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A Risk and Economic Analysis of Dirty Bomb Attacks on the Ports of Los Angeles and Long Beach

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Abstract

This paper analyzes possible terrorist attacks on the ports of Los Angeles and Long Beach using a radiological dispersal device (RDD, also known as a “dirty bomb”) to shut down port operations and cause substantial economic and psychological impacts. Using risk and economic analysis methods, the paper begins by identifying the most likely dirty bomb attack scenarios in terms of sources of radiological material, delivery modes and detonation sites. A project risk analysis is developed for selected scenarios to identify the tasks terrorists need to perform to carry out the project and to determine the probability of the project’s success. The consequences of a successful attack are described in terms of human health effects and economic losses. The findings show that the chances of a successful dirty bomb attack are lower than expected and the health consequences of even a major attack are relatively small. However, the economic consequences from a shutdown of the harbors could result in significant losses. The implications of detecting, intercepting and countering a dirty bomb attack are discussed.

1. Introduction

The Dirty Bomb Threat. Since the events on September 11, 2001, the prospect of a terrorist attack using a radiological dispersal device (dirty bomb) is cited as among one the most serious terrorist threats.(1) Several recently reported incidents confirm the concerns of security officials. In June 2002, the United States (U.S.) arrested Jose Padilla for his involvement with Al Qaeda in planning a dirty bomb attack on the U.S.,(2) and in January 2003, British officials found documents in the Afghan city of Herat indicating Al Qaeda successfully built a small dirty bomb as well as possessed training manuals on using the explosive device.(3) While a dirty bomb never has been successfully used worldwide, the emergence of sophisticated terrorist organizations coupled with the recognized positive tradeoffs associated with pursuing such an attack have increased the attractiveness of dirty bombs.

A dirty bomb is an appealing terrorist attack mode because of the relative ease associated with acquiring radioactive material and building the device, and the ultimate potential for significant health, economic, and psychological consequences. Building of a dirty bomb is a fairly simple process, requiring little more than the skills needed to assemble a conventional bomb.(6) The primary challenge faced by terrorists is procuring the radioactive material. According to the International Atomic Energy Agency (IAEA), nearly every country has devices containing radioactive material useful for the creation of dirty bombs and questions whether security in many of these locations is adequate.(7) Furthermore, significant quantities of radioactive material have been lost, stolen, or abandoned – referred to as ‘orphan sources’ – from U.S. and international facilities. According to an August 2003 General Accounting Office report, since 1998 more than 1,300 radioactive sources have become orphaned in the U.S.(8) Internationally the number of orphan sources is more difficult to determine because the countries do not have systemic procedures for such purposes. A primary concern of U.S. and international security experts is the number of orphan sources scattered throughout the former states of the Soviet Union and the security of nuclear facilities in Pakistan, India and other developing countries.

A dirty bomb consists of radioactive material packaged in conventional explosives. When detonated, the radioactive material scatters into the environment, some forming a radioactive plume, and the remaining quantity falling in clumps or large particulates near the location of the explosion. No nuclear-fission and/or fusion reaction takes places as in a nuclear weapon. However, a dirty bomb can result in both death and injuries from the initial blast of the conventional explosives and radiation sickness and cancer from the radioactive material's contamination. Furthermore, the dirty bomb is widely recognized as having psychological and long-term economic effects that could outweigh its health consequences. More specifically, the panic following an attack could incite chaos leading to additional injuries, unnecessary increases in radiation exposure and overloading of medical facilities. Also, depending on the amount of radioactive material released and dispersed, the contaminated area could require complete evacuation, followed by decontamination efforts that could take months or even years. Locally, this impacts the economy and instills public fear about returning to the region. Nationally, such panic could result in dirty bomb scares, both real and hoaxes, and instigate residual repercussions throughout the economy.

Ports of Los Angeles and Long Beach Vulnerability. Ports are inherently attractive terrorist targets because of the potential for a successful attack to result in lives lost and economic damage to local businesses, harbor operations and the flow of trade worldwide. Overall, ports are major trade nodes, have complex business infrastructures and are difficult to secure due to their extensive size and accessibility by water and land. Most ports are located near major metropolitan regions that rely heavily on the resources and jobs provided by the businesses within the harbors. Also, ports are connected through several different transportation modes (e.g. road, ship and rail), and often industries, businesses, and tourist attractions are close by, presenting terrorists with several options for deception and attack scenarios.

The ports of Los Angeles and Long Beach are particularly appealing targets. They are large and bustling, making up the third busiest ports in the world. Annually, 11.4 million twenty-foot unit equivalent containers traverse through their waterways, totaling in value to about $218 billion.(9) In addition, 36% of U.S. imports enter into the country through these two ports.(10) Dispersed across the harbors are oil refineries, business offices, storage facilities for hazardous materials and cargo, container terminals and more. Cargo is transported to the ports via land, ship or rail, increasing the challenge of securing the region. And whether coming to the ports for work or to make a delivery, many people enter the Los Angeles and Long Beach harbors daily.

Immediately surrounding the ports are parks and various roads leading to fishing wharfs and tourist attractions such as the Queen Mary and cruise line terminals. Also, in the proximity are downtown Long Beach and San Pedro. Traveling to and from these locations are major highways, roads and bridges that either pass through or alongside the ports. The activity in the nearby metropolis and recreational areas makes a terrorist attack on the ports of significant consequence both to the local livelihood as well as to the regional and national economy.

This paper presents a risk and economic analysis of a dirty bomb attack on the ports of Los Angeles and Long Beach. The purpose of this analysis was to identify the threats and vulnerabilities of such an attack, estimate the consequences and outline effective countermeasures. Section two of this paper describes the sources of radioactive material in the

U.S. and abroad that could be used to construct a dirty bomb. Section three summarizes an analysis of 36 attack scenarios and describes a methodology and some preliminary findings for estimating the relative likelihood of a successful attack. Section four presents an analysis of the consequences of the two most likely attack scenarios in terms of the health effects and economic impact of a port shutdown. Section five examines possible countermeasures and their cost effectiveness.

