rad dose. She died on 23 October.[10]

The correct diagnosis of acute radiation sickness was made by Dr. P.F. of the Vigilancia Sanitária on 28 September after M.F.1 and G.S., an employee of D.F.'s, took the remnants of the rotating assembly to Dr. P.F.'s office at the clinic of the Vigilancia Sanitária. The two individuals, M.F.1 and G.S., carried the material in a bag and took a public bus to the clinic, thus contaminating the bus and exposing other passengers to the cesium.

The toll in Goiânia is staggering. In partnership with a team from the IAEA, Brazilian authorities monitored over 112,000 people in the city's Olympic-sized soccer stadium for radiation exposure and sickness. According to the IAEA report on the incident, a total of 249 people were identified as contaminated by the Cesium-137, 151 people exhibited both internal and external contamination, 49 people were admitted to hospitals, with the 20 most seriously irradiated having received doses from 100 to 800 rads. The internally contaminated patients were themselves radioactive, seriously complicating their treatment. In the end, 28 people suffered radiation burns and five people died, including three men, one woman, and one child.[11]

After surveying 10 percent of the Goiânia population at the stadium, authorities initiated a contamination survey of dwellings throughout the city. The study resulted in the identification of 85 buildings with significant levels of contamination. Of these dwellings, seven were determined to be uninhabitable and subsequently destroyed; 200 people were evacuated from another 41 buildings.

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The Brazilian government was at times sloppy in its survey work. Some technicians who surveyed people for radiation did not themselves wear protective garb and were contaminated by victims. Both patients and technicians spread radioactive contamination in Goiânia and even to Rio de Janeiro. For several days nobody remembered to decontaminate the ambulances used in Rio to transport victims from the airport to the naval hospital, which had the country's primary facility for the care of radiation sickness.

A total of 3,500 m^3 of radioactive waste was collected and trucked to a temporary disposal site. Most of the original source material was recovered intact. The IAEA estimates that the total radioactive inventory of the waste, plus that removed from the naval hospital, was roughly 1200 Ci. The remaining material likely remained in the soil or on rooftops and was widely distributed at very low density. It probably remains in the Goiânia environment today.

The radiological incident in Goiânia resulted in a complete revision of Brazilian regulations related to the storage and use of radiation sources. It also demonstrated the far-reaching consequences that a radiation incident, whether accidental or intentional, can cause.

What to Expect

Most RDD scenarios tend to focus on a device that uses high explosive to pulverize and disperse radioactive material. During the March 2003 *International Conference on Security of Radioactive Sources,* held by the IAEA in Vienna, Austria, it appeared that most of the world's radiation protection authorities had adopted that simple scenario as the most plausible. Most of the national delegations at the IAEA conference seemed to accept the hypothesis that terrorists would be incapable of handling radioactive sources in relative safety or performing simple chemical operations on whatever radioactive material they might obtain.

These assumptions may be far too simplistic to use in planning a response to a radiological event. While many terrorist groups are incapable of obtaining or using sophisticated technology, some are capable. We cannot rely on the premise that terrorists are unwilling to die attempting a devastating attack, for we know from experience that many are. Also, we know from Osama bin Laden's videotaped comments about the September 11, 20001 attacks that terrorists will not necessarily know they are about to die. And while most terrorists may not be sufficiently imaginative or skilled to carry out such an attack, enough are to cause concern.

It is important to note that there are a number of methods that can be used to deliver radiological material in addition to the highly publicized method of using conventional high explosives. Radioactive material can be disseminated in the form of discrete sources. Some forms of isotopes can be dissolved in solvents and sprayed widely; still others can be burned or vaporized. Policymakers and radiation protection authorities must consider this, and any complete plan to respond to an RDD must take into account all of the reasonable ways such a device might function, including those so stealthy that the population might ingest or inhale significant doses before an attack becomes apparent.

Recent events reported in the media demonstrate that the terrorist threat is significant. On October 17, 2003, the Washington Times reported that the CIA and FBI were looking for a suspected Al Qaeda terrorist who was believed to have been looking for nuclear material in Canada for use in a dirty bomb. According to the Times, the suspect terrorist was spotted in Hamilton, Ontario, where he was posing as a student at McMaster University, which has a 5-megawatt research reactor. It is believed that he is part of an Al Qaeda terrorist cell planning a dirty bomb attack against the United States and/or its interests.[12]

Generalizations about the RDD threat spectrum can be misleading. Possible devices range from a small package of explosives (< 100 kg) wrapped crudely around a comparatively small radioactive source (1–10 curies) detonated in a crowded area. At the high end of the spectrum up to several tens or hundreds of thousands of curies of material could be dispersed by a sophisticated device, the whole project requiring several physical and chemical processes to assemble and use the device effectively as a weapon.

