3-19-2009

The Economic Impact of a Radiological Dispersal Device (RDE)

Michael T. LeBrun

THE ECONOMIC IMPACT OF A RADIOLOGICAL DISPERSAL EVENT (RDE)

THESIS

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AFIT/GFA/ENV/09-M02

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AFIT/GFA/ENV/09-M02

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THESIS

Presented to the Faculty

Department of Systems and Engineering Management

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Financial Analysis

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March 2009

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

AFIT/GFA/ENV/09-M02

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AFIT/GFA/ENV/09-M02

Abstract

While it will not cause the devastation of a nuclear weapon, the radiological dispersal event (RDE) is particularly dangerous in that it has the potential to cause major economic disruptions. The purpose of this research was to develop a generalized methodology that can be used to assess economic impacts, resulting from a (RDE), occurring in any location and across any industry. Currently, there is no universal approach for measuring the costs or economic impacts on businesses, or a common framework for conducting an economic impact for a RDE. The objective of this research was to aid in the RDE response effort by providing government planners, officials, and key stakeholders with an (pre-RDE) economic assessment tool which can be used to quantify the economic impacts arising from a RDE, thereby facilitating the strategic decision making process. A random study site was selected to use as a practical application for the research methodology.

Through the use of an economic input-output model, the research identified that the economic impacts to the study site's output totaled $1.2 billion, while impacts to labor income totaled $529.6 million. Overall, 21,374 jobs were affected due to the economic disruptions resulting from the RDE.

The culmination of this effort was the development of a generalized, "off the shelf", economic impact assessment tool that can be used to estimate the financial impacts of a RDE, or any localized event which disrupts an economy.

To my beautiful and extremely supportive wife, and my dear sons.

Acknowledgements

It is with sincere appreciation that I would like to thank the following people for their patience, time, and expertise throughout the course of this thesis effort.

- Lt Col David A. Smith, Department of Systems and Engineering Management, Air Force Institute of Technology, WPAFB OH
- Dr. Leonard J. Kloft, Department of Economics, Wright-State University, Dayton OH
- Lt Col Jeffrey S. Smith, U.S. Air Force Academy, Colorado Springs CO
- Lt Col Eric J. Unger, Department of Systems and Engineering Management, Air Force Institute of Technology, WPAFB OH
- Technical Reachback Team, Defense Threat Reduction Agency, Ft. Belvoir VA
- Mr. Brian G. Harcek, 88th CE Directorate, WPAFB OH
- City of Fairborn OH, Engineering Department
- Ms. Toni Weideling, Chamber of Commerce, Beavercreek OH
- Department of Taxation, Ohio
- Mr. David A. Graham, Chie Deputy Auditor, Auditor’s Office, Greene County OH
- Mr. Steve Hipple, Bureau of Labor Statistics, Washington D.C.
- Mr. Jason Nunn, Engineering Division, City of Fairborn

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THE ECONOMIC IMPACT OF A RADIOLOGICAL DISPERSAL EVENT (RDE)

I. Introduction

A destructive act that has become increasingly more attractive to terrorists over the past few years has been the radiological dispersal event (RDE). Many papers have been written and studies conducted on the likely effects and emergency response procedures to a RDE. Several reports indicate that a RDE is less of an "if" scenario and more of a "when" scenario. While it will not cause the devastation of a nuclear weapon, in terms of lost lives and infrastructure, the RDE is particularly dangerous since it potentially can cause major economic disruptions. Additionally, psychological effects resulting from a RDE, like fear or hysteria, have the potential to further exacerbate economic disruptions.

According to the Center for American Progress, a team of nuclear researchers concluded that terrorists are "all but certain" to detonate a radiological weapon within the United States (Grotto, 2005). Several recently reported incidents have supported these concerns. For example, in May 2003, the U.S. arrested an American, Jose Padilla, in Chicago's O'Hare airport for his involvement with Al Qaeda in planning a radiological attack on the U.S. In January 2003, British officials found documents in the Afghan city of Herat indicating that Al Qaeda had successfully built a small radiological explosive device as well as possessed training manuals on how to employ it. Unlike nuclear warheads, designed to kill and destroy through a nuclear blast and heat, RDEs, rely on conventional explosives to disperse radioactive material widely. Since the nature of the RDE threat often is misunderstood, there is no shared appreciation of the problem or how best to address it. The reality is that the threat of a dirty bomb attack by terrorists is a credible one, although the psychological and economic consequences would likely far outweigh any casualties or physical destruction (Carafano, 2004).

The RDE threat is real, and an actual radiological attack could occur on U.S. soil during our lifetime unless preventive actions are taken now. For this reason, officials and planners at all levels of government must take a proactive stance in response to the threat. For a society to mitigate impacts to its financial system, precautionary measures must be implemented now rather than after an attack, when it's too late. A RDE potentially is quite costly, even more so to an unprepared community.

Research Purpose

This research develops a generalized methodology that assesses economic impacts, resulting from a RDE, occurring in any location and to any industry. Additionally, this study focuses solely on quantifying commercial impacts, and does not evaluate cleanup costs, remediation expenses, or impacts to residential property values. Currently, no universal approach for measuring the costs or economic impacts on businesses, or a common framework for conducting an economic impact for a radiological event exists.

Research Objective

Carafano and Spencer (2004) discuss the importance of increased domestic preparations for a radiological attack. Specifically, they address that these efforts should "focus on creating an emergency response system that enables state and local governments to efficiently pool their resources as well as effectively direct federal assets where they are most needed." To increase preparedness and improve the response to a radiological attack, leaders must first have a clear understanding of the threat. By doing so, they will attain a better grasp on the costs and risks associated with a RDE as well as invest financial resources more appropriately for preparation, prevention, and mitigation efforts. Conklin (2005) adds that, "in this era of limited fiscal growth and competing priorities, the federal government will have to work collaboratively with state and local governments, the private sector, nongovernmental organizations, and academia to ensure that the nation is capable of responding to a terrorist attack involving radioactive material."

The objective of this research aids in the response effort by providing government planners, officials, and key stakeholders with a pre-RDE economic assessment tool, which can be used for any region and industry. The tool quantifies the economic impacts arising from a RDE, and thereby facilitates the strategic decision making process. Rapid and effective action is vital to reduce the impact of terrorism and maximize recovery and resiliency to a RDE. It is critical that decision makers are equipped to make informed judgments as effectively and efficiently as possible, thus ensuring that an optimal mix of resources are available readily to deal with a RDE scenario. Disasters of any magnitude, whether manmade or natural, have the potential to create serious harm to an area's commercial base. According to Hardy and Roberts (2003), businesses that experience a disaster face a 40 percent chance of never reopening again and a 30 percent chance of closing within 2 years.

II. Literature Review

Introduction

This chapter examines prior documentation of radiological incidents, the economic fallout resulting from the incidents, and the methodologies that were used to quantify the economic impacts. Since detailed studies of economic impacts resulting from radiological terrorism are scarce, comparable studies such as the adverse affects of natural and manmade disasters on an area's economy are examined as a proxy.

Perception of the RDE Threat

According to the Center for Nonproliferation Studies, the economic impact of a radiological attack has "the potential to be as devastating, if not more so, than the physical attack itself". Furthermore, the decontamination process alone could cost billions of dollars. Potential causes for the extensive costs are that local businesses would have to cease operations for prolonged periods of time due to affected buildings that become unusable, and residents and businesses must relocate until the cleanup process is completed. The public's perceptions of continuing contamination could further persuade residents to settle in other areas and potential tourists to avoid the affected area or city altogether (CNPS, 2004). Additionally, the psychological perception of increased radioactivity in the area could have its own economic impact. Even if decontamination could be reduced to acceptable levels[1], the resulting decrease in an

1 The Environmental Protection Agency acceptable dose limit standards for individual-protection and human-intrusion is 15 millirem per year to a reasonably maximally exposed individual, who would be among the most highly exposed members of the public (EPA, 2008).

area's real estate prices, tourism, and commercial transactions could have long-term negative effects on the area's economy" (CNPS, 2004).

Economic Impacts and Population Resilience

Population resilience is an important factor to consider when dealing with economic impacts caused by disruptive events. Elcock *et al.* (2004) opines that "the detonation of a radiological dispersal device could produce significant social and economic damage, the extent of which would depend largely on how quickly and effectively cleanup levels were established and on public acceptance of those levels" (Elcock, 2004). Elcock's observation reinforces why the current research is critical; and that is to aid planners and city officials in formulating a more effective and efficient response.

One of the greatest drivers behind the overall economic impact of a RDE, and whether a community can successfully rebound from it, is the "resilience" factor. According to Rose *et al*.(2007), "economic resilience is the ability to mute the maximum impacts of an economic shock (disruption) through inherent and adaptive responses at the level of the firm, industry (market), or regional economy" (Rose, 2007). For example, higher resilience means that the majority of a population would return to a RDE area and resume their daily routines only if convinced [by local authorities] that a threat no longer exists. In the case of lower resilience, little to none of the population would return. If the latter scenario occurred, grave impacts could befall a local economy due to the fact that a lack of labor (workers) would adversely affect economic productivity. Without a substantial employment base in place, an economy would have a difficult time rebounding.

In the aftermath of a radiological attack, some residents may refuse to settle in an area that they consider contaminated. Furthermore, businesses, schools, and other industries which serve as the economic foundation for an area, may permanently relocate to an unaffected zone or another city altogether. As New Orleans experienced firsthand in the wake of Hurricane Katrina, much of that city's population never returned afterward. According to the *Economist* (2008), the current population of New Orleans, three years since Hurricane Katrina, showed that the city is currently at about 325,000 people, two-thirds the size that it was before Katrina, and no dramatic changes are expected over for the next few years.

Kindt (2006) discusses different methods that the American Psychological Association has developed in order to help populations enhance their resilience in the face of adverse situations. These methods involve building connections with others throughout the community, taking decisive action, keeping things in perspective, and avoid seeing the crisis as too large to be managed.

Additionally, Elcock *et al*. (2004) stresses how important it is that a population should do all it can to recover quickly from a RDE. Specifically, she notes that if individuals do not resume their normal activities as soon as possible, "economic and health hardships could pose more of a problem than any of the radiation health risks associated with current cleanup standards." Essentially, an unintended consequence of a population's failure to be resilient could force further economic failures.

In addition to resilience, it is equally important that a community expediently recover from a disaster so as to avoid serious adverse impacts to its economy. Every effort should be made to get businesses operational and people back to work to mitigate financial impacts. For example, in the aftermath of Hurricane Katrina, Governor Kathleen Blanco testified before the U.S. Senate that there were 80,850 businesses within Louisiana prior to the storm. Among the 64 total parishes within the state, the hurricane severely impacted 13 of them. The businesses that were severely impacted within the 13 parishes represented 41% of the Louisiana's total businesses (Babineaux-Blanco, 2005).

Economic Impact of a RDE - Twin Ports of Los Angeles-Long Beach

Gordon *et al*. (2005) conducted this study which examined the possible economic impacts associated with a RDE in the twin ports of Los Angeles and Long Beach, California. This study is significant in that it is one of very few that has been published which addresses the effects of a terrorist-induced RDE. Gordon and his economic team at the Center for Risk and Economic Analysis of Terrorism Events (CREATE) identified major United States ports as attractive targets for terrorists, mostly due to the fact that they can be accessed by land, air, and sea, as well as difficult to secure. Furthermore, major ports enable terrorists to achieve one of their most important goals, maximum economic damage. Since ports typically utilize several forms of transportation, including roads, railways, and ships, the closure of a port due to a dirty bomb attack for even a few days could have a severe impact on the supply chain of hundreds or even thousands of companies (Gordon, 2005).

Rosoff and von Winterfeldt (2007) followed-up on Gordon's research by providing a risk and economic analysis of dirty bomb attacks on the ports. They determined that the economic consequences from a shutdown of the harbors due to the contamination resulted in significant losses in the tens of billions of dollars, including decontamination costs, as well as business and property losses. The potential for an extended shutdown of operations (or the amount of time when the economy cannot function) is one of Rosoff's major concerns about a RDE threat to the L.A. - Long Beach ports, simply because the longer the ports are not operating the greater the effects will be on the local, state, and perhaps national economy.

Psychological Effects

As illustrated in the Goiania, Brazil scenario, Rosoff validates the notion of how businesses within the port area could possibly suffer economic losses due to the stigma of having their companies located within a contamination zone. Depending on the amount of commerce that occurs within the area, the business disruption costs could be 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 (Rosoff, 2007). The psychological aspect of contamination could have the ability to cause patrons and residents to leave the area and not return, thus directly causing the economic effects of the RDE.