2. Sources of Radioactive Material

Millions of radioactive sources are distributed worldwide, with hundreds of thousands in varying quantities and sizes currently being used, stored and produced. In the U.S. alone, approximately 2 million licensed sealed sources are in use.(11) Among the 15 member states of the European Union, the European Commission reported that about 500,000 sealed sources have been located.(12) As seen in Table 2.1, spent fuel rods from nuclear reactors and waste facilities, industrial and blood irradiators, and radiography equipment are among some of the primary sources that require radioactive material to operate. For a terrorist to build a dirty bomb, any of the radioactive material necessary for these applications could be employed. Most reports of trafficking incidents or unauthorized movement of radioactive material involve material in the form of the aforementioned sealed sources, with a few incidents involving unsealed sources such as contaminated scrap metal.

Table 2.1: Sources of Radioactive Material

Source	Radioisotope	Radioactivity Level (curies)
Spent fuel assembly	Multiple sources	300,000 - 2,000,000
Industrial irradiator (sterilization & food preservation)	Cobalt 60 (Co 60)	Up to 4,000,000
	Cesium 137 (Cs 137)	Up to 3,000,000
Blood irradiator	Co 60	2,400 - 25,000
	Cs 137	50 - 15,000
Radiotherapy (single and multi-beam)	Co 60	4000 - 27,000
	Cs 137	500 - 13,500
Medical radiography	Co 60	1,000
	Iridium 192 (Ir 192)	1 - 200
Industrial radiography	Co 60	3 - 250
	Ir 192	3 - 250
Calibration	Co 60	20
	Cs 137	60
	Americium 241	10

Sources: Modified (1) Center for Nonproliferation Studies (CNS), The Four Faces of Nuclear Terrorism, 2005; (2) CNS, Commercial Radioactive Sources: Surveying the Security Risks, 2003; (3) IAEA, Categorization of Radioactive Sources, 2003; (4) Personal Communication with Tom Edmunds, Pacific Northwest National Laboratory, August 2004.

Nuclear reactor and waste facilities. In the U.S., nuclear power and waste facilities contain millions of curies of radioactive material that is the mostly deadly in nature, but also extremely difficult to obtain and handle. Nuclear reactors are used to generate electricity and spent nuclear fuel is found near such reactors in pools or dry storage. Nuclear waste facilities are used to store high to low levels of radioactive material. High level radioactive waste is located at several former weapons production sites throughout the U.S. And several low level radioactive waste facilities in the U.S. were developed to dispose of low level wastes such as concrete or soil from dismantled nuclear reactors, medical equipment and tools or soiled protective clothing. Special licenses are issued by the U.S. Nuclear Regulatory Commission (NRC) to ensure the facilities are designed, constructed and operated in accordance with safety standards. In addition, security surrounding nuclear power and waste sites has historically been considered to be extremely high. While the large inventories of radioactive material are appealing to terrorists, such precautions present a formidable challenge to acquiring the material.

Medical, research and industrial facilities. The NRC also issues licenses for medical, research and industrial applications requiring radioactive material. Medical and research institutions use radioactive material in medical diagnosis, sterilization of medical equipment, radiotherapy (both internal and external), and for research in nuclear medicine. Radiotherapy, the treatment of disease with radiation, employs Cobalt 60 (Co 60) and Cesium 137 (Cs 137). These radioisotopes have longer half-lives, 5.3 and 30 years respectively, and contain roughly 1,000 to 30,000 curies (unit of measurement for radioactive material), making them susceptible to security risk.(13) In contrast the materials used for sterilizing equipment and medical diagnosis present a smaller (or less alarming) security concern since they require relatively low amounts of radioactive materials with short half-lives.

Industrial facilities use radioactive material to operate machinery such as food irradiators, gauging devices, well-logging devices and industrial radiography systems. Irradiators pose the greatest security risk because they typically contain thousands to millions of curies of Co 60 or Cs 137.(14) Industrial radiography uses Iridium 192 to check metal parts and welds for defects. These sources contain low quantities of radioactive material, ranging from a few up to approximately 100 curies, but are placed in portable devices that present a security risk.(15) Gauging and well logging devices typically contain at most around 30 curies of radioactive material, thus presenting a minimal security risk.(16) While the NRC is responsible for issuing licenses and monitoring such facilities, security requirements are less stringent than those found at nuclear reactor and waste facilities.

Foreign sources of radioactive material. Internationally, experts are concerned about the security risk associated with spent fuel assemblies and reprocessed material abandoned, lost or poorly guarded in the former states of the Soviet Union. The amount of radioactivity generated by these sources can be in the millions of curies. For example, one spent fuel assembly (with a cross section of 15 cm by 15 cm and about 4-5 meters long) might have an activity level of 300,000 to 2,000,000 curies during the first ten years following removal from the reactor core. There are also approximately 1,000 Radioisotope Thermoelectric Generators (RTGs) that have exhausted their design and are in need of dismantlement. RTG's might include anywhere from 250 to 20,000 curies of radioactive material.(17) Surplus radioactive material coupled with a large number of sites with inadequate protection present opportunities for illegal stealing, selling and trafficking. Compared to the U.S., acquiring material of this quantity without detection is less challenging mostly because of different accountability and security standards.

The former Soviet Union also houses weapons-grade plutonium and uranium produced in excess during the Cold War. If a terrorist were to acquire plutonium or uranium, the material most likely would be saved for use in the construction of a nuclear weapon. However, experts have noted that of all known cases of attempted trafficking, the total acquired material is not enough to build a single nuclear bomb.(18)

In addition, recent reports suggest that several countries traditionally not recognized as posing a serious threat are housing radioactive material noteworthy of concern. In February 2005, the North Korean Foreign Ministry announced the country had manufactured nuclear weapons. Also in February 2005, President Bush in his State of the Union address cited the need to confront countries pursuing weapons of mass destruction - both Syria and Iran were mentioned. While official evidence validating these reports is unclear, investigation into such terrorist threats has given rise to concerns that even a larger number of unaccountable and unprotected radioactive sources exists worldwide.