The most attention has been given to the small, readily achievable dirty bomb, which may indeed be the most probable type of radiological attack. However, almost all experts agree that such an attack would be unlikely to cause mass casualties; rather it probably would cause great disruption and panic, inflicting enormous damage on the economy, but likely giving dangerous doses of radiation only to people close enough to the device to have been wounded or killed by the blast itself.

Very little analysis has been done on the maximum credible events, which have escalated from something resembling the Goiânia incident in Brazil in 1987 (2001 estimates) to present estimates involving hundreds of thousands of curies of ^{90}Sr or ^{137}Cs extracted from Soviet era devices. Almost certainly only a dedicated and well-financed group could pull off a maximum credible event. However, it is likely that some of the major international terror groups, including Al Qaeda, have not only the resources to carry out such an attack, but also the willing martyrs, whose participation would significantly reduce the cost and complexity of any protective systems needed to allow the perpetrator to survive long enough to carry out the attack.

Some analysts believe that a large radiological event would kill at least tens and perhaps hundreds of people. Others believe that it is virtually impossible to produce high enough dose rates to cause serious injury before the affected area can be evacuated, except when significant material is ingested or inhaled. Still others counter that non-explosive delivery systems might not alert responders to the fact that any radiological material had been dispersed, thus stealthily raising the delivered dose to the victims.

It is very nearly impossible to disperse radioactive material from an explosively powered dirty bomb in such a way that victims externally absorb a lethal dose of radiation from the source before they are able to leave the affected area. If reaction to the incident is slow and the nature of the attack is not quickly discerned, it is reasonable to conclude that some people beyond the immediate explosion area will get high enough doses to show some deterministic effects. These could include beta burns on the skin from ^{90}Sr dust, for example, or changes in white blood cell numbers, but they should not include classic radiation sickness symptoms, such as vomiting, hair loss, and even death, except for victims who have inhaled or ingested the radioactive material.

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Stealthier RDDs, not involving explosions, might actually cause deterministic radiation injuries in more people than would a bomb because remedial action might be delayed or because they might be designed to promote ingestion or inhalation. Even a small RDD is likely to do a great deal of real economic damage because of two principal effects: suspension of economic activity and long-term contamination of property, possibly resulting in its permanent loss.

Casualties

While many analysts have suggested that RDDs will neither sicken nor kill very many people, analysis of the Goiânia incident leads to a modification of this conclusion and to a caution: of the 249 contaminated victims of the Goiânia incident, 151 were contaminated internally. That is, they either ate or inhaled radioactive cesium, and the material was incorporated into their bodies. While the amounts ingested seem extremely small (Leide das Neves Ferreira, who died, was the most highly contaminated having consumed only 27 mCi), they were more than adequate to cause death or acute radiation sickness. The actual amounts of material correspond to only a few milligrams or even less.

These minuscule quantities could be transferred from a hand with a little radioactive dust on it to the mouth with the kinds of simple gestures people make all the time. Thorough hand washing, before doing anything else, is probably among the most useful and time-urgent treatments. It may, however, be difficult in an environment with dust from the bomb and rubble still in the air. Indeed, if the air remains dusty, hand washing may be ineffective, while dust masks become essential. If the radioactive material is dispersed surreptitiously, the need for precautions might not be known in time.

The 70-year committed doses that the Goiânia patients would have received had they not been treated with drugs to remove the cesium from their bodies are quite high—for most, well over one rad. Many could be expected to develop cancers as a result.

Fortunately, there are drugs that can assist in purging the body of cesium contamination. The dye Prussian Blue is sold for this purpose under the trade name Radiogardase® by Heyl Pharmaceuticals in Germany. The drug itself is extremely cheap, but unless new suppliers enter the market and gain FDA approval, the pipeline will continue to be very long—12 to 18 months.[13] Prussian Blue was found very effective in Goiânia[14], and while the national stockpile of products for use in the event of an emergency includes stores of Prussian Blue, it would be appropriate for the U.S. government to ensure that the stockpile contains more than the amount needed to treat victims of a single, severe attack. Other chemicals are suitable for removing other radioisotopes from humans and should be thoroughly investigated and probably stockpiled.