Manmade Radiological Incident - Goiania, Brazil

The contamination which occurred in Goiania, Brazil near the end of 1987 was one of the most serious radiological accidents to have occurred to date (IAEA, 1988). This was not a terrorist act, but the consequences of this event provide a reasonable estimate of the possible economic impacts that could be experienced in the wake of a real-world RDE. Furthermore, the Goiania incident is similar to the current study in that the same radioactive material was employed, Cesium-137 (Cs-137). According to nuclear weapons expert John Pike, Cs-137 is the most likely material used in the assembly of a dirty bomb, due to the ease of attainment and the fact that it is available in "low-level waste from medical or research labs, or welding shops and construction sites"

(Boyle, 2002). In the Goiania case, the Cs-137 was acquired from an abandoned radiation-therapy unit when a private radiotherapy institute relocated its business. Two people entered the premises and, not knowing what the unit was, removed the source assembly from the radiation head of the machine, took it home, and dismantled it, subsequently rupturing the capsule which housed the radioactive material. Environmental contamination resulted from the unintentional dispersal of the material, resulting in 249 people externally irradiated, 129 people internally contaminated, and 4 deaths (IAEA,1988).

Economic and Psychological Impacts

The Goiania accident is one of many examples where a contamination event can impose great economic and psychological impacts on an exposed population. It is particularly important to note the psychological aspect of such events, particularly due to the direct affects that they can have on an economy. In the Goiania case, the fear of exposure to radiation, irradiation, and incurable damage to health, caused more than 200 residents to evacuate from the area. Additionally, some of the inhabitants suffered discrimination over radiation contamination, even by their relatives. Sales of cattle, cereals and other agricultural food products, as well as cloth and cotton products (the main economic products of the area) fell by 25% in the period after the accident (IAEA, 1988). Ultimately, the cost from 6 months of intensive cleanup, especially within a 1 square-kilometer area, during which seven houses and several buildings were demolished, amounted to $27.2 million. However, the indirect costs due to negative economic repercussions were estimated in hundreds of millions of dollars. Furthermore, [Goiania] GDP decreased by 20% and it took 5 years to recover (Sohier, 2006).

Manmade Radiological Incident – Chernobyl, Ukraine

The Chernobyl disaster in 1985, which was a much more severe case of radioactive contamination (non-terrorist RDE), occurred when Chernobyl Reactor Vessel - Unit 4 exploded, at the Chernobyl power plant, located in Northern Ukraine on the border of Belarus in 1986. As the result of a subsequent fire which burned for 10 days, large amounts of radioactive material (mostly iodine and cesium radionuclides) were released into the environment (IAEA, 2006). The contamination covered more than 200,000 square kilometers of Belarus, Ukraine and the Russian Federation, and left in its wake serious economic and psychological impacts on the affected population of more than five million people.

Economic and Psychological Impacts

Most of the economies affected by Chernobyl relied heavily on agriculture. Much of the work revolved around manufacturing wood products and food processing. After the accident, 1.9 million acres of agricultural land were removed from service in the three hardest hit countries, and timber production halted over 1.7 million acres of forest. As a result, the local (regional) economies were left in ruin.

According to the IAEA (2006), huge costs weren't confined only to Belarus, Ukraine and the Russian Federation. "Given the spread of radiation outside the borders of the Soviet Union, other countries (i.e. Scandinavia) sustained economic losses as well". Direct and indirect costs that were incurred as a result included actions taken to seal off the reactor and mitigate the consequences in the exclusion zone, relocation of the affected populace (more than 330,000 people) and construction of new housing and infrastructure to accommodate them, and social protection and health care which had to be provided to the affected population. Additionally, lost opportunity costs resulted due to the removal of agricultural land and forests from use, and the lost electricity production at the Chernobyl nuclear plant (IAEA, 2006).

Even today, the economies that were affected by the Chernobyl accident still deal with financial burdens. For example, the Ukraine spends roughly 5 to 7 percent of its government budget on Chernobyl-related issues, while Belarus spent roughly 22.3 percent of their 1991 national budget on Chernobyl-related costs (eventually declining to 6.1 percent in 2002). Between 1991 and 2003, Belarus' total spending on Chernobyl-related costs was estimated at more than $13 billion dollars. Particularly, Ukraine and Belarus have developed severe financial burdens due to the extent of costs incurred; including large sums of money which continue to be paid in the form of social benefits for as many as 7 million victims in the three countries (IAEA, 2006).

Despite the economic hurdles that many of the affected areas faced as a result of Chernobyl, psychological impacts further exacerbate the adverse economic conditions. According to findings from the Chernobyl forum, despite the fact that remediation efforts have enabled "clean food" production to remain possible in many of the affected areas, and has made farming safe, the stigma of Chernobyl has caused some consumers to reject products from affected areas. The area's food processing operation has been particularly hard-hit by this "branding" issue (IAEA, 2006). As a result, agricultural revenues have fallen, production in other areas has declined, and some facilities have closed altogether. In terms of resilience, the majority of inhabitants who lived in the vicinity prior to the disaster permanently resettled elsewhere due to the extent of radiation, either by choice or by government mandate.

Economic Consequences of Natural Disasters

RDEs and natural disasters can share similar consequences. Some of these similarities consist of magnitude of physical destruction, potential for contamination, and psychological effects. Each characteristic, individually or collectively, potentially plays a significant role in determining overall economic effects on a local economy.

Hurricane Katrina

Hurricane Katrina was particularly significant in that it demonstrated how a natural disaster single-handedly could destroy a significant portion of an area's economic base (Milligan, 2006). According to Burton and Hicks (2005), initial aggregate damage estimates on the economies of Louisiana, Mississippi, and Alabama due to Hurricane Katrina were calculated (on infrastructure, residential, commercial structures, content and equipment) to be in excess of $156 billion.

Furthermore, in her testimony to the Senate Finance Committee in 2005, Louisiana Governor Kathleen Blanco pointed out the lack of precedent in America's history for the scale or type of economic challenges presented by Katrina (Babineaux-Blanco, 2005). Similar to what could be expected from a terrorist-RDE scenario, the fallout of Hurricane Katrina is relevant to the current study in that an event of this magnitude had never been experienced before. Hurricane Katrina is a great illustration of how a disaster can take a region by surprise and reveal to governing officials the lack of preparation to deal with a crisis of this scale.

In terms of economic impact, the employment base (which is a big part of an economy's growth) was most notably affected. According to the National Hurricane Center, the hurricane severely impacted workplaces in New Orleans and other heavily populated areas of the northern Gulf Coast, which resulted in thousands of lost jobs and millions of lost tax revenues (Milligan, 2006). These consequences are both widespread and long-lasting due to their impacts on large population and tourism centers, as well as the petroleum and transportation industries. Citing Federal Emergency Management Agency (FEMA) data, the Louisiana Recovery Authority said that approximately 360,000 residents were forced to leave the state (Milligan, 2006). This represents roughly 8 percent of Louisiana's workforce - which is a notable amount of labor to leave the area. Like what would happen in the event of a RDE, economic activity in the Gulf Coast region either partially or entirely ceased for a time while clean-up efforts occurred. In terms of contamination, the New Orleans' area dealt with mold (excessive moisture) and the economy suffered from the mass exodus of local businesses and residents, which stripped the local economy, particularly local governments, of much needed revenues especially during a time when they needed these funds the most.

Additionally, the National Hurricane Center stated that economic and environmental effects could be an ongoing ordeal, mostly due to the impacts inflicted upon key industries, such as tourism, oil and gas, and transportation. Numerous workplaces were severely impacted by the hurricane in New Orleans. Thousands of jobs and millions of dollars in tax revenues were lost by communities and states (Milligan, 2006). After all costs were tallied, the final damage cost from Hurricane Katrina exceeded more than $110 billion, the costliest hurricane in U.S. history (Katrina Relief, 2009).

National Planning Scenarios: Radiological Attack - Radiological Dispersal Devices

The National Planning Scenarios report (2006) is formulated on an annual basis by federal homeland security experts. It serves as a disaster preparedness tool for entities at all levels of government, to assist in the preparedness planning process and to identify the potential scope, magnitude, and complexity of potential major events.

In the March 2006 report (version 21.3), "Radiological Attack" was listed as one of many potential hazards faced by the United States. The radiological scenario illustrated within this report is relevant to the current research in that many of the same variables are shared. These similarities include:

- **Radioactive Material Used**: Cesium-137 (Cs-137)

Note: Cs-137 is considered to be the easiest material to acquire, since it can be found in some hospital, commercial, and industrial equipment. It is highly dispersible, soluble, and radioactive. When it is dispersed, it is difficult to cleanup.

- **Amount of Radioactive Material Used**: 2,300 Curies

Note: Most commercial and industrial radioactive equipment generally contain this amount of material.

- **Potential target**: Moderate-to-large urban area; business district
- **Intent of the RDE**: Conduct a highly visible attack; create fatalities, fear, and economic disruption
- **Mode of Dispersal**: 3,000 lb truck bomb

Economic Impact

Furthermore, according to the report, the DHS projects that economic losses would be hundreds of millions of dollars from a RDE. These losses would primarily be driven by lost business productivity (displaced workers), tax revenues, and property as a result of the complete shutdown of the contaminated area (NPS, 2006).

Population Resilience and Psychological Factors

The National Planning Scenarios radiological scenario illustrates another example of how population resilience could help lessen the economic impact from a RDE. In the event that residents show no sign of resettling into their former domiciles, or businesses and schools permanently relocate to an unaffected zone or another city altogether, a local economy would be more likely to collapse. However, depending on the target area, its size, and its historical, economic, and political significance, the will to recover and repopulate would vary widely from long-term decline to complete revitalization (NPS, 2006).

Radioactive Dosages

Andrew Karam, radiation safety officer of the University of Rochester, remarks that the biggest health risk from a dirty bomb would not necessarily be cancer, but panic. He stresses that in the event of a RDE, it is paramount that local officials provide accurate and timely information to their citizens, otherwise many deaths and injuries could be experienced in the form of traffic accidents as people flee the area, or from anxiety-induced heart attacks. Furthermore, he adds that the radiation dose from a dirty bomb would be relatively small. For example, “even a potent dirty bomb, consisting of a radioactive cobalt-60 rod used for food irradiation would deliver an average dose of a few tenths of a roentgen equivalent man (rem) for people within a half-mile radius (AIG 1). This compares to the 360 millirem (mrem) average dose that a person receives from natural and manmade radiation sources, and 5 REM, the typical annual dose limit for nuclear and radiation workers. Normally, most radiation workers receive less than 1 rem of exposure annually (DOE, 2000).

Economic Impact Modeling

Economists and researchers utilize a variety of methods in order to quantify the economic impacts of a shock to a financial system. Shields and Deller (2003) explain how local leaders and citizens increasingly face difficult questions about the impacts of changes to an economy. "They inquire how these changes will affect local economic indicators such as employment, income and population, and the demand for public services". Specifically, it is this area where economic impact modeling can be valuable. For instance, economic impact modeling focuses on how a local economy functions, how various elements of the local economy are interrelated, and how a change in one industry may affect other industries.

By examining relationships within an economy, important aspects of economic change (i.e. employment, output, and income) in government and commercial revenues can be better predicted.

Input-Out (I-O) Analysis

Economic impact modeling provides an important means of quantifying economic disruptions caused by natural or man-made, exogenous or endogenous shocks to an economy. The I-O model, to a great extent, is a detailed accounting system of inter-industry activities within an economy. I-O modeling is a useful method to determine the economic impact when new money enters a community through investment, revenues, or income, some of it is re-spent one or more times in the local economy, thereby creating additional economic impact. This impact is most often measured in terms of employment or income (Meek, 2000). I-O analysis can also measure contractions equally well.

Cheng *et al*. explains that the ratio of the total effects to the direct effect defines the multiplier. For example, if a terrorist disruption occurs in a region's transportation industry. The *direct* impact of the disruption is estimated in economic terms such as the gross product, employment, revenue or other indicators, in the transportation sector. The *indirect* impact is estimated by the economic losses in other industrial sectors caused by the transportation service interruption. The *induced* impact is the sum of economic losses due to reduced household income and consequently reduced household spending in the entire economy. In summation, the I-O model is used to provide an estimate of the total impact of a disruption incident on a region's economy, compared against the baseline scenario, i.e., the expected performance of the economy before the disruption.

Previous Uses of I-O Analysis

The Southern California Planning Model (SCPM) is an economic impact assessment model that has been used to evaluate regional economic impacts in the region of southern California. "It is a highly disaggregated regional input-output model of the southern California economy that was previously used to estimate the impacts of earthquakes and other disasters in southern California" (Gordon, 2005). The SPCM is essentially a derivative of I-O modeling, but on a regional scale. The model was originally developed for the five-county Los Angeles metropolitan region, and has the unique capability to allocate all impacts, in terms of jobs or the dollar value of output, to 308 sub-regional zones, mainly individual municipalities. In Rosoff and vonWinterfeldt's (2007) study, the SCPM was utilized in order to estimate the economic impacts of three economic shutdown scenarios - short (15 days), medium (120 days), and long (one year), caused by a simulated radiological attack.

