Economic Consequences of a Rad/Nuc Attack:

Cleanup Standards Significantly Affect Cost

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Overview

- Importance of Economic Consequence Evaluation
- Evaluation Taxonomy
- Cleanup Standards
- Economic Consequences
- Conclusion

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Why Evaluate Economic Consequences?

- Loss of life, property destruction, and loss of economic activity have significant consequences
- Loss of use of productive assets can extend for long periods and generate considerable economic loss
- Economic impacts need to be addressed in sequential order:
  - Detonation,
  - Atmospheric dispersion and deposition,
  - Fallout from the weapon.
- Weapon characteristics provide the boundary conditions for the response:
  - How large is the affected area?
  - What actions need to be taken to protect the population?

Economic Evaluation Taxonomy

The decision to invest in countermeasures can be viewed as a tradeoff between investment cost and the economic consequences of an event.

High Value Target

Consequences Evaluation

- 7 locations (including bridges, tunnels, downtown)
- 3 Nuc Yields
- 1 RDD Yields
- D&D cleanup
  - D&D to 2 cleanup levels:
  - 15 mrem/yr
  - 2 rem/yr
- High correlation to cleanup level

Expanded Consequence Evaluation

How many distinctive target types should be considered?

- Are there "classes" of targets?
  - Really Big Cities
  - Medium Size Cities
  - Small Cities
  - Border Cities
- What weapon yields for each class of target?
- How many cleanup levels should be evaluated?

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Economic Consequence Calculation Methodology

- Literature review yields numerous methodologies for economic evaluation. Data used in this analysis:
  - Federal Reserve Bank of New York Study[1]
  - Sandia National Lab RadTran V Economic Model
- Focus on five broad categories of cost ($2005):
  - Loss of productivity from earnings forgone
  - Indirect economic effects or multiplier
  - Loss and damage to building structures
  - Decontamination and decommissioning (D&D) cost (including disposal)
  - Evacuation Cost
- Analysis does not cover the universe of all possible economic impacts
- Diversity of meteorological conditions not evaluated
  - Same physical consequence plume evaluated for different locations
- Focus on sensitivity analysis of cleanup standards

1. Jason, Bram, James, Orr, and Carol Rapaport, "*Measuring the Effects of the September 11 Attack on New York City*", FRBNY Economic Policy Review, November 2002.

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Economic Consequence Criteria

- Selected five locations from isolated rural to high density urban areas:
  - Lukeville, AZ
  - Charleston, SC
  - Detroit, MI
  - San Ysidro, CA
  - New York City, NY
- Evaluated consequences for 4 weapon types:
  - 0.7kT nuclear weapon
  - 13kT nuclear weapon
  - 100kT nuclear weapon
  - 10kCi Cs-137 RDD
- Evaluated five potential cleanup levels

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Potential Range of Cleanup Guidance for a Rad/Nuc Event – Which One Do We Use?

15 mrem/yr	EPA, "Establishment of Cleanup Levels for CERCLA Sites With Radioactive Contamination" (e.g., Hanford Site)
25 mrem/yr	NRC, Final Rule on Radiological Criteria for License Termination (10 CFR Part 20 Subpart E)
100 mrem/yr	Health Physics Society Position Statement, "Guidance for Protective Actions Following a Radiological Terrorist Event"
500 mrem/yr	EPA, "Manual of Protective Action Guides and Protective Actions for Nuclear Incidents," 400-R-92-001, … "doses in any single year after the first will not exceed 0.5 rem "
2 rem/yr	EPA, "Manual of Protective Action Guides and Protective Actions for Nuclear Incidents," 400-R-92-001, … "doses in first year will not exceed 2 rem "
5 rem/yr	NRC, "Standards for Protection Against Radiation," recommendation and established dose limit for workers of 5 rem/yr (10 CFR 20 Subpart C)

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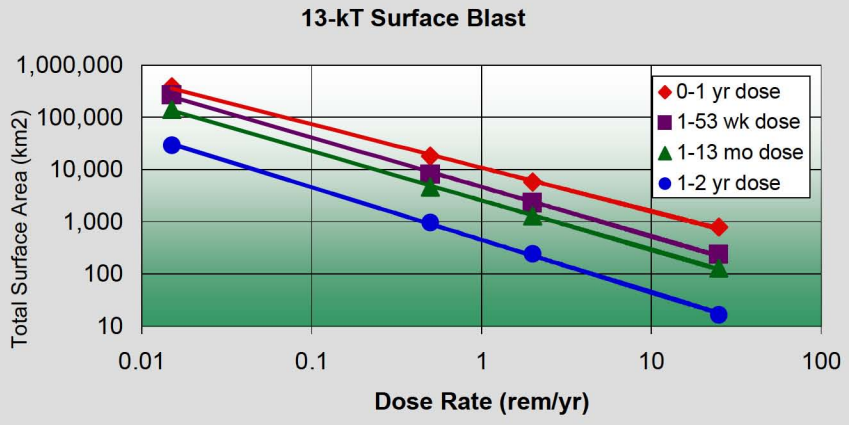
Radioactivity Decays Over Time



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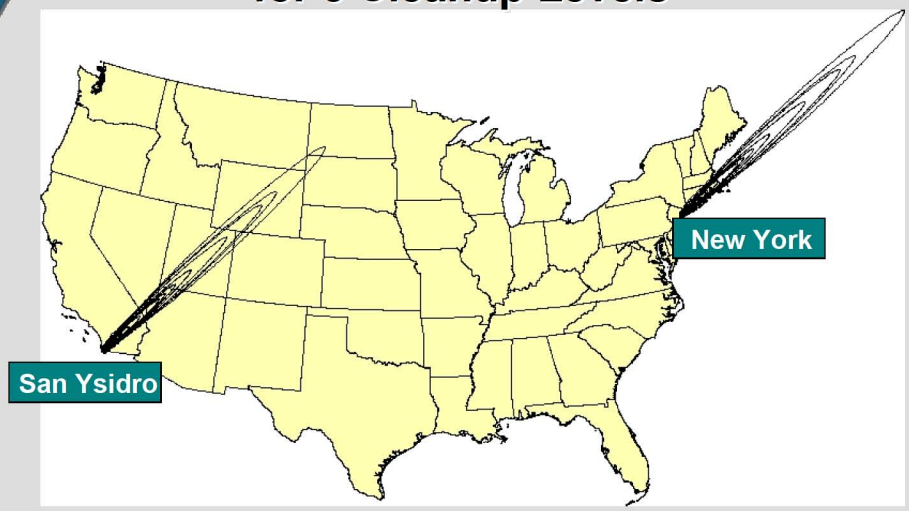
Hypothetical 100 kT Plume Contours for 5 Cleanup Levels



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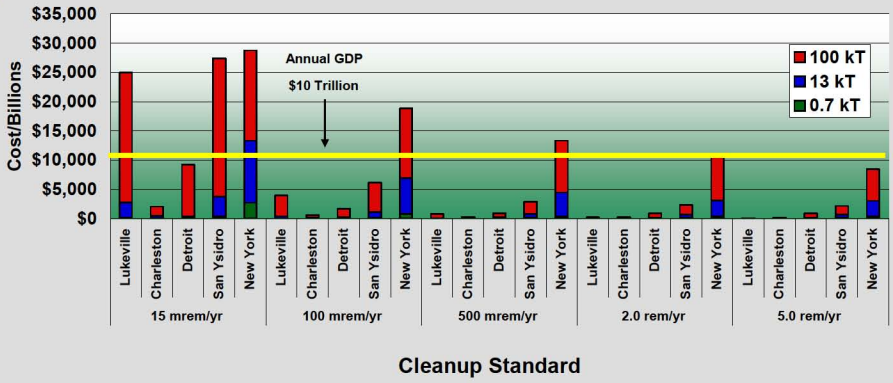
Consequence Summary By Cleanup Level for Hypothetical Weapon Events