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Not all of the internally contaminated patients in Goiânia participated in the events during which the ^{137}Cs was known to have been handled. Examination of the maps of the city provided by the IAEA indicates that many were victims of secondary contamination (they came in contact with persons who had been in direct contact with the source) or even tertiary contamination (there was an additional, unknown intermediate person or other vector between the internally contaminated victim and the radioactive source). It is known that many internally contaminated victims came into contact with the radioactive cesium in bars and restaurants.[15]

The Brazilian authorities moved to seal off the central area where contamination was known to be present. This action was effective in excluding human beings but not feral cats. It is believed that the fur of the animals became contaminated and that they spread radioactive material beyond the central area.[16]

In some respects this is quite similar to the October 2001 anthrax attacks through the U.S. mail. Anthrax spores were transmitted indirectly, because of leakage during mail processing, to postal workers and even to an elderly woman in New England, who may have received a letter that had come into contact with a piece of mail in one of the contaminated sorting centers.

Because people might ingest or inhale radioactive material, it is not reasonable to assume that the human toll from a large RDD would be small or negligible outside the direct range of a dirty bomb blast. The U.S. should be prepared to cope with tens, hundreds, or conceivably thousands of victims of acute radiation sickness. Patients with internal contamination also pose a hazard to attending medical staff. The caregivers may be forced to limit their time with the patient or to work from behind shields or both.

Range of Sizes

A Small Device (1-100 Ci). This first case considers an unsophisticated RDD containing, at most, 100 curies of a gamma-emitting isotope such as ^{60}Co or ^{137}Cs dispersed by less than 100 kg of high explosive.

Regardless of how small the radioactive device, all areas that may have received some radioactive material will have to be evacuated and closed off for monitoring and decontamination. This is likely to include checking both interiors and exteriors of buildings for radiation. In all likelihood, such an examination would take several weeks or more to estimate the contamination over an extended area. During the initial monitoring period, it is nearly certain that all economic activity in the affected area would cease, in part because of the need to determine the extent of contamination, and in part because of the reluctance of the public to enter an area thought to be radioactive, no matter how small the dose rate. The period of mandatory evacuation resulting from the need to take precautions against even a very small device is certain to be several days, and could be many weeks or even months.

During the evacuation period, small and undercapitalized businesses, such as small delicatessens, independent bookstores, and clothing stores, will suffer from diminished or even zero cash flow. In turn, small business owners will need to furlough or fire employees, will more than likely be unable to pay suppliers (who will then suffer cash flow problems), and probably will be unable to pay mortgages. Even with business interruption insurance, a wave of bankruptcies is likely to follow, unless the government steps in and offers subsidies to everyone from business operators to owners of buildings to mortgage holders. However, all commercial insurance policies sold in the United States appear to exclude damage from radiation. Residents living within the affected zone will also need to be evacuated and sheltered, adding to the already high economic cost associated with the RDD incident. It is unlikely that they will be able to return to their homes for weeks or months, if at all.

Furthermore, the streets in the affected area will require decontamination, as will the exteriors of buildings. Depending upon the location of air intakes and open windows, interiors may also require treatment. Unfortunately, there are no well-established technologies for wide area decontamination of modern built-up areas.

Many of these same problems plagued the recovery from the collapse of the World Trade Center, although the surrounding area was reoccupied within a few days or weeks of the tragedy, and limited economic activity resumed quickly.

In Washington, D.C., an area the size of the National Mall could be affected by a simple dirty bomb—perhaps a few curies of material and a few kilograms of explosive—though the target would most likely be a government facility or a business or residential district, not just open space. More efficient RDDs relying on other means to disseminate the same amount of radioactive material could easily contaminate a significantly larger area.

A Large RDD (1,000–10,000 Ci). The response of the Brazilian public and government to the Goiânia incident and the effects of the radioactive material approximate the experience of an RDD event and are enormously instructive.

The majority of the damage done to the Goiânia region was caused by the nearly total cessation of economic intercourse with the rest of Brazil. The area's primary business is agriculture. As a result of the incident it became impossible for farmers in the area to sell any of their produce to the rest of Brazil. In order to circumvent the boycott, local farmers took to labeling their products as grown in nearby, unaffected areas. The Brazilian national government forbade travel by Goiânians outside the region unless the travelers had certificates that they were uncontaminated, increasing the physical and psychological isolation of the local citizens. Years after the event some prejudice against Goiânian products remains; the local government, hoping to "make lemonade" from the sour affair, changed its flag to include the trefoil that symbolizes radiation.

most hospitals do not have specialized clinics for treating radiation injuries or contaminated patients

If a large RDD incident were to occur in the United States, whether accidental or intentional, we also would expect to see massive decontamination efforts, possibly including the destruction of a large number of structures.

