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

CREATE Report

June 12, 2005

Heather Rosoff

and

Detlof von Winterfeldt

School of Policy, Planning and Development
University of Southern California
Los Angeles, CA 90089-1450
This research was supported by the United States Department of Homeland Security through the Center for Risk and Economic Analysis of Terrorism Events (CREATE) under grant number EMW-2004-GR-0112. However, any opinions, findings, and conclusions or recommendations in this document are those of the authors and do not necessarily reflect views of the United States Department of Homeland Security. We would like to thank Richard John for major contributions in the probabilistic modeling. We would also like to thank Elsa Lee for major contributions in developing scenarios and estimating probabilities. The staff of the National Atmospheric Release Advisory Center (NARAC) at the Lawrence Livermore National Laboratory provided us with example plumes and exposure estimates. The CREATE economics team headed by Peter Gordon, Jim Moore, and Harry Richardson provided the economic impact estimates. We also benefited from many discussions with teams at national laboratories working on dirty bomb issues, including Battelle Pacific Northwest Laboratories, Sandia National Laboratory, and Lawrence Livermore National Laboratory.
Abstract

This paper analyzes possible terrorist attacks on the ports of Los Angeles and Long Beach using a radiological dispersal device (dirty bomb) to shut down their operations and cause substantial economic and psychological impacts. Using risk and economic analysis methods, the paper first identifies the most likely attack scenarios in terms of sources of radiological material, delivery modes and detonation sites. For each of these scenarios, a project risk analysis is developed to determine the tasks terrorists would have to perform and the probability of the project’s success. Next, the consequences of a successful attack are described in terms of human health effects and economic losses. The main results 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 due to a shutdown of the harbors could be very large. Implications for 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) has been cited as among one the most serious terrorist threats.(1) Several recently reported incidents increased 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 how to use the explosive device.(3) However, a dirty bomb never has been successfully used worldwide.

A dirty bomb is an attractive 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. The building of a dirty bomb is recognized by experts as being a fairly simple process, requiring little more than the skills needed to assemble a conventional bomb.(6) Assuming this is true, the primary challenge faced by terrorists is procuring the radioactive material. However, 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 account for because the countries do not have systemic procedures for such purposes. However, 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 falling in clumps or large particulates near the location of the explosion, some forming a radioactive plume. No nuclear-fission reaction takes place 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 effects. 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.

*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. Ports are vulnerable since they 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, 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 and the regional and national economy.

This paper presents a risk 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, including health effects and economic impacts of a port shutdown, and discuss effective countermeasures. The next section 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 puts forth a methodology
and some preliminary findings for estimating the relative likelihood of a successful attack.

Section four presents the results of an analysis of the consequences of the two most likely attack scenarios in terms of health effects and economic consequences. Section five examines possible countermeasures and their cost effectiveness.

### 2. Sources of Radioactive Material

Millions of radioactive materials have been 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.\(^{(11)}\) And 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

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

*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.*
waste facilities, industrial and blood irradiators, and radiography equipment are among some of the primary sources that require radioactive material to operate. To build a dirty bomb, any of the radioactive material necessary for these applications could be employed.

Nuclear reactor and waste facilities. In the U.S., nuclear power and waste facilities contain millions of curies of radioactive material that is mostly deadly in nature, but also extremely difficult to obtain and handle. While nuclear reactors are used to generate electricity, nuclear waste facilities store high to low levels of radioactive material. Spent nuclear fuel is found near nuclear reactors in pools or dry storage. 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 is 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, making them susceptible to security risk. To the contrary, the procedures for
sterilizing equipment and medical diagnosis do not give rise to security concern since they require extremely low doses of material with short half-lives.

Industrial facilities use radioactive material to operate 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 medical, research and industrial 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.\(^{(17)}\) Compared to the U.S., acquiring material of this quantity without detection is less challenging in the former Soviet Union due to different accountability and security standards. The surplus of radioactive material and the large number
of sites with inadequate protection present opportunities for illegal stealing, selling and trafficking.

In addition, the former Soviet Union 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.\(^{18}\)

3. Attack Scenarios

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:

1. Theft of radioactive material from a radiotherapy device in a U.S. hospital
   (5,000 Ci of Co 60) 

2. Theft of radioactive pellets from a blood or industrial irradiator in a U.S. facility
   (50,000 Ci of Cs 137) 

3. Purchase of a spent fuel assembly from a former Soviet Union nuclear power or reprocessing plant (1,000,000 Ci of several isotopes) 

In the 5,000 Ci scenario, 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 50,000 Ci scenario is assumed to be the same as the 5,000 Ci scenario, except that a different source and larger quantity of material is stolen from a U.S. blood
or industrial irradiator. The 1,000,000 Ci scenario involves the purchase of a spent fuel assembly in Chechnya that is transported to the U.S. by ship. Each scenario is characterized by the type of bomb constructed, delivery mechanism, and detonation site.