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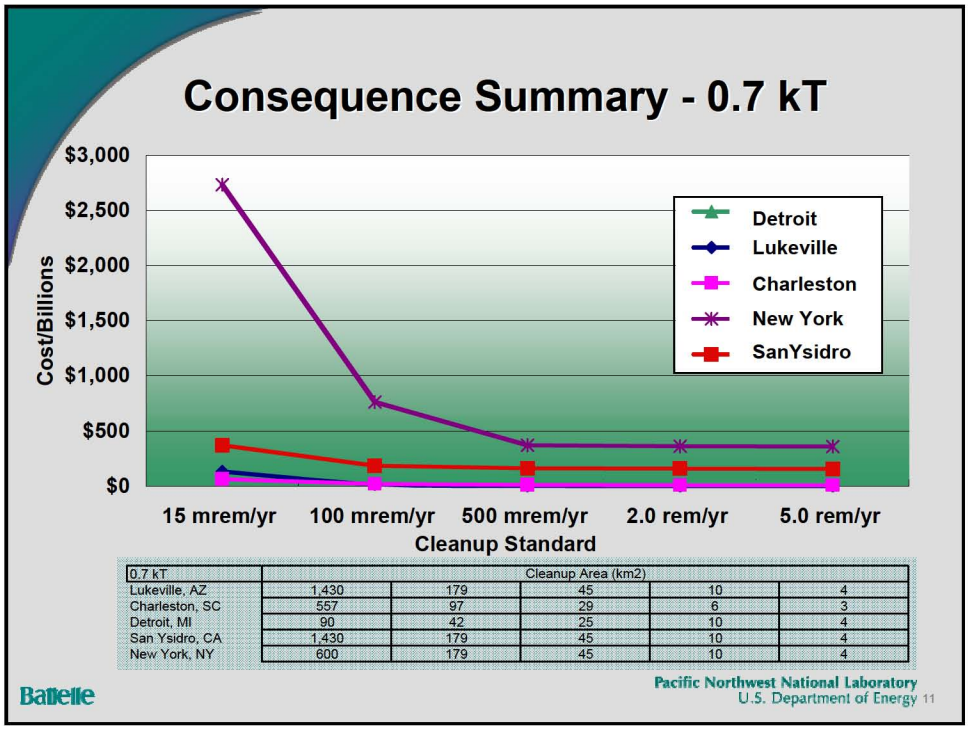
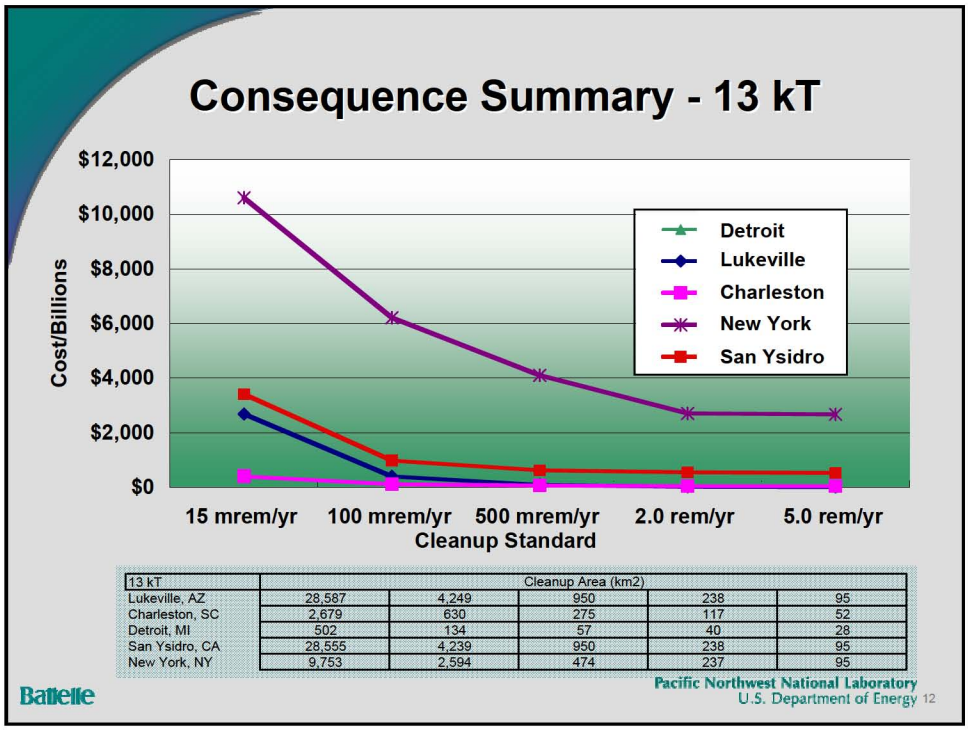
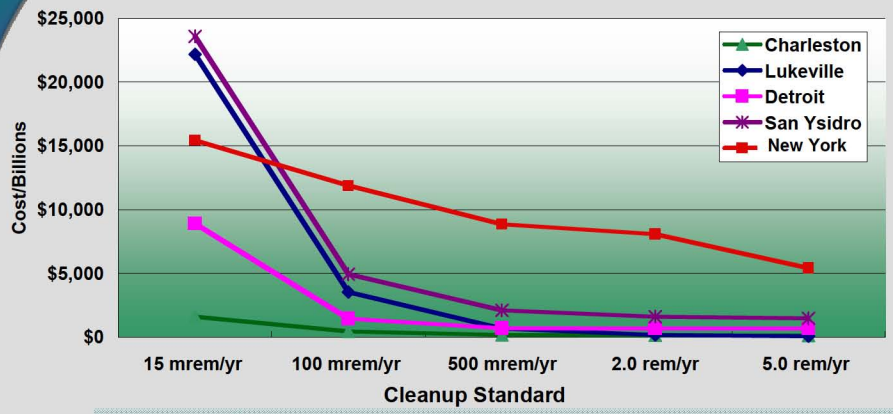


0.7 kT	Cleanup Area (km2)				
Lukeville, AZ	1,430	179	45	10	4
Charleston, SC	557	97	29	6	3
Detroit, MI	90	42	25	10	4
San Ysidro, CA	1,430	179	45	10	4
New York, NY	600	179	45	10	4



13 kT	Cleanup Area (km2)				
Lukeville, AZ	28,587	4,249	950	238	95
Charleston, SC	2,679	630	275	117	52
Detroit, MI	502	134	57	40	28
San Ysidro, CA	28,555	4,239	950	238	95
New York, NY	9,753	2,594	474	237	95

Consequence Summary - 100 kT



100 kT	Cleanup Area (km2)				
Lukeville, AZ	235,887	37,427	7,275	1,951	802
Charleston, SC	7,337	2,212	703	412	283
Detroit, MI	85,669	7,551	122	89	69
San Ysidro, CA	235,636	37,381	7,269	1,944	799
New York, NY	17,745	10,197	5,233	923	504

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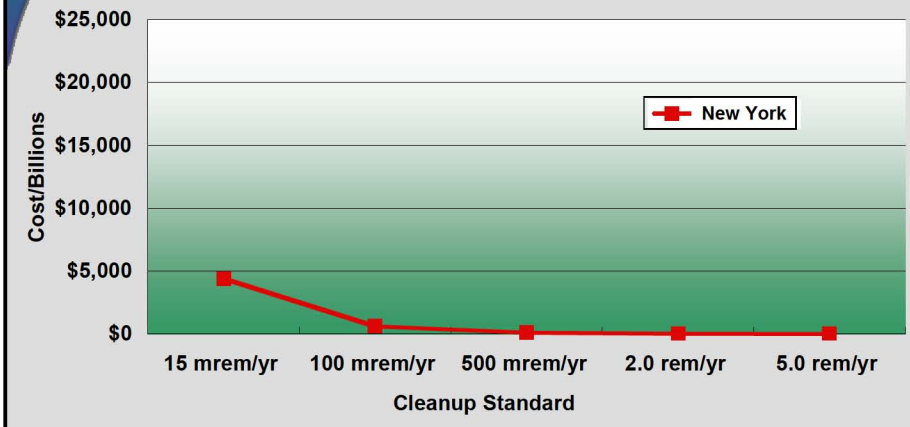
Consequence Summary - 10 kCi Cs-137



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Conclusions

- Economic consequences of a Rad/Nuc event are highly dependent on cleanup standards
  - Cleanup costs generally increase dramatically for standards more stringent than 500 mrem/yr
- Cleanup to the most conservative current standards (no matter what the class of target or weapon event) magnifies the consequences of the event
- Because such an event could potentially spread contamination very widely, even an event in a “remote” location could have huge economic consequences
- A risk-based approach to the development and application of cleanup standards is needed
  - Policy implications of such a cleanup need to be fully evaluated
  - Cleanup after a weapon event will be vastly different from cleanup of a contaminated industrial facility or former weapons production facility

