**Attachments to the DHS S&T Technical Review of NRC Draft Report "*Department of Homeland Security's Biological Risk Analysis: A Call for Change.*"**

# Attachment A

## (1) Ezell and VonWinterfeldt Summary of Risk and Decision Analysis Expert Polling. (2) Technical note summarizing literature review of PRA and other probabilistic applications for “intelligent adversary” terrorism risk analysis.

21 May 2008

Dr. Ralph J. Cicerone
President, National Academies of Sciences
500 Fifth Street, NW
Washington, DC 20001

Dear Dr. Cicerone:

The NRC Committee's report entitled "Department of Homeland Security Bioterrorism Risk Assessment: A Call for Change" includes a key recommendation, upon which the Committee partially bases its conclusion that DHS and senior government leadership should discard the DHS' 2006 Bioterrorism Risk Assessment (BTRA)[1]. Recommendation #2, and its rationale as described in the NRC Report asserts that "DHS should use…decision-oriented models that explicitly recognize terrorists as intelligent adversaries…"[2] In the expository text preceding this recommendation in the NRC's Executive Summary, the Committee writes:

> "BTRA represents adversarial decisions by probabilities assessed by subject matter experts. However, when dealing with an intelligent, goal-oriented, and resourceful adversary (the terrorist), the exclusive use of subjectively assessed probabilities for terrorist decisions is inappropriate. For decision problems as complex as BTRA, the probability that an adversary will choose a course of action should be an output of analysis, not an input."[3]

In Chapters 1 and 7, the Committee goes on to support Recommendation #2 by stating that probabilistic risk analysis (PRA) "…as used in the BTRA, is the wrong framework for modeling risks that are inherently dependent on the choices made by intelligent adversaries"[4] and that "The 2006 BTRA does not consider intelligent adversaries. The BTRA probability assessment of terrorist decisions is independent of the potential consequences of the attack."[5] Also in Appendix D, the Committee states that there are "…weaknesses in the use of event trees to model terrorist actions since it does not model the actions of an intelligent adversary."[6]

These criticisms of BTRA come very close to a rejection of PRA and event trees approaches in the context of terrorism risk analysis. In response, DHS S&T commissioned a technical note that reviews relevant scholarly literature (Ezell and von Winterfeldt, 2008, attached to this document), and has polled top-tier decision and risk analysis experts to examine the key issues raised in the NRC Report. The experts were:

1. Vicki Bier, Ph.D., Professor, Department of Industrial and Systems Engineering, University of Wisconsin-Madison
2. John Garrick, Ph.D., Adjunct Professor, Department of Civil & Environmental Engineering, Vanderbilt University (Member, National Academy of Engineering)
3. Yacov Haimes, Ph.D., Lawrence Quarles Professor of Engineering and Applied Science Director of the Center for Risk Management of Engineering Systems, University of Virginia
4. Ralph Keeney, Ph.D., Research Professor of Decision Sciences, Duke University (Member, National Academy of Engineering)

[1] NRC Committee on Methodological Improvements to the Department of Homeland Security's Biological Agent Risk Analysis. "DRAFT: Department of Homeland Security Bioterrorism Risk Assessment: A Call for Change." Washington, D.C.: National Academies Press, 2008. Recommendation #13, Pages ES-11, ES-12.
[2] NRC Committee. "DRAFT: A Call for Change" Page ES-6.
[3] NRC Committee. "DRAFT: A Call for Change" Pages ES-5,6
[4] NRC Committee. "DRAFT: A Call for Change" Page 1-9.
[5] NRC Committee. "DRAFT: A Call for Change" Page 7-2.
[6] NRC Committee. "DRAFT: A Call for Change" Page D-1.

5. L. Robin Keller, Ph.D., Professor, Operations and Decision Technologies, University of California
6. Elizabeth Pate-Cornell, Ph.D., Professor and Chair Department of Management Science and Engineering, Stanford University (Member, National Academy of Engineering)
7. Henry Willis, Ph.D., RAND Corporation

Because the experts polled were not necessarily familiar with BTRA, their responses addressed the use of PRA and event trees in general. Issues related to the actual *implementation* of PRA in the 2006 BTRA, as well as other issues related to Recommendation #2 (such as how subject matter elicited information was handled, and whether it is defensible to separate attack probabilities from consequences) are addressed elsewhere by DHS.

Garrick, Keeney, Pate-Cornell, Keller, and Willis agreed with the basic conclusions expressed by Ezell and von Winterfeldt that PRA and event trees are useful tools in terrorism risk analysis. Even experts expressing reservations about the exclusive use of PRA (Bier, Haimes) advocated *adding* other approaches as complements and supplements (including many of the same approaches the Committee suggests), not *replacing* probabilistic analyses.

In conclusion, some of the top scientists in the fields of risk and decision analysis support the use of PRA and event trees at least as one possible approach to address terrorism risks. Other models and tools like the decision tree approach proposed by the Committee may well be useful supplements or complements to more standard approaches, but, like PRA, they first have to prove their value through peer reviewed publications and impactful applications.

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# Probabilistic Risk Analysis and Terrorism Risk

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May 21,2008

For more than thirty years, probabilistic risk analysis (PRA) has been a major tool for assessing risks and informing risk management decisions by government and businesses in areas as diverse as industrial safety, environmental protection, and medical decision making (see, for example, Kaplan and Garrick, 1981; Garrick, 1984; Bedford and Cooke, 2001; Bier and Cox, 2007; Pate-Cornell, 2007). The more recent application of PRA to terrorism risks is new however, and not uncontroversial. In this note, we take a broad view of PRA, including any probabilistic approach involving tools like event trees, fault trees, decision trees, and influence diagrams.

A major challenge in risk analysis of terrorist attacks is the fact that terrorists, unlike nature or engineered systems, are intelligent adversaries and may adapt to our defensive measures. Some have argued that because of this adaptive nature, alternative tools like game theory and agent-based modeling are needed to assess the risks of terrorist events. While we do not take issue here with the possible value of these alternative approaches, we aim to make a case 1) that PRA is an important and useful approach for quantifying terrorism risks and has value in guiding risk management decisions; and 2) event trees can be used as part of a terrorism PRA to decompose the universe of terrorism scenarios.

**1. Probabilistic risk analysis is useful to quantify terrorism risk**

In the first issue of the journal *Risk Analysis*, Kaplan and Garrick (1981) published an important paper in risk analysis, which defined risk as the triplet of scenario, likelihood, and consequence. For the following twenty-seven years, the risk and decision analysis communities have cited this seminal paper and used many of the concepts and tools developed in it. More recently, Garrick et al. (2004) advocate the use of PRA for assessing terrorism risk, specifically for assessing the probabilities of terrorist attacks. The studies by Garcia (2006), McGill et al. (2007), Paté-Cornell and Guikema (2002), Rosoff and von Winterfeldt (2006), Willis (2007), and von Winterfeldt and O'Sullivan (2007) are examples of risk analyses that use PRA and probabilities of terrorist attacks.

Willis (2003, 2007), McGill et al. (2007), and other terrorism risk researchers operationalize terrorism risk as the product of threat, vulnerability and consequences. More specifically, threat is defined as the probability of an attack (weapon, delivery mode, target, etc.), vulnerability is the probability that the attack is successful, and consequences are the losses that occur (fatalities, injuries, direct and indirect economic impacts, among others) in the case of a successful attack. Losses are multidimensional and are often aggregated by equivalent losses using a common unit (Keeney and von Winterfeldt, 2007). Hence, a useful indicator of terrorism risk is expected loss and the benefit of terrorism countermeasures can be quantified as the reduction in expected loss.

In this probabilistic framework, the attack probabilities are by far the hardest to assess, requiring knowledge about the motivations, intent, and capabilities of terrorists (largely the domain of the intelligence community), as well as knowledge about past events. While it is very difficult to make absolute probability judgments, relative judgments in terms of rank orders or ratios are easier to make. For example, while it may be difficult to assess the absolute probability that a particular

terrorist group will engage in a radiological attack in the United States in the next ten years, many might argue that such an attack is more likely than an attack using a nuclear device, considering the relative difficulties of executing these attacks. There is extensive literature on the elicitation of expert probability judgments, which suggests how to elicit probabilities in the face of such complexities (for a recent summary, see Hora, 2007).

The main argument against the use of probabilities of attacks for terrorism risk analysis is that these probabilities depend on our defensive action and that they shift with time. Nevertheless, it seems reasonable to start with a baseline of defensive actions, current terrorist motivations, intent, and capabilities (based on data, intelligence and other expertise), and then assess probabilities conditional on this baseline. We take it for granted that all probabilities are conditional on our current state of knowledge. While it is perhaps more difficult to spell out these conditions precisely in terrorism risk analysis, there is no fundamental difference in this type of conditioning compared to conditioning probability judgments in the case of natural or engineered systems.

Once we introduce new defensive actions, it is, of course, important and necessary to re-assess these probabilities. For example, as von Winterfeldt and O'Sullivan (2006) pointed out, the use of MANPADS countermeasures will have a strong deterrence effect on terrorists who may contemplate the use of MANPADS weapons to attack commercial airplanes. Decision trees and influence diagrams were very useful for displaying and analyzing such dependencies.

**2. Event trees can help to decompose the universe of terrorism scenarios.**

Probabilities of complex events are hard to assess directly, and it is therefore often useful to decompose the assessment into components and to assemble the components using standard

probability calculus. There are many alternative decomposition tools, including event trees, fault trees, decision trees, influence diagrams, and belief nets. When the intention is to divide a very large universe of events into a structured set, event trees are useful as part of a baseline assessment of terrorism risk, beginning with an initial choice of weapon and target, and following through the path from attack, success or failure, to eventual consequences.

Event trees have been used to decompose terrorism scenarios in the scholarly research of Koller (2000), Ezell et al. (2001), Viscusi (2003), and Wilson (2003). Rosoff and von Winterfeldt (2007) use event trees to track the paths to failure or success of a dirty bomb attack and von Winterfeldt and O'Sullivan (2006) use a combination of decision and event tees to quantify the costs and benefits of MANPADS countermeasures.

In the commercial world, several companies supporting insurance risk management decisions have used an event-tree like partitioning of terrorist events, based on targets, weapons, delivery modes, etc., combined with expert judgments to obtain relative probabilities for each partition. Risk Management Solutions, Inc. (for a brief description, see Willis, 2007), has used this approach to both natural disasters and terrorism. Similar approaches have been used by ABS and AIR, International.

Haimes (2006) suggests the use of multiple techniques for assessing terrorist actions as probabilities. He reminds us that "no single model or methodology can effectively meet all the challenges of tracking terrorism through scenario generation and structuring, updating and quantifying the value of intelligence, assigning priorities to the scenarios in a well-established risk-based methodology, … or track terrorists' attack plans." (p. 686-687) We agree that multiple approaches are needed to address the complex issue of terrorism, including event trees, decision trees, influence diagrams, game theory, and agent based models. In this context however, PRA and event

trees have already been shown to be useful approaches for assessing terrorism risks, especially for creating a baseline comparison of these risks.

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# Attachment B

## Denning, Richard S. "NAS_Review__08-28-06__Methodology—UNCLASS_v3.ppt"

# Quantitative Risk Assessment of Bioterrorism Events - Methodology

**Richard S. Denning, Ph.D.**
Battelle

NAS Committee Briefing
28 August 2006

# Presentation Objectives

- Provide overview of approach taken to the Quantitative Risk Assessment performed for the 2006 Assessment
  - Because of the sensitivity of the topic and the availability to the general public, this presentation includes no quantitative results
- The translation of an event-tree based approach from nuclear power plant accident risk to biological terrorism risk is in general straightforward
  - We will identify elements of the approach where important choices were made (where alternatives exist)
- There are some areas where we plan to make significant changes
  - Manner in which subject matter experts are used
  - Expanded economic modeling
  - Will be discussed in presentation tomorrow.

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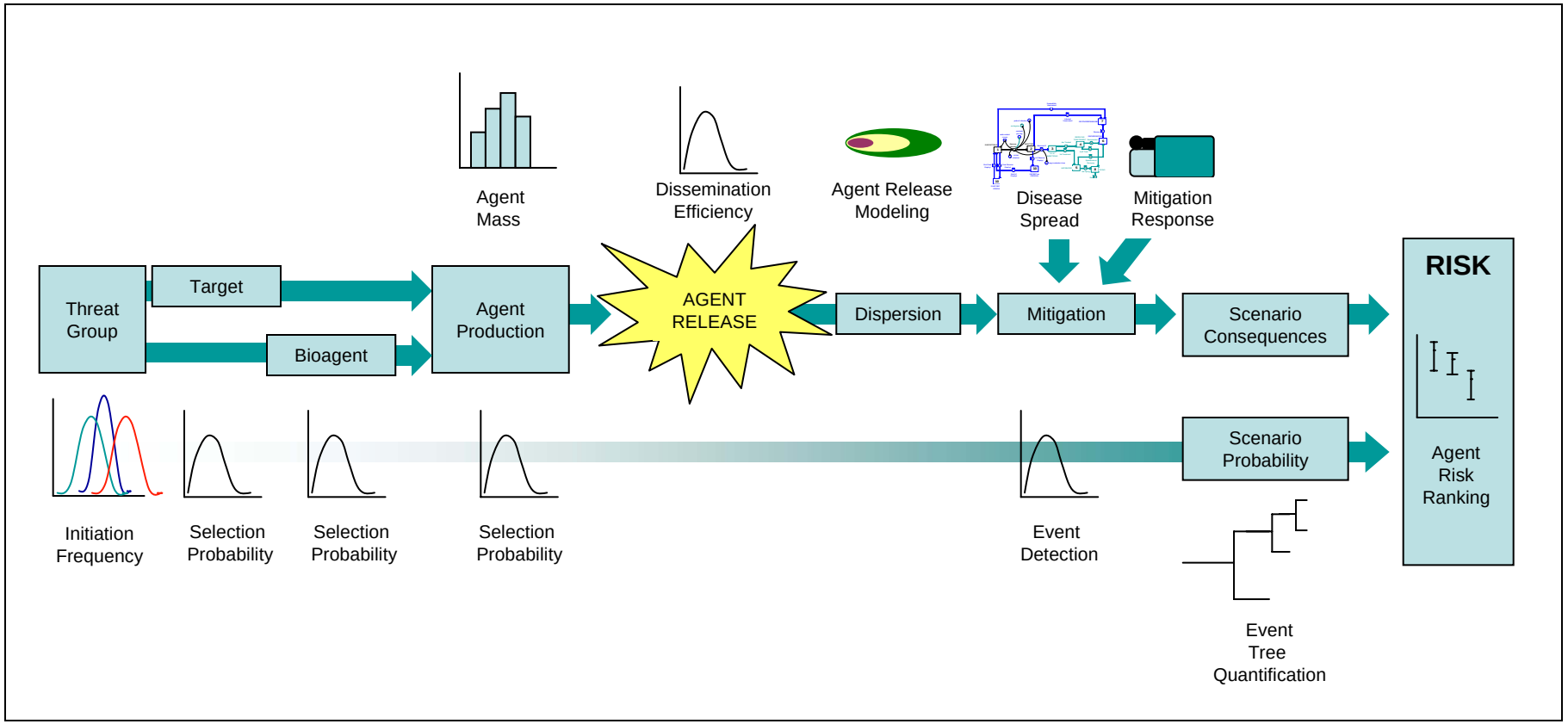
# Scenario Analysis and Consequence Modeling

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# Probabilistic Risk Assessment (PRA) - Fundamentals

- "Risk is the potential for some unwanted event to occur. Risk is a function of the likelihood of the event and its consequences." (National Infrastructure Protection Center, 2002).
- The term PRA is applied to a method of assessing accident risk for nuclear power plants (WASH-1400, 1973-1975)
  - Now also widely used for chemical and aerospace risk
  - Of particular value for low frequency, high potential consequence events in which there is not a sufficient data base to assess risk using conventional statistics

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# Probabilistic Risk Assessment (PRA) - Fundamentals

- PRA divides the spectrum of possible events into a discrete set of scenarios. For each scenario, $s_i$
  - Estimate consequence, $C_i$
  - Estimate probability, $p_i$
  - Aggregate the risk from the set of all triplets $<p_i,s_i,C_i>$
- The PRA approach is often referred to as triplet analysis or scenario analysis.
- In contrast to the more qualitative, attribute-based risk assessment approaches.