*Type of bomb constructed.* The type of dirty bomb constructed can vary in sophistication depending on the quantity and size of the radioactive material used and the amount of time provided to assemble the device. When constructing the dirty bomb, 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. Depending on these factors, a dirty bomb might result in very minor consequences (dispersing a few clump of radioactive material in a fairly small area) or significant consequences (dispersing a large fraction of the radioactive source material as aerosols or fine particulates into the air).

Also, the time allocated for bomb construction is fairly sensitive to the possibility of detection following material theft or black market purchase. If the theft or purchase is 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. In cases where the theft has gone undetected, the terrorist has the opportunity to pay closer attention to the sophistication of bomb design.

*Delivery modes.* Terrorists are likely to select a delivery mode that provides for the least probability of detection and increases the level of damage to the ports. As such, the vehicle of choice is based upon what is the ideal means of transport to the detonation site. The ports of Los Angeles and Long Beach are surrounded by land, air and sea access. 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 one of cargo trains. With respect to arriving through one of 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 an alternative mode of transport, although less likely because of additional security barriers associated with gaining access to them.

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._ For a terrorist, the optimal detonation site causes damage resulting in lives lost and economic consequences. To increase the effects of the bomb, the selected location is best characterized by 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 a bridge or in a helicopter would enhance the dispersal of the materials. 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, 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, high wind velocity blowing out to sea and a detonation site located miles from the harbors might deem the attack insignificant.
Probabilities of Scenarios. The analysis examined a total of 36 possible terrorist attack scenarios – 12 for each of the source scenarios. The theft of 5,000 Ci from a U.S. radiotherapy device originally was considered as a modest source of radioactive material for a small-scale dirty bomb attack. The analysis of this scenario was discontinued because detonating a dirty bomb of this size may only release a small amount of radioactivity into the air (500-2,000 Ci) and would thus be not very effective in an open space. 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, the research focused primarily on the two high-end scenarios, theft of 50,000 Ci from a U.S. based blood or industrial irradiator and purchase of a 1,000,000 Ci Russian spent fuel assembly.

After evaluating the conditions for building a dirty bomb, choosing a mode of transport and selecting a detonation site, the analysis was narrowed down to the four mostly likely attacks associated with the 50,000 Ci and 1,000,000 Ci scenarios. Figures 3.1 and 3.2 show how we deduced four attack scenarios from this analysis. In the 50,000 Ci scenario, we assumed this quantity of material could be used to produce a portable dirty bomb of moderate consequence. In addition, because the theft is U.S. based, terrorists would plan to access the port via land using a truck. As such, the boxes labeled “Likely” indicate that a terrorist would most likely consider the following two scenarios: detonating the dirty bomb when (1) driving over one of the bridges entering into the Los Angeles and Long Beach harbors, or (2) on one of the access roads closer to the vicinity of the ports. Comparatively, the boxes labeled “Unlikely” signify possible, yet unlikely, attack scenarios. Unlike driving over public bridges or on city streets, obtaining access to a plane or helicopter leaves terrorists facing security challenges and other formidable barriers to attack execution success. Detonation of a dirty bomb near a ship or railway inside the port is
also appealing to terrorists, as any attack that takes place within the ports will increase the level of direct damage to a port’s infrastructure. Yet, for reasons such as increased security and population density, the chance of detection is greater compared to a detonation site outside the port. The boxes labeled “Not Plausible” are those scenarios that logically don’t make sense for a terrorist to carry out. For example, there is no train on the Vincent Thomas Bridge, a possible detonation point. As such, it would not make sense to detonate a dirty bomb stored in a train on any of the bridges in the vicinity of the harbor.