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Back-up Slides

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Nagasaki Data

Yield ("Fat Man")	21	kT
Detonation Height	500	m
Population	240,000	people
Leveled Area	6.7	km^2
Prompt Fatalities	73,884	people
Prompt Injuries	74,909	people

Hiroshima Data

Yield ("Little Boy")	12.5	kT
Detonation Height	580	m
Population	255,000	people
Leveled Area	12.6	km^2
Prompt Fatalities	140,000	people

Economic Consequence Calculation Methodology

- Focus on four broad categories of cost ($2005):
  - Loss of productivity from earnings forgone
    - Net present value (NPV) of lost life assumed to be $2.8M
    - OMB discount rate of 7%
  - Loss and damage to building structures and building damage:
    - Utilized RadTran V for farm and urban areas ($29M to $220M per km^2)
    - Utilized projected WTC rebuild cost for high density urban areas ($6B to $19B per km^2)
  - Decontamination and decommissioning (D&D) cost:
    - Sandia National Lab RadTran V Model for farm and urban areas ($90M to $270M per km^2)
    - Utilized WTC cleanup cost for high density urban areas ($3B to $24B per km^2)
  - Evacuation Cost ($3K to $5K per (people/$km^2$) per km^2)
  - Indirect economic effects or multiplier effects (46% low impact; 82% high impact)

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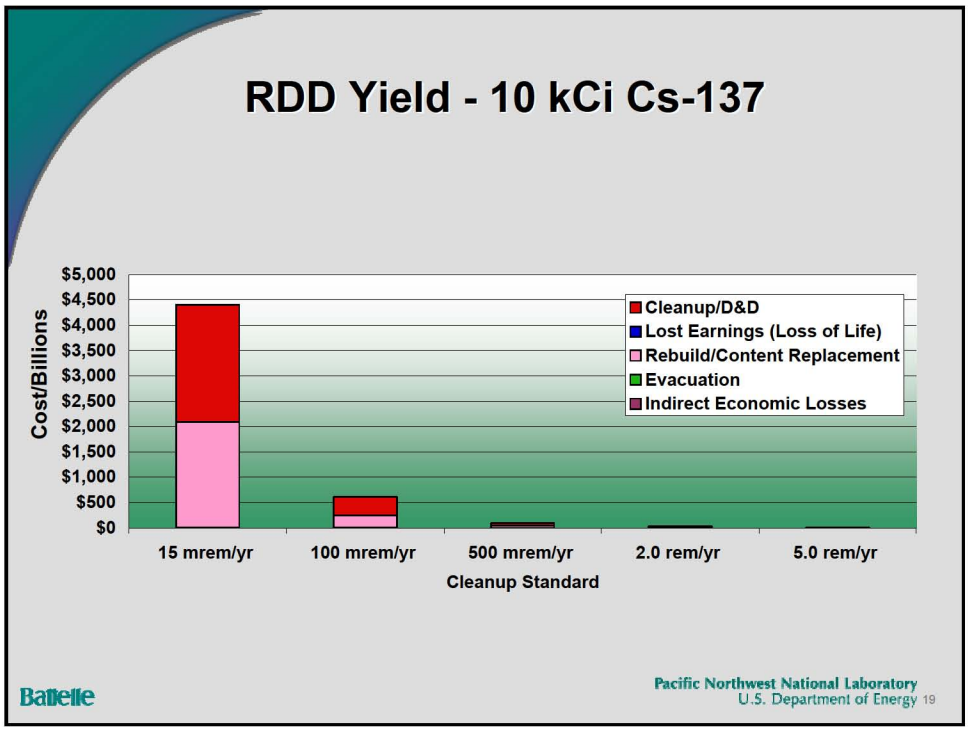
RDD Yield - 10 kCi Cs-137
Cost/Billions
$5,000
$4,500
$4,000
$3,500
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Cleanup/D&D
Lost Earnings (Loss of Life)
Rebuild/Content Replacement
Evacuation
Indirect Economic Losses
15 mrem/yr
100 mrem/yr
500 mrem/yr
2.0 rem/yr
5.0 rem/yr
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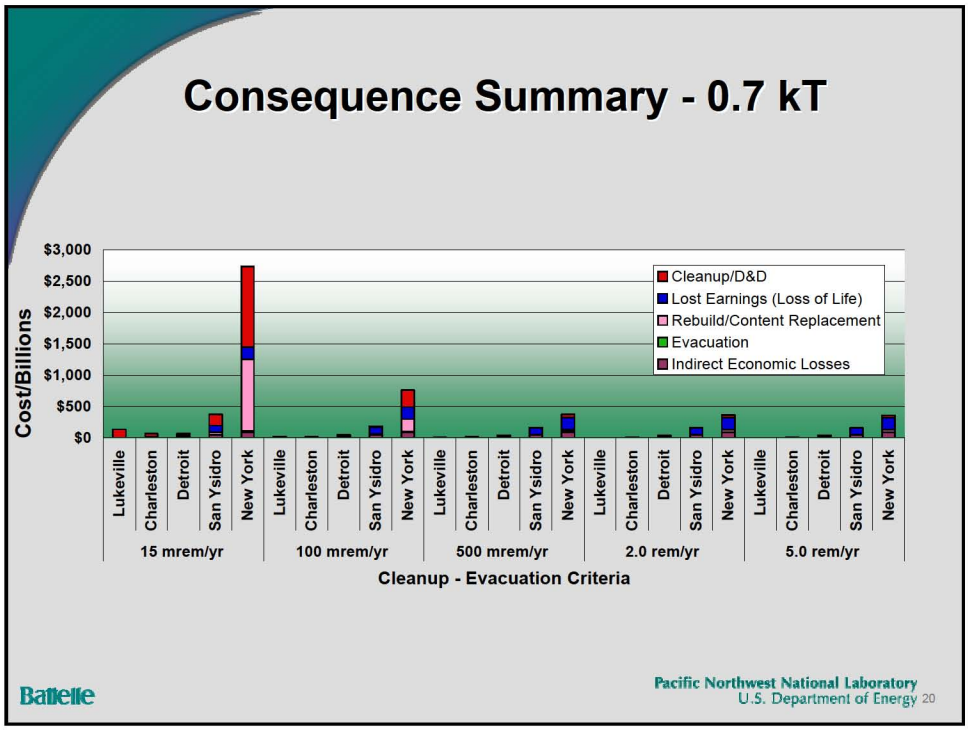
Consequence Summary - 0.7 kT
Cost/Billions
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Cleanup/D&D
Lost Earnings (Loss of Life)
Rebuild/Content Replacement
Evacuation
Indirect Economic Losses
Lukeville
Charleston
Detroit
San Ysidro
New York
15 mrem/yr
100 mrem/yr
500 mrem/yr
2.0 rem/yr
5.0 rem/yr
Cleanup - Evacuation Criteria
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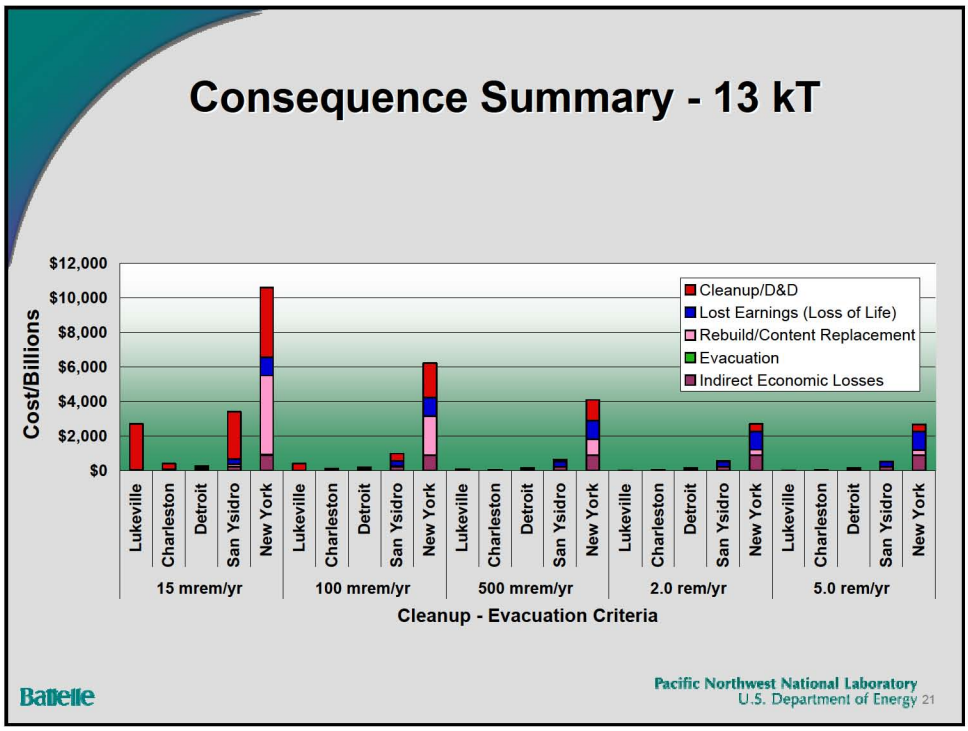
Consequence Summary - 13 kT
Cost/Billions
$12,000
$10,000
$8,000
$6,000
$4,000
$2,000
$0
Cleanup/D&D
Lost Earnings (Loss of Life)
Rebuild/Content Replacement
Evacuation
Indirect Economic Losses
Lukeville
Charleston
Detroit
San Ysidro
New York
15 mrem/yr
100 mrem/yr
500 mrem/yr
2.0 rem/yr
5.0 rem/yr
Cleanup - Evacuation Criteria
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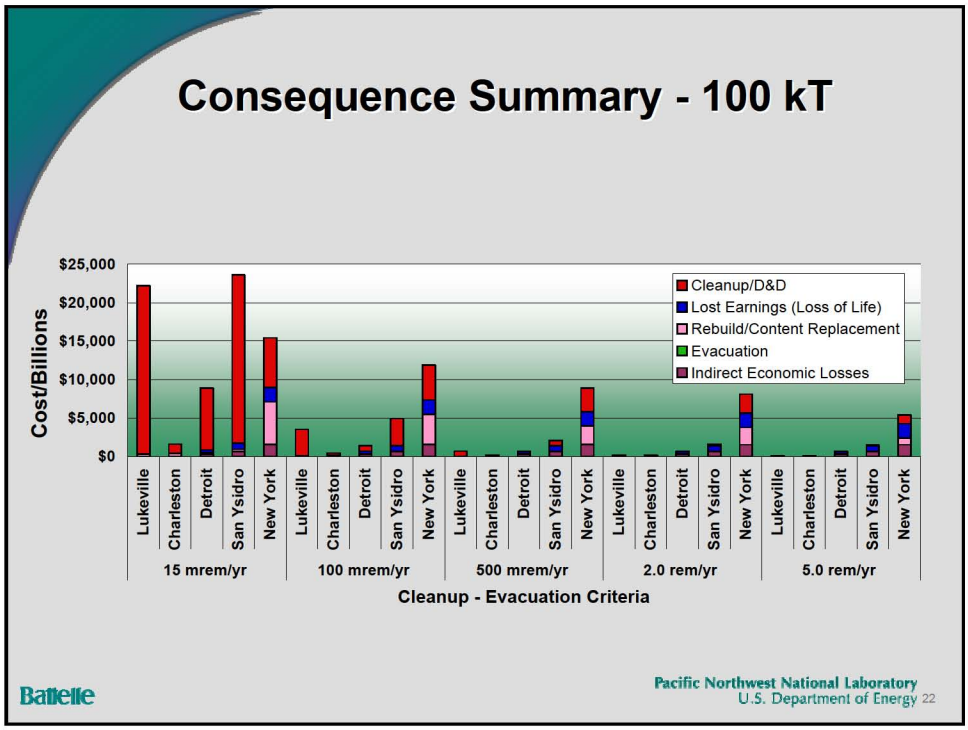
Consequence Summary - 100 kT
Cost/Billions
$25,000
$20,000
$15,000
$10,000
$5,000
$0
Cleanup/D&D
Lost Earnings (Loss of Life)
Rebuild/Content Replacement
Evacuation
Indirect Economic Losses
Lukeville
Charleston
Detroit
San Ysidro
New York
15 mrem/yr
100 mrem/yr
500 mrem/yr
2.0 rem/yr
5.0 rem/yr
Cleanup - Evacuation Criteria
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ECONOMIC CONSEQUENCES OF A RAD/NUC ATTACK: CLEANUP STANDARDS SIGNIFICANTLY AFFECT COST