Super RDDs (> 10,000 Ci). It is difficult to predict the consequences of an attack using this much radioactive material, however, we can glean some information from previous incidents. The Chernobyl reactor fire, for example, released a large amount of material but injected most of it high into the atmosphere. In this case, an entire city, Pripyat, and a large agricultural area were abandoned and fenced to prevent unauthorized entry. The levels of residual radiation where people are allowed to live in the Chernobyl region remain considerably higher than those currently permitted by the U.S.

The economic consequences would be greater than those in the case of a large RDD under similar conditions but probably not proportional to the increase in source strength because more of the material probably would remain near the site of dispersal. Delivery of RDDs in this size range would very likely sicken and kill the perpetrators.

Some super RDDs can be shielded against detection with a comparatively thin layer of lead. The larger the RDD the more lead is required and the more easily the RDD can be detected.

Whether the United States is attacked by large or small RDDs, and whether the devices use explosives, are dispersed by some other means, or are simply emplaced, the consequences are certain to be serious, costly, and long lasting. It is not difficult to imagine devices that could kill tens and sicken hundreds, and it is not impossible to envision devices that could be ten times as lethal Nevertheless, an RDD is first of all an economic weapon. Cost estimates to restore lower Manhattan after the September 2001 attack range up to $40 billion plus loss of economic activity. The consequences of a large or super RDD might well be more costly.

Effects

Decontamination Levels and Economic Damage. All of us on planet Earth are continuously exposed to radiation. It comes in the form of cosmic radiation, carbon-14 in the air from the decomposition of plants or produced by cosmic rays, and even our own breathing. Naturally occurring radiation also comes from the soil and rocks around us—uranium is one of the most common solid elements making up the crust of the earth. On average, natural background radiation from all sources is 300 milli-rem/year, or 0.3 rem/year, including 0.2 rem/year from natural radon gas.

The intensity of cosmic radiation increases with altitude, where the atmosphere offers less protection, so moving from Washington, D.C., to Denver, Colorado, for example, increases the background to 500 milli-rem/year. Commercial jet aircraft fly at altitudes above 30,000 feet most of the time; their crews are exposed to significantly higher background radiation than someone who stays at sea level. One might expect cancer rates in Denver to exceed those in Washington, D.C. because of the higher cosmic radiation background found at higher altitudes. As well, the Denver area is situated over uranium-bearing rocks, which provide a steady stream of radioactive radon gas. However, in reality, the cancer rates in the two cities are quite similar.

Americans commonly accept the need for medical x-rays for diagnosis. While a chest x-ray or a dental exam delivers a very low dose of radiation, many modern procedures for diagnosis do not. For example, a computer-assisted tomographic scan of the head (crucial for stroke victims, diagnosing head injuries, and so on) delivers a dose of about two rem to the skull. This is the equivalent of six years of natural background in only a few minutes. No stroke or transient ischemic attack victim[17] in a hospital emergency room waiting to find out if he/she is bleeding in the brain or has a clot blocking blood to a part of the brain, would reject a CAT scan because of the infinitesimal amount of long-term risk posed by the procedure.

Acute Exposure to an RDD. How do background and medical procedures compare with doses from the kinds of sources likely to be used in RDDs? The dose rate from one curie of ^{137}Cs at one meter is 0.4 rem/hour. Standing next to such a source for a year (8,760 hours) would result in 3,500 rem exposure, an amount almost 12,000 times the normal background dose and certainly lethal.

However, no victim of an RDD attack using explosively dispersed radioactive material will spend more than minutes or at most hours close to the source of radiation. The important thing to remember about exposure to a dirty bomb is that anyone who survives the initial bomb blast should have no problems leaving the area in time to avoid injury from external sources of radiation. Some people in the immediate area of the detonation of an explosive dirty bomb might well receive prompt radiation doses high enough to cause serious injury or even death. Persons that close, however, are more likely to be killed promptly by the bomb blast than the radioactive material. The most likely ways for an RDD to sicken or kill victims with radiation are by stealthy dispersal of radioactive material or distribution of lump sources that go undetected by the local civil defense authorities (something unlikely to be possible very much longer)[18], or by detonation of a dirty bomb that contains amounts of radioactive material sufficient to cause serious external irradiation (25,000 Ci or more would be a reasonable estimate) or that causes radioactive material to be ingested or inhaled, producing internal exposure.

Local authorities should be prepared to treat a number of cases of acute radiation exposure in the aftermath of an RDD, including persons with only external exposure as well as those with potentially far more deadly internal exposure. Most hospitals, however, do not have specialized clinics for treating radiation injuries or contaminated patients. Advance preparation should include construction of facilities for decontaminating victims and training medical and paramedical staff to recognize acute radiation sickness and radiation burns.