III. Methodology

This research uses the Hazards Prediction and Assessment Capability (HPAC) application to model a simulated radiological release into the atmosphere. Based on the size and location of the plume output, businesses affected within the proposed study site area are identified by industry, and financial data (i.e. annual revenues) is collected for each commercial entity. An I-O model is built, which uses IMPLAN. Results of the I-O model include three economic effects as they pertain to a region's output, employment, and labor income.

1. **Direct Economic Effects**: the changes in the industries directly impacted by the economic shock.
2. **Indirect Economic Effects**: (i.e. supply chain impacts) the changes in inter-industry purchases as they respond to the new demands of the directly affected industries.
3. **Induced Economic Effects**: typically reflect changes in spending from households as income increases or decreases due to the changes in production.

Furthermore, the economic impacts on output, employment, and labor income are measured at five different points over the span of a year. This is meant to clarify the magnitude of the problem over time. This economic model demonstrates the impact to an affected economy, and as a result, the importance it is for government entities to take action sooner rather than later with regard to cleanup and remediation efforts.

Proposed Study Site Selection

First, identify a study site suitable for the purposes of the study. When selecting a location, it is important to understand why terrorists commit the acts that they do.

According to Club de Madrid (2005), terrorist acts are typically motivated by psychological, political, religious, cultural, or economic reasons. Terrorists also prefer to conduct their destructive operations in high-visibility; public areas where they can be witnessed by as many people as possible (CNPS, 2004).

Since this study assesses the economic impacts of a terrorist act (RDE), the proposed study site used within this research (Figure 1) was selected based upon its proximity to key financial and commercial establishments, a military installation, airfield, and major university.

Practical Application

A 'mid-size' city serves as realistic location for a potential RDE attack scenario. No prior, detailed study exists that examines the economic impacts of a RDE terrorist attack on a mid-size city. Mid-size cities (i.e. Dayton OH, Fayetteville NC, and Little Rock AR) are important to consider as possible targets for a RDE, due mainly to similarities they share with their much larger counterparts (i.e. Washington D.C., New York City, and Los Angeles). For example, like larger metropolitan areas, mid-size cities contain major medical facilities, military installations, international airports and large manufacturing or agricultural bases; however, smaller urban areas provide terrorists with a softer target.

As opposed to larger population centers, smaller cities are more vulnerable to attack since they are generally easier to access. This ease of accessibility is further strengthened by a lack of extensive security measures, which are typically afforded to larger cities. As a result, fewer logistics (i.e. time, resources) would be required to carry out a RDE. Additionally, simultaneous RDE attacks within several mid-size cities could quite feasibly be easier and cheaper than initiating a RDE in a larger city. After all, mid-size cities possess fewer financial resources than large cities. Fewer financial resources could make it more difficult to absorb the costs associated with a RDE, placing these areas at a higher risk for insolvency.

Since September 11, 2001, major urban areas within the nation have received millions of dollars in funding from the Department of Homeland Security (DHS) for preparedness and training purposes, meant to serve as anticipatory measures against future terrorist attacks (DHS, 2008). Despite the fact that mid-size cities receive some allocation of funds from the DHS, these amounts often pale in comparison to the funds that larger cities receive.

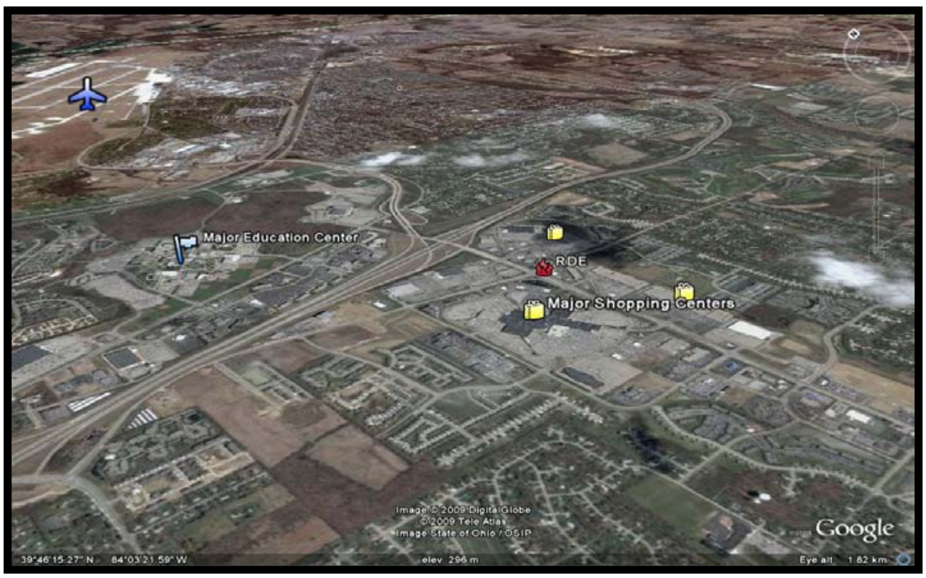

Figure 1. Proposed Study Site

Hazards Prediction and Assessment Capability (HPAC)

The next step involves modeling a radiological release. This was accomplished using HPAC. The software predicts the effects of hazardous material releases into the atmosphere, as well as its collateral effects on civilian and military populations (DTRA, 2008). The HPAC application is appropriate for the current research in that it is currently used in all military command centers throughout the world and has been used during the Salt Lake Olympics, Bosnia conflict, Atlanta Olympics, Presidential Inauguration, and Gulf War illness studies (CSE, 2004). It is the accepted dispersion model for the Department of Defense.

To run a RDE simulation in HPAC, the program requires user-defined specifications which must first be must be first input in order to get the desired output. Appendix B provides a detailed breakdown of what inputs were used and what other steps were taken to create the radiological dispersal model for this study.

Once HPAC completes the simulation, the generated output takes the form of a cigar-shaped plume. The areas closest to the blast site contain the highest integrated dose levels of radiation, while further from ground zero the levels taper off. The plume is divided into four color-coded contour areas, each color indicating a different integrated dose limit (Figure 13) as illustrated by the plumes output profile.

Create a Map Overlay

The next step determines the commercial activities that are affected by the RDE. Since HPAC lacks a detailed mapping feature, the plume was saved as a JPEG file (Figure 3) and superimposed onto an aerial photomap application (i.e. Google Earth), to provide a clearer picture as to which business areas within the economy were directly affected with possible contamination (Figure 4). The image was placed over the mapping application based on the lat/long coordinates that were input into the HPAC model. To assist with the identification of local area business, an area's commercial information may be attained through local government entities (i.e. city hall, chamber of commerce).

Boundary of Potential Impacts (BPI)

Since HPAC simulates dispersals based on historical weather data, there is a chance that an actual RDE event may not replicate the output produced by the program. A "boundary of potential impacts" was created in order to address this uncertainty (Figure 2). In the event that the plume does not follow the path of HPAC's dispersion model, a radius taken from ground zero to the outermost point of the plume was measured and a boundary was drawn in all directions, encompassing ground zero and all businesses within the radius. Therefore, in conjunction with the businesses directly impacted by the plume (Quadrant 1), all of the other businesses located within the BPI will be examined as well so as to tackle this uncertainty.

Data Collection

Once the affected businesses were identified, the next step identifies the economic parameters necessary to calculate the economic impacts. For the purposes of this research, annual revenues, sales and property (real and special) taxes, and building and land appraisal values were used. This information was collected from the following sources:

- **Greene County OH Auditor's office**: 2008 Property-Land Values
- **County Business Patterns (2006)**: Employment and Business Data
- **Economic Census (2002)**: Revenue Data
- **Hoovers Online**: Revenue Data
- **Securities and Exchange Commission**: 10K Reports; square footage sales data

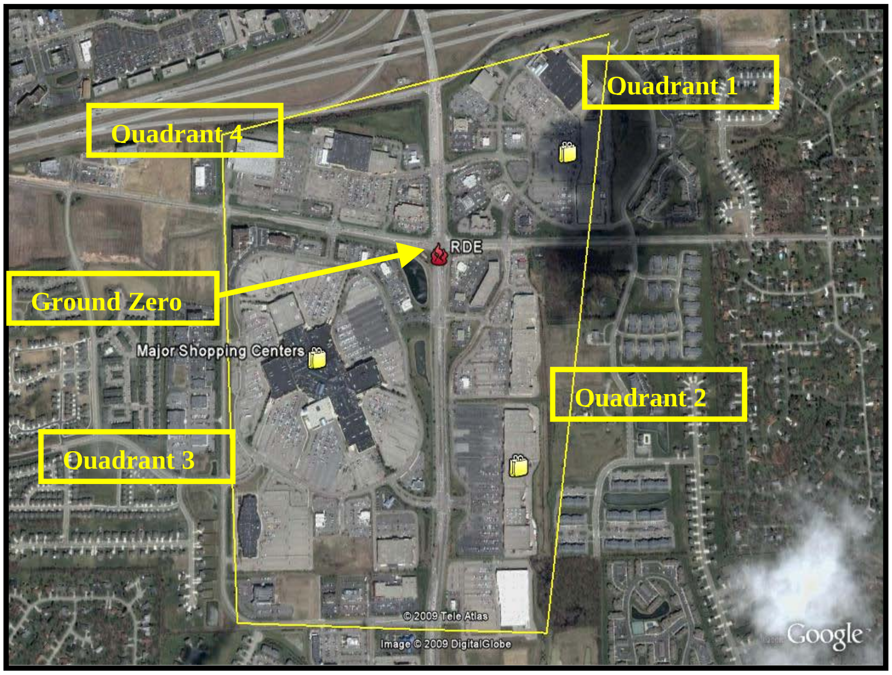

Figure 2. Boundary of Potential Impacts

Deriving Annual Sales Revenue

The annual sales data necessary to conduct the economic impact analysis was difficult to collect. The majority of businesses are unwilling to release their annual sales information for fear of it being made public. As a substitute, annual revenue for each affected business is derived using two different data sources. For the larger businesses, where financial data is readily available through online sources such as the Securities and Exchange Commission, annual revenues are calculated using sales per square foot data and average square feet per store data. Since square footage data is not as readily available for the smaller, lesser known (and often private) businesses, annual revenues are estimated using annual revenue ranges found within the 2002 Economic census.

North American Industry Classification System (NAICS)

Prior to creating the I-O model, all businesses within the BPI must first be industry coded (Table 1). This is an important step because IMPLAN measures impacts on individual industries, not individual businesses. Industry coding is accomplished through the use of the North American Industry Classification System (NAICS). The NAICS is the standard used by Federal statistical agencies to classify business establishments for the purpose of collecting, analyzing, and publishing statistical data related to the U.S. business economy.

NAICS	Business
442110	Ashley Furniture, RTA
442110	Original Mattress
442299	Pier 1
442299	Williams-Sonoma
443111	HH Greg
443112	Best Buy
443112	Circuit City
443112	Radio Shack
443112	Rex
444110	Lowes
445291	The Great American Cookie Co.
445292	Godiva Chocolatier
445292	Rocky Mountain Chocolate Factory
445292	Waggoner Chocolatier

Table 1. Sample NAICS Groupings

Sector Coding

Once all businesses are classified by NAICS, IMPLAN further consolidates these codes into sectors (Table 2). IMPLAN has the ability to examine 509 different sectors of an economy. Sectors 1 through 494 are made up of NAICS coded industries. To use the IMPLAN multipliers to determine direct, indirect and induced effects, revenues need to be aggregated by sector. Then these revenue totals may be calculated against the multipliers.

IMPLAN Sector	Description	NAICS
1	Oilseed farming	11111 11113
2	Grain farming	11113 11114 11115 11116 11119
3	Vegetable and melon farming	111200 1112
4	Tree nut farming	111335 111335
5	Fruit farming	11131 11132 11133 exc. 111335
6	Greenhouse and nursery production	111400 1114
7	Tobacco farming	11191

Table 2. Sample IMPLAN Sector Scheme

IMPLAN I-O Modeling

The Impact Analysis for Planning (IMPLAN) software application is used to create an I-O model to measure the direct, indirect and induced effects of the RDE on the economy's output, employment, and labor income. The IMPLAN I-O model is suitable for this analysis since it provides the user with regional-specific economic data of each branch of economic activity within an area's financial system. It can be adjusted to any region or area within the U.S. The program computes multipliers for any given industry in any given location, based on industry composition and geographic area. By simulating a "shock" to one branch of an economy (i.e. a RDE), the user can see how that impact ripples throughout other industries and institutions within the economy. Further more, a particular strength of IMPLAN is its social accounts matrices (SAM) component. A SAM is useful because it illustrates the actual magnitude of taxes and transfer payments which flow between institutions, as well as value added components (i.e. payments made by industry to workers, interest, profits, and indirect business taxes).