3. Scenarios and Probabilities

To analyze the dirty bomb threat to the ports of Los Angeles and Long Beach, we explored the danger of varying sources and quantities of radioactive material (measured in curies – Ci), as well as the differences in such attacks when the material originates from domestic versus international locations. We considered three scenarios, each depicting either a small, medium, or large-scale attack:

1. Low radioactivity scenario: Theft of radioactive material from a radiotherapy device in a U.S. hospital (1,000 to 10,000 Ci)
2. Medium radioactivity scenario: Theft of radioactive pellets from a blood or industrial irradiator in a U.S. facility (10,000 to100,000 Ci)
3. High radioactivity scenario: Purchase of a spent fuel assembly from a former Soviet Union nuclear power or reprocessing plant (100,000 to 2 million Ci)

In the low radioactivity scenario, we assumed the radioactive material is stolen from a U.S. hospital, transported to a warehouse near the port for construction and driven into the port by suicide bombers for detonation. The medium radioactivity scenario is modeled similarly to the low radioactivity scenario, except that a different radioactive source and larger quantity of material is stolen from a U.S. blood or industrial irradiator. The high radioactivity scenario involves the purchase of a spent fuel assembly in Chechnya that is transported to the U.S. by ship and detonated during cargo offloading. In developing the source scenarios, the type of bomb constructed, delivery mode, and detonation site were the primary criteria considered.

Type of bomb constructed. The type of dirty bomb constructed can vary in sophistication depending on the quantity and type of radioactive material used and the amount of time provided to assemble the device. Furthermore, the level of the terrorist's expertise in balancing the use of explosives with the nature and quantity of radioactive material determine the severity of the blast effect and plume formation. A successfully built dirty bomb might result in very minor consequences (dispersing a few clumps of radioactive material over a fairly small area) or significant consequences (dispersing a large fraction of radioactive material as aerosols or fine particulates into the air).

Also, the time allocated for bomb construction is sensitive to the possibility of detection following material theft or black market purchase. If detected, only limited time may be provided for building the bomb. Under time constraints, the terrorists might simply use the vehicle carrying the radioactive material as the detonation device. If undetected, the terrorist has the opportunity to pay closer attention to the intricacies and sophistication of the bomb design.

Delivery modes. Terrorists are likely to select a delivery mode that has a low probability of detection by port security, yet maximizes the potential for damage to the ports. As such, the vehicle of choice is based upon what is the ideal means of dirty bomb transport to the detonation site. The ports of Los Angeles and Long Beach are accessible by land, air and sea. A truck, car or train might be the best mode of transport if entering the port by one of the surrounding access roads or as a package on a cargo train. With respect to arriving through the ports' waterways, a cargo ship, cruise ship or recreational boat most likely provide the most flexibility. Nearby helicopter landing pads and airports make planes and helicopters alternative modes of transport, although less likely because of additional security barriers associated with gaining access to their launch sites.

In addition, the vehicle selected depends on the size and weight of the dirty bomb. A bomb's dimensions vary based on the amount of conventional explosive and radioactive material used in construction. Typically, radioactive material tends to be easily packaged because it comes in either a powder or pellet form. However, the shielding material can be bulky and heavy. The bomb's surface area is altered most significantly when explosives are packaged around the radioactive material. Ultimately, the bomb can be designed to fit into something as small as a suitcase or as large as a van.

Detonation site. To increase the effects of the dirty bomb, the detonation site is carefully selected based upon the ease with which it can be accessed, how elevated it is above the ground and its compatibility with the weather conditions surrounding the ports. Detonation site access is evaluated based on variables such as population density, location within or outside of the ports, and the selected mode of transport for executing the attack. Explosion of a dirty bomb in an elevated area, like on a bridge or in a helicopter, would enhance the dispersal of radioactive material. Finally, weather conditions as well as wind direction and velocity are considered as they affect the size and directional flow of the radioactive plume. Overall, for a terrorist, the optimal detonation site causes damage resulting in lives lost and economic consequences. A location that is less visible and susceptible to suspicious behavior is critical to enhancing the probability of attack success. However, too few people in the surrounding vicinity, winds blowing out to sea and a detonation site located miles from the harbors might deem the attack insignificant.

Probabilities of Scenarios. Our analysis examined a total of 36 possible terrorist attack scenarios – 12 for each of the source scenarios. In the low radioactivity scenario, the theft of a small quantity of radioactive material from a U.S. radiotherapy device originally was considered suitable for a small-scale dirty bomb attack. The analysis of this scenario was discontinued because detonating a dirty bomb of this size might result in the release of only a small fraction of radioactivity (200-2,000 Ci). Knowing this amount of material might have a limited effect in an open space could deter terrorists from pursuing such an attack scenario. If terrorists were to obtain radioactive material of this quantity, they probably would plan for its release within an enclosed facility or building where the dispersal effects would have a greater impact. As a result, our research focused primarily on the two high-end scenarios, a medium-scale attack based on stolen radioactive material from a U.S.-based blood or industrial irradiator and a large-scale attack using large quantities of material from a Russian spent fuel assembly.

After evaluating the conditions for building a dirty bomb, we examined possible modes of transportation and detonation sites for both the medium and high radioactivity scenarios. Table 3.1 shows the four transportation scenarios and three detonation site scenarios considered for both courses. With the help of a counterintelligence analyst, we classified each cell as either “not plausible,” “unlikely,” or “likely.” Because these judgments are considered sensitive information, the table serves only as a model of the methodology used.

However, the logic behind these judgments can be illustrated through a couple of cases. For example, in the medium radioactivity scenario, the dirty bomb will likely be constructed in the U.S. and delivered to the port by truck, train, helicopter, or plane. When considering delivery by train, it is not plausible for the bomb to be detonated on any of the major bridges leading into the harbors, as none are equipped with train tracks. Similarly, for the high radioactivity scenario, the dirty bomb will likely be constructed abroad and shipped to the U.S. in a cargo container. In this case, it is unlikely detonation would occur on the major bridges leading into the harbors. To a terrorist, logistically such an attack scenario might be perceived as too challenging, as well decrease the probability of attack success, when attempting to unload the container to a truck in hopes of potentially finding a better detonation site on land.

Using these qualitative judgments, we narrowed the 24 medium and high radioactivity scenarios down to four (two for each of the source scenarios). The two transportation/location scenarios within each source scenario were not significantly different in judged probability or consequences, so only one was analyzed for each source scenario. Due to the sensitivity of the information, the analytical results of this portion of the project are not included in Table 3.1.