Removal of external contamination can be accomplished simply by thorough washing, with careful attention given to removing radioactive material clinging to hair. Internal exposure, on the other hand, poses far greater hazards to the victim, whose tissues are being continuously irradiated from the inside. Internal contamination can occur in many ways: Leide das Neves Ferreira, the six-year-old girl who died in the Goiânia incident, rubbed the $^{137}CsCl$ material on her body and subsequently ate a sandwich that was believed to have been contaminated with material from her hands.

Victims of radiation are not contagious in the normal sense of the word, and once they have showered or bathed, those who suffered only external contamination pose no hazard to medical personnel. This is an important fact about which medical personnel should be educated. An isolation ward is not necessary, although public reaction may require some limitations on access to victims.

Patients who have been internally contaminated must be treated with due regard for the fact that they and their human waste are radioactive and that everything that comes into contact with them will become contaminated. They will require special facilities, specialist physicians, and appropriate instrumentation to measure the degree of contamination. The medical caregivers will need to take precautions to prevent their own contamination and to shield them from the radiation emitted by the patient. If the Brazilian experience is any guide, not all physicians will be willing to accept the (minimal) risks attendant to treatment of internally contaminated victims.

Long-Term Exposure to Contamination From an RDD. It is often stated that exposure to low levels of radiation for long periods of time may lead to an increase in the death rate from cancer. This argument is based on the linear, no-threshold (LNT) hypothesis that states that any amount of radiation causes irreparable injury to the body, and that the increased risk of cancer is directly proportional to increased exposure.[19] Using the LNT assumption, exposure to one rem of radiation results in a 4 in 10,000 increase in the cancer death rate (the data largely come from atomic bomb survivors, whose results may not be typical of long-term exposure to low doses). About 2000 out of every 10,000 living Americans will die from all forms of cancer; it is not clear that an additional four cases per 10,000 could be detected and attributed to radiation exposure, even with careful analysis. Despite the caution with which it should be treated, the LNT hypothesis underlies radiation protection and clean-up regulations.

The present U.S. standard is that the additional cancer risk to the general population from man-made radiation (other than for medical therapeutic uses) should not exceed one case per thousand people. The Environmental Protection Agency (EPA) has set a requirement that the increased dose for the general public above background for non-medical radiation should not exceed 100 milli-rem per year (0.1 rem). Radiation workers, who are informed of the risks and consent to accept them, are generally allowed higher exposures. They may be exposed to 5 rem in one year once or twice in their working lives.

Decontamination

Two decontamination standards have been set for cleanup after a radiation release. The Nuclear Regulatory Commission allows an additional 25 milli-rem of absorbed radiation dose per year, while EPA permits only 15 milli-rem per year; both figures should be considered in the context of the 300 mill-rem/year of background radiation always present. The limits on residual radiation after cleanup are the doses a person would receive who spent 24 hours a day, 7 days

Carcinogenic Effects of External Radiation Exposure (LNT Hypothesis)

Type of Radiation Exposure	Increased Cancer Risk
Four medical CAT scans	4 cases per thousand
70 years in Denver as compared to Washington, D.C. (difference in natural background only)	6 cases per thousand
70 years of jet plane travel (difference in cosmic ray background only)	9–10 cases per thousand
70 years at 100 milli-rem above natural background (EPA limit for general public)	3 cases per thousand
70 years at site-decontamination limit	0.6 cases per thousand (6 per 10,000)

a week for 40 years in an affected area. They do not take into account the fact that most people do not stay in either their homes or their workplaces 100 percent of the time. Even so, this degree of decontamination is not overly difficult to achieve after the usual radiation incident, a small spill or breakage of a weak source in a laboratory environment. Achieving it on a large scale in a populated area with many different kinds of buildings would be difficult.

Nevertheless, under present regulations and applicable laws, any building that cannot be decontaminated so that the dose rate from residual radioactive debris from any radiation accident is below the limits set by either EPA and NRC may not be occupied. Such a structure would have to be abandoned in place and fenced off, or razed and removed, with all materials going to a low-level radioactive waste dump. This would be a very expensive remedy.

Is the remedy reasonable in light of the actual risks? The cancer-causing effects of several different long-term external exposures to radiation under the LNT hypothesis are given in the table. The decontamination limits of EPA and NRC, while satisfactory for a laboratory environment and spills of small radioactive sources, limit the increased cancer risk from a terrorist attack to far less than the increased risks accepted daily by virtually all Americans. If the current limits on residual radiation levels were maintained after an attack, even a small RDD, poorly dispersed, would require the leveling of large portions of a city for an uncertain, but certainly small, reduction in the long-term cancer rate.

only about half of the sources were found by any given team, and some sources were not found by any of the search teams

It is plausible that relaxing the cleanup standard by a factor of ten would reduce the area that requires intensive cleanup and decontamination by the same factor. In turn, that may reduce many of the economic consequences by a similar but smaller factor, because any estimate of economic consequences should include reduced public willingness to conduct business as usual in the affected region. The process for changing the regulatory standards for residual radiation in the event of attacks on the United States should be explored immediately, and any necessary legislation should be prepared.