Recent economic data collection improvements made by the Bureau of Economic Analysis, U.S. Census Department, and other governmental and private organizations, have made the I-O model one of the most important, popular and accurate methods for measuring the economic impacts on a region due to exogenous or endogenous policy and economic changes (Cheng *et al*., 2006). I-O models have been successfully applied in other economic disruption estimations, such as electric power outages (Rose *et al*., 1997), hypothetical earthquakes (Okuyama *et al*., 1999), and hurricanes (Lamb, 1995).

Assumptions

Type of Radiological Material Used

Generally, the most hazardous radioactive materials are found in nuclear power plants and sites where nuclear weapons are made and security is high. As a result, obtaining materials from these areas would be extremely difficult to accomplish. According to John Pike, Nuclear Weapons Expert and Director of Global Security, it would be more likely that radioactive materials for use in a RDE is obtained from low-level waste such as medical or research labs (i.e. diagnostic procedures, cancer treatments), or welding shops and construction sites (i.e. industrial radiography) (Boyle, 2002).

Therefore, for the purposes of the current study, it is assumed that the simulated RDE will contain Cs-137. Experts believe that this material will be the most likely substance used in the event of a possible RDE (Boyle, 2002), since this radioactive isotope is one of two (Cobalt-60 being the other) elements most commonly used within industrial and commercial sources (generally less secure sources).

Amount of Radiological Material Dispersed

For the purposes of the current study, 2,300 curies of Cs-137 will be used. This amount has been well-documented as the most common amount that could reasonably be obtained from available sources (Ferguson, 2003). A capsule of the radioisotope cobalt-60 (Co-60) used in some cancer treatment applications contains about 2,000 curies.

Amount of Explosives Used in the RDD

The magnitude of the explosion is another aspect of a RDE that a terrorist can manipulate to achieve a greater effect. Depending on the intentions held by the attacker, the explosive portion of a RDE can range from minimal damage to infrastructure (and private property) to complete destruction of an intended target.

Zimmerman and Loeb (2004) examine a case where a "small" device is detonated using less than 100 pounds of high explosive. For the purposes of this research, the simulated amount of high explosives used in the (ground-based) RDE will be 100 pounds.

IV. Results and Analysis

This chapter discusses the economic impacts resulting from a simulated RDE attack on a mid-size city within the United States. Direct, indirect, and induced economic impact estimations on production, employment, and labor income will be computed for the entire BPI (Figure 2) as well as the area primarily affected by the release, Quadrant 1. Overall, 161 businesses were affected, comprising 19 sectors.

HPAC Model Results

The HPAC dispersal simulation generates the following cigar-shaped plume (Figure 3). This plume represents the integrated dose levels of the radiological material over a 365 day period. Based on historical data, HPAC predicted the plume as traveling on a northeasterly trajectory from ground zero. Overall, the total area covered by the plume was .107 km^2 (~ 216.48 sq ft).

The plume is superimposed over an aerial photomap to attain a clear picture as to the commercial areas affected directly (Figure 4).

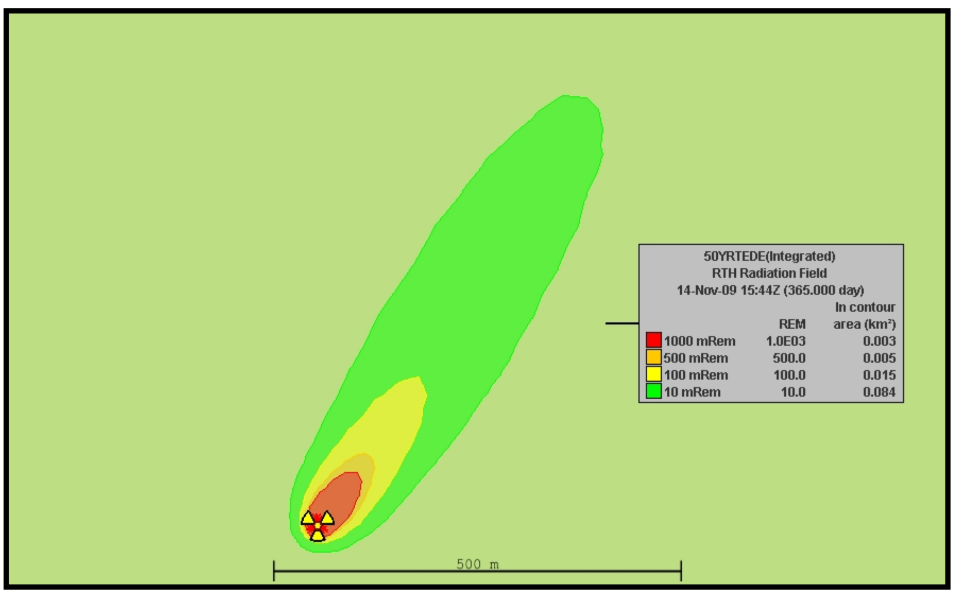

Figure 3. HPAC Results (365-Integrated)

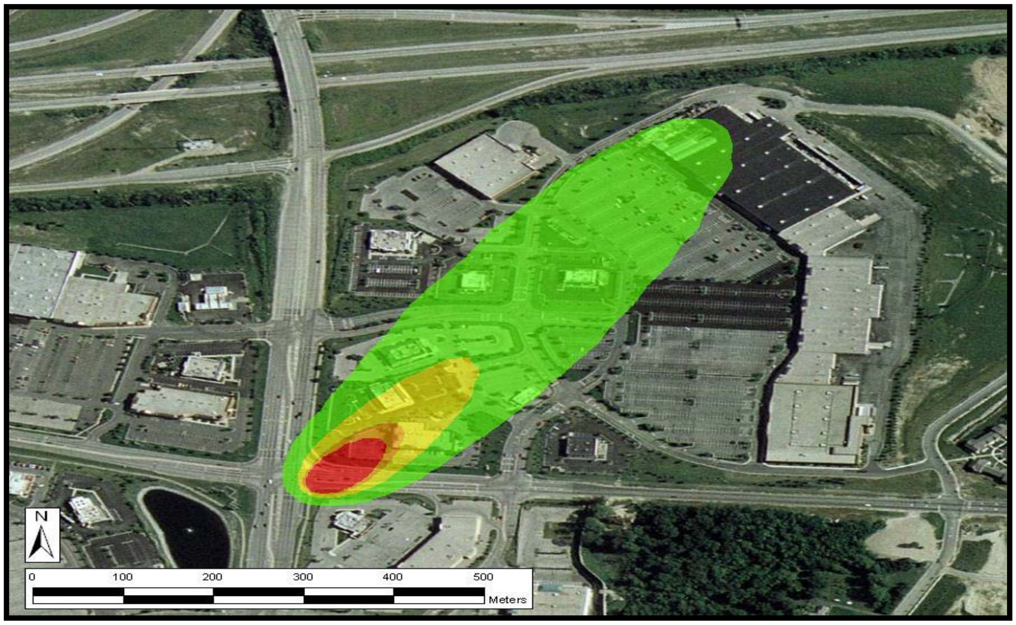

Figure 4. Plume Superimposed Over a Map

Data Collection Results

Data Collection

The annual sales (and sales tax) data necessary to conduct the economic impact analysis was difficult to collect. The State Department of Taxation as well as the County Auditor's Office explained that individual firm numbers are confidential tax information and is unavailable to the public. Furthermore, the majority of businesses were hesitant about releasing their annual generated sales information, for fear of it being made public.

As a substitute, annual revenues for each affected business were derived using two different data sources. For larger businesses, financial data was more readily available through online sources such as the Securities and Exchange Commission. Annual revenues were calculated using sales per square foot data and average square feet per store data. Annual revenues generated for smaller, lesser known private businesses were estimated using annual revenue ranges found within the 2002 Economic census, since square footage data is not as available for these institutions.

Revenues Collected

Once all annual revenue data was collected for each business located within the BPI (Figure 2), the sum totaled $595,051,138 (Table 3). The annual revenues collected by quadrants were:

	Annual Revenue
Quadrant 1 (Directly Impacted):	$117,740,066
Quadrant 2:	$112,758,961
Quadrant 3:	$211,884,068
Quadrant 4:	$152,668,043
Total	**$595,051,138**

Table 3. Total Revenues Collected

These values (Table 3) are not impacts. They are simply the amounts of estimated revenues that are earned within each quadrant and collectively.

Sales Taxes Lost (Estimated)

Based on the total amount of annual revenues estimated within the BPI, estimated sales taxes lost to the local government were calculated. The sales tax rate of the affected county is currently 1.0%, while the sales tax rate of the state is currently 5.5% (Table 4).

	Tax Rate	Annual Revenues Generated	Lost Sales Taxes
Greene County	1.0%	$595,051,138	5,950,511
Ohio State	5.5%	$595,051,138	32,727,813
Quadrant 1 Sales Taxes Lost (County)	1.0%	$117,740,066	1,177,401
Quadrant 1 Sales Taxes Lost (Sales)	5.5%	$117,740,066	6,475,704

Table 4. Sales Taxes Lost (Est.)

Economic Impacts Resulting from Property

Appraised values for the buildings and land within the BPI are attained through the area's county auditor website. According to Table 5, $205,507,560 worth of land and buildings are affected by the RDE. This is only a one-time value, where lost property taxes (real and special), is a recurring annual value that will be continuously impacted from the disruption.

2008 Property Values			
Quadrant Subtotals	Appraised Value (Land)	Appraised Value (Building)	Property Tax Total (Real & Special)
1 (Directly Impacted)	$15,366,410	$21,060,550	$849,719
2	$15,635,190	$20,583,450	$832,329
3	$25,765,340	$82,899,950	$2,636,222
4	$11,273,390	$12,923,280	$715,165
Grand Total	$68,040,330	$137,467,230	$5,033,435

Table 5. Property Value & Tax Impacts

Overall Impacts to Output, Labor Income, and Employment

The direct, indirect, and induced effects were measured for output, employment, and labor income among the 19 different sectors affected. Table 6, illustrates the impacts within the entire BPI. Overall, the impact to output totaled $1.2 billion. Labor income earned by workers and proprietors totaled $529.6 million, and 21,374 jobs were impacted. Table 7 illustrates the proportion of direct, indirect, and induced effects on overall economic impact. Table 7 demonstrates that despite the majority of focus placed on direct economic impacts, indirect and induced effects are usually on par or in excess of direct impacts.

OUTPUT	Overall Annual Economic Impact
Total Direct Impact	$594,676,138
Total Indirect Impact	$113,541,074
Total Induced Impact	$502,043,817
Total	$1,210,261,029
EMPLOYMENT	
Total Direct Impact	13,755
Total Indirect Impact	1,124
Total Induced Impact	6,496
Total	21,374
LABOR INCOME	
Total Direct Impact	$265,583,657
Total Indirect Impact	$40,331,810
Total Induced Impact	$223,717,379
Total	$529,632,846

Table 6. Overall Economic Impacts to BPI

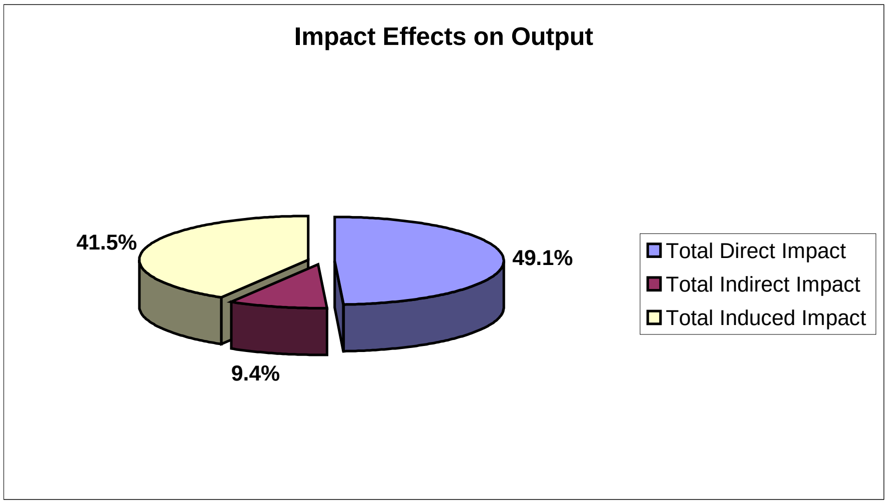

Table 7. Proportion of Effects on Overall Output

The direct, indirect, and induced effects measured for output, employment, and labor income within the area directly impacted (quadrant 1) are displayed within Table 8. Overall, the impact to output totaled $726.6 million. Labor income lost by workers and proprietors totals $100.4 million, and 3,626 jobs are lost.