Table 3.1: Transportation and Location Scenarios

		TRANSPORTATION			
		TRUCK	SHIP	TRAIN	PLANE/HELI
LOCATION	Bridge				
	Harbor - Ground				
	Harbor - Elevated				

Probabilities of Success. Microsoft Project was used to lay out the details for both remaining scenarios. This software originally was created to provide businesses with a computer tool that tracks a project’s progress by task, timeline and resources. A terrorist attack operates much like any other complex business project, starting with an attack planning phase, followed by the actual preparations for the attack and culminating with the attack execution. For both the medium and high radioactivity scenarios, Microsoft Project was used to outline planning, preparing and execution tasks, and defined each in terms of task duration and number of resources (people) required. For example, in the medium radioactivity scenario, the project starts with tasks such as planning how and where the attack will take place, determining who will be involved in the attack scenario and establishing a means of communication among the operatives. Next, preparations begin, which include tasks such as traveling into the U.S. and purchasing explosives for the dirty bomb. Ultimately, the planning and preparation tasks come together with the execution of the dirty bomb attack on the ports of Los Angeles and Long Beach.

Each task was entered into Microsoft Project through a table format known as a Gantt chart. They were inserted chronologically and coupled with relevant details, such as predecessor information, task duration and resources needed. Once the Gantt chart was completed, the tasks were grouped together to form what is termed a network diagram. The network diagram is a graphic layout of the entire attack scenario from start to finish. Figures 3.1 and 3.2 are snapshots taken from the medium radioactivity scenario network diagram. They illustrate the steps involved for two separate tasks, building the dirty bomb and transporting the dirty bomb into the harbors. For example, Figure 3.1 shows how building a dirty bomb involves obtaining the explosive and radioactive material prior to assembling the device. Figure 3.3 depicts how all the individual tasks come together to form the network diagram. The upper left parallelogram represents the start of the initial planning for the dirty bomb attack. The box on the far right signifies project completion with dirty bomb detonation.

Figure 3.1: Microsoft Project Tasks – Building the Dirty Bomb

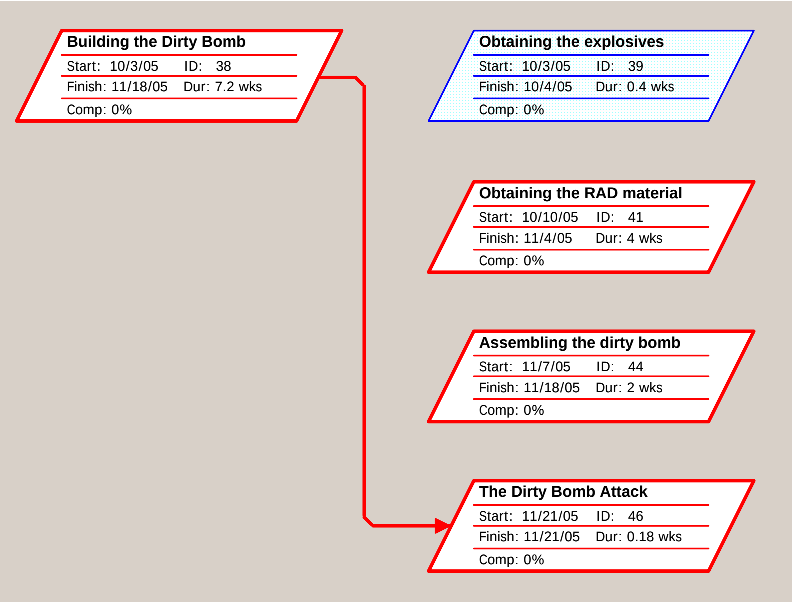


Figure 3.2: Microsoft Project Tasks – Transporting the Dirty Bomb

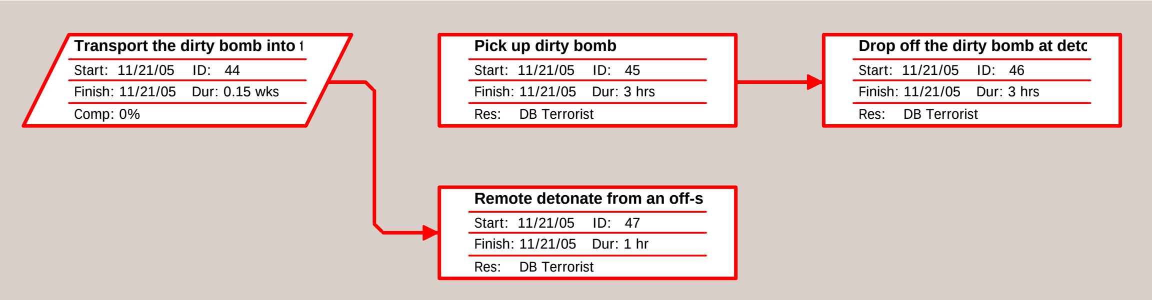
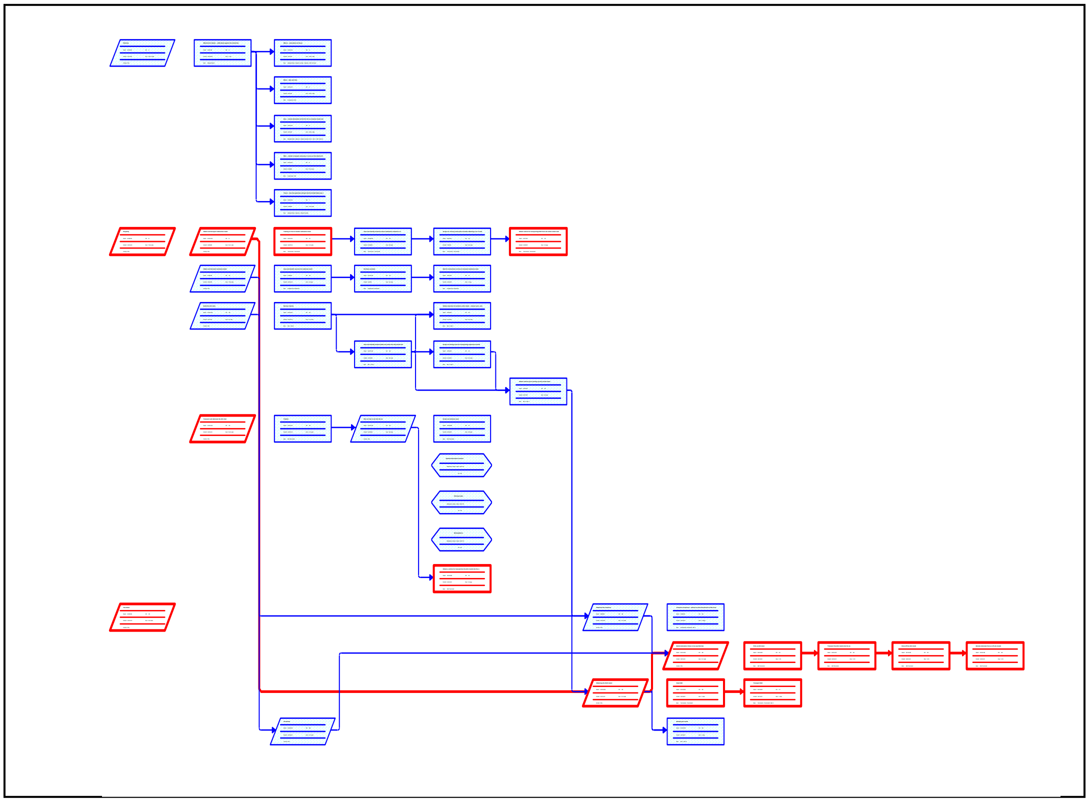