Direct Decontamination. There are no proven methods to decontaminate the exteriors of large buildings or to decontaminate large outdoor areas, other than to remove buildings and soil. Some experts have stated categorically that cleanup of external surfaces of buildings to current decontamination limits may not, in any case, be technically feasible. Removal of contaminated material from a building could pose a greater hazard than leaving the material in place because of the need to confine the isotope-laden dust scraped or sandblasted off. While not currently possible, chemical removal of contamination from buildings might prove possible in the future. Many experts label our only presently viable technology as "muck and truck," meaning that all one can do is dig up the soil, tear down contaminated buildings, and haul all of the contaminated material to a radioactive waste storage facility. It is also possible that a sacrificial layer of a "sticky" substance, something like a transparent paint, could be applied to the building before an RDD incident and stripped off afterward. Sacrificial layers would be expensive to apply and to remove and dispose of, once contaminated. They can obviously be considered for the highest value targets, either national symbols such as the Capitol or extremely valuable structures.

At present, the direct costs of physical decontamination of large outdoor areas are difficult, if not impossible, to estimate in a credible way. However, it is certain that they will be very high, particularly if current environmental laws and regulations on residual radioactivity remain in force.

In principle, decontaminating an area of "lumped" sources (for example, conventional sealed sources) should be easy. A radioactive source should be detectable from a long distance using existing detectors, and workers in protective garb and with proper handling tools should be able to remove them. In practice, however, locating the sources has not proven as easy as previously thought. In a recent and very realistic Swedish exercise using instruments in cars, trucks, and aircraft to search for concealed sources, only about half of the sources were found by any given team, and some sources were not found by any of the search teams.[20] This does not provide confi-dence that all sources distributed by a resourceful terrorist would be located, even after officials knew that a search was required. It also indicates that some contaminated areas might go undetected even if an explosive or other large-scale RDD were used.

Economic Impact

It is likely that any RDD involving more than a few curies of radioactive material will contaminate some areas so heavily that decontamination will not be attempted. The areas will either be abandoned (as was the town of Pripyat, near the Chernobyl reactor) and fenced, or the buildings will be razed and the soil scraped to a depth of a meter or so, and both building waste and soil will be taken to a low-level radioactive waste depository (as happened at Goiânia). Even after cleanup has been accomplished, there will likely be residual public fear of the site. Tourist traffic will likely never resume, and commerce will be handicapped. If an agricultural area is involved, the farmers may find it difficult to market their produce.

The economic impact on a major metropolitan area from a successful RDD attack is likely to equal and perhaps even exceed that of the September 2001 Al Qaeda attacks in New York City and in Washington, D.C. The estimated cost to return the lower Manhattan area to the condition prior to the September terrorist attacks was in excess of $30 Billion. The immediate response costs exceeded $11 Billion.[21]

Much of the private cost of recovery from the September 2001 attacks was paid by insurance. That would not be the case following an RDD attack, because radiation is a specifically *excluded* risk in virtually all policies written in the United States. The government will have to step in to subsidize economic recovery after an attack, or some form of insurance reform will have to occur before an attack, in order to facilitate economic recovery.

The economic toll inflicted by a radiological attack will be high. It is unlikely that anything but a super-RDD will kill more than a few hundred Americans, but the task of cleaning up to currently acceptable levels of residual radiation will be enormous. There is not yet any technical solution other than razing structures and carting them away. This leaves us with the task of devising policy for the post-attack era now so as to prevent us from being hamstrung by our own laws and regulations.

Conclusions and Recommendations

Radiological dispersion devices pose a unique threat to the United States. While an RDD attack is unlikely to cause mass fatalities, it is apt to cause mass panic and great economic damage. There remain many uncertainties in the spectrum of responses. Despite the sense of vulnerability to terrorism created by the September 11, 2001 terror attacks, an adequate system of licensing and control of radioactive sources designed to combat deliberate and malign misuse or misappropriation of radioactive material has not been put into place.

some kind of legislative or regulatory remedy should provide relief to Americans in the wake of an RDD attack

Responses to an attack are complicated by jurisdictional issues. Some sources are regulated by the Nuclear Regulatory Commission, while others are controlled by state agencies. The NRC and the Environmental Protection Agency have significantly different cleanup standards. Finally, the plume from an explosively driven RDD is likely to cross city, county, and even state lines and require a high degree of cooperation among unrelated organizations in the face of likely mass panic. A great deal of additional effort to pre-plan local responses is required.