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ABSTRACT

Property destruction, loss of life, and injuries sustained from a nuclear or radiological attack have significant economic consequences. The loss of productive assets can extend for long periods and generate significant economic loss. Economic impacts caused by an event need to be addressed in sequential order beginning with the detonation, atmospheric dispersion, and deposition of the fallout from the weapon. Weapon characteristics provide the boundary conditions for the response, including defining how large the response area is and what specific actions need to be taken to protect the population in the target area. These economic consequences are highly dependent on the magnitude of the weapon event and do not scale in a linear fashion.

The cost to clean up or remediate the affected area will depend on the cleanup standard applied to the event and is highly sensitive to this standard. Currently, there are no cleanup standards specifically designed for Rad/Nuc terrorist events, but it is likely that the existing Environmental Protection Agency (EPA) and Nuclear Regulatory Commission (NRC) standards would apply defacto. The Department of Energy (DOE) has spent billions of dollars on superfund cleanup, under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) guidance, at former weapons production sites, and the cleanup is expected to continue through 2035. This paper offers an economic perspective on the magnitude of the consequences for a selected class of targets in the United States, with an emphasis on cost sensitivity as the cleanup standard changes.

INTRODUCTION

The prospect of a nuclear attack on the United States was long thought to be restricted to the domain of state actors. Following the terrorist events of September 11, 2001, and other more recent terrorist activities around the world, concerns about all types of terror attacks, including potential radiological and nuclear attacks, have been magnified. The spotlight has shifted to countermeasures that will either reduce the likelihood or reduce the consequences of a radiological or nuclear (Rad/Nuc) terrorist attack.

The decision to invest in Rad/Nuc countermeasures can be viewed as a tradeoff between investment cost of the countermeasure and the consequences of the event. There are both physical consequences and economic consequences that would result from a Rad/Nuc event. Economic impacts caused by an event, and the subsequent response to the event, need to be addressed in sequential order and begin with the physical impacts of the detonation, atmospheric

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dispersion, and deposition of the fallout from the weapon. Physical consequences dictate the response function including the long-term cleanup and site restoration actions taken. One of the recurring themes regarding event response is that there are currently no federal standards that cover the long-term site restoration and cleanup following a radiological or improvised nuclear device (IND) terrorist attack.

The cost to clean up or remediate the affected area is highly sensitive to the cleanup standard applied to the event. There are currently no cleanup standards specifically designed for Rad/Nuc terrorist events, but it is likely that the existing EPA and NRC standards would apply defacto [1].

The General Accounting Office (GAO) reports that the current EPA and NRC cleanup standards differ and these differences have implications for both the pace and ultimate cost of cleanup [2].

The Department of Energy (DOE) has spent billions of dollars on superfund cleanup at former weapons production sites and the cleanup is expected to continue through 2035 [3]. In 2003 recognizing the importance of this issue, the Department of Homeland Security (DHS) tasked an interagency working group to address the issue of Protective Action Guidelines (PAGs) for radiological dispersal devices (RDDs) and improvised nuclear device (IND) incidents. DHS anticipates a draft of that guidance to be issued in the *Federal Register* in June of 2005.

This paper offers an economic perspective on the magnitude of the consequences for selected targets with an emphasis on cost sensitivity as the cleanup standard changes. The work described provides a framework within which the physical consequences of a Rad/Nuc attack can be translated into the economic consequences in U.S. dollars. These effects need to be understood in order to prescribe appropriate countermeasures and policy remedies.

A METHODOLOGY FOR ECONOMIC CONSEQUENCE CALCULATIONS

For this study, "Rad/Nuc" spans a range of possible nuclear weapons and one large radiological dispersion device:

- 0.7 kT nuclear weapon
- 13 kT nuclear weapon
- 100 kT nuclear weapon
- 10 kCi Cs-137 RDD

Five potential targets were selected ranging from an isolated rural area to very high density urban areas. All of the following targets are located on U.S. Borders and/or Ports of Entry into the United States:

- Lukeville, AZ
- Charleston, SC
- Detroit, MI
- San Ysidro, CA
- New York City, NY

The taxonomy of location, weapon yield, and contamination contours was parameterized and fed into the National Atmospheric Release Advisory Center (NARAC) Model to generate the physical consequences. Consequences vary based upon assumptions about where the population is at the time of the attack (home vs. work, indoors vs. outdoors), on what meteorological conditions are assumed, and on the prompt versus fallout effects of the weapon. Those assumptions are classified and not discussed in this paper.