### Table 3.1: Theft from a Research or Industrial Facility

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>TRANSPORTATION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TRUCK</td>
</tr>
<tr>
<td>Bridge</td>
<td>Likely</td>
</tr>
<tr>
<td>Harbor - Ground</td>
<td>Likely</td>
</tr>
<tr>
<td>Harbor - Elevated</td>
<td>Not Plausible</td>
</tr>
</tbody>
</table>

A 1,000,000 Ci source could be used to produce a portable dirty bomb of severe consequence. Because the purchase of radioactive material takes place overseas in the former Soviet Union, the most logical attack scenarios terrorists might pursue would entail entering the port by water on a cargo ship. The “Likely” boxes indicate a terrorist would most likely consider the following two scenarios: remote detonation of the dirty bomb when (1) the cargo ship carrying the device is docked within one of the respective ports, or (2) one of the cranes raises the cargo container carrying the device. The “Unlikely” boxes illustrate that, while such an attack by train or truck is possible, there are additional risks and difficulties associated with
carrying out these scenarios. The planning and preparing required to remove the dirty bomb from
the cargo container in hopes of finding a better detonation location by land or air increases the
chances of detection significantly. The “Not Plausible” boxes represent cases that are logically
not possible or highly implausible. For example, it is very unlikely that terrorists would chose to
ship radioactive materials into one harbor, then ship it to the ports of Los Angeles and Long
Beach for detonation. Aircraft attacks are implausible, because of the weight of the material.

Table 3.2: Purchase or Theft of a Russian Spent Fuel Assembly

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>TRANSPORTATION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TRUCK</td>
</tr>
<tr>
<td>Bridge</td>
<td>Unlikely</td>
</tr>
<tr>
<td>Harbor - Ground</td>
<td>Unlikely</td>
</tr>
<tr>
<td>Harbor - Elevated</td>
<td>Not Plausible</td>
</tr>
</tbody>
</table>

Probabilities of Success. The two “Likely” scenarios in Table 3.1 and 3.2 differ only in
minor ways (bridge vs. port location in Table 3.2 and ground vs. elevated location in Table 3.2).
Further analysis was therefore conducted on only two scenarios: Ground location in or near the
port for the 5,000 Ci truck scenario and elevated cargo location in the port for the 1,000,000 Ci
ship scenario.

Microsoft Project was used to lay out the details for both scenarios. This software
originally was created to provide businesses with an electronic tool that tracks a project’s
progress by task, timeline and resources. A terrorist attack operates much like any other complex
project, starting with an attack planning phase, followed by the actual preparations for the attack
and culminating with the attack execution. For both the 50,000 Ci and 1,000,000 Ci scenarios, Microsoft Project was used to outline planning, preparing and execution tasks, and defined each in terms of task duration and number of resources required. For example, in the 50,000 Ci 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 for 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 50,000 Ci scenario network diagram. They illustrate the steps involved for two separate tasks, building the dirty bomb and transporting the dirty bomb into the harbors. More specifically, Figure 3.1 shows how building the dirty bomb involves obtaining the explosive and radioactive material prior to assembling the device. Figure 3.3 depicts how all the individuals 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

Building the Dirty Bomb
Start: 10/3/05 ID: 38
Finish: 11/18/05 Dur: 7.2 wks
Comp: 0%

Obtaining the explosives
Start: 10/3/05 ID: 39
Finish: 10/4/05 Dur: 0.4 wks
Comp: 0%

Obtaining the RAD material
Start: 10/10/05 ID: 41
Finish: 11/4/05 Dur: 4 wks
Comp: 0%

Assembling the dirty bomb
Start: 11/7/05 ID: 44
Finish: 11/18/05 Dur: 2 wks
Comp: 0%

The Dirty Bomb Attack
Start: 11/21/05 ID: 46
Finish: 11/21/05 Dur: 0.18 wks
Comp: 0%

Start: 11/21/05 ID: 46
Finish: 11/21/05 Dur: 3 hrs
Res: DB Terrorist

Figure 3.2: Microsoft Project Tasks – Transporting the Dirty Bomb

Transport the dirty bomb into
Start: 11/21/05 ID: 44
Finish: 11/21/05 Dur: 0.15 wks
Comp: 0%

Pick up dirty bomb
Start: 11/21/05 ID: 45
Finish: 11/21/05 Dur: 3 hrs
Res: DB Terrorist

Remote detonate from an off-s
Start: 11/21/05 ID: 47
Finish: 11/21/05 Dur: 1 hr
Res: DB Terrorist

Drop off the dirty bomb at dete
Start: 11/21/05 ID: 46
Finish: 11/21/05 Dur: 3 hrs
Res: DB Terrorist