OUTPUT	Quadrant 1 Annual Economic Impact
Total Direct Impact	$111,096,622
Total Indirect Impact	$113,541,074
Total Induced Impact	$502,043,817
Total	**$726,681,513**
EMPLOYMENT	
Total Direct Impact	2,202
Total Indirect Impact	209
Total Induced Impact	1,215
Total	**3,626**
LABOR INCOME	
Total Direct Impact	$51,111,450
Total Indirect Impact	$7,581,151
Total Induced Impact	$41,751,354
Total	**$100,443,955**

Table 8. Economic Impacts to Quadrant 1

Effects of the RDE on Regional Gross Domestic Product (GDP)

The annual economic impact on output for the entire BPI totaled $1,210,261,029. According to the U.S. Bureau of Economic Analysis, the state GDP (Current Dollars-2007) of the impact area was $466,309,000,000. As a result, the annual state GDP decrease due to the disruption is approximately .26%.

According to the U.S. Bureau of Economic Analysis, the city GDP (Current Dollars-2006) of the impact area was $33,547,000,000. As a result, the annual city GDP lost is approximately 3.6%.

Economic Impacts Measured Over 365 Days (Output and Labor Income)

The economic impacts of output and labor income are measured over the span of one year. This demonstrates how impacts to an affected economy accrue over time. As a result, it shows the importance for government entities to take action sooner, rather than later, with regard to cleanup and remediation efforts. To calculate realistic estimates, these impact totals took seasonality factors into consideration. Rather than spread the impacts evenly over the twelve month period, total sales per month were examined to determine the peaks and troughs of each industry's business cycles. For example, since November and December are usually major sales periods for the retail industry (due to the Christmas holiday season), more weight was given toward calculating impacts for those months, as opposed to slower months like June. Tables 8 and 9 list the 19 different sectors that were affected as well as the accumulated impact each sector experienced. The tables demonstrate that with time, the economic impacts begin to accumulate; signaling to decision makers that a course of action needs to occur otherwise the situation could become more expensive if nothing is done.

	Output (Annual)				
	30 Days	60 Days	90 Days	180 Days	365 Days
General Merchandise	$46,372,563	$92,187,890	$137,828,034	$275,706,387	$556,161,384
Clothing/Accessories	$12,484,677	$24,468,324	$38,033,018	$78,141,736	$157,758,927
Electronics/Appliance	$8,738,640	$16,966,321	$26,122,841	$53,510,957	$107,848,948
Food Services/Drinking Places	$7,425,228	$14,850,457	$22,275,685	$44,551,370	$89,102,741
Sporting Goods/Hobbies	$5,819,634	$11,581,935	$17,688,966	$35,675,232	$71,710,141
Building Material/Garden	$5,075,350	$10,032,406	$15,493,694	$31,536,325	$64,156,283
Hotels/Motels	$4,131,163	$8,262,325	$12,393,488	$24,786,975	$49,573,950
Misc. Store Retailers	$2,916,673	$5,785,652	$8,838,070	$17,858,050	$36,226,670
Motion P/Video	$2,350,607	$4,701,213	$7,051,820	$14,103,639	$28,207,278
Furniture	$1,116,191	$2,214,969	$3,481,077	$10,294,084	$14,338,313
Telecommunications	$1,157,597	$2,315,194	$3,472,791	$6,945,582	$13,891,164
Health/Personal care	$495,567	$993,512	$1,473,406	$2,921,698	$5,865,181
Personal Care	$387,558	$775,116	$1,162,673	$2,325,347	$4,650,694
Food/Beverage	$255,958	$505,942	$755,781	$1,510,144	$3,041,314
Health	$191,726	$383,452	$575,178	$1,150,356	$2,300,713
Fitness/Recreational Centers	$131,363	$262,727	$394,090	$788,180	$1,576,360
Gas Stations	$100,020	$184,400	$318,699	$722,906	$1,558,682
Photographic Services	$125,405	$250,811	$376,216	$752,432	$1,504,863
General/Consumer Goods Rental	$65,619	$131,238	$196,858	$393,713	$787,425
	$99,341,538	$196,853,882	$297,932,383	$603,675,112	$1,210,261,029

Table 9. Output Impacts per Sector

	Labor Income (Annual)				
	30 Days	60 Days	90 Days	180 Days	365 Days
General Merchandise	$21,013,276	$41,774,047	$62,455,434	$124,933,670	$252,019,126
Clothing/Accessories	$5,303,375	$10,393,917	$16,156,073	$33,193,884	$67,014,527
Electronics/Appliance	$2,508,507	$8,079,942	$12,440,589	$25,483,746	$51,361,354
Food Services/Drinking Places	$2,712,430	$5,424,860	$22,276,127	$16,274,580	$32,549,159
Sporting Goods/Hobbies	$2,660,741	$5,295,186	$8,087,409	$16,310,744	$32,785,933
Building Material/Garden	$2,217,617	$4,383,548	$6,769,796	$13,779,445	$28,032,371
Hotels/Motels	$1,730,821	$3,461,642	$5,192,463	$10,384,925	$20,769,850
Misc. Store Retailers	$1,368,509	$2,714,640	$4,146,841	$8,379,034	$16,997,628
Motion P/Video	$625,680	$1,251,360	$1,877,040	$3,754,080	$7,508,160
Furniture	$479,530	$951,578	$1,495,513	$3,093,458	$6,159,916
Telecommunications	$408,891	$817,783	$1,226,674	$2,453,348	$4,906,695
Health/Personal care	$219,215	$439,481	$651,764	$1,292,418	$5,865,268
Personal Care	$162,132	$324,264	$486,397	$972,793	$1,945,586
Food/Beverage	$114,921	$227,160	$339,334	$678,031	$1,365,503
Health	$103,551	$207,101	$310,652	$621,304	$1,242,608
Fitness/Recreational Centers	$59,474	$118,949	$178,423	$356,847	$713,693
Gas Stations	$43,499	$80,196	$138,602	$314,393	$677,872
Photographic Services	$48,987	$97,974	$146,961	$293,921	$587,843
General/Consumer Goods Rental	$33,379	$66,758	$100,137	$200,274	$400,549
	$41,814,536	**$86,110,385**	**$144,476,229**	**$262,770,894**	**$532,903,642**

Table 10. Labor Income Impacts per Sector

V. Conclusions and Future Research

Discussion

Modeling a Random Act

After the simulated radiological dispersal, the impact point of the explosion could potentially have many people passing through the contaminated area (i.e. commuters, rescue workers, civilians) prior to anyone's knowledge that radioactive material was used. As a result, contamination to individuals would more than likely not be confined to one small area, but spread over many miles from the initial site of the dispersal. For example, as demonstrated by the radiological incident in Goiania, Brazil, contaminated people were located over a hundred miles away from where the radioactive material was initially spread. Therefore, the idea that contamination will be spread out from the original release point must be considered when conducting further research. Chances are that contamination will not be confined to one small area.

Population Resilience

The resiliency of a population is more challenging. In the wake of a RDE, the levels of resilience demonstrated by a given population may differ depending on the location of the attack. For example, a location's historical or cultural significance could be a determining factor as to whether a community would "run to the hills" or stay and rebuild. A population's reaction to a catastrophic situation in Omaha may be different than an event which occurs in Los Angeles or Washington D.C. In terms of economic impact, the resilience of a population can either make or break an economy. For example, after the September 11, 2001 tragedies, the resulting economic impacts resulting from the destruction on Manhattan (a major national financial hub) could have been far worse if it were not for the city (and nation) coming together for the common good and rebounding quickly.

Recommendations

As illustrated within this research, the economic fallout resulting from a RDE has the potential to be quite costly. Therefore, officials and planners at all levels of government must assume a proactive posture when dealing with the threat. The method outlined within this research serves as a tool that planners and officials in any location can use to facilitate the planning and decision making process. Through informed decision making and strategic planning, leaders can make effective decisions as to what preventive measures should be in place or how resources should be optimally allocated among competing options in the event of a RDE occurring within their area.

A “pre-RDE” economic impact analysis allows key stakeholders to attain a better understanding of the possible magnitudes and ranges of possible economic impacts resulting from a RDE. As a result, leaders can better determine whether or not their economies can withstand a radiological attack. If recovery and resiliency to a RDE is to be maximized, effective and efficient planning is critical.

Future Research

Omitted Economic Parameters

This study focused solely on quantifying *commercial* economic impacts resulting from a RDE. Other economic parameters, such as cleanup and remediation costs, or residential considerations are not considered. Realistically, the overall economic impacts would have been higher if these additional parameters were included within the economic impact calculations.

Additionally, indirect business tax multipliers measure other lost tax revenues to the local government (besides lost property and sales taxes). By including these effects, a better picture would be presented as to the impact total to government income.

Economic Impact of a RDE on Two or More Localized Areas

This study looked only at the economic impacts of a RDE on one localized area. As explained previously (Chapter 1), simultaneous RDE attacks within several mid-size city areas could also be an attractive alternative for terrorists. Due to the "soft target" nature of a mid-size city, the logistics for a terrorist cell could quite feasibly be cheaper than setting a RDE off in a larger city.

Direct, Indirect, and Induced Effects

Many tend to focus on the direct effects of an economic disruption and fail to look at the indirect and induced effects, despite the fact that direct effects comprise a small portion of the overall damage while indirect and induced effects tend to be greater in magnitude. A possible reason for this is that indirect and induced effects are lagging indicators, so they accumulate over time, whereas direct effects are experienced immediately.

Rather than combine all three effects into one chart (i.e. bar, pie, scatter), it is important to make distinctions between them. When creating a chart, make three separate charts depicting each effect or make two charts combining indirect and induced effects and leaving direct effects by itself. If all three effects are displayed in aggregate, it is impossible to tell how much each effect is contributing to overall impact (Table 7).

Timing of the Dispersal Event

Conducting a radiological dispersal scenario during a peak commercial time of the year (i.e. Black Friday) increases the potential for business disruptions as well as increased potential for affecting many people (i.e. holiday shoppers).

Method of Dispersal

Air dispersal has a much greater chance of spreading radioactive material further than a ground based scenario. Using an airplane or hot weather balloon to disperse material could result in a significant economic impact on a community.

Limitations

IMPLAN®

While IMPLAN does a good job at estimating economic impacts to output, employment and labor income, the software does have limitations. The economy is a dynamic and complex entity. Economic data is constantly changing, even by the second. To generate input-output models, IMPLAN typically utilizes economic data that is not real-time. Multipliers that are used to assess economic impacts are typically derived from a single year's data (i.e. 2007 economic data). This means that the models are "static" and do not take into account the inherent changes of an economy over time. Therefore, it is important that an IMPLAN generated I-O model should be re-run as soon as the latest IMPLAN software release is made available in order to capture the most current economic information.

HPAC®

HPAC outputs are generated based on historical weather data that the application uses in determining the size and direction of the plume. Since historical weather data is not a clear predictor of future weather performance, the plume generated for this study may not accurately reflect actual weather conditions on the day of initial dispersal.

Conclusion

The motivation behind this study is due to the ever-increasing potential of the RDE threat. The RDE threat is real, and an actual radiological attack could occur on U.S. soil within our lifetime unless preventive actions are taken now. For this reason, officials and planners at all levels of government must take a proactive stance in response to the threat. For a society to mitigate impacts to its financial system, precautionary measures must be implemented now rather than after an attack, when it's too late.

This research examines the economic impacts of a RDE on the commercial sector of a random economy. When economic impacts resulting from a shock to an economy are evaluated, it is important to understand that direct economic effects are not the only effects. Typically when an economy is impacted, the focus tends to be on direct impacts and less on the indirect and induced impacts. Indirect and induced economic effects must also be considered, simply for the reason that when combined, these effects generally exceed the direct damages.

The methodology outlined within this composition is unique in that it aids in the RDE response effort by providing government planners, officials, and key stakeholders with a pre-RDE economic assessment tool which can be used across all regions and industries. Furthermore, the majority of information used within the model is readily available to anyone. The methodology may be used to help facilitate planning as well as effective and efficient decision making in response to the threat. As a result, preventive measures can be in place, resources efficiently allocated, and recovery and resiliency maximized before the RDE occurs.