Figure 3.3: Schematic View of the Complete Project



For the medium and high radioactivity scenarios, each of the planning, preparing and execution tasks was associated with a certain probability of detection. To determine how the probability of detection affects overall attack success, we collaborated with a counterintelligence analyst to identify the most vulnerable tasks and assigned a probability of success to each. Table 3.2 lists some of these tasks for the medium radioactivity scenario. For example, the theft of radioactive material is clearly a very vulnerable task from the perspective of the terrorists.

Table 3.2: Medium Radioactivity Scenario Vulnerable Tasks

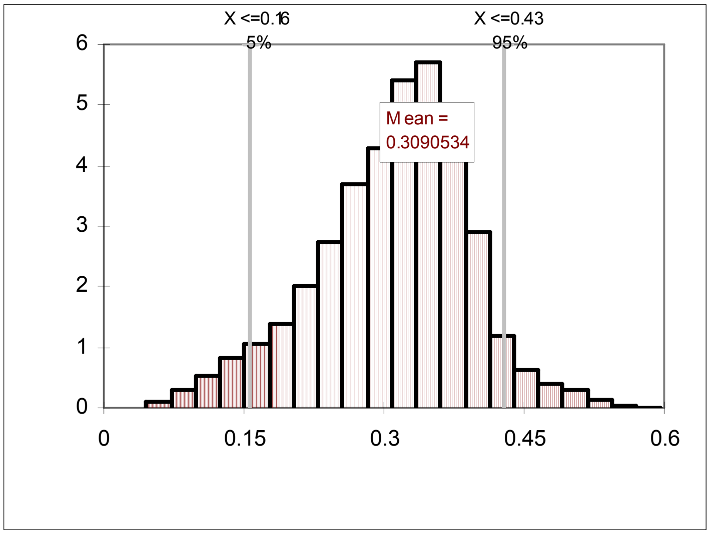
TASKS
Travel in the U.S. - the coordinator
Obtain a job at the selected facility (for stealing the radioactive material)
Steal radioactive material from research hospital
Transport radioactive material to construction site
Casing of the Los Angeles & Long Beach ports
Travel in to the U.S. - attack executioners
Assemble the dirty bomb
Transport the dirty bomb
Dirty bomb detonation
Second explosition

The probability of success for each of these tasks depends upon the complexity of the task, the number of people involved, and the time required to perform the task. Preliminary assessments of success probabilities were made for a given estimate of the number of people involved and task duration. A logit model was used to estimate variations in these probabilities as a function of changes in the number of people and time to task completion. We then developed probability distributions over the number of people and time for each task and used a probabilistic simulation model (@Risk by Palisades, Inc.) to simulate the uncertainty around the overall success probability of each task.

The research team, with the help of a counterintelligence analyst, used only publicly available, open-source data to make all assessments. The data represent very preliminary estimates and are largely illustrative of the methodology used. Refinements of these probability estimates would require access to classified data as well as the use of established procedures for formal elicitation of probabilities from personnel currently working counterintelligence and counterterrorism operations.

An example of the results from the medium radioactivity scenario probabilistic simulation is shown in Figure 3.4. Interestingly, the probabilities of success are relatively small (less than 60%). This is because for the overall project to be successful, all individual tasks must be successful. As the uncertainty and risk affecting the success of the vulnerable tasks listed in Table 3.3 varies, this in turn affects the overall probability of project success. Of course, terrorists may engage in multiple, independent projects, thus increasing the probability that at least one of them succeeds.

Figure 3.4: Distribution over the Probability of a Successful Attack (Medium Radioactivity Scenario)



4. Consequences

The consequences of a dirty bomb attack fall into three categories: (1) immediate fatalities and injuries due to blast effects and acute radiation exposure, (2) medium and long-term health effects caused by airborne dispersal of radioactive material, and (3) economic impacts resulting from shutting down port operations – including evacuations, business losses, and clean-up costs. In both the medium and high radioactivity scenarios, we assumed that 5-30% of the material was released into the air as aerosols or fine particulates. This results in a plume carrying roughly 500-30,000 Ci in the medium radioactivity scenario and 5,000-600,000 Ci in the high radioactivity scenario. The ranges of various damage estimates are shown in Table 4.1.

Table 4.1: Ranges of Consequence Estimates[1]

Consequences	Medium Scenario	High Scenario	Measure
Blast and Acute Radiation Effects	up to10	up to 50	Fatalities
Latent Cancers	up to 100	up to 500	Fatalities
Port Shutdown and Related Business Losses	up to 200 million	30-100 billion	Dollars
Evacuation Cost (Plume)	negligible	10-100 million	Dollars
Business Loss (Plume)	negligible	1-3 billion	Dollars
Property Values (Plume)	negligible	100-200 million	Dollars
Decontamination Costs (Plume)	10-100 million	10-100 billion	Dollars

Blast Effects and Acute Radiation. The immediate fatalities and injuries following the explosion of the dirty bomb depend on the amount of explosives used and the population density in the area near the detonation site. The blast effects primarily impact the area within a hundred feet of the detonation point.(19) Unless the bomb is set off in a very densely populated area, the effects are likely to cause only a few fatalities and several injuries. Acute radiation sickness might occur if bystanders or emergency workers that rush to assist blast victims suffer from prolonged exposure to highly radioactive material. For example, during a 2004 dirty bomb exercise held in Long Beach, emergency workers immediate response efforts revealed inadequacies. Had this been a real attack, they probably would have suffered from some level of radiation exposure, though most likely not in a range that produces acute radiation effects.