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# 2006 Risk Assessment Scope

- Assess the risk in the U.S. from bioterrorism
  - Twenty-eight bioagents
  - Fatalities, illnesses, and direct economic impact
  - Characterize the uncertainty in risk results
- Time frame – Conditions as they would be expected to exist in the period 1 January 2006 to 31 December 2010
- Risk is averaged over the time period of one year
- Threat organizations are represented by generic categories
- Targets are represented by generic categories of targets – but analysis of scenarios performed at as low a level as possible (for surrogate targets)
- Risk is regionally averaged over the U.S.

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# Event Tree

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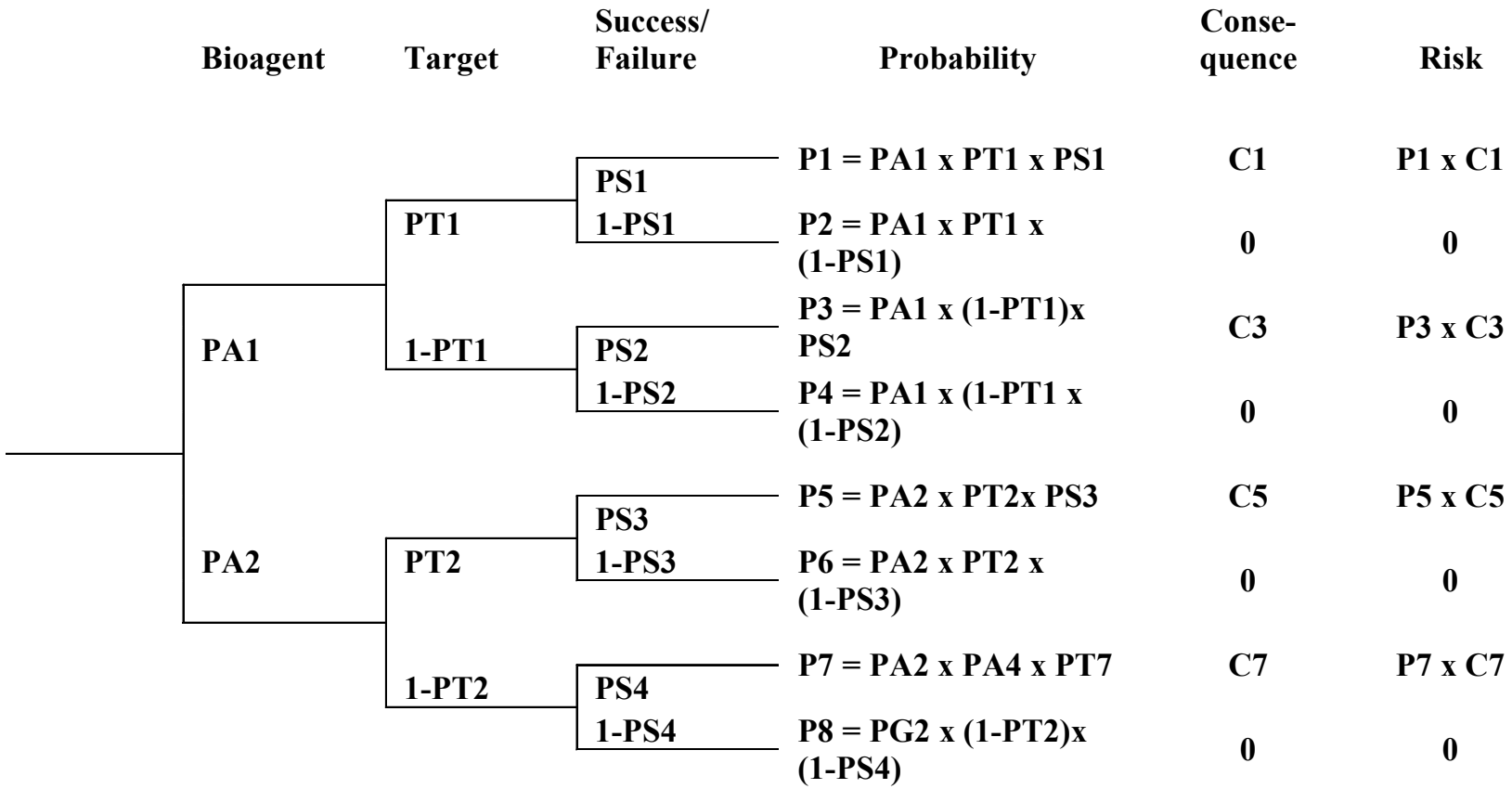
# Event-Tree Based Method

- The event-tree based method is a direct extension of PRA as used in nuclear power plants
  - But no role for fault tree analysis as used for nuclear power plant accident risk
- An event-tree (decision tree) is a visual tool that is used to represent multiple outcomes of consecutive events
- In the following simple example, the event tree has two branches per event …

# An Event-Tree Based Method – Simple (Binary) Event Tree




$$R = \Sigma(Pi \times Ci)$$

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# Comparison with Example Tree

- The event tree used in the study has 17 events
- Each event has multiple branches, rather than two
  - The tree is much too big to be drawn
- Each branch probability (split fraction) is represented by a distribution, rather than a single probability
  - These distributions represent uncertainty in knowledge of terrorist capabilities and likely actions
- Each pathway through the tree is a “scenario”
- The scenario probabilities are represented by high dimensional joint distributions, rather than a single set of values
  - Latin hypercube sampling, a stratified Monte Carlo technique, is used to construct a sample (500) from the joint distribution
- For a single agent (*B. anthracis,* the causative agent of anthrax), the complete event tree results in more than 35 million scenarios

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# 2006 Risk Assessment Event Tree

| No. | Event Heading | Phase |
|---|---|---|
| 1 | Frequency of Initiation by Terrorist Group | Agent/Target/Dissemination Selection |
| 2 | Target Selected | |
| 3 | Bioagent Selected | |
| 4 | Mode of Dissemination (also determines wet or dry dispersal form) | |
| 5 | Mode of Agent Acquisition | Acquisition |
| 6 | Interdiction during Acquisition | |
| 7 | Location of Production and Processing | |
| 8 | Mode of Agent Production | Production and Processing |
| 9 | Preprocessing and Concentration | |
| 10 | Drying and Processing | |
| 11 | Additives | |
| 12 | Interdiction During Production and Processing | |
| 13 | Mode of Transport and Storage | Transport and Storage |
| 14 | Interdiction during Transport and Storage | |
| 15 | Interdiction during Attack | Attack |
| 16 | Potential for Multiple Attacks | |
| 17 | Event Detection | Response |

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# Event Tree Branches and Dependencies – Target and Bioagent Selection

| Event # | Event Heading | Branches | Event Dependencies |
|---|---|---|---|
| 1 | Frequency of Initiation by Terrorist Group | 1.1 Frequency of International Terrorist Organization | |
| | | 1.2 Frequency of State-Sponsored Organization | |
| | | 1.3 Frequency of Domestic Terrorist Organization | |
| | | 1.4 Frequency of Small Group or Individual | |
| 2 | Target Selection | 2.1 Large Open Building | 1 |
| | | 2.2 Small Enclosure | |
| | | 2.3 Large "Divided" Building | |
| | | 2.4 Large Outdoor Spaces | |
| | | 2.5 Water Pathway | |
| | | 2.6 Food Pathway | |
| | | 2.7 Human Vectors | |
| | | 2.8 Contact (letters) | |
| 3 | Bioagent Selection | 3.1-3.28 Probability of Bioagent Selection | 2 |

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# Event Tree Branches – Selection of Dissemination Mode

| Event # | Event Heading | Branches | Event Dependencies |
|---|---|---|---|
| 4 | Mode of Dissemination (also determines wet or dry dispersal form) | 4.1 Ground-level point release from stationary sprayer | 1,2,3 |
| | | 4.2 Ground-level point release from stationary fogger | |
| | | 4.3 Ground-level release from mobile sprayer (outdoor only) | |
| | | 4.4 Ground-level release from mobile fogger (outdoor only) | |
| | | 4.5 Aerial release from mobile sprayer (outdoor only) | |
| | | 4.6 Aerial release from mobile fogger (outdoor only) | |
| | | 4.7 Ground-level point release of explosive with slurry | |
| | | 4.8 Ground-level point release of explosive with powder | |
| | | 4.9 Ground-level release from stationary blower | |
| | | Other Targets – (food, water, human vector, or contact dissemination) Branch 4.1 has unit probability. | |

# Event Tree and Branches – Acquisition

| Event # | Event Heading | Branches | Event Dependencies |
|---|---|---|---|
| 5 | Mode of Agent Acquisition | 5.1 Environmental/Clinical Isolation | 3 |
| | | 5.2 Insider-Supported Theft | |
| | | 5.3 Outsider Theft | |
| | | 5.4 Purchase From State Program | |
| 6 | Interdiction and Technical Failure to Acquire | 6.1 Interdicted or Technical Failure | 1,3,5 |
| | | 6.2 Not Interdicted or No Failure | |

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# Event Tree and Branches – Production

| Event # | Event Heading | Branches | Event Dependencies |
|---|---|---|---|
| 7 | Location of Production and Processing | 7.1 International Production | 1 |
| | | 7.2 Domestic Production | |
| 8 | Mode of Agent Production | 8.1 High Technology | 1,3 |
| | | 8.2 Medium Technology | |
| | | 8.3 Low Technology | |
| 9 | Preprocessing and Concentration | 9.1 High Technology | 1,2,3,4,8 |
| | | 9.2 Medium Technology | |
| | | 9.3 Low Technology (No Concentration Performed) | |

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# Event Tree and Branches – Production and Processing

| | | | |
|---|---|---|---|
| 10 | Drying and Processing | Dry Dispersal Modes | 1,2,3,4 |
| | | 10.1 High Technology | |
| | | 10.2 Medium Technology | |
| | | 10.3 Low Technology | |
| | | Wet Dispersal Modes – Branch 10.1 has unit probability | |
| 11 | Additives | 11.1 Additives Included | 1,2,3,4 |
| | | 11.2 No Additives | |
| 12 | Interdiction During Production and Processing | 12.1 Interdicted | |
| | | 12.2 Not Interdicted | |

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# Event Tree and Branches – Transport, Attack and Response

| Event # | Event Heading | Branches | Event Dependencies |
|---|---|---|---|
| 13 | Mode of Transport and Storage | 13.1 Cold Storage, Cold Transport | 1,2,3,4 |
| | | 13.2 Cold Storage, Room Temperature Transport | |
| | | 13.3 Room Temperature Storage, Room Temperature Transport | |
| 14 | Interdiction during Transport and Storage | 14.1 Interdicted | 7 |
| | | 14.2 Not Interdicted | |
| 15 | Interdiction during Attack | 15.1 Interdicted | |
| | | 15.2 Not Interdicted | |
| 16 | Potential for Multiple Attacks | 16.1 Single Attack | 1 |
| | | 16.2 Multiple Attacks | |
| 17 | Event Detection | 17.1 Event Observed | 2,3,4 |
| | | 17.2 Event Detected by Monitoring System | |
| | | 17.3 Event Not Detected | |

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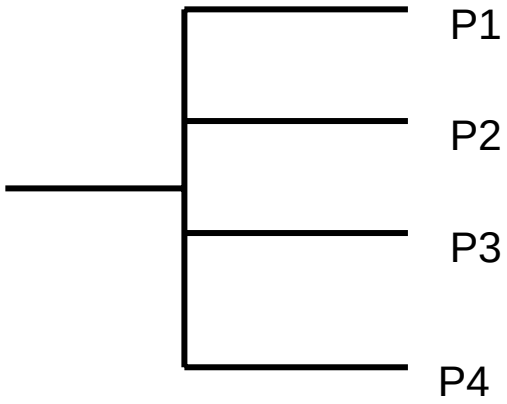
# Use Rob's

- Consider an event with four branches
- Three probabilities are required: P1, P2, P3.
- The final branch has probability 1-P1-P2-P3




- Multi-way splits are converted to a series of binary splits for specifying probability distributions

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# Example Event Tree Quantifications

- Terrorist Organizations
- Quantification of Initiating Events
- Selection of Targets
- Selection of Bioagents
- Acquisition

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# Definition and Characterization of Threat Organizations

- Definition of four categories of threat organizations
  - International Terrorist Group
  - State Supported Group
  - Domestic Group (e.g. Paramilitary)
  - Individual or Small Group
- Technical capabilities
- Financial resources
- Motivation – psychological impact, revenge, political influence, deaths, illnesses
- Activity level – historical frequency of initiators