Start: 11/21/05 ID: 46
Finish: 11/21/05 Dur: 3 hrs
Res: DB Terrorist
For the 50,000 Ci and 1,000,000 Ci attack 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 identified the most vulnerable tasks and assigned a probability of success to each. Collaborating with a counterintelligence specialist, we identified the most vulnerable tasks for further analysis. Table 3.3 lists these tasks for the 50,000 Ci scenario. For example, the theft of radioactive material is clearly a very vulnerable task from the perspective of the terrorists.
Table 3.3: 50,000 Ci Scenario Vulnerable Tasks

<table>
<thead>
<tr>
<th>TASKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel into the U.S. - the coordinator</td>
</tr>
<tr>
<td>Obtain a job at the selected facility (for stealing the radioactive material)</td>
</tr>
<tr>
<td>Steal radioactive material from research hospital</td>
</tr>
<tr>
<td>Transport radioactive material to construction site</td>
</tr>
<tr>
<td>Casing of the Los Angeles Port</td>
</tr>
<tr>
<td>Travel in the U.S. - attack executioners</td>
</tr>
<tr>
<td>Assemble the dirty bomb</td>
</tr>
<tr>
<td>Transport the dirty bomb into the LA Port</td>
</tr>
<tr>
<td>Phase 1: Dirty bomb detonation - first explosion</td>
</tr>
<tr>
<td>Phase 2: Second explosion</td>
</tr>
</tbody>
</table>

The probability of each of these tasks being successful depends on the complexity of the task, the number of people involved, and the time it takes to perform the task. Preliminary assessments of probabilities of success were made for a given estimate of the number of people involved and the time to completion. A logit model was used to estimate changes of these probabilities as a function of changing the number of people and time to 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.

All assessments were made by the research team with the help of a counterintelligence specialist, using only publicly available, open-source data. They represent very preliminary estimates and are largely illustrative of the methodology used. Refinements of these probability estimates would involve access to classified data as well as use of established procedures for the formal elicitation of probabilities from counterintelligence experts.
An example of the overall result of the probabilistic simulation is shown in Figure 3.4 for the 50,000 Ci scenario. Interestingly, the probabilities of success are relatively small (less than 60%). This is due to the fact that for the overall project to be successful, all individual tasks must be successful. 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 (50,000 Curie Scenario)**

4. Consequences

The consequences of a dirty bomb attack roughly fall into three categories: immediate fatalities and injuries due to the blast effects and acute exposure from radioactive material, medium and long-term health effects due to airborne dispersal of radioactive material, and economic impacts due to shutting down port operations, evacuations, business losses, and clean-up costs. In both the 50,000 Ci and 1,000,000 Ci scenarios, we assumed that 20% of the material was released into the air as aerosols or fine particulates, thus creating a plume with 10,000 Ci or 200,000 Ci, respectively. The ranges of estimates are shown in Table 4.1.
### Table 4.1: Ranges of Consequence Estimates

<table>
<thead>
<tr>
<th>Consequences</th>
<th>10,000 Ci Release</th>
<th>200,000 Ci Release</th>
<th>Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blast and Acute Radiation Effects</td>
<td>0-10</td>
<td>0-50</td>
<td>Fatalities</td>
</tr>
<tr>
<td>Latent Cancers</td>
<td>0-10</td>
<td>0-500</td>
<td>Fatalities</td>
</tr>
<tr>
<td>Port Shutdown and Related Business Losses</td>
<td>0-200 million</td>
<td>30-100 billion</td>
<td>Dollars</td>
</tr>
<tr>
<td>Evacuation Cost (Plume)</td>
<td>negligible</td>
<td>10-100 million</td>
<td>Dollars</td>
</tr>
<tr>
<td>Business Loss (Plume)</td>
<td>negligible</td>
<td>1-3 billion</td>
<td>Dollars</td>
</tr>
<tr>
<td>Property Values (Plume)</td>
<td>negligible</td>
<td>100-200 million</td>
<td>Dollars</td>
</tr>
<tr>
<td>Decontamination Costs (Plume)</td>
<td>10-100 million</td>
<td>1-100 billion</td>
<td>Dollars</td>
</tr>
</tbody>
</table>