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[1] The lower end of the health effect ranges include cases in our simulation where one or more of the following might occur: (1) unsuccessful airborne releases due to faulty construction of the dirty bomb; (2) wind flowing away from populated areas; and (3) low radioactive doses (100 mrem or less) that produce no health effects. More refined consequence assessments using variations of (1) - (3) can be conducted using standard consequence assessment methods developed for nuclear power plant accidents. These methods involve sophisticated computer codes and expert elicitation procedures to encode probability distributions. The ranges in Table 4.1 should be considered preliminary for the purpose of an illustration of the analysis' capabilities.

Overall, the severity of radiation sickness depends on the dose and duration of exposure. For example, total body exposure to about 100 rem results in radiation sickness, and 400 rem causes radiation sickness and death in half of the exposed individuals. (22)

Health Effects Due to Airborne Releases. The incidence of health effects following the detonation of a dirty bomb depend largely on the source and amount of radioactive material used, and the sophistication of the detonation device. If successfully detonated, a respirable fraction of the material will be released into the air that varies from about 1% to 80% of the original source.(21) The remaining material will fall in clumps or larger particulates within hundreds of feet of the detonation site. In addition, weather conditions, wind direction and wind velocity exacerbate the situation, as they predicate the formation of the radioactive plume.

Figures 4.1 and 4.2 show the medium and high radioactivity scenario plumes, respectively. These examples are hypothetical and not based on specific models. However, we have obtained similar plumes from the National Atmospheric Release Advisory Center (NARAC) to verify that these examples are realistic. The following calculations were conducted with the NARAC plumes (not included), but the results would be very similar when applied to the plumes shown.

The plume in Figure 4.1 defines an inner ellipse with more than 1 mrem exposure per hour and an outer ellipse covering an area exposed to more than 0.1 mrem per hour. NARAC model calculations for a similar plume suggest that the total four-day effective dose equivalent exceeds 1,000 mrem or 1 rem in the inner ellipse and 100 mrem in the outer ellipse. To put these numbers into perspective:

- Public background radiation exposure is about 300 mrem per year
- A single CAT scan (for medical diagnostic purposes) creates an exposure of 1.3 rem
- Worker radiation standards are set at 5 rem per year
- Radiation effects occur around 1,000 rem or higher

Figure 4.1: Hypothetical Plume due to a Release in the Medium Scenario

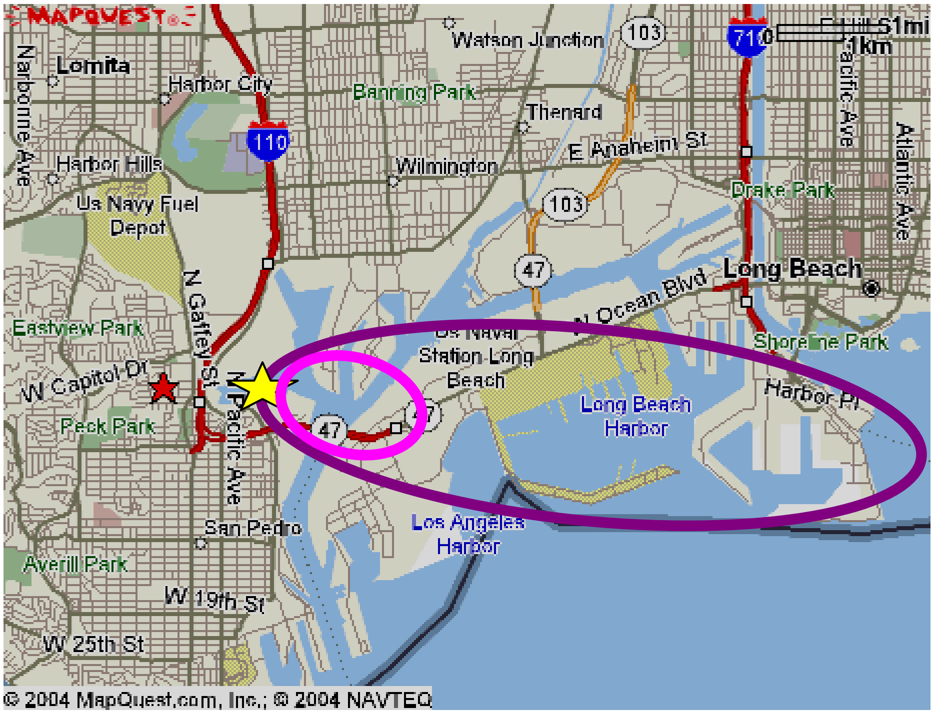
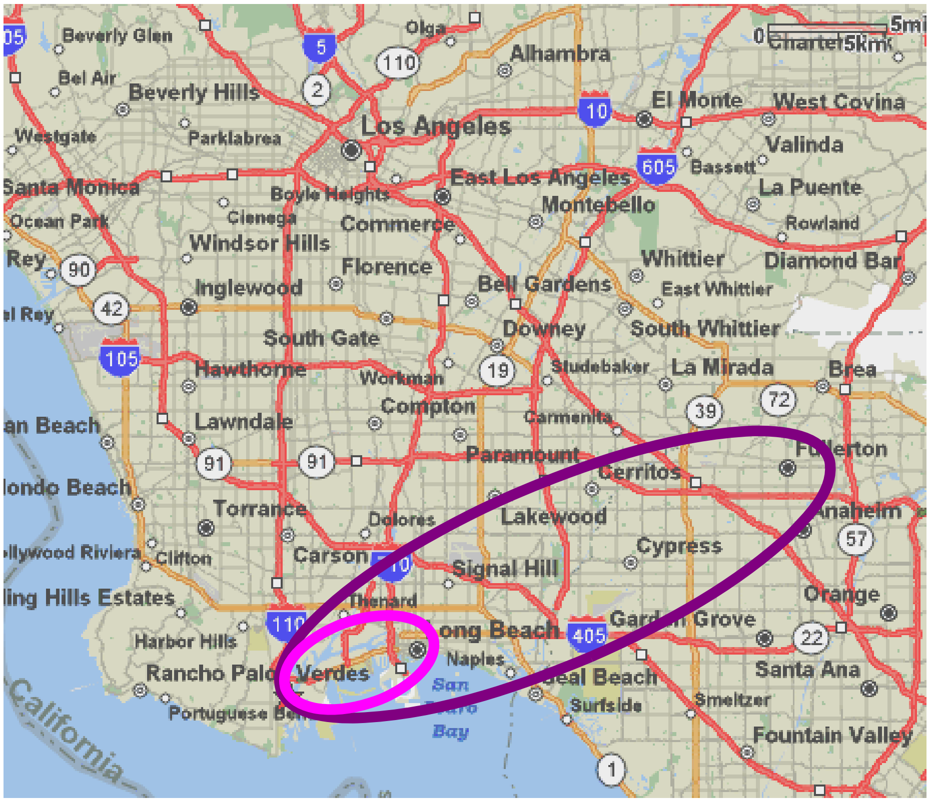