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# Initiating Event Frequency

- Initiating frequencies for categories based on international historical data plus Intelligence input – log normal distributions
- Initiating frequency refers to an action taken to begin the process leading to the release of bioagent

| Category | 5th | Mean | 95th |
|---|---|---|---|
| International | | | |
| State Supported | | | |
| Domestic | | | |
| Individual/Small | | | |

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# Targets/Surrogates - Airborne

- Large Open Building
  - Shopping Mall
  - Entertainment/Political/Religious
  - Transportation Terminal
- Small Enclosure
  - Transportation Unit
- Large Divided Building
  - Cruise Ship
  - Public/Private Building
- Large Outdoor Spaces
  - Urban Center
  - Urban Event
  - Stadium

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# Targets/Surrogates - Other Pathways

- Water
  - Public water supply
- Food
  - Milk
  - Packaged food
  - Produce
- Vectors
  - Contagious person(s)
- Contact
  - Letter

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# Targets/Attributes - Airborne

- Large Open Building
  - Potential for large consequences
  - Includes religious targets
  - Includes political targets
- Small Enclosure
  - Potential for modest consequences
  - Relatively little agent required
  - Low cost
- Large Divided Building
  - Potential for modest to large consequences
  - Includes political targets
- Large Outdoor Spaces
  - Potential for very high consequences
  - Includes some political targets
  - Symbolically U.S. targets

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# Targets/Attributes - Other Pathways

- Water
  - May be perceived as high consequences
- Food
  - Potential for moderate consequences
  - Low cost
  - Potential for non-lethal or economic consequences
- Vectors
  - Potential for very high consequences
- Contact
  - Low number of consequences
  - Affects targeted individuals or groups

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# Probability of Target Selection

| Target | International | |
|---|---|---|
| | Mean | Var |
| Large Open Building | | |
| Small Enclosure | | |
| Large Divided Building | | |
| Large Outdoor Space | | |
| Water | | |
| Food | | |
| Vectors | | |
| Contact | | |

- Relative probabilities based on pair-wise comparisons taking attributes into account

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# Bioagent Selection

- Which comes first target selection or bioagent selection?
  - Either is possible
  - 2006 Study assumes that target comes first but targets and bioagents are closely correlated
  - 2008 Study plan to elicit both ways and combine
  - Inconceivable combinations of targets and bioagents were eliminated a priori
  - Poor choices were allowed to be selected with a high probability of failure

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# Bioagent Selection (Cont)

- IC SMEs made a coarse ranking of relative probabilities of bioagent selection (primarily based on “familiarity”)
- Battelle did a more detailed assessment based on ease of acquisition, lethality, and stability

$$\text{Agent Selection Probability} = \text{SME}^{0.6} \times \text{Agent Characteristics}^{0.4}$$

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# Mode of Dissemination

- Branching only is required for inhalation exposures
- Dissemination modes
  - Ground-level point release from stationary sprayer
  - Ground-level point release from stationary fogger
  - Ground-level release from mobile sprayer
  - Ground-level release from mobile fogger
  - Aerial release from mobile sprayer
  - Aerial release from mobile fogger
  - Ground-level point release of explosive with slurry
  - Ground-level point release of explosive with powder
  - Ground-level point release from stationary blower

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# Mode of Dissemination

Mode of Dissemination for International Terrorist Organization, for Bioagent A, for Large Open Space

| Mode | Mean Prob |
|---|---|
| Ground level, point, sprayer | |
| Ground level, point fogger | |
| Ground level, mobile sprayer | |
| Ground level, mobile fogger | |
| Aerial, mobile sprayer | |
| Aerial, mobile fogger | |
| Ground-level, explosive with slurry | |
| Ground-level, explosive with powder | |
| Ground-level, stationary blower | |

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# Mode of Agent Acquisition

Qualitative Assessment of Acquisition Potential

| Bioagent | Env/ Clin. Iso | Insider Theft | Outsider Theft | Purchase |
|---|---|---|---|---|
| Bioagent A | Very Low | Low | Low | Very Low |
| Bioagent B | High | High | High | Low |

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# Consequence Calculations

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# 2006 Risk Assessment Consequence Analysis

- Intent of the analysis is to be as realistic as practical
- Three measures of consequence determined – fatalities, illnesses, direct economic cost
- Sources of variability are identified
- Using data from a variety of sources, distributions are developed, e.g. population density of cities in the U.S., number of shoppers in malls, attendees of sporting events
- For all pathways, exposure equations are expressed in the same form

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# Consequences for Each Scenario

- Consequences are expressed as distributions
  - Each distribution ($C_i$) captures variability in possible outcomes of a specific scenario ($s_i$)
- Consequence distributions are built from multiple component distributions
  - $C_i = X_i * Y_i * Z_i$
- Conditional component distributions can be used
  - $Y_i|X_i$
- Monte Carlo simulation is used to estimate consequence distributions

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# Basic Consequence Equations (All Terms are Distributions)

- **MT = target mass**
  - Tradeoff - maximize production but minimize risk of being discovered
  - MT distribution based on range of production time (one week to 8 weeks)
- **MR = MT * QF1 * QF2 * QF3 * QF4 * QF5**
  - MR = mass release
  - QF1 = production quantity factor
  - QF2 = processing quantity factor
  - QF3 = drying factor
  - QF4 = storage factor
  - QF5 = transportation factor

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# Basic Consequence Equations

- **MRE = MR * QFA * QFR * QADD**
  - MRE = effective mass release
  - QFA = active fraction after dissemination (inhalation modes)
  - QFR = respirable fraction after dissemination (inhalation modes)
  - QADD = additive factor
- **CI = RI|MRE * MEI|RI**
  - CI = number of illnesses
  - RI|MRE = illnesses given effective mass release
  - MEI|RI = epidemiological illness factor given the number of ill
- **CF = CI * RF|MRE * MFI**
  - CF = number of fatalities
  - RF|MRE = deaths per illness given effective mass release
  - MFI = medical mitigation/epidemiological factor

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# Consequence – Scenario Relations

- Unique component distributions are not specified for each scenario ($s_i$)
  - With over 35 million scenarios, this is not feasible.
- Each component is specified to depend on a small subset of tree events
  - For example, mass produced depends on Terrorist Group and Production Method
- Significant analysis and simulation goes into the development of component distributions
  - For example, there is simulation, a response surface model, and a set of approximately 50 HPAC runs behind specific outdoor release components
- Some event tree layers are inconsequential to consequences
  - For example Mode of Agent Acquisition

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# Consequence – Scenario Relations (continued)

- In spite of making each component depend only on necessary tree layers, combinatorics still come in to play when calculating consequences
  - Eleven of the 17 layers matter
- For a single agent (*B. anthracis*), there are nearly 140,000 unique consequence distributions
  - For mass, illness, and fatality
- Each distribution is represented with a sample of 1,000 values but converted to a histogram for risk calculations
  - Requires mixing distributions using scenario probabilities

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# Risk Calculations


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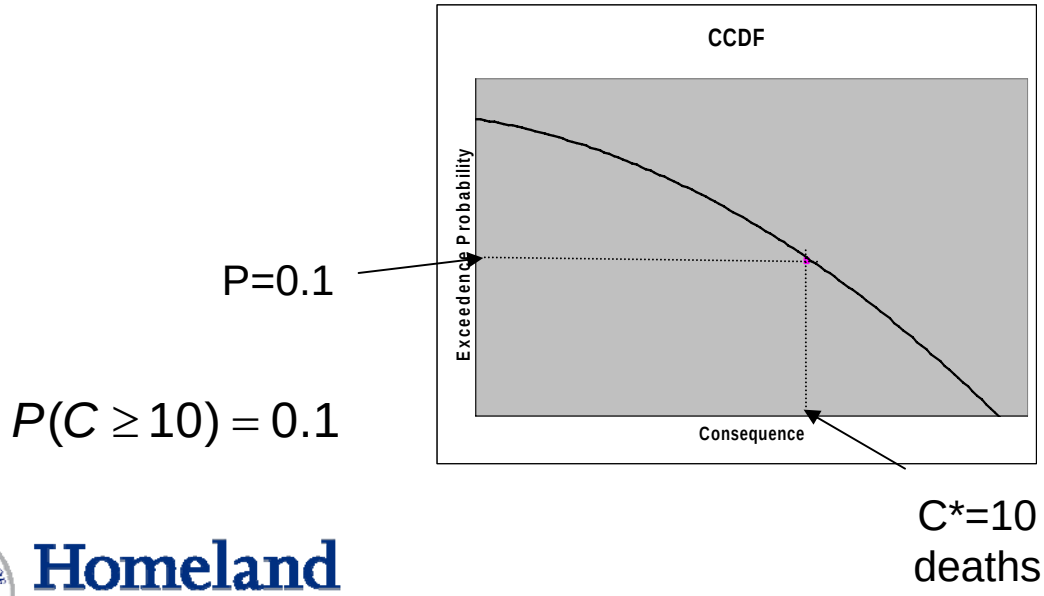
# The Risk Curve

- Risk is often defined as the probability of events times their consequences – does not differentiate between high consequences with low frequencies and low consequence events with high frequencies
- In PRA, a more general definition is used that provides a measure of frequency of events as a function of consequences. For a specific value of consequence (C*) on the x-axis, the curve describes the frequency of bioterror acts that result in C* or larger consequences.

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# Treatment of Uncertainty

- If policy decisions are to be based on the results of risk analyses, they must be made with full understanding of the associated uncertainties
- Uncertainty analysis is integral to the PRA approach
- Two types of uncertainty are considered
  - Aleatory (variability)
  - Epistemic (state of knowledge)
- Distributions are developed for each of the inputs to the analysis
- Monte Carlo analysis is used to develop a sample from each distribution
- The process results in a family of risk curves

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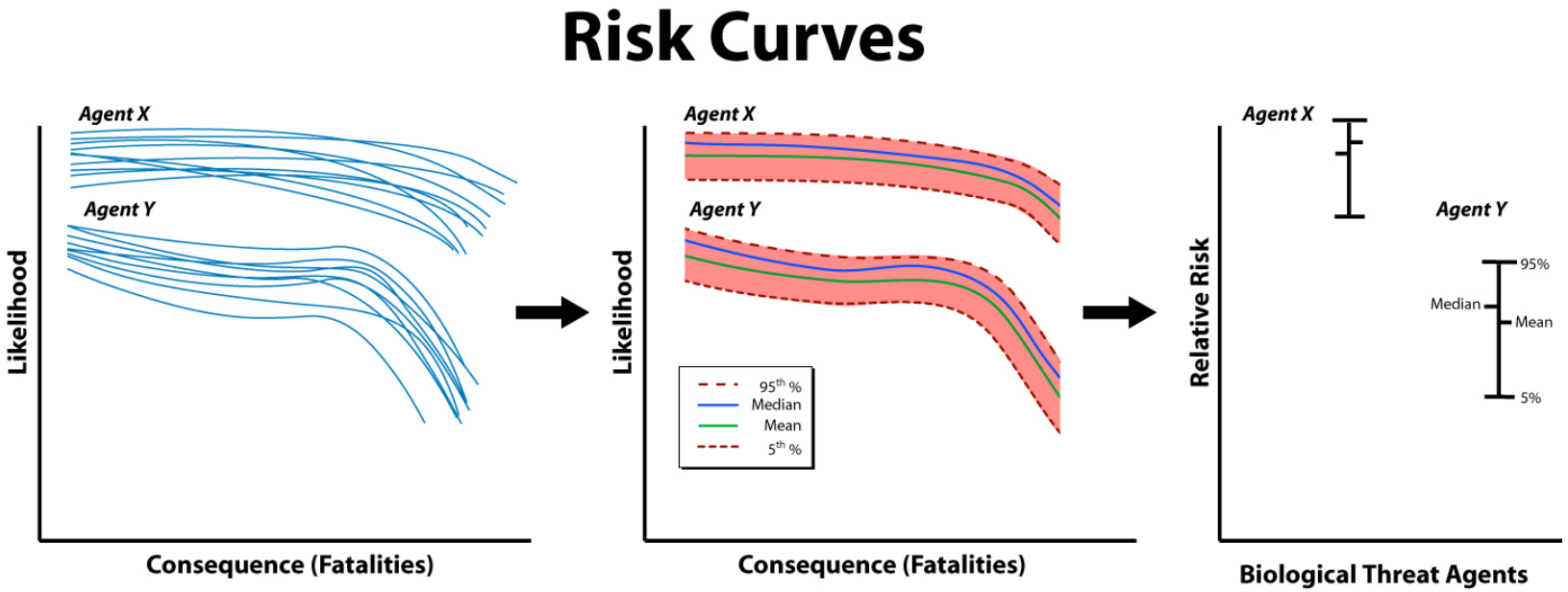
# The Risk Analysis Produces a Family of Risk Curves That Can Be Summarized in a Number of Ways