The following specific recommendations should be implemented:

- The Department of Energy weapons laboratories, in cooperation with other agencies and institutions, should identify, test, and deploy technologies that will enable rapid cleanup and decontamination of buildings, vehicles, and people.
- To reduce economic disruption, the permitted level of residual radioactivity after cleanup from an attack (not ordinary radiological accidents) should be raised by a factor of ten. If this requires legislation, the Administration should develop a bill and send it to Congress. Acceptance of the increased levels of residual radiation will require a program of public education about the risk that should begin soon.
- Because Americans cannot presently obtain any sort of insurance to cover radiological terrorism, it is all but certain that even the smallest of attacks will result in economic catastrophe for the victims.[22] Indeed, unavailability of insurance against a specific peril makes that peril seem even more dangerous than it really is. The cost of cleanup, even if feasible, is likely to be too great to be borne by individual owners and businesses. Indeed, cleanup to the degree that buildings could be reoccupied might not be possible. Writing off entire properties that could be restored if funds were available will be dispiriting and add to any economic downturn. Even if an individual homeowner or a specific business can afford to decontaminate a dwelling, store or factory, it is not good public policy to push the costs onto a few and to abandon the many who are unable to afford restoration. Just as the Federal government provides subsidies for flood insurance, so it should also provide some form of national insurance against radiological terrorism. There is ample additional precedent. The Price-Anderson Act already provides insurance in the event of a nuclear accident caused by a licensed company or facility acting within the terms of its license. Price-Anderson compensated the victims of the Three Mile Island event; the power company was protected. We recommend that Congress quickly establish a fund to compensate uninsured victims of radiological terror or that the government mandate the inclusion of radiation as an insurable risk in standard-form insurance policies. If every American paid a small premium, the risk would be spread wide enough so that the individual policy cost increment was small.
- It is likely that raising the permitted level of residual radioactivity in order to reduce the area requiring intensive decontamination will reduce the property values in the affected zone. This can be offset by a one-time, direct payment by the federal government to the property owners, or by noting that if the permitted level were not raised, the property value would decrease to zero because the area would be closed off or the buildings demolished. Some kind of legislative or regulatory remedy should provide relief to Americans in the wake of an RDD attack.
- NRC licensing rules should continue to be toughened. In particular, the United States must require foreign suppliers to verify that shipments of radioactive materials into the United States are sent only to holders of valid licenses for the materials being acquired; regulations should compel shippers to notify the NRC in advance of making a shipment.
- U.S. exporters of radioactive material should be required to verify that their consignees have valid national licenses to receive the material. Radiation protection authorities in the destination state should be notified of the proposed shipment before the material is actually sent.
- The United States should stockpile Radiogardase® in sufficient quantities to treat at least 1,000 victims in each of ten cities for at least one month. The medication should be deployed in such a way that at least 1,000 patient-days worth can be available in any city within 2 to 4 hours after an attack. This will probably require purchasing many times the 10,000 30 day treatments that one would infer is a minimum based on the IAEA report on Goiânia, and it will require an appropriate distribution system.
- Programs to recover orphan sources in the United States and abroad should be fully funded on a continuing basis. A one-time cleanup of known sources will not protect against sources orphaned in the future.
- Very large radioactive sources, particularly those used in the former Soviet Union, should be retired and replaced with benign technologies.
- Where feasible, non-radioactive technologies such as X-rays and accelerators should be substituted for radioactive sources. This will reduce the opportunities for loss, theft and misuse of radioactive materials.
- Inbound cargo must be screened not only for strong sources of radiation but for heavy metals, such as lead, that could be used to shield intense sources from radiation monitors. This screening would also complicate smuggling of nuclear weapons.
- An appropriate program of public education about the dangers of RDDs, how to behave after an attack, and about the high probability of surviving an attack without serious injury or additional risk of cancer should be instituted in a timely manner.

Radiological attacks against the United States are a matter for urgent concern, but not for panic. A number of steps can be taken now to reduce the probability of such an attack and to aid recovery. It is likely that very few Americans will be killed directly, suffer radiation sickness, or even have a measurably increased risk of cancer from an attack, although casualties will be greater if the terrorists have a good understanding of how to disperse the agent. Even the smallest attack is likely to do grave economic damage to the affected area. The amount of damage will depend upon the amount and kind of radioisotope used, the effectiveness of the dispersal method, where the attack is executed, and the strictness of environmental regulations that govern post-attack decontamination and reoccupation.