Figure 4.2: Hypothetical Plume due to a Release in the High Scenario



While these numbers may not be comforting to those exposed to 100 mrem or more, it is clear that the health impacts will be relatively small.

Initial exposure to radioactivity occurs through inhalation of contaminated material as the plume passes over an area. Typical calculations assess the amount of exposure during the first four days following the event. To get a rough first order approximation of the 4-day exposure, the analysis assumed median exposure values (500 mrem) in the outer ellipse of the plume and higher exposures in the inner ellipse (2 rem) in order to calculate and integrate population doses. All persons located in the area covered by the radioactive plume are susceptible to radiation exposure and contamination (both internal and external).[2] Of those impacted, the findings showed that the medium radioactivity release scenario manifested into tens of latent cancers and the high radioactivity release scenario resulted in hundreds of latent cancers. These cancers would not occur immediately or even in the short term, but could take years or even decades to develop.

While Figures 4.1 and 4.2 identify the area in which short and medium term exposure to radioactive materials could occur, there also might be a significant level of ground deposition resulting in long term exposure consequences. Radiation from deposition is usually referred to as “ground shine.” The process by which deposed material is resuspended, inhaled, or gets into the food chain are complicated. Only a fraction of this radioactive material eventually is absorbed by people, thus creating the same effect as the inhalation of material transported

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[2] Radioactive contamination and exposure could occur if radioactive materials are released into the environment following an accident, natural event or act of terrorism. Radiation exposure occurs when a person is near to or exposed to a radiation source. For example, when a person has an x-ray, he or she is exposed to radiation. Radioactive contamination results when radioactive material settles on or in an object or person. For example, a contaminated person has radioactive materials on their skin or inside their body. Air, waiter, plants and buildings also could become contaminated.

through the plume. This process will occur continually until decontamination procedures are effective.

According to the NARAC models, the ground shine contours are similar to those shown in Figures 4.1 and 4.2 with the outer ellipse defining areas above 100 mrem per year and the inner ellipse defining areas exceeding 1 rem per year. To get a first order approximation of the health effects, we assumed all the ground shine would be absorbed by people living in the plume area during the first year following the attack. This assumption is clearly pessimistic, since only a fraction of the ground contamination would be resuspended or get into the food chain during this time. Next, we assumed decontamination would be successful within a year following the attack and that no additional ground shine occurs thereafter. This assumption is probably optimistic, since decontamination might take longer and some ground shine might remain even after decontamination procedures. Together, these assumptions imply that the health effects due to ground shine are approximately the same as those due to the first four days of plume exposure. Both estimates are included in the health effect ranges shown in Table 4.1.

Economic Consequences. One of the major concerns about the dirty bomb threat to the ports of Los Angeles and Long Beach is the potential for an extended shutdown of the region's operations. While it is very hard to predict how long the ports would be inoperable following the medium and high radioactivity attacks, it is understood that large areas of the ports would be subjected to short, medium or even long term closures because of:

- Concerns of dock worker about returning to work
- Concerns of shippers about delivering goods to the harbors
- Extensive procedures related to decontamination activities

Several shutdown scenarios were analyzed, ranging from short (15 days) to medium (120 days) to long (one year). A regional, spatially disaggregated input-output model was used to estimate the total regional and national impact of these three shut down scenarios.(22) The results are shown in table 4.1. The 15 day shut down has a small impact (about $300 million) because most ships would simply wait out the port closures and businesses would be supplied through other ports. The 120 day and one year shut down, in contrast, have significant impacts ($63 and $252 billion, respectively) because they account for the economic impacts of a delay of delivering goods as well as all ripple effects throughout the nation's economy that such long-term delays involve. This includes costs ranging from the loss of local dockworker jobs to the reduced income and possible forced closure of nationwide businesses not receiving necessary parts or retail products.

Additional analysis focused on the costs associated with the evacuation of the plume area and reductions of property values and business losses resulting from stigmatization of businesses in the contaminated region. We assumed all residents and businesses would evacuate for one week from a plume with higher than 100 mrem activity (see Figures 4.1 and 4.2). In addition, property values in the plume area were estimated to drop by 25% during the first year following the attack and then recover to previous levels.(23) Finally, we assumed business activity would be reduced by 10% for the first year following the attack and then return to former levels.(24)

The results in Table 4.1 show that the economic impacts of the evacuation are small. This occurs because the evacuees would likely continue their business as usual, albeit from shelters, homes of family or friends, or hotels. The cost of the (temporary) reduction in property values is in the hundred of millions, but not nearly in the same magnitude as the cost of shutting down the ports. The cost of business disruptions could be fairly large, certainly in the billions of dollars, but only if one assumes the majority of businesses relocate outside of the region or cease to exist.

In addition to the social costs inflicted upon the contaminated region, there are extensive costs associated with decontaminating surfaces with depositions of radioactive material. More specifically, the cost of decontamination depends on the required clean up level and the cost of disposing low-level radioactive material. One study estimated extremely large costs (in the trillion dollars) for a high radioactivity scenario plume.(25) This was based on the assumption that the clean up standards would be those promulgated by the Environmental Protection Agency (15 mrem) and the cost of disposal would be similar to that imposed by the current low-level radioactive waste sites at Barnwell in North Carolina or at Envirocare in Utah. Using less stringent clean up standards (e.g. one rem) and disposal costs closer to those of a landfill, these cost estimates can be reduced by a factor of 1,000. Nevertheless, the clean up costs are still in the billions (see Table 4.1).