*Blast Effects and Acute Radiation.* The fatalities and injuries from the detonation’s blast effects depend on the amount of explosives used and the population density in the area near the detonation site. The blast effects will occur primarily 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 poisoning might occur if bystanders or emergency workers rush to help blast victims and get in close contact with highly radioactive material for an extended period of time. In a 2004 dirty bomb exercise held in Long Beach, emergency workers rushed to the scene without protective suits. Had this been a real attack, they probably would have been exposed to significant amounts of radiation, though most likely not in a range that produces acute radiation effects. Once the radiation danger is recognized, hazardous material teams can establish an appropriate perimeter (typically several hundred feet) to avoid excessive radiation exposure by bystanders or emergency workers without proper protective gear.
Health Effects Due to Airborne Releases. Depending on the source and amount of radioactive material, the sophistication of the detonation device, and other factors, a fraction of the material will be airborne. This airborne and respirable fraction of the material can vary tremendously, from about 1% to 80% of the original source.\(^{(20)}\) 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 velocity determine the eventual development of a radioactive plume. Figures 4.1 and 4.2 show examples of the 10,000 Ci and 200,000 Ci 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 of an area with 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 CT scan conducted 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 10,000 Curie Release

Figure 4.2: Hypothetical Plume due to a 200,000 Curie Release
While these numbers may not be comforting to those exposed to 100 mrem or more, it is clear that although the plumes shown in Figures 4.1 and 4.2 define a fairly large area, not all of which is of direct health concern.

The initial exposure to radioactivity occurs through inhalation of the contaminated material as the plume passes through the area. Typical calculations consider the exposure during the first four days. To get a rough first order approximation of the health effects due to these 4-day exposures, the analysis assumed median exposure values (500 mrem) in the outer ellipse of the plume and higher exposures in the inner ellipse (2 rem) to calculate and integrate population doses. For the 10,000 Ci release scenario, this resulted in tens of latent cancers. The 200,000 Ci 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 longer 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 through the plume. This process will occur continually until decontamination is effective.

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 areas 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. 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.

The lower end of the health effect ranges included cases of our simulation in which one or more of the following occurs: (1) unsuccessful airborne releases due to faulty construction of the dirty bomb; (2) wind direction away from population 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.

Economic Consequences. One of the major concerns about a dirty bomb attack on the Los Angeles and Long Beach harbors is the potential threat for shutting down the ports for an extended period of time. While it is very hard to predict how long the ports would be shut down following the 5,000 Ci and 1,000,000 Ci attacks, it is understood that large areas of the ports would be subjected to short, medium or even long term closures because of:

- Decontamination activities
• Concerns of dock worker about returning to work
• Concerns of shippers about delivering goods to the harbors

Since it is hard to predict the length of the shut down, several 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.\textsuperscript{(21)} The results are shown in table 4.1. The 15 day shut down has a small impact (about $100 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 because they account for the economic impacts of a delay of delivering goods as well as all ripple effects throughout the economy that such long-term delays involve. For example, businesses not receiving necessary parts or retail products will have reduced income or may even be forced to close..

We also assessed the costs associated with evacuations in the plume area and reductions of property values and business losses due to stigmatization of businesses in the plume. Specifically, 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. Finally, we assumed business activity would be reduced by 10% for the first year following the attack and then return to former levels.\textsuperscript{(22)}

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 costs 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 costs 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.

*Decontamination Costs.* The cost of decontaminating surfaces with depositions of radioactive material 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) even for a 10,000 Ci plume. This was based on the assumption that the clean up standards would be those promulgated by the Environmental Protection Agency (15 mrem) and the costs of disposal would be similar to those 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).

**Summary of consequences.** Our preliminary analyses of a dirty bomb attack on the Los Angeles and Long Beach harbors clearly show the cost of shutting down the harbors is the most significant consequence. Short term fatality risks, in contrast, are minor and even latent cancer fatalities are relatively small. Evacuation and business disruption in the plume area is relatively small compared to the impact of the port shut down. Clean up costs could be substantial, even exceeding the costs of the port shut down, but only, if stringent EPA standards are applied and exorbitant fees for disposal are paid.

5. **Countermeasures**

Current efforts to counter the threat of a dirty bomb attack involve a plan to check all cargo for radiological contents. For example, on June 4, 2005, Secretary Chertoff announced
that all entry and exit points of the Los Angeles and Long Beach ports would be equipped with sensitive radiological detection devices in the form of portals.\textsuperscript{(24)} The goal is to have every truck exiting the harbors go through a radiation portal and thereby virtually assure radioactive material detection prior to entering the mainland U.S. This is certainly a step in the right direction, as radiation portals are very effective and relatively unobtrusive measures to detect even very low levels of radiation.\textsuperscript{(26)}

However, as the discussion below shows, significant threats remain, even within the specific set of scenarios analyzed in this paper. To begin with, the current plan to place the portals at the truck exits of the ports only results in container inspections as they leave the harbor. An attack involving an explosion during cargo offloading, as described in the 1,000,000 Ci scenario, would not be protected by this countermeasure.