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Notes

[1] Samuel Glasstone and Philip J. Dolan, *The Effects of Nuclear Weapons,* 3[d] ed. (Washington, DC: U.S. Departments of Defense and Energy, 1977), 578, et seq.

[2] The customary unit by which "absorbed dose" of radiation is measured in the United States is called the roentgen after Wilhelm Roentgen, who discovered x-rays. Since not all radiation is equally effective at inflicting damage on humans, a "quality factor" has been introduced to include the damage. The quality factor for beta and gamma radiation is taken as 1 and that for alphas and neutrons as 10. The rem or "roentgen effective in man" is a measure of effective absorbed radiation dose and is corrected for the fact that alpha radiation and neutrons are far more damaging to a human being than are betas and gammas. Hence, a rem is equal to the dose in roentgens times the quality factor. The rest of the world uses the metric unit "gray" (Gy) for absorbed dose and "sievert" (Sv) for equivalent dose. One gray equals 100 rads; one sievert equals 100 rem.

[3] "Nuclear Security: Federal and State Action Needed to Improve Security of Sealed Radioactive Sources," United States General Accounting Office, August 2003, GAO-03-804.

[4] Private communication with Abel Gonzalez, head of waste disposal and security, IAEA, and Richard Meserve, then-chairman, U.S. Nuclear Regulatory Commission.

[5] Private communication with Richard Meserve.

[6] Private communication with Joel Lubenau.

[7] See www.nrc.gov/what-we-do/state-tribal/agreement-states.html.

[8] Most information taken from *The Radiological Accident in Goiânia* (Vienna: International Atomic Energy Agency, 1988). Accounts of the incident vary in their details, but it is felt that the official IAEA report forms the best available basis for subsequent analysis. Much of the text in this section is an abbreviated paraphrase of parts of the IAEA chronology, 22–29.

[9] The IAEA report identifies people only by initials. Other reports use full names.

[10] Alex Neifert, accessed at www.nbc-med.org/SiteContent/MedRef/OnlineRef/CaseStudies/csGoiânia.html.

[11] Where numbers in the text differ from those in the official IAEA report it is because the authors have obtained more recent and complete information from participants in the response to the event.

[12] "Al Qaeda pursued a 'dirty bomb,'" *The Washington Times,* October 17, 2003.

[13] Department of Homeland Security Working Group on Radiological Dispersal Device (RDD) Preparedness, Medical Preparedness and Response Sub-Group. 5/1/03 version.

[14] *The Radiological Accident in Goiânia,* International Atomic Energy Agency (Vienna: 1988), chapters 5 and 6.

[15] Telephone interview with Dr. Carlos Nogueira de Oliveira of the IAEA, 12 August 2003. Dr. Nogueira headed the Brazilian government's response in Goiânia.

[16] Interview with Dr. Nogueira de Oliveira .

[17] A transient stroke lasts only a few minutes and occurs when the blood supply to part of the brain is briefly interrupted.

[18] "Sensors May Track Terror's Fallout," *The Washington Post,* June 2, 2003, A1.

[19] The linear, no-threshold rule is conservative. No firm threshold has been established. Many scientists believe that the LNT rule is not supported by experimental evidence and that there is a threshold dose and dose rate below which the body is able to repair itself.

[20] R.R. Finck and T. Ulvsand, "Search for orphan gamma radiation sources: experiences from the Barents Rescue 2001 Exercise," in *Security of Radioactive Sources,* International Atomic Energy Agency (Vienna: 2003), pp 123-138.

[21] "Financial Impact of the World Trade Center Attack," prepared for the Finance Committee of the New York State Senate, January 2002.

[22] "State Farm won't cover nuke losses." *USA Today,* February 27, 2003 (web edition, http://www.icnj.org/SiteDocuments/News/2-28-2003/statefarmwontcovernukelossesusa_2-28-2003.htm). This article describes the addition of a nuclear exclusion (including radioactive contamination) to State Farm auto insurance policies in addition to existing exclusions on homeowner and commercial policies. The Chubb Group of insurance companies excludes radioactive contamination from, inter alia, its marine insurance: http://www.chubb.com/businesses/cargo/ocean_marine/oceancargo/basic.html. See also "The Insurance Implications of Terrorist Attacks," *Independent Insurance Agents of America,* web version at: http://vu.iiaa.net/Docs/Terrorism/TerrorismWhitePaper.pdf. The IIAA states explicitly that no coverage is provided under medical insurance, automotive, home owners, commercial, building and personal property, business income and extra expense, physical damage, etc. insurance policies in the United States.

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