5. Countermeasures

Current efforts to counter the threat of a dirty bomb attack involve plans to check all cargo for radiological contents.(26) For example, on June 4 2005, Secretary Chertoff announced that the Los Angeles and Long Beach ports will be equipped with sensitive radiological detection devices to screen all international cargo entering the harbor.(27) This is certainly a step in the right direction, as radiation portals, for example, are very effective and relatively unobtrusive measures to detect even very low levels of radiation.(28) However, the following discussion shows that significant threats remain, even within the specific set of scenarios analyzed in this paper. While we have identified several additional effective countermeasures, only limited details can be revealed for security reasons.

Consider the current plan to place radiation our preliminary analysis of delivery modes and locations of a dirty bomb attack, these countermeasures are not sufficient to mitigate the risk dirty bomb attacks. In particular, additional radioactive detection measures would be useful in the perimeter and buffer zone of the ports.

Furthermore, one of the complicated aspects of countering terrorism is that terrorists shift their attack modes in response to our defensive actions. In the case of radiological detection devices, it seems likely that terrorists would attempt to develop attack scenarios that avoid any newly installed radiation detection devices. Thus, trucks or cars having to go through screening check points would be a less choice method of attack. Instead, terrorists might opt for delivery vehicles that completely bypass detection measures.

Another problem with radiological detection devices is the anticipated rate of false alarms. These devices can detect radioactivity levels very close to background. They have the potential to pick up radiation from many sources other than weapons grade material or radioactive material used in dirty bombs. For example, some naturally occurring material, such as granite, has low radioactivity levels that might be detected. People who recently received medical procedures involving radiography also are likely to set off alarms. It is very important to define the sensitivity of the detection devices at the “correct” level (balancing the costs of missing a threatening device against the cost of too many false alarms). Significant research exists in this area, known as “signal detection theory,” that can guide the operators of these systems to set the “correct” level of sensitivity.(29)

When optimizing the sensitivity of the detection devices, the costs and benefits of false alarms, hits, misses, and correct rejections (using the signal detection terminology) have to be considered carefully together with the probability that a piece of cargo might contain a radiological device. Fortunately, the initial inspection at the radiation portal is a relatively efficient process. However, if the alarm is set off, the truck or container must go into a special inspection cue. Such secondary inspections create shipment delays, require significant amounts of manpower and incur large operational costs.(30)

In addition to highlighting ways of modifying current countermeasures efforts at the ports of Los Angeles and Long Beach, our research demonstrated how a terrorist attack can be interrupted at many stages. The project risk analysis identifies the attack tasks most susceptible (from the terrorists' point of view) to disruption and thus defines the terrorists' vulnerabilities (see Table 3.1 for an example). In the dirty bomb scenarios discussed in this paper, the findings suggest that the most cost-effective solution is to prevent or interdict the purchase or theft of radiological material. Radioactive material in the U.S. is highly regulated by the NRC and thefts are difficult to carry out successfully. In our attack scenario involving theft from a research or industrial facility, we hypothesized that an employee would assist in attempting to bypass NRC barriers. As such, one implication of focusing on this phase of the attack would be the benefit associated with improving security of the facility, particularly management of employees with access to radioactive sources. Similarly, in the scenario involving theft or purchase of significant material in the former Soviet Union, U.S. and IAEA cooperation in securing these facilities and other non-proliferation safeguards also is advantageous.

6. Conclusions

A terrorist attack upon the U.S. using a dirty bomb is possible, perhaps even moderately likely, but would not kill many people. Instead, such an attack primarily would result in economic and psychological consequences. Moreover, it would not be easy to carry out a dirty bomb attack. Considering the difficulties associated with obtaining and transporting radioactive material, building the dirty bomb, and detonating the device successfully, our preliminary analyses suggest the chances of a successful attempt are no better than 60%. Of course, multiple attempts would increase these chances. For example, with three independent attempts, each having a probability of 60% success, the probability that at least one of them succeeds is 94%. While our probability estimates are mostly illustrative, the chances of terrorists succeeding with an attack that involves relatively low-level radioactive material from a U.S. facility are larger than their chances of succeeding with the import of a large quantity of foreign sources. This is because transporting foreign source material through a number of international ports increases susceptibility to detection.

If a dirty bomb attack is successful, the consequences depend primarily on the amount of radioactive material in the detonated source term, the amount released into the air, weather conditions and the population density in the impacted region. The two scenarios analyzed in detail suggest there would be some, but fairly limited health effects and possibly significant economic impacts.

The most costly economic impact would result from a lengthy shut down of the ports and decontamination efforts. The length of the harbor shut down would in part depend on the decision to declare access to the ports as safe. In a national emergency, standards of safety different from those promulgated by the EPA may be appropriate. For example, NRC worker safety may be more appropriate than public safety standards. The same also holds true for clean up standards. Because we don’t know how policy makers and harbor workers will react in such an emergency, we have parameterized the length of the harbor shutdown, from 15 days to one year, corresponding to roughly $138 million to $100 billion in costs.

The economic consequences of evacuations, property value impacts, and business losses due to stigmatization in the plume area are in the billions, but not in the tens or hundreds of billions. People and the economy are presumed to respond in a resilient way. Many people would relocate for some time out of the areas with relatively high levels of radioactivity (100 mrem or more), but they would not stop working. Also, businesses may relocate and later return to their original location. Similarly, effects on property values may be severe in the short term, but like in many other disasters, return back to normal in a year or so.

Regarding countermeasures, our analysis clearly supports ongoing programs to install radiation detection technology around the harbor. In addition, the analysis raises concerns regarding the security risks associated with cargo material as it is offloaded from ships, but not yet transported through the portals, incoming containers from the U.S. mainland (by truck, small boat or air), and harbor perimeter control. Finally, the analysis suggests preventing terrorism by interdicting vulnerable activities during the planning and preparing stages of an attack scenario. Such action might include being more proactive in controlling and protecting the original sources of radioactive material.

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