Our focus here was primarily on the economic consequences of a nuclear weapon attack; the impacts of an RDD are still under investigation and will merit further research.

Weapon characteristics, including the type of weapon, the quantity of material, and how the dispersion is achieved, provide the boundary conditions for the response including how much area is impacted and what actions need to be taken to protect human health and the environment. The physical consequences derived from weapon characteristics were then used to calculate economic consequences in five broad categories of cost:

1. Loss of productivity from earnings forgone
2. Indirect economic effects or "multiplier"
3. Loss and damage to building structures and building contents
4. Decontamination and decommissioning referred to as cleanup cost
5. Evacuation cost

These economic consequences, including the cost and time to clean up from the event, are highly dependent on the magnitude of the weapon event and do not scale in a linear fashion.

The consequences of a nuclear weapon detonation are estimated to have both significant loss of human life and substantial cleanup and reconstruction costs. A high degree of outright destruction of property (buildings, public infrastructure, and productive capital equipment of all sorts) will occur due to the detonation. In general, the economic cost of this type of loss is just the lost productivity of the capital (including human capital) destroyed. In a market economy, it is a reasonable approximation to use market values as a surrogate for the value of this production.

The economic and psychosocial effects of an RDD attack are expected to be more significant than the potential loss of human life and building destruction [4]. In the event of a radiological dispersion event, there is a set of economic consequences generated as a result of the event and a set of economic consequences that is independent of the magnitude of a radiological event because of public perception about the dangers associated with RDDs.

In order to derive consequence estimates, an economic evaluation taxonomy was established to determine what potential targets and cleanup levels should be evaluated for the five broad categories of economic consequences.

The responses to nuclear weapon events can be thought of as phases: 1) the initial emergency response and evacuation, 2) the intermediate response where most emergencies have been handled and the focus shifts to cleanup, and 3) the cleanup phase where recovery and cleanup actions are designed to reduce radiation levels in order for land/buildings to be re-used or re-inhabited.

Our primary focus is on phase 3. The cleanup cost for an area is highly dependent on the cleanup standard used, the cleanup technology employed, and the radiological (and other safety) conditions under which cleanup is conducted. Decontamination efforts will include cleaning or sandblasting the exterior or completely demolishing affected buildings, safely disposing of generated radioactive waste, decontaminating the emergency vehicles used in the response and

recovery process, and many other activities. These efforts alone could cost billions of dollars and take decades to accomplish, depending on the magnitude of the radiological event and the cleanup level employed.

Because of our interest in the impacts of cleanup levels on the cost, we considered a range of potential cleanup levels from existing standards and protective action guidelines that might ultimately apply to a terrorist attack (Figure 1). This taxonomy was applied to all five potential targets for the purpose of providing a consequence valuation methodology. On a scale of most conservative to least conservative, the Environmental Protection Agency (EPA) standard governing cleanup at sites with radioactive contamination represents the most conservative level that we evaluated. The intent of this paper was to assess the sensitivity, not to determine which cleanup standard is best.

15 mrem/yr	EPA, "Establishment of Cleanup Levels for CERCLA Sites With Radioactive Contamination" (e.g., Hanford Site)
25 mrem/yr	NRC, Final Rule on Radiological Criteria for License Termination (10 CFR Part 20 Subpart E)
100 mrem/yr	Health Physics Society Position Statement, "Guidance for Protective Actions Following a Radiological Terrorist Event"
500 mrem/yr	EPA, "Manual of Protective Action Guides and Protective Actions for Nuclear Incidents," 400-R-92-001, ... "doses in any single year after the first will not exceed 0.5 rem "
2 rem/yr	EPA, "Manual of Protective Action Guides and Protective Actions for Nuclear Incidents," 400-R-92-001, ... "doses in first year will not exceed 2 rem "
5 rem/yr	NRC, "Standards for Protection Against Radiation," recommendation and established dose limit for workers of 5 rem/yr (10 CFR 20 Subpart C)

Figure 1. Cleanup Levels Evaluated for Economic Consequences

There are a large number of economic variables that could potentially be included in the calculation of impacts. These include psychological impacts and long-term societal impacts of living under enduring heightened security conditions. Our intent was to quantify those elements we believed were most representative of this type of terrorist attack. A discussion of those five variables follows.

Loss of Productivity from Earnings Forgone

To calculate the loss of human capital due to death from a weapon event, we used a "lifetime-earnings loss" method outlined in a study by the Federal Reserve Bank of New York [5]. This method estimates individual economic losses by estimating a worker's annual earnings over his or her remaining working lifetime. The estimated earnings are then discounted to the current time period (net present value) using a discount factor of 7%, which is the OMB rate to discount lifetime earnings lost and includes a "social factor" to account for the other societal losses that result from premature death. Ex ante, the number of affected workers is tied to the geographic size of the event.

Indirect Economic Effects or "Multiplier"

There will be "indirect" economic impacts associated with the consequences of a nuclear or radiological attack. For example, during the decontamination process, buildings in the affected area would not be functional. Residents would have to be relocated. Businesses would have to do the same or simply halt their activities until completion of the decontamination. Depending on the nature of business conducted inside those buildings, the regional and national economy could be negatively impacted. A resulting decrease in the area's real estate prices, tourism, and commercial transactions could have long-term negative effects on the area's economy.

There are several economic methods whereby "multipliers" are applied to the estimated direct costs (lost income) to estimate the indirect economic impacts. These values may be estimated on the basis of information about the nature of the affected businesses in the response area. The indirect impacts will be larger if the markets for directly affected sectors are beyond the local economic area. In essence, these sectors are "export" driven. If these sectors are no longer allowed to operate, then the impacts will be severe because supporting businesses in the local area will be forced to scale back. We derived multipliers from the FRBNY 9/11 study [5] as follows:

- Low impact scenario (10 kCi Cs-137 RDD, and 0.7 kT nuclear weapon) – 46% of lost earnings
- High impact scenario (13 kT and 100 kT nuclear weapon) – 82% of lost earnings

Decontamination and Decommissioning or Cleanup Cost

Cleanup and restoration of buildings and land after a Rad/Nuc event will be complicated by the need to decontaminate and, potentially, demolish radiologically contaminated buildings and land. The cost of this cleanup will be highly dependent on the areal extent of cleanup, which, in turn, is highly dependent on the level of cleanup required. The cost of cleanup of any given area will be dependent on the relative level of economic development or financial investment that has been made in the area of concern. The approach taken in this study was to develop unit cost factors ($\$/km^2$) for the cleanup of areas having different levels of population density; population density being used as a surrogate for economic activity. Cleanup cost data primarily came from two sources:

- The economic model provided as a companion to the RADTRAN 5 computer program developed for analysis of the consequences and risks of radioactive material transportation (see http://ttd.sandia.gov/risk/radtran.htm). [6] This economic model was initially developed to estimate the economic consequences of plutonium-dispersal accidents.
- The FRBNY study of the economic effects of the 9/11 terrorist attack on New York City, "*Measuring the Effects of the September 11 Attack on New York City*" [5].

RADTRAN 5's companion economic model includes estimated unit costs ($\$/km^2$) for: emergency actions (e.g., applying fixatives) following the event; access control (e.g., guards) to prevent unauthorized access to the contaminated areas; radiological characterization; decontamination/demolition operations; and disposal of radiologically contaminated waste. These elements were summed together to obtain the total cost of cleanup and site restoration.

RADTRAN 5 varies these costs depending on whether the area is an urban area that is lightly contaminated, moderately contaminated, or heavily contaminated or whether the area is farm or range land. The unit costs from the economic model, assuming offsite disposal of radioactive waste, are summarized in Table 1.