Appendix A: Terms Defined

- **Curie (Ci)**: a unit used to measure radioactivity.
- **Direct Economic Effect**: the changes in the industries to which a final demand change was made.
- **Dispersion Duration (DD)**: amount of time that the Hazard Prediction and Assessment Capability (HPAC) program simulates the scattering of radiological particles throughout the air.
- **Effective Dose Equivalent**: the sum of the dose equivalents to the organ or tissue (H_T) and the weighting factors (W_T) applicable to each of the body organs or tissues that are irradiated (Nuclear Glossary, 2003-2006).
- **Economic Impact**: changes that occur to a financial system, typically caused by endogenous or exogenous shocks. Examples of economic impacts include (but are not limited to) changes in:
    - a region's employment base (i.e. lost jobs, lost wages, temporary unemployment due to subsequent business inoperability),
    - amount of income collected (i.e. taxes, business generated revenues)
    - output/productivity
- **Indirect Economic Effect**: the changes in inter-industry purchases as they respond to the new demands of the directly affected industries.
- **Induced Economic Effect**: typically reflect changes in spending from households as income increases or decreases due to the changes in production.
- **Integrated Dose**: a (cumulative) dose of radiation one would receive if they were to be located within a contaminated area for a consecutive amount of time.

- **Mid-Size City**: an urban area with a population of roughly 100,000 to 300,000 people (CRC, 2006).
- **Millirem**: One thousandth of a rem (0.001 rem)
- **North American Industry Classification System (NAICS)**: is the standard used by Federal statistical agencies in classifying business establishments for the purpose of collecting, analyzing, and publishing statistical data related to the U.S. business economy (NAICS, 2007).
- **Radiological Dispersal Device (RDD)**: also referred to as a “dirty bomb. It consists of radioactive material packaged in conventional explosives. At a basic level, an RDD combines a conventional explosive, such as dynamite, with radioactive material.
- **Radiological Dispersal Event (RDE)**: the detonation of an RDD, whether deliberately or accidentally.
- **Roentgen Equivalent Man (REM)**: a unit of absorbed dose defined as the number of rads times a quality factor. It represents a dose equivalent or a dose that is correlated with injury due to radiation exposure (Nuclear Glossary, 2003-2006).
- **Total Effective Dose Equivalent (TEDE)**: the sum of the deep-dose equivalent (for external exposures) and the committed effective dose equivalent (for internal exposures). (Nuclear Glossary, 2003-2006).

Appendix B: Modeling a Radiological Release using HPAC

I. Radiological Dispersion Device Specifications

a. In order to create a new HPAC product, select 'Create New' when the program opens

b. Select 'Edit' in the main toolbar

- Select 'Add incident'

    i. Select 'Radiological Weapon Incident' (Figure 5)

- A window entitled 'Radiological Weapon Incident Edit' will then appear

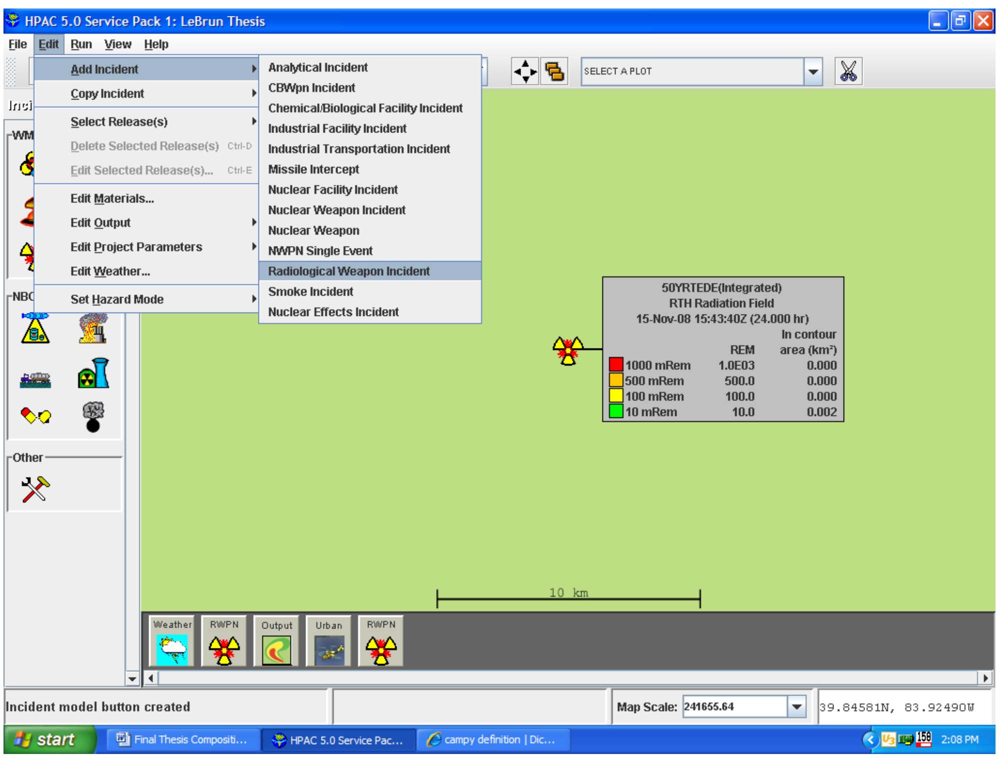

Figure 5. Radiological Incident Specification

II. Inputs Used within the Study

a. Under the 'Where' tab, the following specifications were used:

- **Type**: Lat/Lon
- **Lat/Lon Mode**: deg, min, sec
- **Surface Position**: Enter the degrees, minutes, and seconds of the proposed study site (Figure 7)
    - **Latitude**: 39 46 12°N
    - **Longitude**: 84 3 6°W

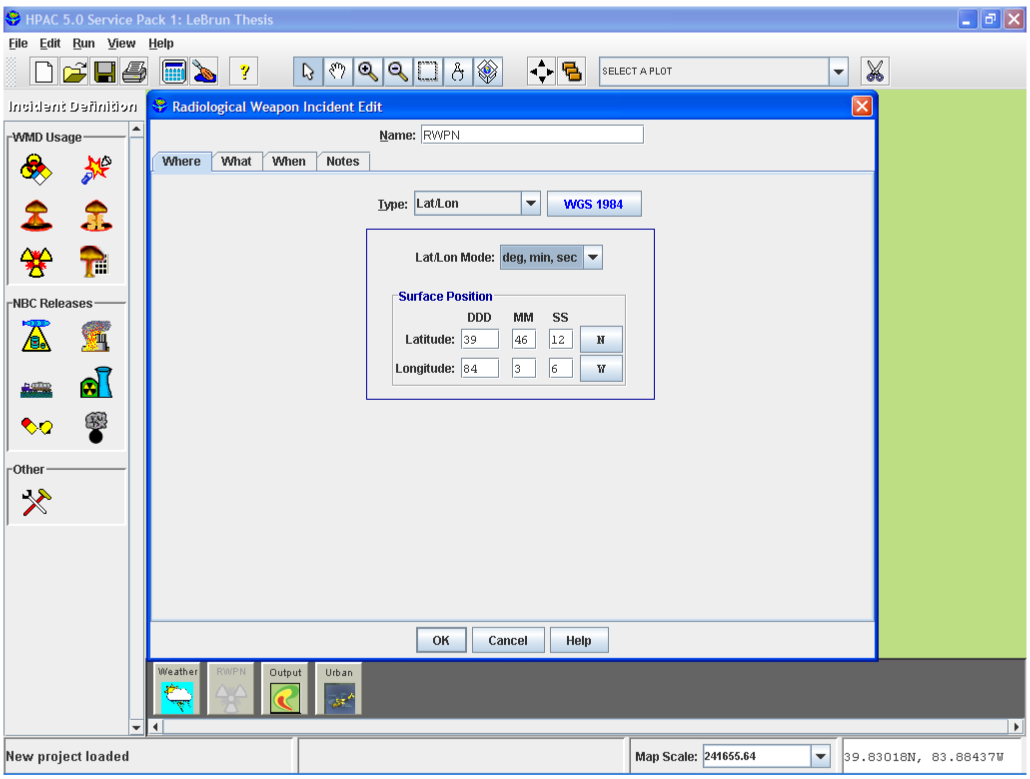

Figure 6. 'Where' Tab Inputs

b. Under the 'What' tab (Figure 8), you would input the following specifications:

- **Entered as an**: Explosive RDD

- **Source Description**: User specified Device
- **High Explosive (HE) Mass**: 100 pounds WHY, explain more in chapter 2?
- **Type of Material**: Cesium-137
- **Form of Material**: Salt
- **Material Activity**: 2,300 curies (Ci)
- **Modifications to source term**: None
- **Calculation Radius**: Enter how far out you want the plume to be calculated; set to 5.0 kilometers
- **Dispersal Duration (DD)**: the length of time that the model will run; takes weather into account; set to 365 days
- **Exposure Duration (ED)**: keep it at the default setting of '365.25 days'; used to find out the dose rate over time; how far out in the future to model the health effects

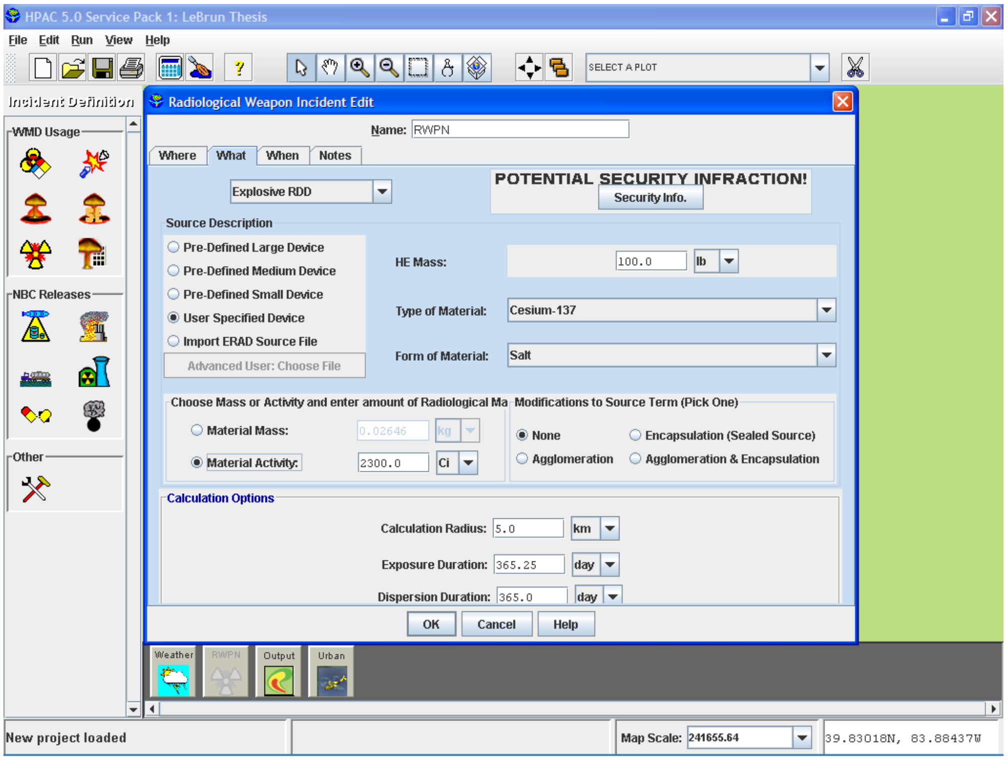

Figure 7. 'What' Tab Inputs

c. Under the 'When' tab (Figure 9), the following specifications were input:

- Start of Incident: Will display the current date and time
- Select 'OK'