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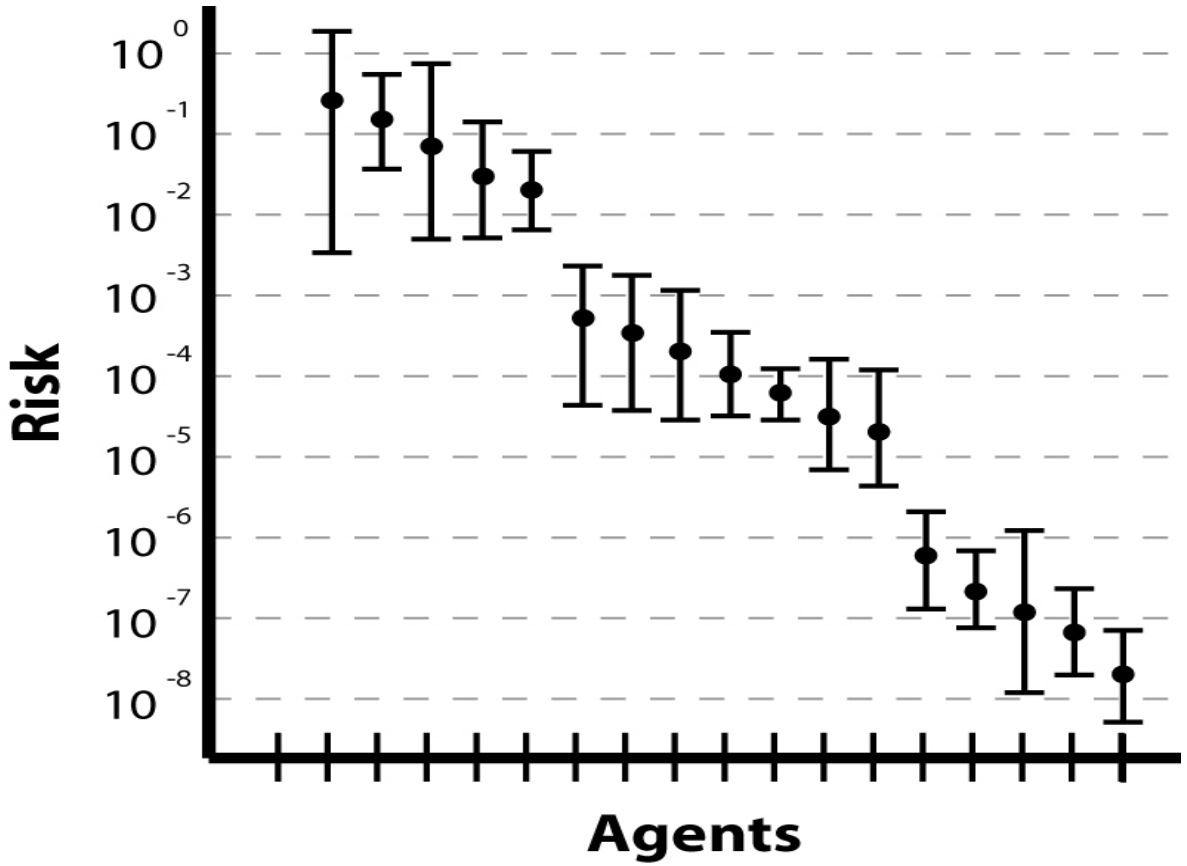
# The 2006 Study Was Focused on Ranking the Bioagents by Their Relative Risk

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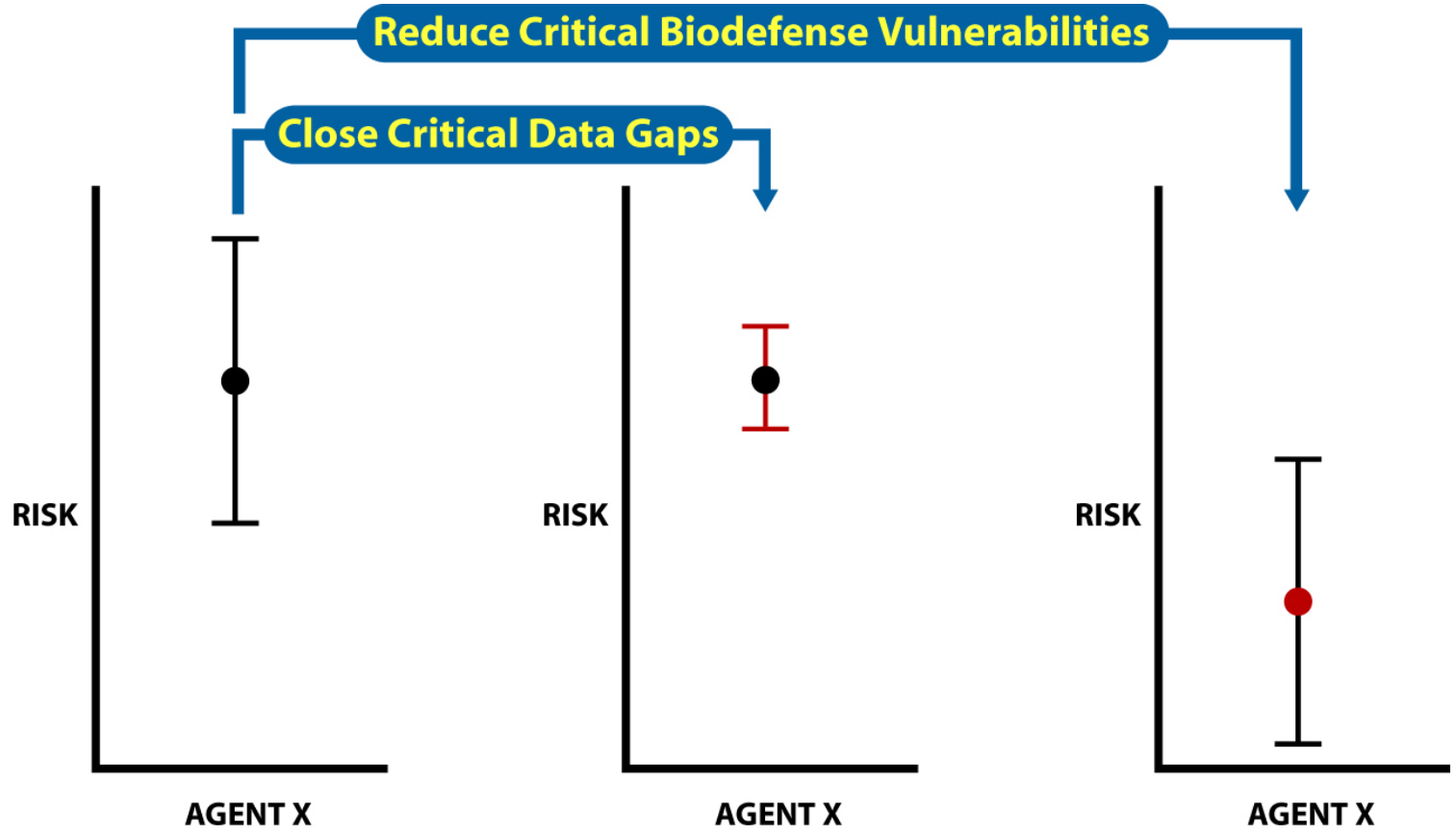
# Data Gaps and Vulnerabilities Affect Bioterrorism Risk in Different Ways

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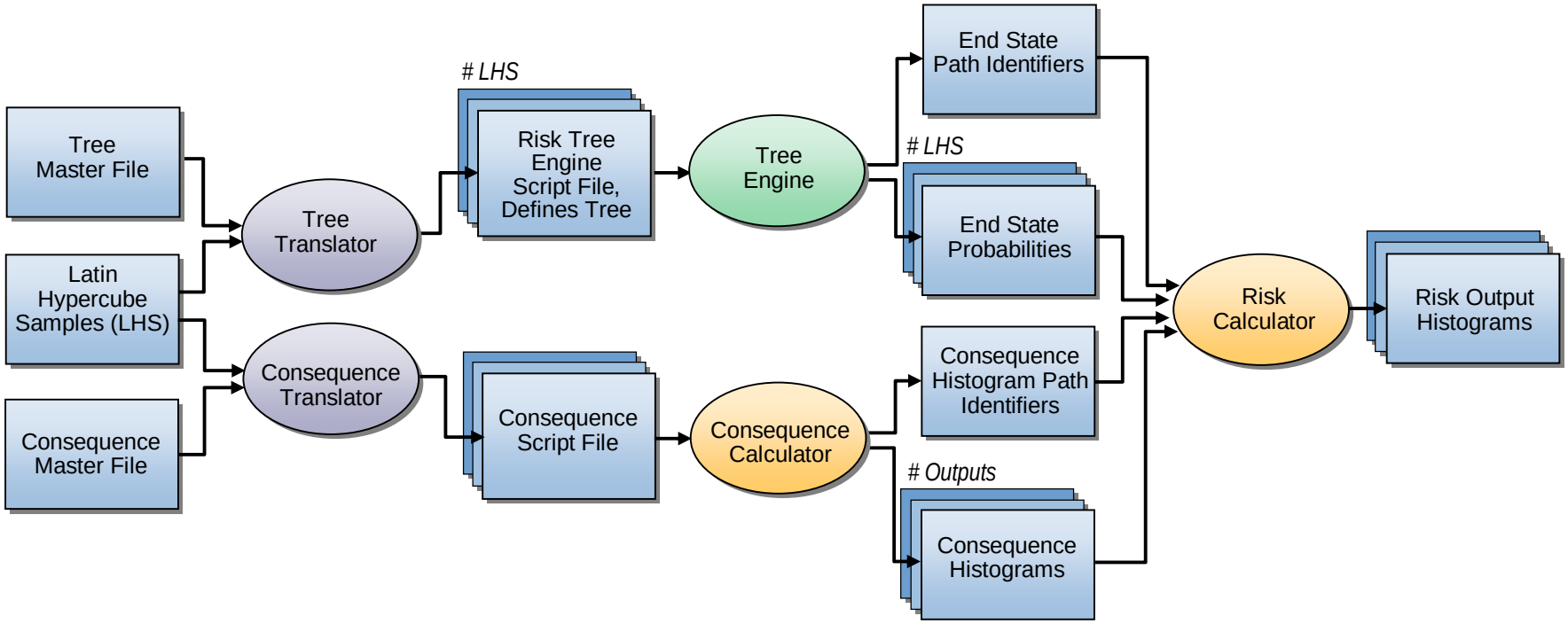
# Calculation Engine




Calculation Engine

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# Key Elements of Decomposition Approach Used in 2006 Study

- Use of event tree/scenario-based analysis versus alternatives
- Use of goal production quantity with quantity/quality factor modifiers
- Concept of activity initiation leading to an event or multiple events
- Emphasis on expectation value of probability density functions
- Normalization of results to total risk
- Treatment of scenario surrogates as a sublevel under the eight major categories of targets (to be changed)
- Treatment of uncertainty including the separation of uncertainties into aleatory and epistemic components

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# Attachment C

## Carnell, RC, *et al.* "NAS_Review__08-28-06-06__ConsequenceModels—UNCLASS_v2.ppt"

# 2006 DHS Bioterrorism Risk Assessment: Review of Scenario and Consequence Analysis

**Robert Carnell, Mary Shell, Jon-David Sears, Brian Hawkins, Traci Hale**

Battelle

Committee on Methodological Improvement to the Department of Homeland Security's 2006 Bioterrorism Risk Assessment

28 May 2006

# 2006 Bioterrorism Risk Assessment

- Overview
  - Branch Probabilities and Uncertainty Management
  - Consequence Modeling
    - Indoor Inhalation
    - Outdoor Inhalation
    - Foodborne and Waterborne
  - Medical Mitigation and Epidemiological Spread Modeling
  - Risk Calculations

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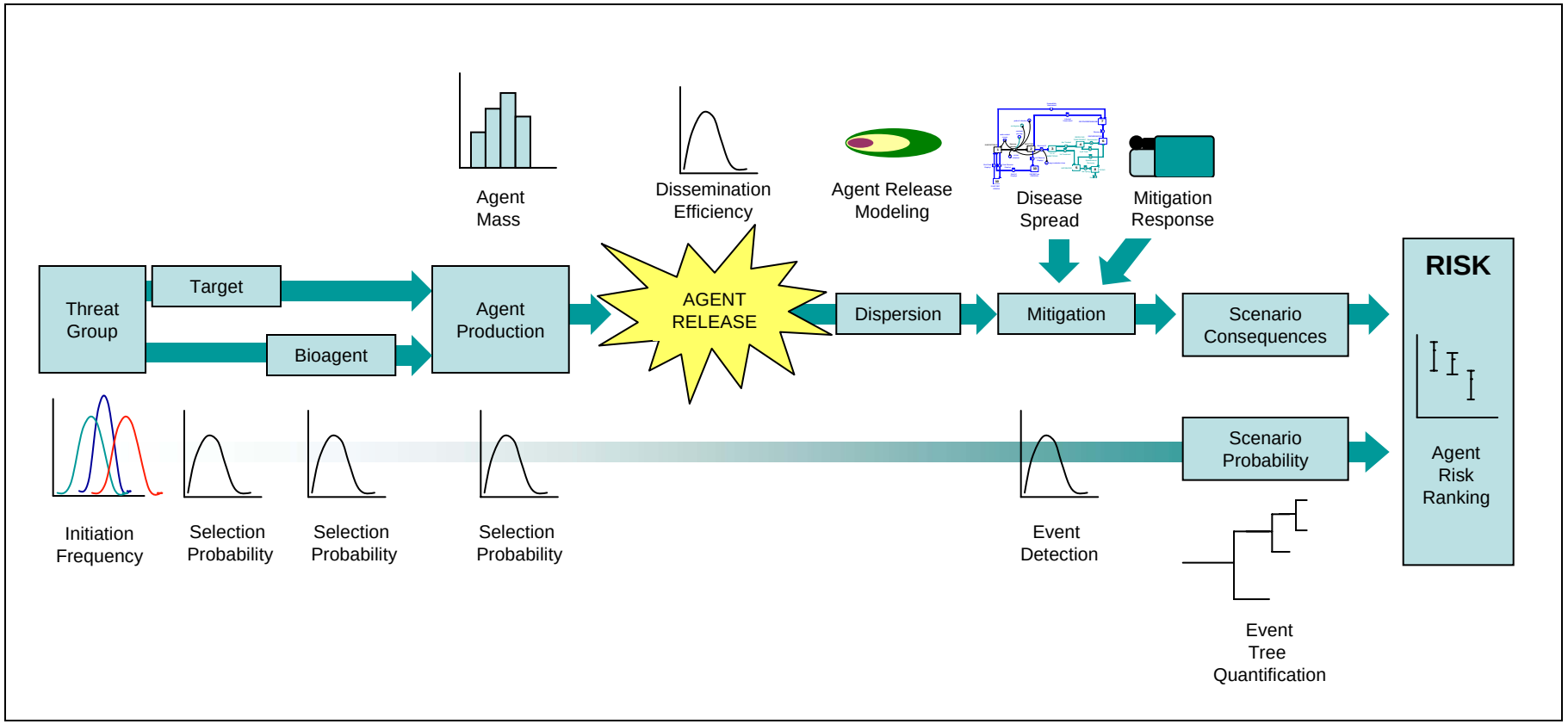
# Scenario Analysis and Consequence Modeling

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# Branch Probabilities and Uncertainty Management