Table 1. Summary of Unit Costs for D&D, Building Replacement, and Evacuation Valuation

Area Description	D&D Unit Cost Per km^2 (2005$)	Replacement Unit Cost Per km^2 (2005$)	Evacuation Cost Per Person	Comments
Farm or Range Land	$93 million	$1.2 million	$4,500	Applied to contaminated areas having a population density of less than 50 people/km^2.
Lightly Contaminated Urban	$130 million	$29 million	$2,600	Applied to urban areas having a population density greater than 50 people/km^2 and less than 3,000 people/km^2 and requiring a decontamination factor (DF) of 1-2 to remediate to the required cleanup standard.
Moderately Contaminated Urban	$182 million	$45 million	$3,300	Applied to urban areas having a population density greater than 50 people/km^2 and less than 3,000 people/km^2 and requiring a DF of 2-10 to remediate to the required cleanup standard.
Heavily Contaminated Urban	$275 million	$220 million	$4,500	Applied to urban areas having a population density greater than 50 people/km^2 and less than 3,000 people/km^2 and requiring a DF greater than 10 to remediate to the required cleanup standard. This level of decontamination is difficult to achieve and cost may exceed the property value. **RADTRAN 5 assumes that heavily contaminated buildings and structures are demolished rather than decontaminated.**
High Density Urban	$2.7 billion	$6.6 billion	$4,500	Applied to urban areas having a population density greater than 3,000 people/km^2 but less than 10,000 people/km^2 and requiring a DF greater than 10 to remediate to the required cleanup standard.
Very High Density Urban	$24 billion	$19 billion	$4,500	Applied to urban areas having a population density greater than 10,000 people/km^2 and requiring a DF greater than 10 to remediate to the required cleanup standard.

The urban area upon which the RADTRAN 5 economic model derives its unit cleanup costs is assumed to have an average population density of 1,344 people/km^2. This is significantly lower than high density metropolitan areas such as New York City, which has an average population density of over 20,000 people/km^2. For this reason, the unit costs derived from RADTRAN 5 were not considered to be a good estimate for the cleanup of higher density population areas.

To estimate the impacts on New York City, a proxy for high density urban areas was derived from the FRBNY study, [5] which reported a value of $1.5 billion to clean up and restore the 16-acre World Trade Center site after the terrorist attack. This equates to $24 billion/km^2 in 2005 dollars. This is almost two orders of magnitude greater than the RADTRAN 5 economic model unit cost for cleanup of a heavily contaminated urban area. Furthermore, the cost of cleanup of the WTC site would undoubtedly have been much higher had it been destroyed by a Rad/Nuc event. On the other hand, the WTC site is not representative of New York City in general or any other major population center in the United States because of the unique and very high value buildings that stood on this site. Taking these important points into consideration, this FRBNY data was used to derive the unit cleanup costs for the high and very high density urban areas reported in Table 1.

Loss and Damage to Building Structures

The costs to replace and/or rebuild property damaged or destroyed as the result of a Rad/Nuc event, or to compensate owners for the loss of use of this property (including business income loss), were also calculated using unit costs derived from the RADTRAN 5 companion economic model and the FRBNY 9/11 study. As with site cleanup and restoration, these costs are highly dependent on the areal extent and level of contamination. These unit costs are also presented in Table 1.

The unit costs for lightly, moderately, and heavily contaminated urban areas and for farm and range land were derived from the RADTRAN 5 economic model. Again, for the reasons presented previously, the unit costs derived from the RADTRAN 5 economic model were not considered to be a good estimate of the cost to rebuild high population density areas after a Rad/Nuc event. The unit costs for these areas were derived from the FRBNY 9/11 study.

The FRBNY 9/11 study reported a value of $11.9 billion to replace the buildings and contents of the WTC complex, equating to $193 billion/km^2 in 2005 dollars (and which does not include business income loss). This is almost three orders of magnitude greater than the RADTRAN 5 economic model unit cost for replacement of destroyed property in a heavily contaminated urban area having an average population density of 1,344 people/km^2. As discussed previously, however, the WTC site is not representative of New York City in general or any other major population center in the United States because of the unique and very high value buildings that stood on this site and which will be replaced with equally high value buildings. The replacement value reported in the FRBNY study is therefore likely to be much higher than would be expected for the average high density urban area. Taking this important point into consideration, the FRBNY data were used to derive the unit cleanup costs for high and very high density urban areas reported in Table 1.

Evacuation Cost

The cost to evacuate and relocate the population living within areas contaminated as a result of the Rad/Nuc event was calculated using unit costs derived from the RADTRAN 5 economic model. This cost is assumed to depend on the level of contamination; at higher contamination levels, the population is denied access for longer periods of time. RADTRAN 5 varies these costs in the same major categories as the D&D and Replacement Costs. Unit costs used for evacuation are presented in Table 1.

OBSERVATIONS FROM APPLICATION OF THIS METHODOLOGY

The effects of nuclear weapons have been studied and documented intensively. Fallout will decay based on the individual isotopic half-lives, the most energetic (and most dangerous) decaying in hours or days while longer-lived isotopes persist for months and years. The dose rate from fallout drops by a factor of 1,000 48 hours after detonation, and over 90% of the dose is received in the first year after a nuclear weapon event [7]. This dose response time after detonation is important when estimating the cost of cleanup, site restoration, and rebuild after a Rad/Nuc event. Figure 2 illustrates this by showing the land area requiring cleanup for different cleanup criteria (residual dose rates) for different time periods following detonation of a 13-kT nuclear weapon. As shown, the surface area requiring cleanup decreases by a factor of 10 to 100 during the second year following detonation as compared with the first year following

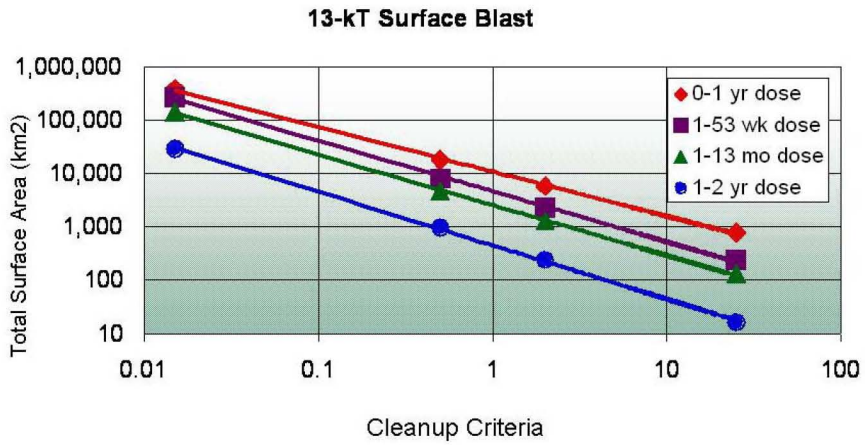


Figure 2. Area Requiring Remediation for Different Cleanup Criteria

detonation. Since cleanup would likely not be completed during the first year following detonation, this analysis estimated the cost of cleanup of that land area remaining contaminated above the cleanup criteria 1 year after detonation.

In the case of the RDD event, however, little radioactive decay will occur during the time period of remediation (first year or two). For this reason, the cost of cleanup of an RDD event was based on the land contaminated by fallout over the first year following the event.

We then took the physical plume contours for each of the three nuclear weapon yields and the five cleanup levels and plotted those in the five target locations. Figure 3 illustrates this concept with the plume 1-2 yr contour for the 100-kT nuclear weapon in New York City, NY, and San Ysidro, CA.

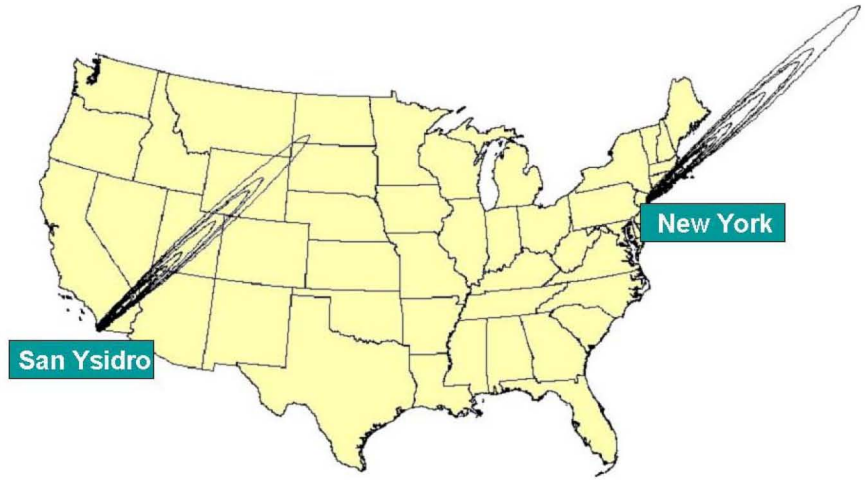


Figure 3. Hypothetical Plume Contours for 100-kT and 5 Cleanup Levels

The plume contours used represent a generic "wind condition." Clearly, wind conditions impact the radioactive fallout after a nuclear weapon event and the ability to value damage depends on where the damage occurs. The plume in New York City blows into the Atlantic Ocean; although not depicted here, the plume for Detroit goes into Canada and Lake Erie. For this high-level

analysis, our damage assessment is limited to the continental United States and represents surface area cleanup excluding groundwater contamination.