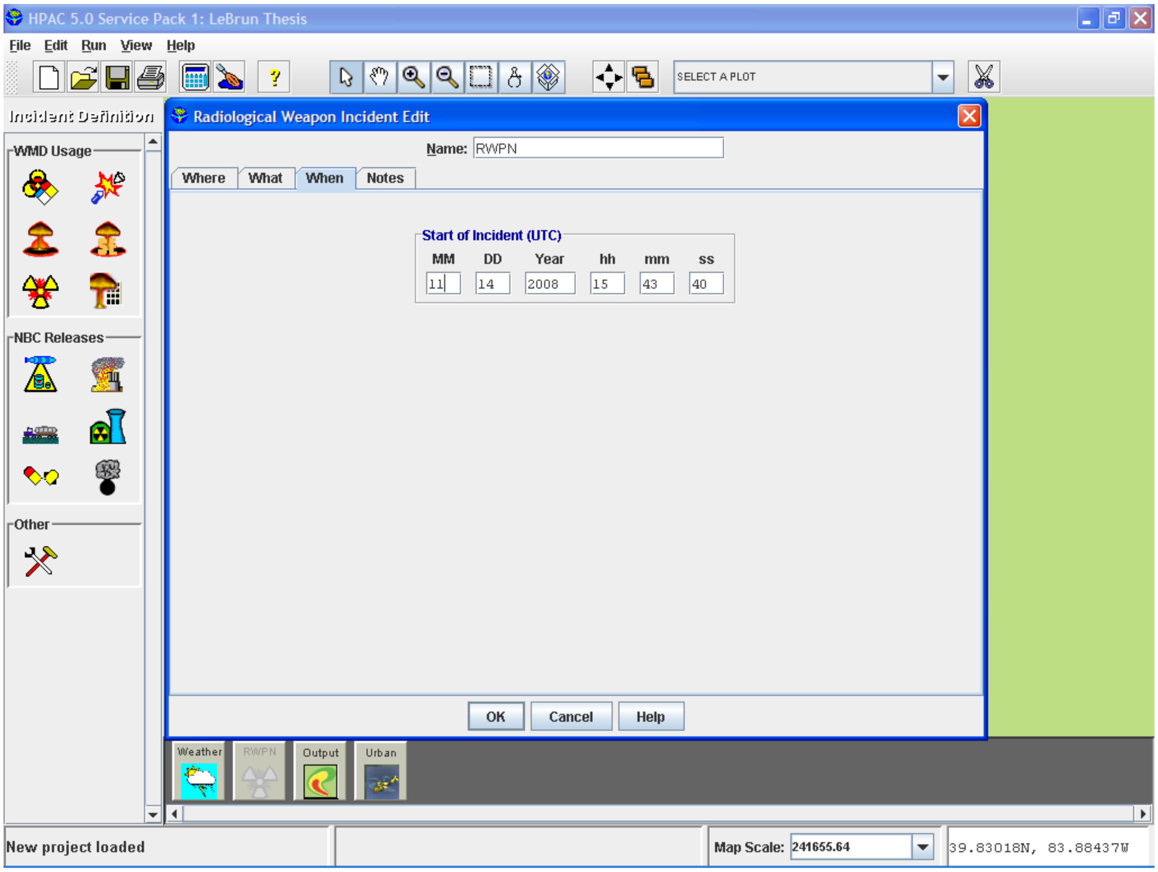

Figure 8. 'When' Tab Inputs

d. Select 'Edit' in the main toolbar (Figure 10)

- Select 'Edit Weather'
- Select 'Yes'

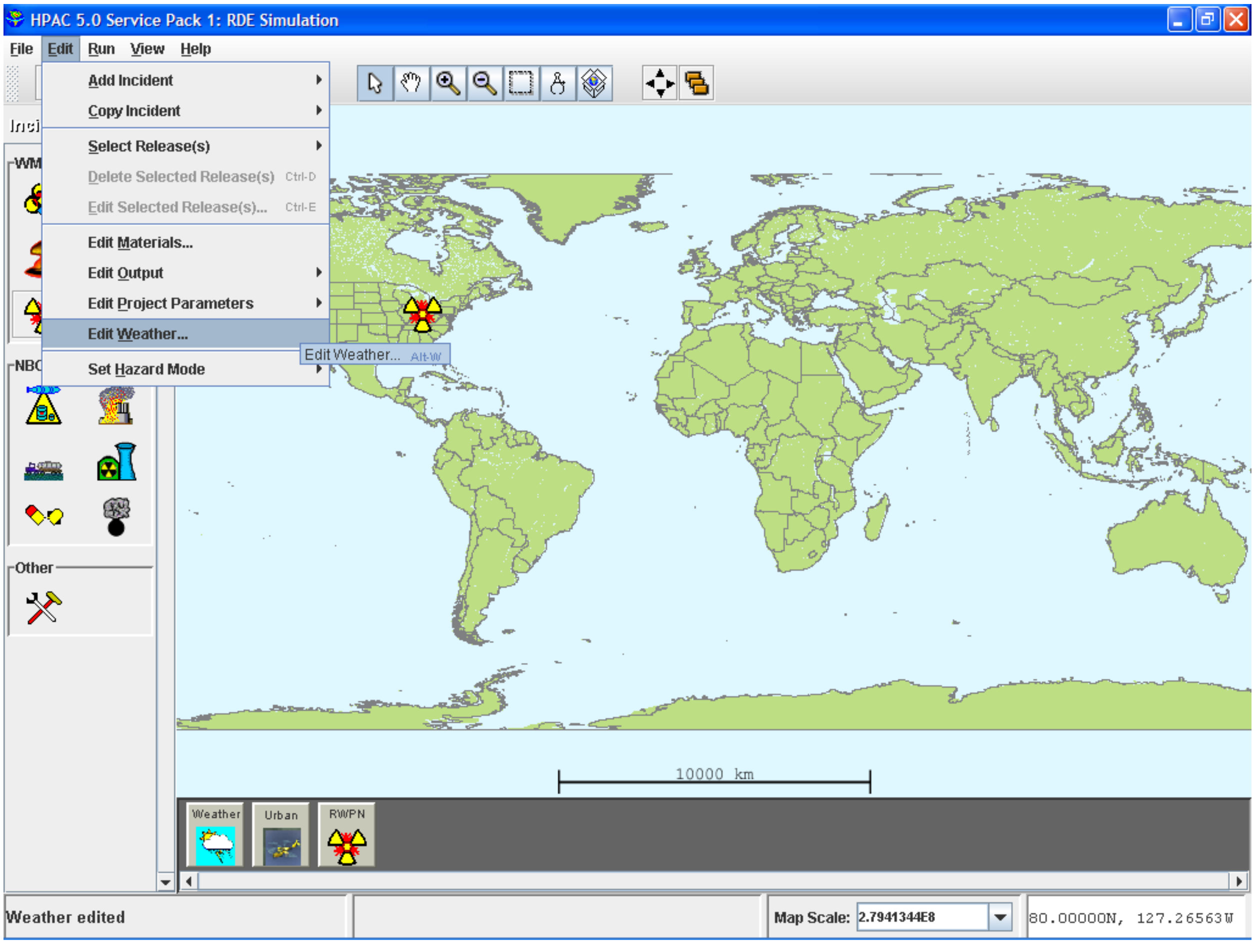

Figure 9. Weather Editing

e. Select 'Run' in the main toolbar

- Select 'Compute Results' (Figure 11)

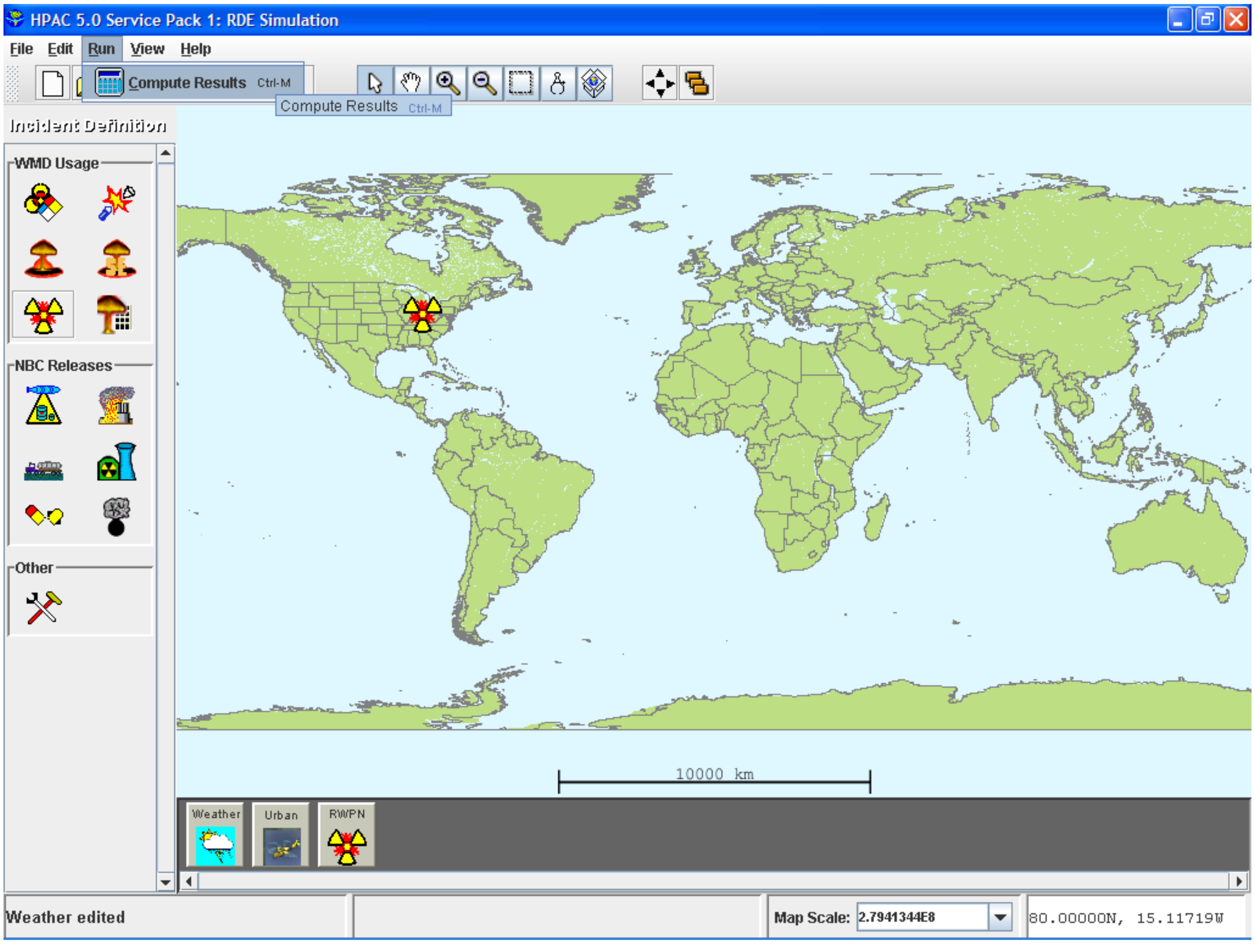

Figure 10. Computation of Results

f. The simulation is completed once the 'Dispersion Info' box appears

- Select 'OK'

g. The 'Dispersion Calculation' box remains

- Select 'OK'

III. Customizing the Results to the Study:

a. Right click on the 'Output' icon located at the bottom right-hand side of the window (alongside the Weather, Urban, and RWPN icons)

b. Select ‘Plot’

- Select ‘Custom’ (Figure 12)

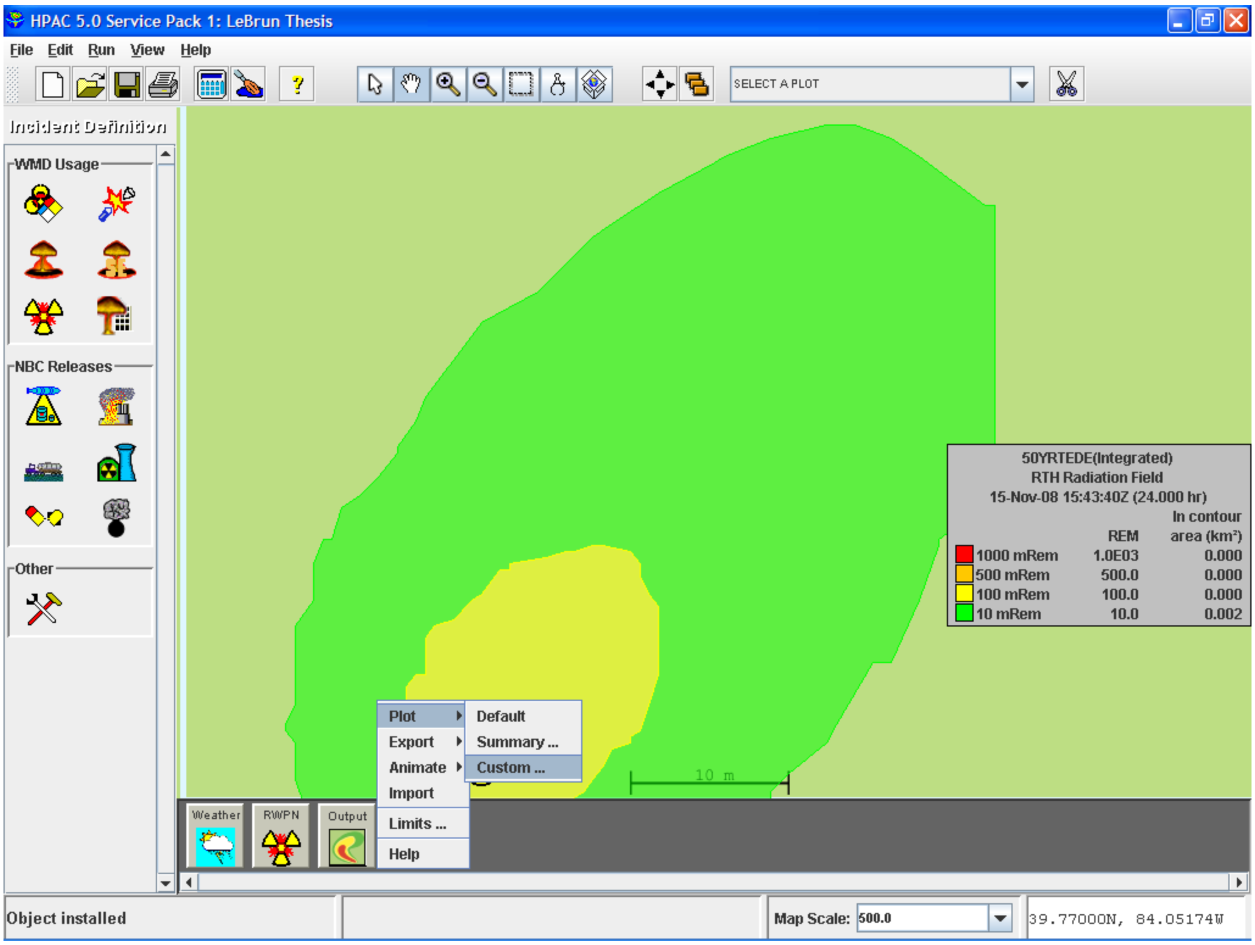

Figure 11. Customizing the Plume Output

c. Under the ‘Field Selection’ Tab

- Class: RTH Radiation Field
- Choice: 50YRTEDE
- Kind: Integrated
- Category: Surface Data