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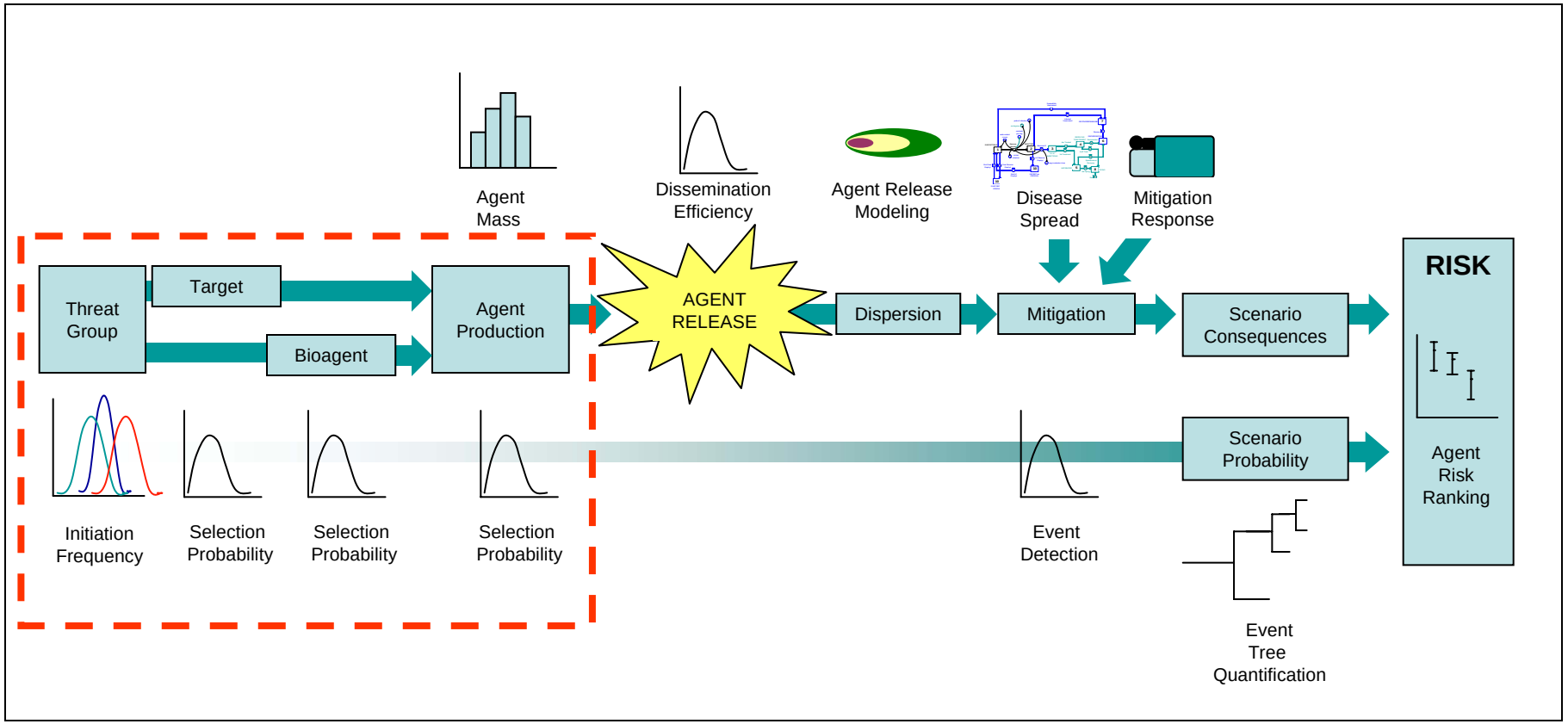
# Branch Probability

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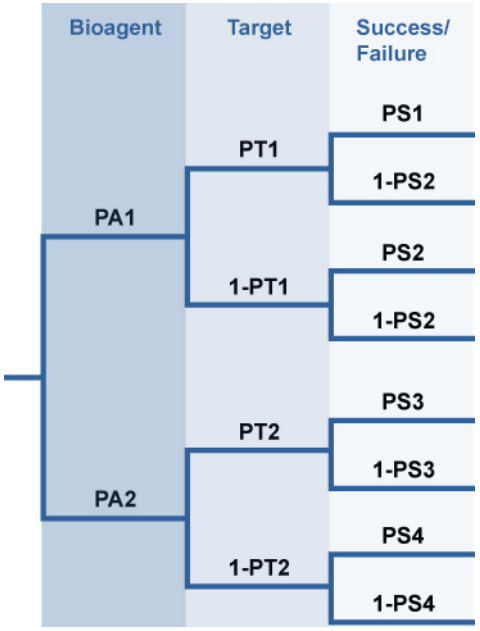
# Probabilistic Risk Assessment

- PRA divides the spectrum of possible events into a discrete set of scenarios. For each scenario, $s_i$
  - Estimate consequence, $C_i$
  - Estimate probability, $p_i$
  - Aggregate the risk from the set of all triplets $<s_i,p_i,C_i>$
- Probability estimates are calculated for end-nodes on the event tree corresponding to scenarios. Each distinct path through the tree is a unique scenario.
- Consequence estimates are calculated using models given that the event tree scenario occurred.

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# Probabilistic Risk Assessment

- PRA divides the spectrum of possible events into a discrete set of scenarios. For each scenario, $s_i$
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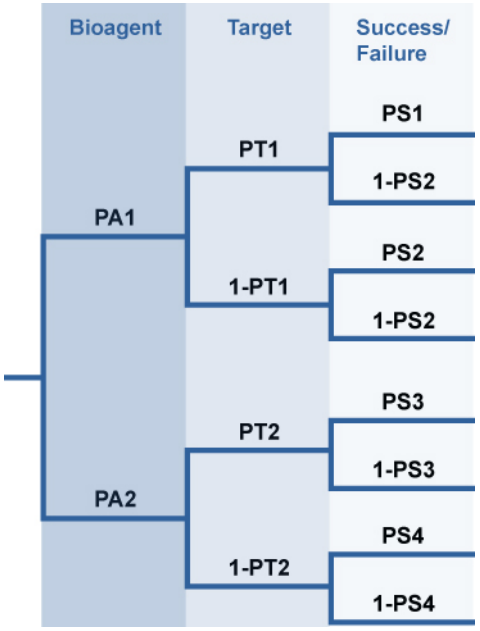

# Event Tree Calculations

- Develop probability distributions for all branch splits in the event tree based on Subject Matter Expert (SME) opinion.
- Use a Latin hypercube sample to efficiently characterize the joint distribution of all the branch splits and thus the end-node probabilities.

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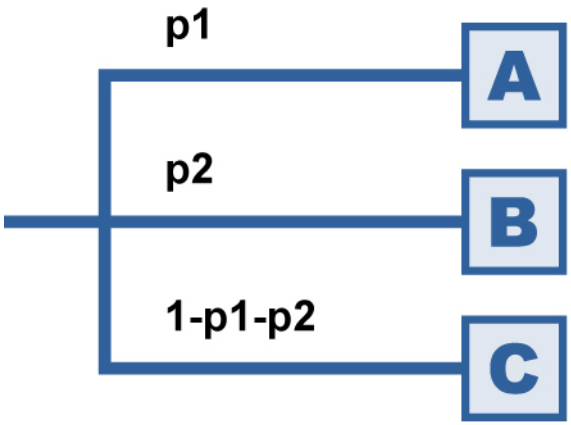
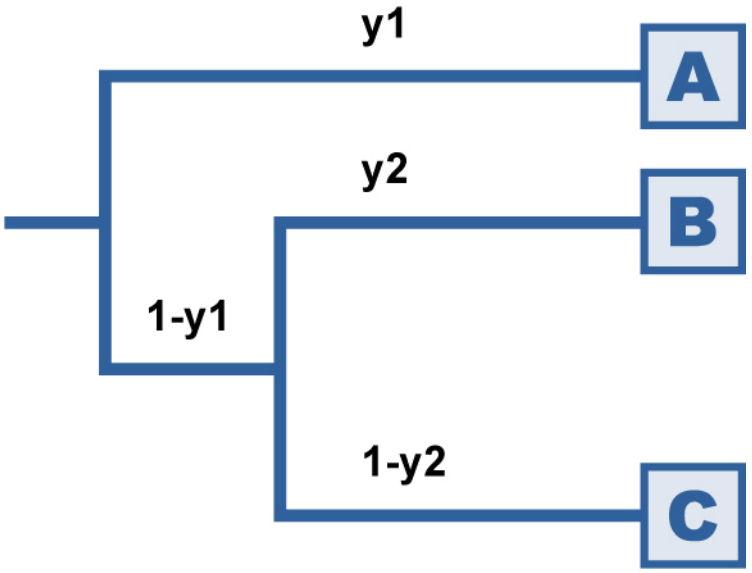
# Original Approach

- Solicit probabilities from the SMEs as a series of binary probabilities with variance estimates

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# Original Approach

- For example,
  - What is the probability of event A?
    - y1 with a range from $y1_{Lower}$ to $y1_{Upper}$.
  - What is the probability of event B given not A?
    - y2 with a range from $y2_{Lower}$ to $y2_{Upper}$.
- Upper and Lower probabilities were interpreted as $5^{th}$ and $95^{th}$ percentiles.
- Beta distributions were then fit to these estimates

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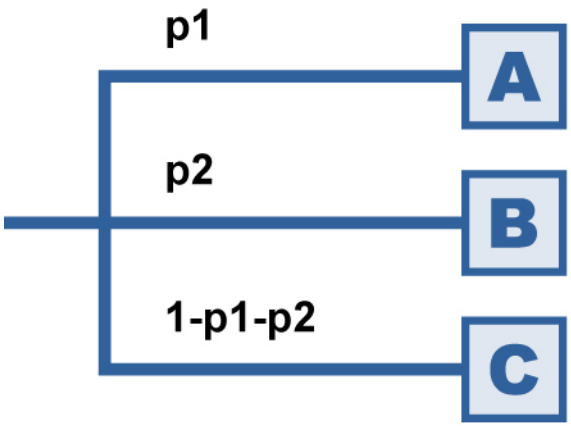
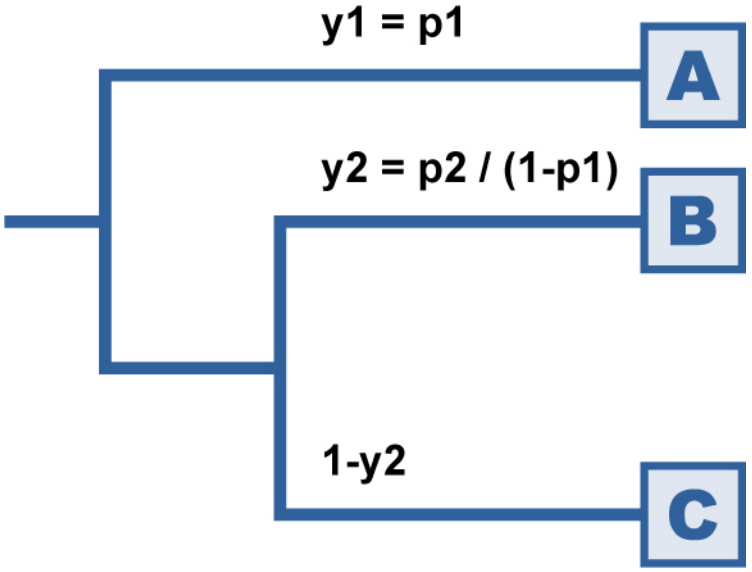
# Original Approach (Modified)

- In practice, it was difficult for the experts to assess probabilities in this conditional manner.
- Instead, probabilities were assigned in the multi-way split and then transformed into binary splits from which beta distributions could be sampled.

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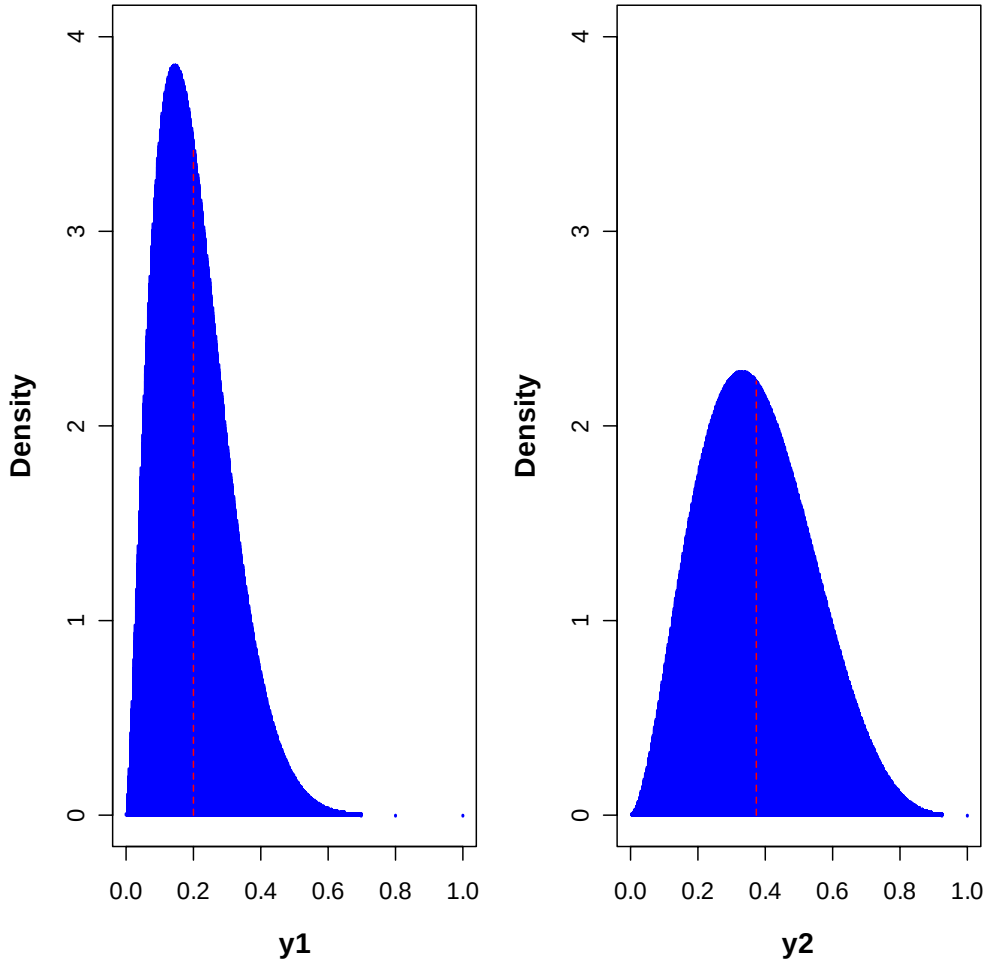
# Binary Splits