The results of our analysis are shown in Figure 4. As anticipated, the economic consequences are highest for the largest nuclear weapon yield and the most conservative cleanup level. New York City nets the highest economic damage across the cleanup spectrum, because of its dense population and high value real estate. Note that the economic consequences for New York City across almost every cleanup level meet or exceed $10 trillion, which is roughly equivalent to the annual Gross Domestic Product (GDP) of the U.S. economy.

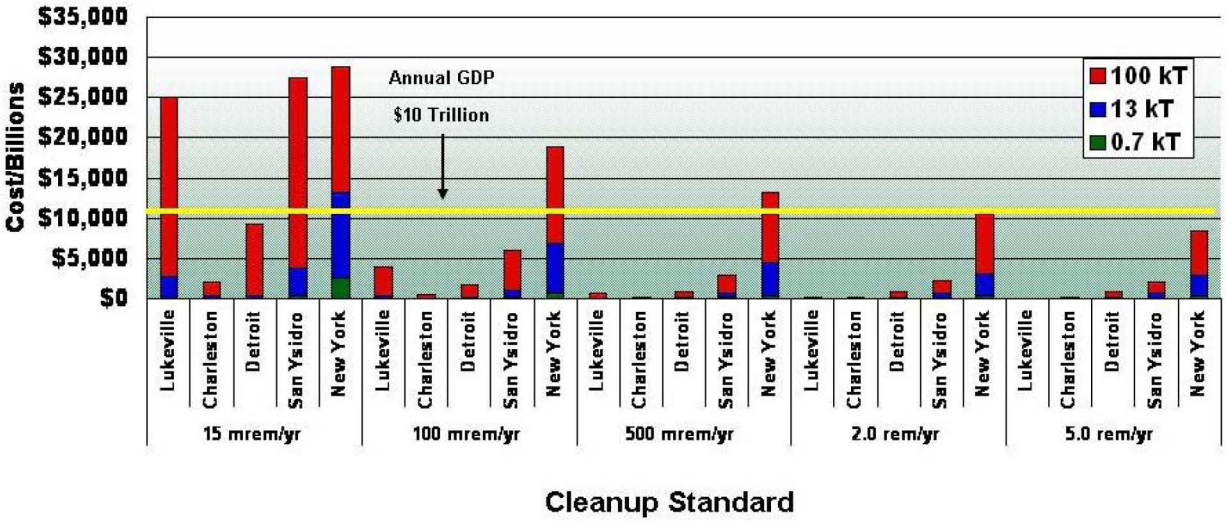
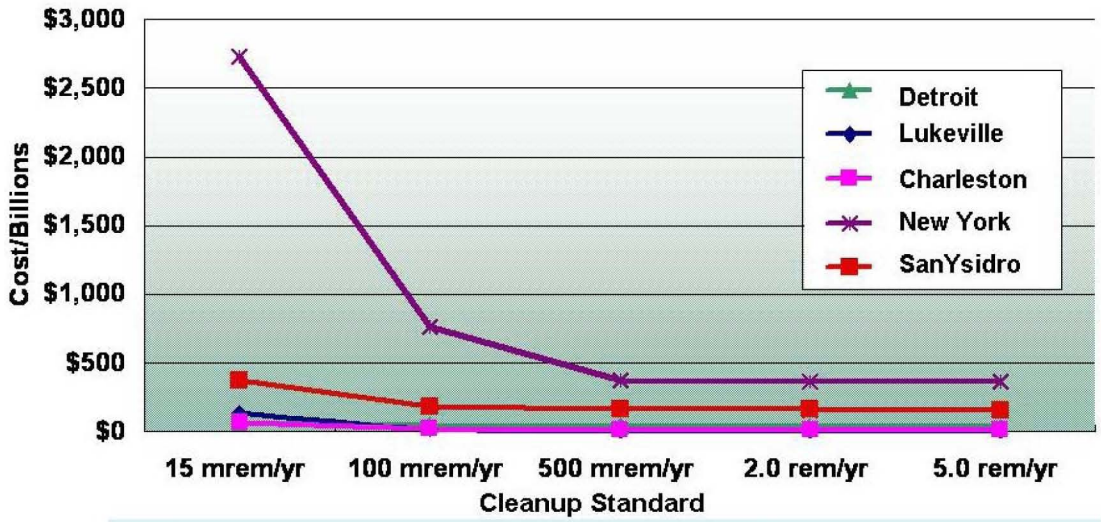


Figure 4. Consequence Summary for Hypothetical Weapon Events and Cleanup Levels

Figures 5, 6, and 7 represent the consequence summaries for each nuclear weapon event. The area impacted and requiring long-term cleanup is a function of the standard selected as represented in the data table under the graph. Individually and collectively, the economic consequences are highest for the most conservative standard evaluated.

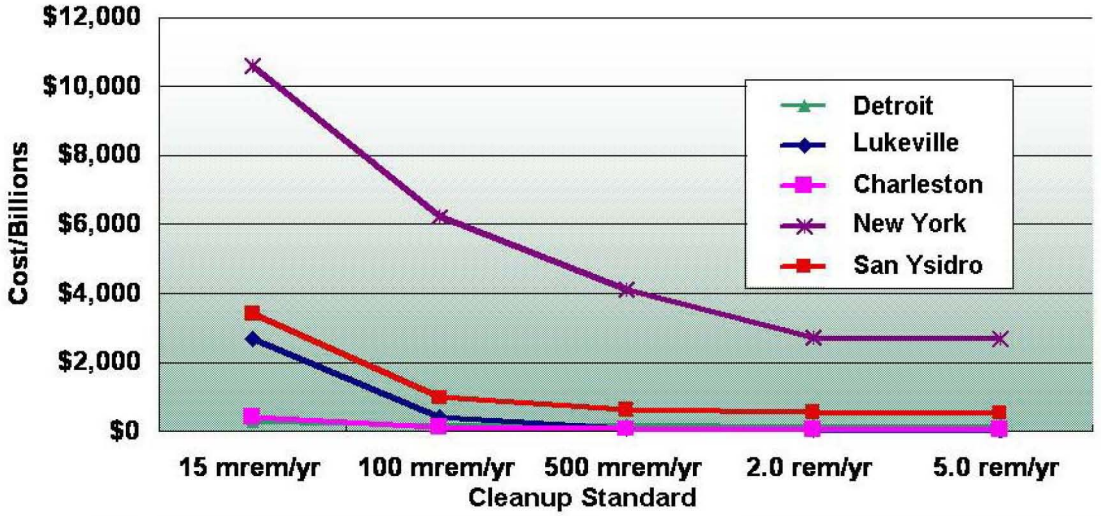
Figure 8 provides a summary of the economic consequences by the five broad categories evaluated. This representation demonstrates that it is the cleanup cost (or D&D cost) that is the largest individual contributor to economic consequences across the cleanup level spectrum until we reach the least conservative cleanup level, at which point the loss of life is the largest cleanup cost.

In the case of an RDD, the type of contamination depends only on the source material(s) (no nuclear process is involved), and the extent of contamination depends on the physical form of the source and the effectiveness of the dispersal mechanisms. The ultimate fate of the contamination (and thus long-term consequences) is dependent on a complex chain of transport, uptake, exposure, and remediation processes. Fallout from an RDD explosion would be very different from that of a nuclear weapon detonation because there would be no large thermal cloud to inject the radioactive material into the atmosphere, and the amount of radioactive material would be much less than that generated in a nuclear weapon event. A preliminary assessment of the economic consequences of a 10 kCi Cs-137 RDD in New York City is presented in Figure 9.