- Type: Mean Value (M)
- Time: The date immediately above 'User Input'

d. Under the 'Contour Selection' Tab (Figure 13)

- Select 'Mode' under the Population/Area Selection
  - Check the box 'Compute Population/Area'
  - Under 'Population/Area', select Area
  - Under 'Computational Method', select 'Within Contour'
  - Note: Selecting these options will enable the user to determine how much area (by sq ft) is covered by each (colored) contour
  - Select 'OK'

e. Select 'Custom' under the Selection Mode

- In the 'Level' box, enter '10'
- Select 'Green Bright' from the 'Color' dropdown menu
  - In the 'Label' box, enter '10 mrem
  - Under 'Contour Scaling', leave the scale set at '1.0'
  - Select 'Add'
  - Your first customized value will appear in the white box
  - Do the same as above for 100, 500, and 1,000 mrem; use different colors to represent each dose level (i.e. 100-yellow, 500-orange, 1,000-red)

IV. Saving the customized values

a. Once all of your custom values are located within the white values box, select the ‘Export’ button immediately to the right of the white values box.

- Name your (*.cha) file
- Select ‘Save’

Note: Rather than retype all of your custom values each time you want to run a simulation, all you have to do is select the ‘Import’ button immediately to the right of the white values box. Select your custom (*.cha) file and then press ‘Open’.

b. Select ‘Display’

c. Your customized plume will appear with an output profile that will display each level of contamination in millirem. (Figure 14)

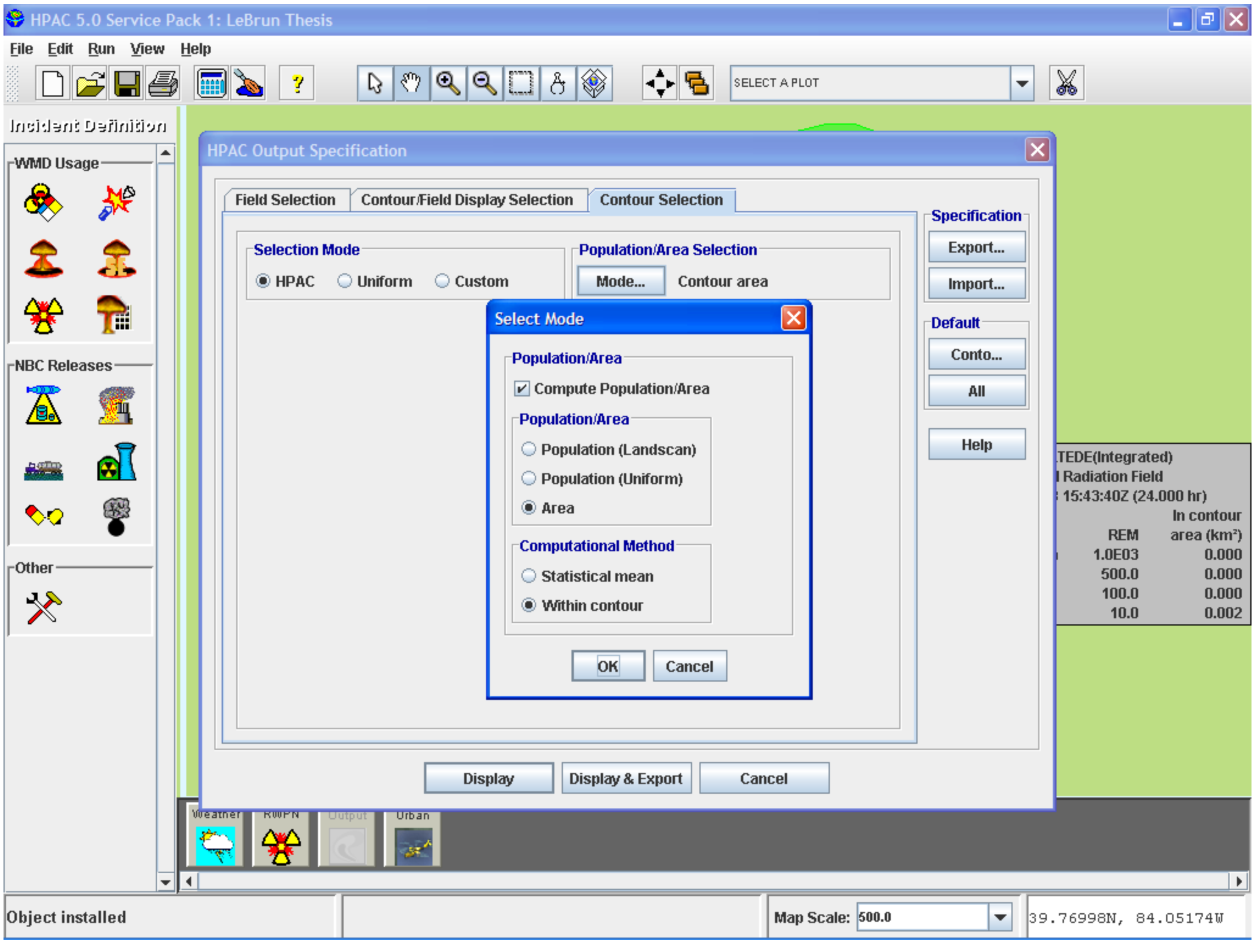

Figure 12. Contour Selection Options

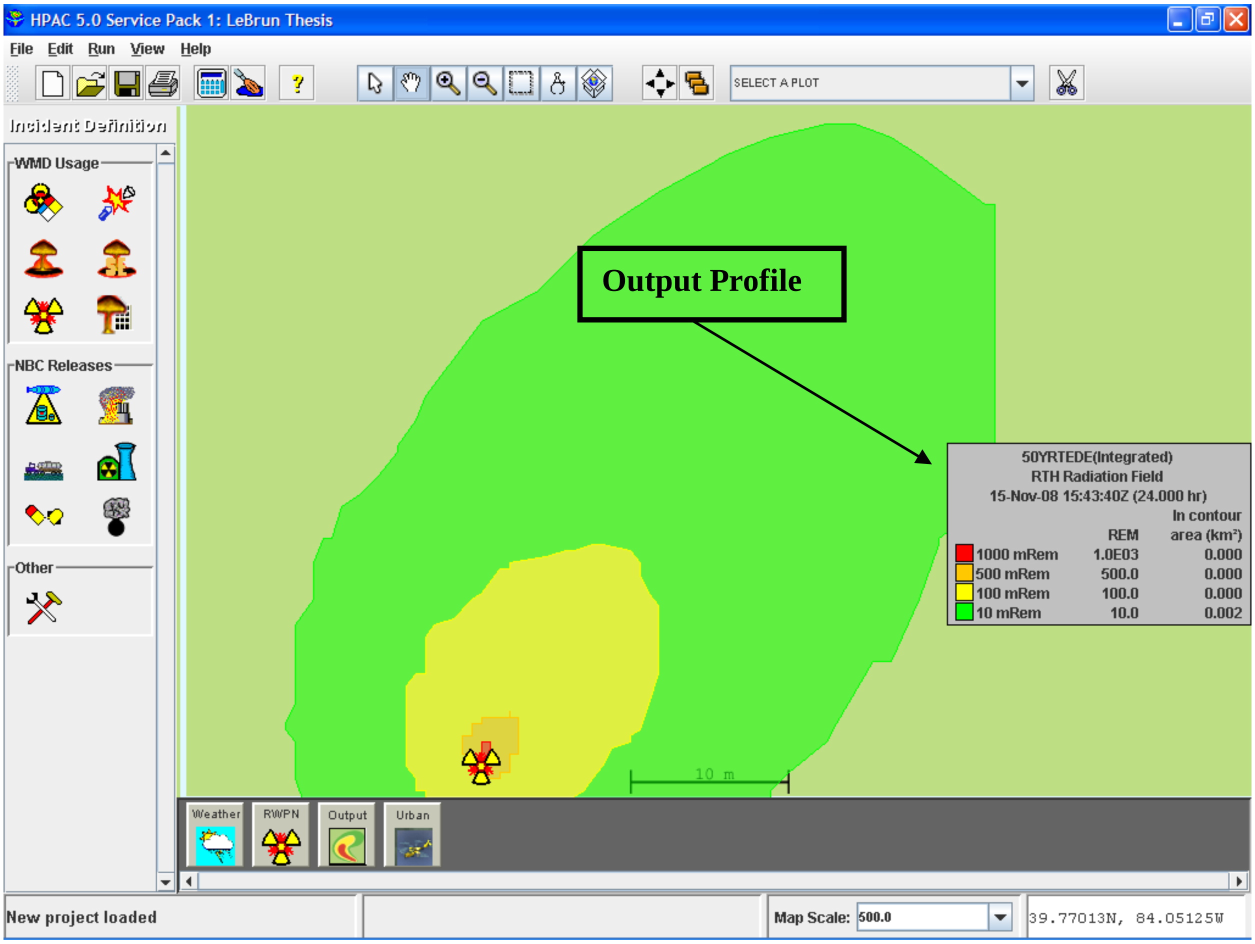

Figure 13. Customized Plume Results

- Red = 1,000 mrem/yr
- Orange = 500 mrem/yr
- Yellow = 100 mrem/yr
- Green = 10 mrem/yr

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REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 074-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From – To)*
26-03-2009	Master's Thesis	Jun 2008 - Mar 2009

4. TITLE AND SUBTITLE	
The Economic Impact of a Radiological Dispersal Device (RDE)	**5a. CONTRACT NUMBER**
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) LeBrun, Michael T., Captain, USAF	**5d. PROJECT NUMBER** N/A
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S)	**8. PERFORMING ORGANIZATION REPORT NUMBER**
Air Force Institute of Technology Graduate School of Engineering and Management (AFIT/EN) 2950 Hobson Way WPAFB OH 45433-7765	AFIT/GFA/ENV/09-M02
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Ferguson, Marcus G., Major, USAF 711th Human Performance Wing, Biosciences Division, Counterproliferation Branch 2711 K Street, Building 434 WPAFB, OH 45433 DSN: 674-4652	**10. SPONSOR/MONITOR'S ACRONYM(S)** 711 HPW/RHPC **11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

12. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

13. SUPPLEMENTARY NOTES

14. ABSTRACT
While it will not cause the devastation of a nuclear weapon, the radiological dispersal event (RDE) is particularly dangerous in that it has the potential to cause major economic disruptions. The purpose of this research was to develop a generalized methodology that can be used to assess economic impacts, resulting from a (RDE), occurring in any location and across any industry. Currently, there is no universal approach for measuring the costs or economic impacts on businesses, or a common framework for conducting an economic impact for a RDE. The objective of this research was to aid in the RDE response effort by providing government planners, officials, and key stakeholders with an (pre-RDE) economic assessment tool which can be used to quantify the economic impacts arising from a RDE, thereby facilitating the strategic decision making process. A random study site was selected to use as a practical application for the research methodology. Through the use of an economic input-output model, the research identified that the economic impacts to the study site's output totaled $1.2 billion, while impacts to labor income totaled $529.6 million. Overall, 21,374 jobs were affected due to the economic disruptions resulting from the RDE. The culmination of this effort was the development of a generalized, "off the shelf", economic impact assessment tool that can be used to estimate the financial impacts of a RDE, or any localized event which disrupts an economy.

15. SUBJECT TERMS
Economic Impact, dirty bomb, radiological dispersal event, input-output model, assessment tool

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	b. ABSTRACT	c. THIS PAGE			Lt Col David A. Smith (AFIT/ENV)
U	U	U	UU	68	**19b. TELEPHONE NUMBER** *(Include area code)* 937-785-3636 ext. 4711

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18

	Form Approved *OMB No. 074-0188*