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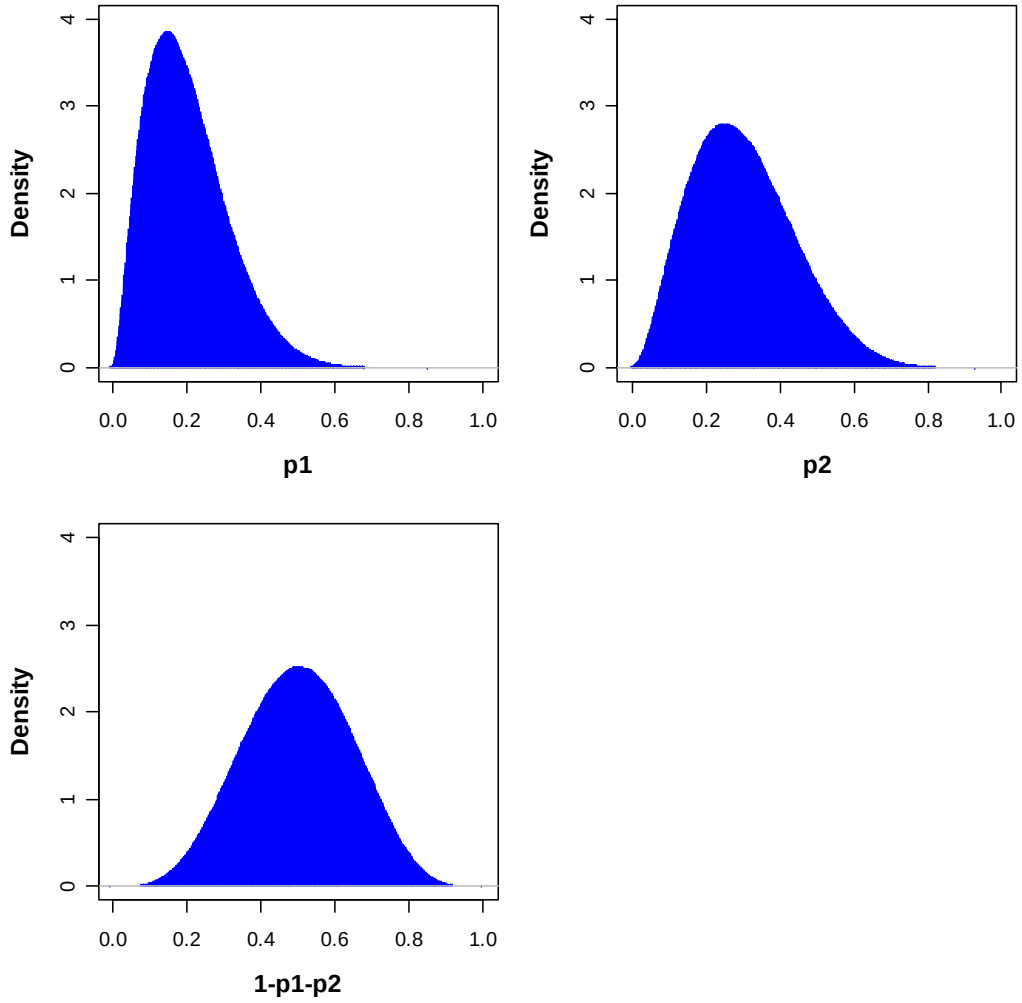
# Multi-way Split

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# New Approach (2008)

- Allow experts to define the means of the multi-way split distributions, either directly or through a series of binary questions
- Binary questions would result in branch splits being characterized by a series of beta distributions as described above.
- Multi-way split specifications will be characterized using Dirichlet distributions
  - Use a tuning parameter to adjust the variance of the set of distributions. This does not affect the mean of each branch, but it does allow experts to visually make the distributions reflect the certainty in their estimates.

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# Demonstration of Elicitation Tool

- The SME elicitation tool uses a Microsoft Excel interface, with R as the underlying statistical engine.
- Example
  - Suppose an expert is asked to assess the relative likelihood of a plan to acquire an agent through environmental isolation, insider theft, outsider theft, and purchasing.
  - Suppose further that the expert thinks that isolation is the most likely, insider theft is 25% less likely, outsider theft is 50% less likely, and purchase is 75% less likely.
  - The mean probabilities of the branches are then 0.4, 0.3, 0.2, and 0.1 respectively
  - Suppose further that the expert feels that the true probability of isolation is just as likely to be on the interval (0.2, 0.6) as outside of it.

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# Tree Combinatorics

- The event tree used in the study has 17 events
- Each event has up to 9 branches
- Over 3000 probability distributions are sampled from in the Latin hypercube with a sample size of 500.
- When the >3000 variables of the LHS are used to compute end-node probabilities, a sample of 500 end-node probabilities results.
- For a single agent (*B. anthracis,* the causative agent of anthrax), the complete event tree results in **more than 35 million scenarios**
  - 2.2 million scenarios are non-interdicted
  - 870,000 scenarios are non-interdicted, and non-zero
  - Only the non-interdicted and non-zero end-nodes are associated with consequence distributions.

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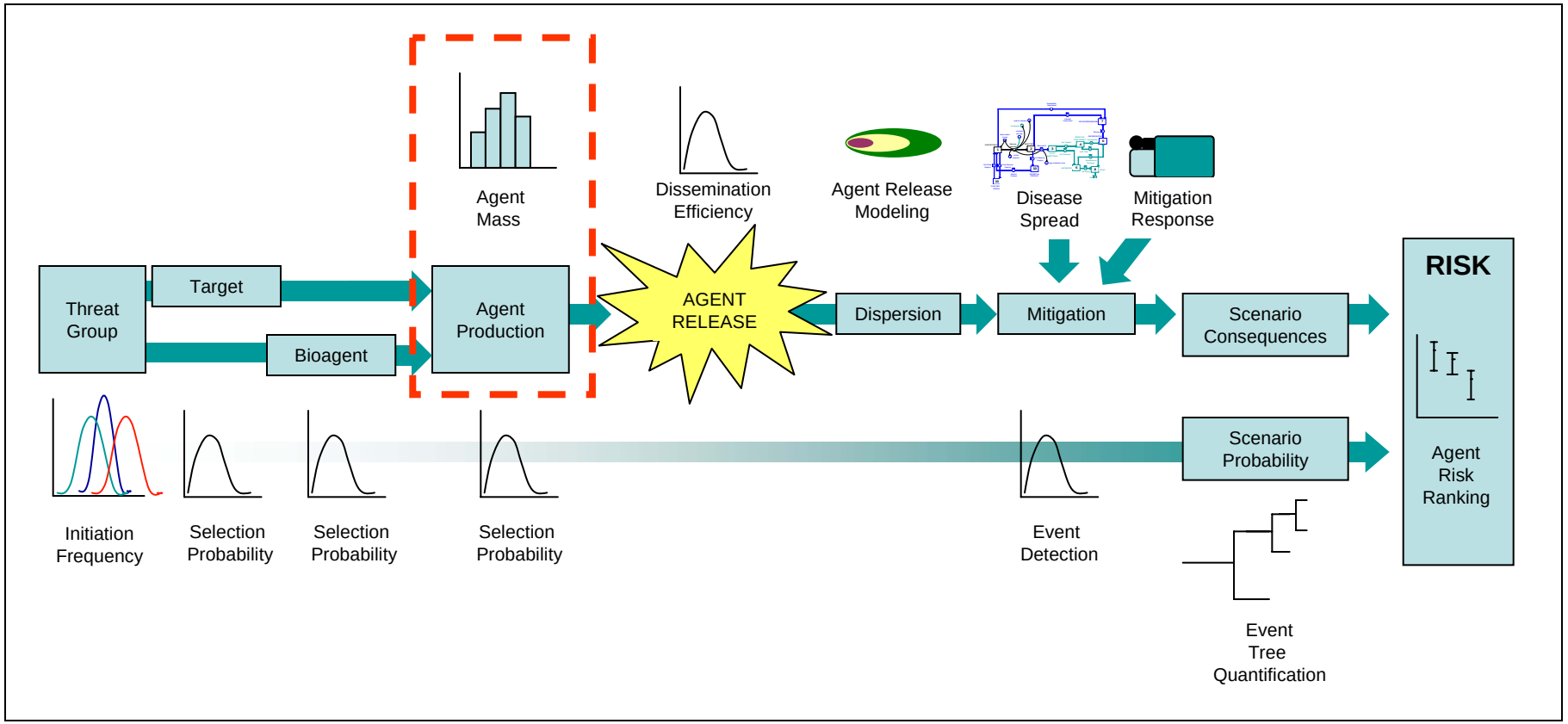
# Production Calculations

# Production Assessment

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# Production Calculations

- Consequence is affected by the quantity and quality of biological material that is released. These material properties are determined by the production and processing events that are selected.
- Threat organizations characterized by high levels of technology and funding have a greater probability of selecting options resulting in a product of higher quantity and quality as well as a greater probability of success.
- The quantity of mass produced is dependent on the unique growth characteristics of each agent, and can vary orders of magnitude across the agent types.

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# Production Calculations

- **MT = target mass**
  - MT distribution based on range of production time (one week to 8 weeks)

- **MR = MT * QF1 * QF2 * QF3 * QF4 * QF5**
  - MR = mass release
  - QF1 = production quantity factor
  - QF2 = processing quantity factor
  - QF3 = drying factor
  - QF4 = storage factor
  - QF5 = transportation factor

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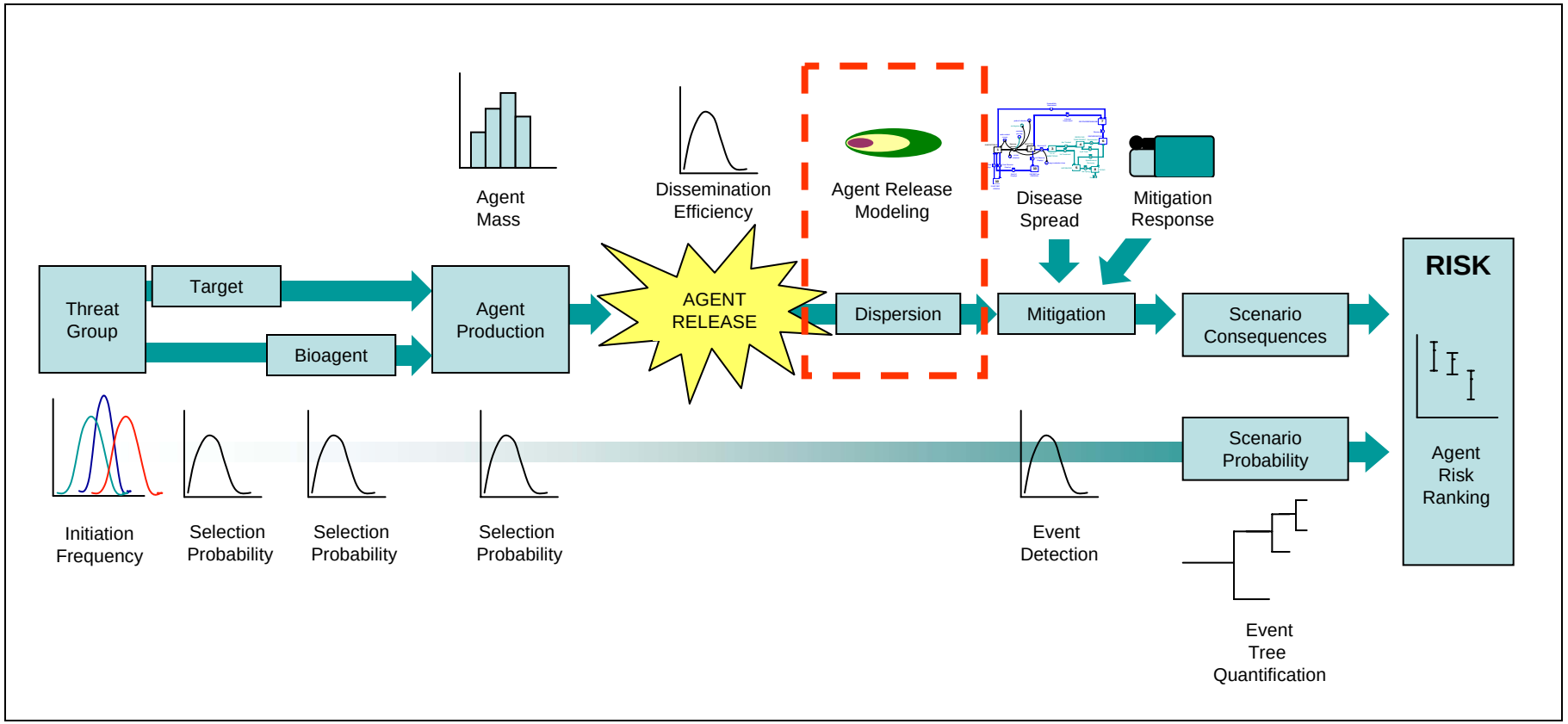
# Consequence Modeling

# Consequence Modeling

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# Consequences Overview

- Risk outcomes depend on both the probability of a scenario and the consequences generated by that scenario.
- A large number of possible scenarios exist involving the use of biological agents by terrorists. Major categories considered in this assessment are:
  - Inhalation – Outdoor and Indoor
  - Food
  - Water
- The major factor controlling the consequences of a particular scenario is the mass released.

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# Inhalation Consequences

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# Inhalation Consequences Overview

- To define the effective mass release (MRE), the release mass (MR) from production is adjusted by several quality factors controlling what fraction of the released mass may contribute to an inhalation exposure that may lead to an illness or infection.