Another problem with radiological detection devices is the anticipated rate of false alarms. These devices can detect radioactivity levels very close to background, and thus will likely pick up radiation from many sources other than weapons grade material or material used in dirty bombs. For example, some naturally occurring material 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.\textsuperscript{(27)}

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 brief (seconds) and straightforward. However, if the alarm is set off, the truck or container must go into a special inspection cue. This delays its shipment and possibly clogs up the area in which secondary inspections take place. In addition, secondary inspections could require a significant amount of manpower and associated costs.\(^{(28)}\)

Other security risks still remain that cannot be eliminated with radiation detection portals around the ports. One of this paper’s scenarios involved the delivery of a dirty bomb with a truck entering the harbor area. The layout of this attack scenario suggests that it might be desirable that trucks entering the harbor be subjected to radiation detection devices as well. Furthermore, terrorists could detonate the dirty bomb outside of the harbor perimeter and evade the radiological detection devices all together. Radiological detection devices along the main thoroughfares into the harbor might be a good additional security measure to consider.

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 radiation portals, it seems likely that terrorists would try to develop an attack scenario that avoids these portals. Thus, attacks with entering containers, using cars outside of the perimeter of the port, or using small boats or aircraft will become more likely.

Another important implication of this research is that a terrorist attack can be interrupted at many stages. In the dirty bomb scenarios discussed in this paper, perhaps 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 will be difficult. In our scenario involving theft from a research or industrial facility, we hypothesized the use of an employee. These types of scenarios suggest there are benfits associated with improving security
management of employees with access to radioactive sources. In the scenario involving theft or purchase of significant material from a nuclear reactor or reprocessing plant in the former Soviet Union, U.S. and IAEA support in securing these facilities is helpful.

Other intelligence and security measures also could help counter a possible dirty bomb attack. The project risk analysis can identify the attack tasks most susceptible (from the terrorists’ point of view) to disruption and thus define the terrorists’ vulnerabilities (see Table 3.1, for example). In scenarios involving the theft of radioactive materials from a U.S. research or industrial facility, clearly the most effective countermeasure is to improve security at the facility. Similarly, scenarios involving the purchase or theft of foreign materials, measures typically associated with non-proliferation safeguards should be examined.

6. Conclusions

A terrorist attack upon the U.S. using a dirty bomb is possible, perhaps even moderately likely, but it will not kill many people. Instead, such an attack results primarily in economic and psychological consequences. Moreover, it is not easy to perform a dirty bomb attack. Considering the difficulties in obtaining and transporting the radioactive material, building the dirty bomb and detonating it successfully, our preliminary analyses suggest that the chances of a success of a single 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% of 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 radioactive sources from a U.S. facility are larger than their chances of succeeding...
with an import of a large quantity from foreign sources. This is because transporting the foreign
source material through a number of international ports increases susceptibility to detection.

If a dirty bomb attack is successful, the consequences depend on the amount of
radioactive material in the detonated source term, the amount released into the air, and other
assumptions. The two scenarios analyzed in detail suggest there will be some, but fairly limited
health effects and possibly significant economic impacts. The most costly economic impact will
result from a lengthy shut down of the ports and decontamination efforts.

The length of the harbor shut down will 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 is 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.

Interestingly, the economic consequences of evacuations, property value impacts, and
business losses due to stigmatization in the plume area are not as large as previously considered
(in the billions, but not in the tens or hundreds of billions). People and the economy are
presumed to respond in a resilient way. For instance, while many people will relocate for some
time out of the areas with relatively high levels of radioactivity (100 mrem or more), they will
not stop working. Similarly, businesses may relocate and later return to their original location.
Also, 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, this paper’s analysis clearly supports ongoing programs to install radiation detection portals around the ports. The analysis also raises additional issues regarding the detection of materials offloaded, but not yet transported through the portals, incoming containers, and perimeter control. It also suggests being more proactive in controlling and protecting the original sources of radioactive material.
References

(8) The Port of Long Beach and Port of Los Angeles, ibid.
(9) General Accounting Office, ibid.
(10) General Accounting Office, ibid.
(12) Ferguson, ibid.
(13) Ferguson, ibid.
(14) Ferguson, ibid.
(22) P. Gordon, J.E. Moore, Q. Pan, and H. Richardson, ibid.
(28) Susan E. Martonosi, David S. Ortiz, and Henry Willis, ibid.