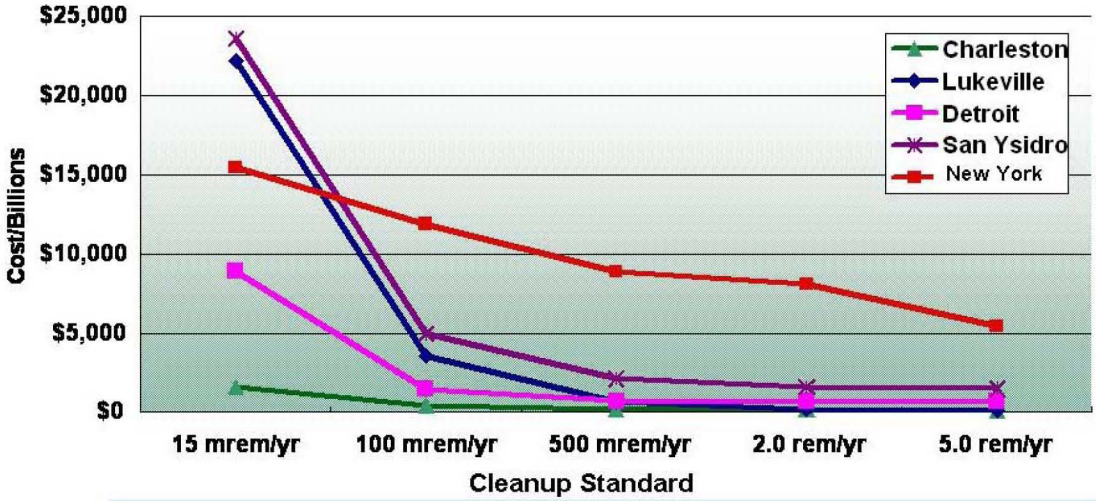
0.7 kT	Cleanup Area (km2)				
Lukeville, AZ	1,430	179	45	10	4
Charleston, SC	557	97	29	6	3
Detroit, MI	90	42	25	10	4
San Ysidro, CA	1,430	179	45	10	4
New York, NY	600	179	45	10	4

Figure 5. The 0.7-kT Weapon Event



13 kT	Cleanup Area (km2)				
Lukeville, AZ	28,587	4,249	950	238	95
Charleston, SC	2,679	630	275	117	52
Detroit, MI	502	134	57	40	28
San Ysidro, CA	28,555	4,239	950	238	95
New York, NY	9,753	2,594	474	237	95

Figure 6. The 13-kT Weapon Event



100 kT	Cleanup Area (km2)				
Lukeville, AZ	235,887	37,427	7,275	1,951	802
Charleston, SC	7,337	2,212	703	412	283
Detroit, MI	85,669	7,551	122	89	69
San Ysidro, CA	235,636	37,381	7,269	1,944	799
New York, NY	17,745	10,197	5,233	923	504

Figure 7. The 100-kT Weapon Event

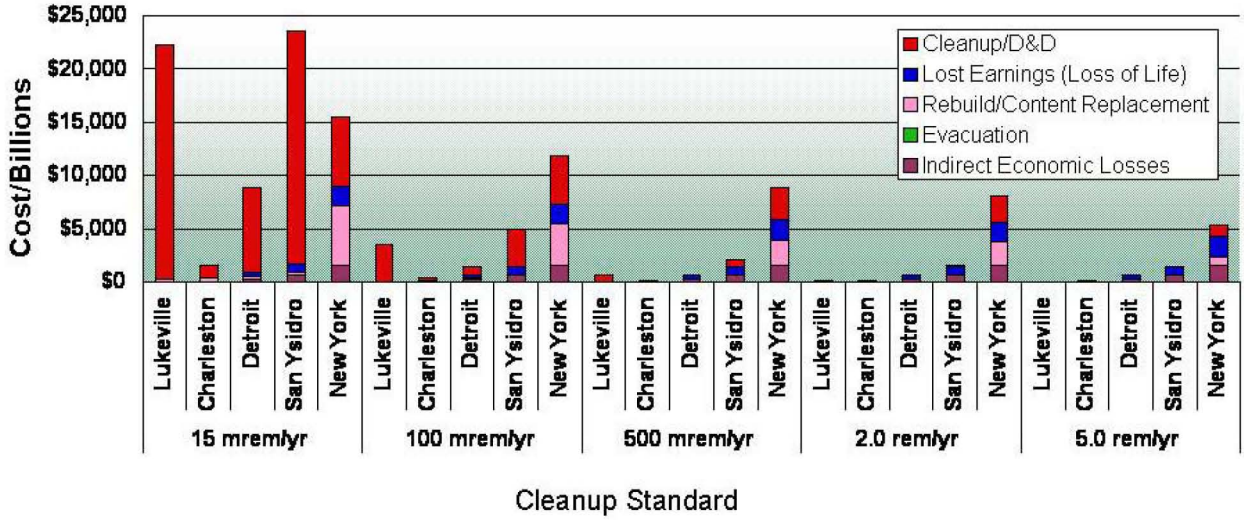


Figure 8. Summary by Five Categories Evaluated

There is virtually no loss of life with the Cs-137 event, but the cleanup cost and the cost to rebuild and/or replace buildings is once again significant, particularly for the most conservative standard (one-half of the annual U.S. GDP).

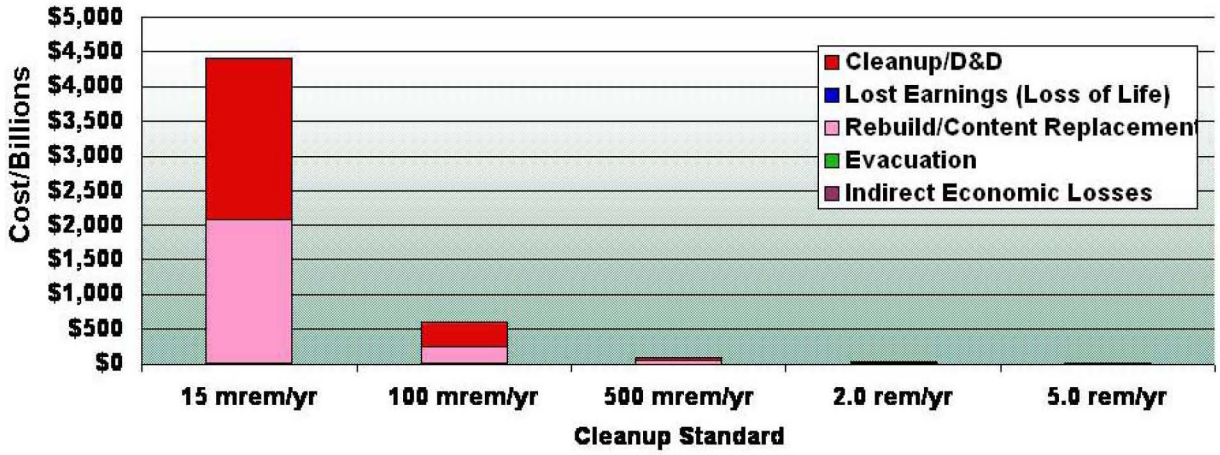


Figure 9. 10-kCi Cs-137 Detonation in New York City

CONCLUSIONS

The methodology described in this paper provides a framework for evaluating the major cost components following a nuclear weapon event. There are several observations that can be made from the results thus far:

- The economic consequences of a Rad/Nuc event are highly dependent on and closely coupled to the cleanup level selected.
- Cleanup costs generally increase dramatically for standards more stringent than 500 mrem/yr.
- Cleanup to the most conservative standard evaluated (15 mrem/yr) magnifies the economic consequences of the event irrespective of the class of target or weapon yield.
- Because such an event could potentially spread contamination very widely, even an event in a "remote" location could have huge economic consequences.
- A risk-based approach to the development and application of standards is needed.

There are no national standards for acceptable decontamination of a radiological weapon event, and the EPA standards used under CERCLA were enacted to address growing concerns about the need to clean up uncontrolled, abandoned hazardous waste sites and to address future releases of hazardous substances into the environment. Cleanup after a weapon event such as one of those described in this paper will be vastly different from the cleanup of a contaminated industrial facility or former weapons production facility. The standard selected will impact both the cost and the pace of the cleanup. Policy level attention to cleanup standards is warranted.

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