  **MRE = MR * QFR * QFA * QADD**

  - Respirable fraction (QFR)
  - Active fraction (QFA)
  - Additive factor (QADD)
- A large number of scenarios are then used to estimate consequences
  - Specific models for outdoor and indoor scenarios are used to estimate the unmitigated initial illnesses and deaths
    - Outdoor modeling results are approximated by a response surface model incorporating all variable parameters
  - Ranges are used for variable parameters to capture the variability of consequences outcomes

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# Inhalation Dissemination Modes

- 9 available modes of dissemination for inhalation exposures
  - Line sources are unavailable for indoor targets

| **Available Dissemination Modes** | **Source Model** |
|---|---|
| Ground-level release from stationary sprayer (wet) | Continuous Point |
| Ground-level release from stationary fogger (wet) | |
| Ground-level release from mobile sprayer (wet) | Ground Line |
| Ground-level release from mobile fogger (wet) | |
| Aerial release from mobile sprayer (wet) | Aerial Line |
| Aerial release from mobile fogger (wet) | |
| Ground-level release of IED (wet) | Instantaneous Point |
| Ground-level release of IED (dry) | |
| Ground-level release from stationary blower (dry) | Continuous Point |

# Dissemination Modes – Respirable Fraction

- Respirable fraction (QFR) – amount of biological agent considered at least inhalable after a dissemination event
  - For this assessment, particles less than 10 µm in diameter
  - For dry modes, QFR depends on quality of powder produced
  - For wet modes, QFR depends on droplet size and slurry solids fraction
- Example case: stationary fogger spraying anthrax slurry
  - Slurry is 0.5% solids by mass
  - Droplets have a log-normal size distribution with MMD of 30 - 50 µm and GSD of 2.0
  - Assuming complete evaporation, MMD will shrink to about 5 – 9 µm and QFR will be 80 - 60%

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# Dissemination Modes – Active Fraction

- Active fraction (QFA) – amount of biological agent undamaged by a dissemination event
- Based on experimental data where possible
- For agents with no data available, available values are modified on the basis of agent hardiness
  - Spores – generally the hardiest of organisms
  - Vegetative – generally the most fragile of organisms
  - Viruses – dependent on virus structure
  - Toxins – dependent on toxin structure

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# Dissemination Modes – Additive Factor

- Additive factor (QADD) - additional quality factor reflecting whether steps have been taken to improve survivability of the biological agent through the use of additives.
- The use of additives may greatly effect the outcome of a scenario, so whether or not additives are used becomes very important.
- The probability of using additives increases with increased funding and technical capability of terrorist groups.
- Preliminary approach assumes that when additives are not used, the survivability of biological agents is significantly reduced.

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# Atmospheric (Outdoor) Dispersion Modeling

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# Other Dissemination Variables

- Foggers and sprayers coupled to a moving platform produce line sources which have other important characteristics:
  - Platform velocity
  - Release rate/duration
- Used to determine mass disseminated per line length
  - Higher mass per line length results in larger areas of illnesses and deaths
- Also used to calculate length of line sprayed
  - Line sources are modeled on a per km basis and scaled to the calculated line length
- Example: ground-level moving fogger
  - Assuming ground-level velocity of 60 km/hr (about 40 mph), fogger spray rate of 1 lpm, 5 L total liquid at 5% solids concentration
  - Results:
    - Mass/km =50 g/km
    - Line length = 5 km

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# Outdoor Targets

- Surrogates are:

  - urban area – open stadium – urban event

- Parameters include:
  - Effective mass of biological agent released
  - Target area – based on several examples for each surrogate
  - Population density – based on several examples for each surrogate
  - Percentage of population indoors – urban area only
    - Average building protection factor of 1.9 means people indoors receive lower exposure
  - Range of meteorology – based on frequency of occurrence
  - Aerial releases may also occur from multiple release heights
  - Agent decay – varies for different agents

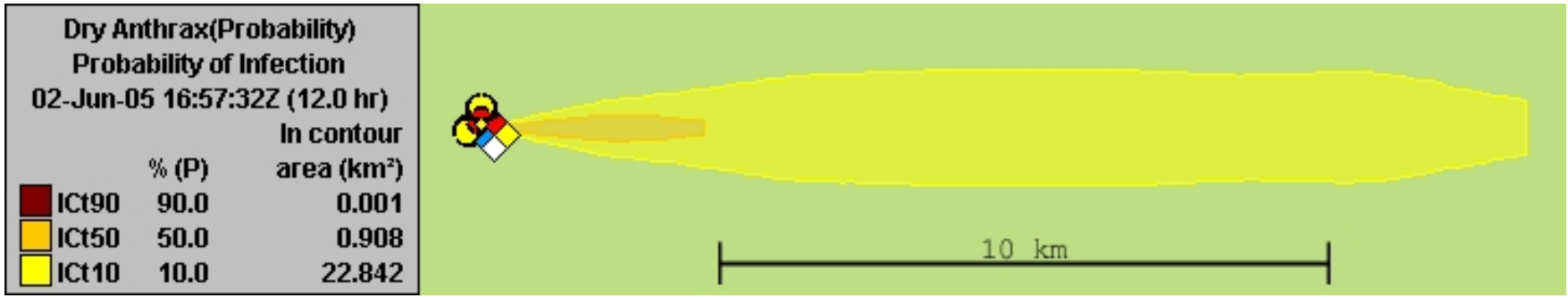
# Outdoor Modeling

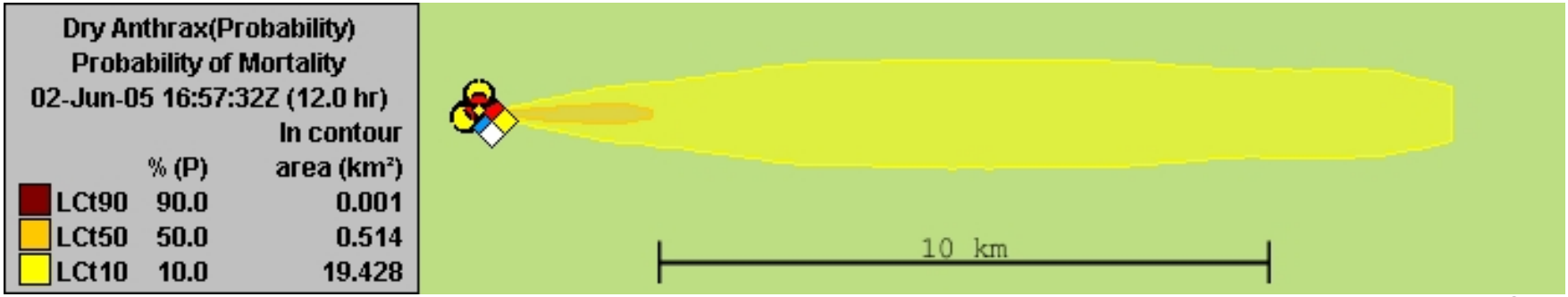
- Hazard Prediction and Assessment Capability (HPAC) v. 4.0.4 SP1
  - Detailed atmospheric transport and diffusion model developed by DOD and accredited in many studies by Institute for Defense Analysis and others
  - Predicts contours for probability of illness/infection and probability of mortality
- Casualty calculations are based on areas for 10%, 50% and 90% probability of illness and mortality
  - Indoor populations have lower probability because of protective building effects.
  - Agents which do not have dose-dependent probability of mortality use the probability of illness curves with the mortality rate.

$$\text{Illnesses} = \left\{ \begin{matrix} \text{Population} \\ \text{Density} \end{matrix} \right\} * \{\text{Area}\} * \left\{ \begin{matrix} \text{Probability} \\ \text{Of Effect} \end{matrix} \right\}$$

# Outdoor Modeling Results

- Example: anthrax from stationary fogger over urban area
  - Assuming effective release mass of less than 100 g, population density of 4,000 people/km2, 80% of population indoors, most frequent meteorological conditions



# Outdoor Inhalation Summary

- Consequences for the broad range of scenarios considered here were predicted using an accredited model.
- Many dissemination parameters were allowed to vary over a range of values to reflect the variation in possible outcomes for a particular mass released.
- A matrix of cases varying the dissemination parameters was completed for each agent and a response surface approximating the results was generated.
- Final outdoor consequence results were drawn from the response surface model for many combinations of dissemination parameters and mass released to correspond to the many end-state tree scenarios.

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# Indoor Aerosol Dispersion Modeling

# Indoor Inhalation Modeling Introduction/Background

- What is a well mixed model and what does well mixed mean?
  - A well mixed volume is defined as a volume which is characterized by a single uniform concentration (local variations in concentration are negligible/neglected).
    - Also referred to as a Continuously Stirred Tank Reactor (CSTR) in many engineering circles.
  - A well mixed model is one which uses one or more well mixed volumes to approximate reality.
    - Well mixed models are commonly used in indoor air quality modeling

*"All models are wrong. Some are useful"* - George E.P. Box

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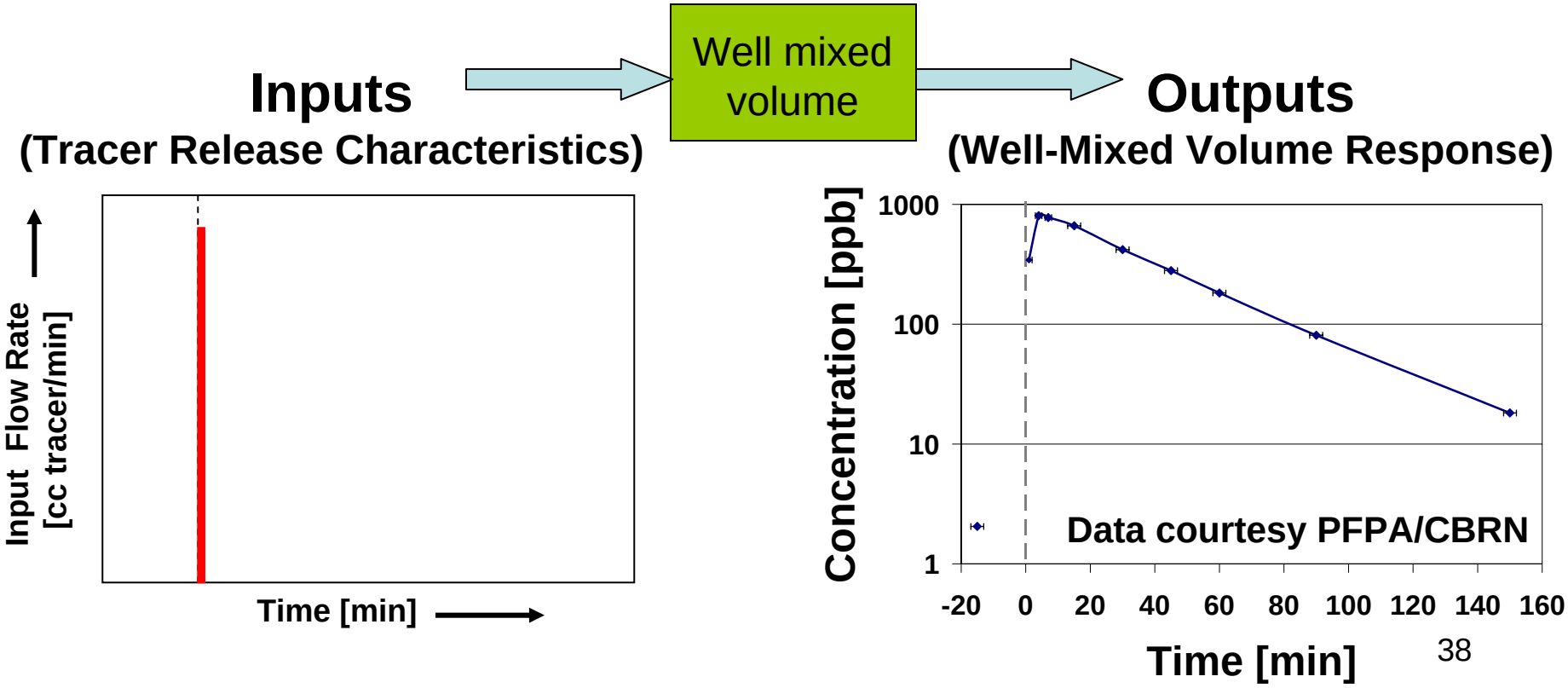
# Indoor Inhalation Modeling Introduction/Background

- Instantaneous Release (Burst / IED)
  - Is a well-mixed model applicable/accurate?
    - Illustrative Examples

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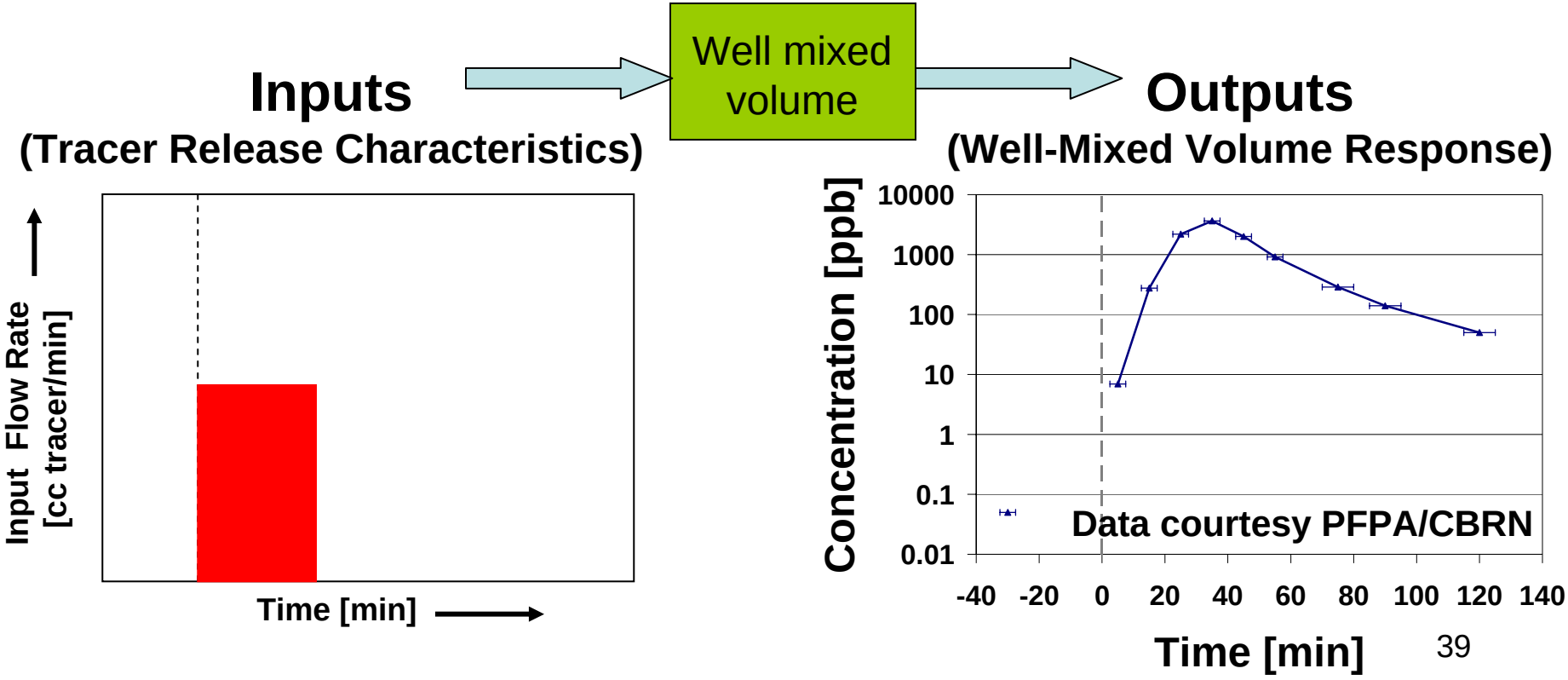
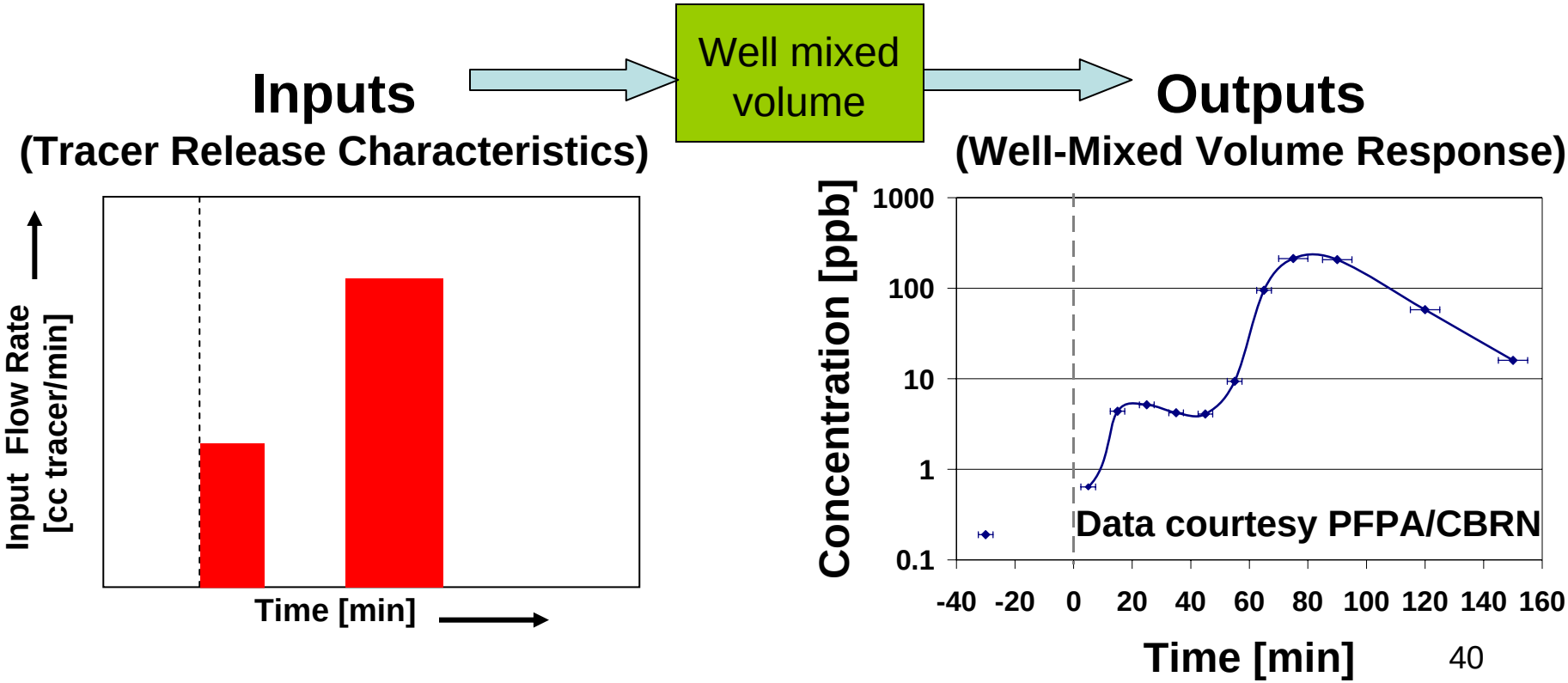
# Indoor Inhalation Modeling Introduction/Background

- Single Continuous Release (fogger / sprayer)
  - Is a well-mixed model applicable/accurate?
    - Illustrative Examples



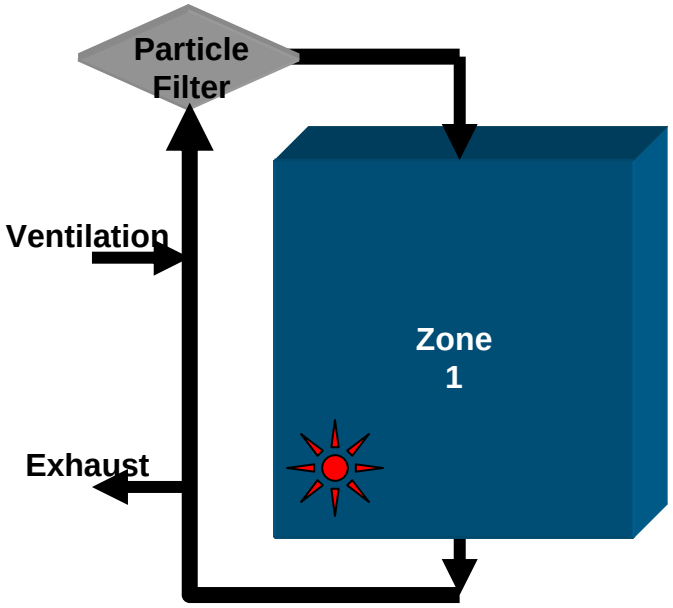
# Indoor Inhalation Modeling Introduction/Background

- Two Staggered Continuous Releases
  - Is a well-mixed model applicable/accurate?
    - Illustrative Examples



# Indoor Inhalation Modeling
# Single Zone Indoor Model

- 2006 DHS Bioterrorism Risk Assessment used a single zone indoor inhalation model
  - Analytical solution (easy to solve, low calculational requirements)
  - Generic approach (to a 1st order approximation, applies to all buildings)

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# Indoor Inhalation Modeling
# Single Zone Indoor Model

- Using a simple mass balance on the single zone volume, an analytical solution can be obtained.
  - A differential mass balance yields

$$\left[\frac{dC}{dt}\right] = \left[\frac{MRE}{t_{Gen}\,V}\right] - \left[(\tau_{rem} + D)C\right]$$

where $\tau_{rem} = \frac{Q}{V} + \eta_{Filter}\frac{Q_{Recirc}}{V}$

**Change in the zone's concentration** = **Rate of mass added to the system via continuous release** - **Rate of mass removal from system by flushing, filtration, and agent decay.**

**Nomenclature of Variables and Symbols**

C = zone concentration [mg/m$^3$]
t = time [min]
D = agent decay rate [%/min]
MRE = continuous release rate [mg/min]
$t_{Gen}$ = release duration [min]
V = zone volume
Q = makeup air flow rate [m$^3$/min]
$Q_{Recirc}$= recirculated air flow rate [m$^3$/min]
$\eta_{Filter}$ = filtration efficiency [%]
$\tau_{rem}$ = removal rate constant [min$^{-1}$]

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# Indoor Inhalation Modeling
# Single Zone Indoor Model

- Integrating the differential mass balance yields an analytical solution of the concentration at any given point in time.
  - Valid for both continuous release scenarios and instantaneous release scenarios.
  - Resulting concentration function can easily be integrated to yield an analytical function of exposure as a function of time.

$$C(t) = \frac{MRE}{t_{Gen}\, V\left(\tau_{rem} + D\right)} + \left( C_o - \frac{M_{Gen}}{t_{Gen}\, V\left(\tau_{rem} + D\right)} \right) e^{-\left(\tau_{rem} + D\right)\left(t - t_o\right)}$$

**Nomenclature of Variables and Symbols**

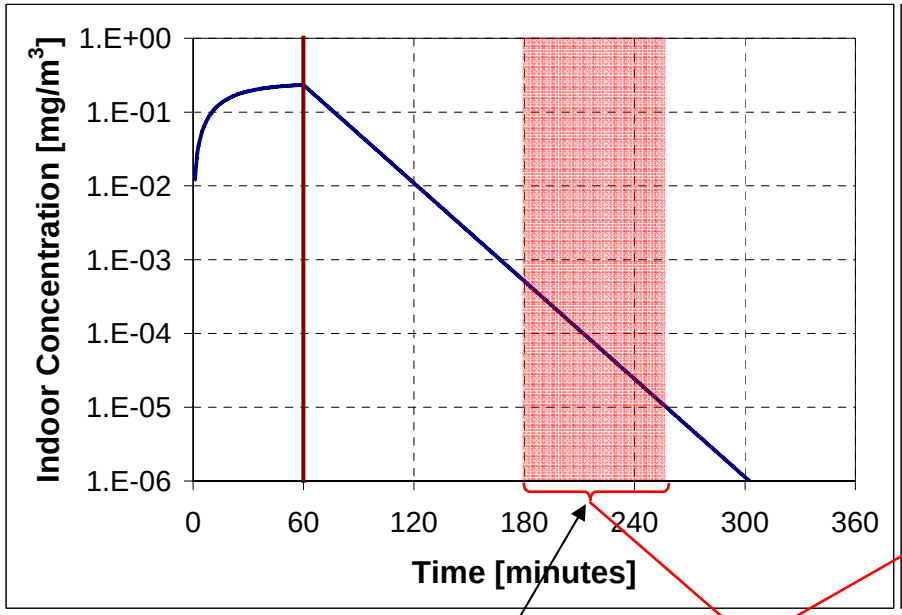
$C_o$= zone concentration at $t_o$ [mg/m$^3$]
$t_o$ = reference time of known concentration [min]

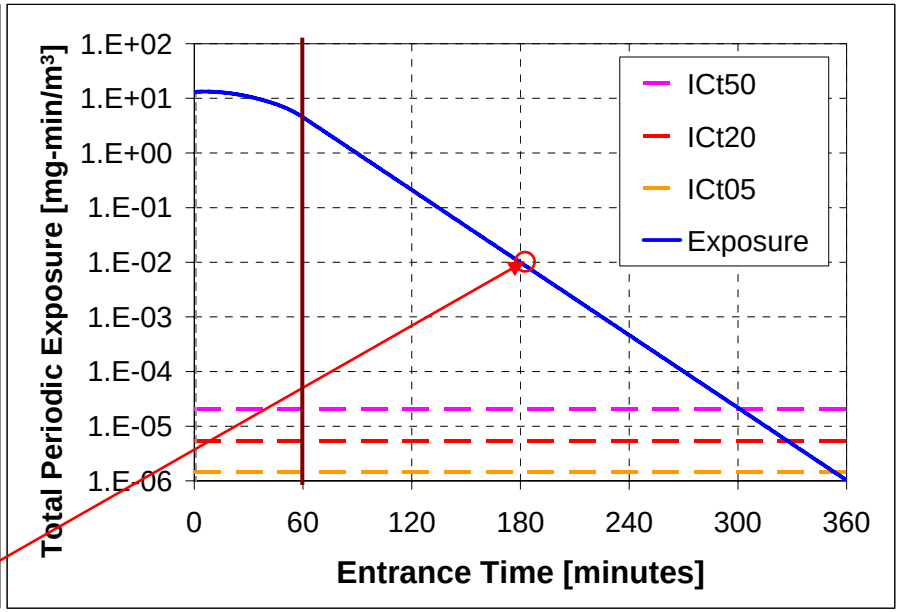
# Indoor Inhalation Modeling
# Single Zone Indoor Model

- Two population exposure models were used.
  - **Pulse** – A single population enters the zone and remains for a set duration.
    - Examples: Church, Theatre, Airplane, Subway Car, etc…
    - Metrics: Percentage of Fatalities or Illnesses in the Pulse population.
  - **Step** – People continuously enter the zone at a finite rate, remain for a set duration, then leave the zone at the same rate at which they enter.
    - Similar to the approach used to derive the model only the quantity considered is people instead of air.
      - A “well-mixed zone for people”
    - Examples: Shopping Malls, Museums, Airplane Terminals, Subway Platforms, etc…
    - Metrics: Number of Fatalities or Illnesses divided by the rate of people entering or leaving the zone.

# Indoor Modeling Results

- Step population exposure calculation example
  - Predicted concentration is well-mixed across entire volume
  - Exposure is predicted as a function of entrance time and length of stay (e.g. 80 minutes)

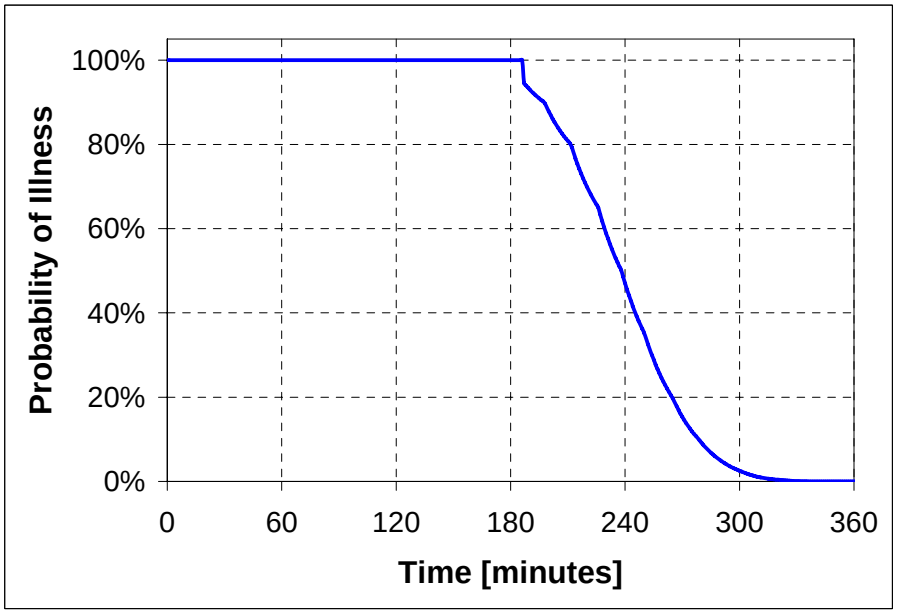


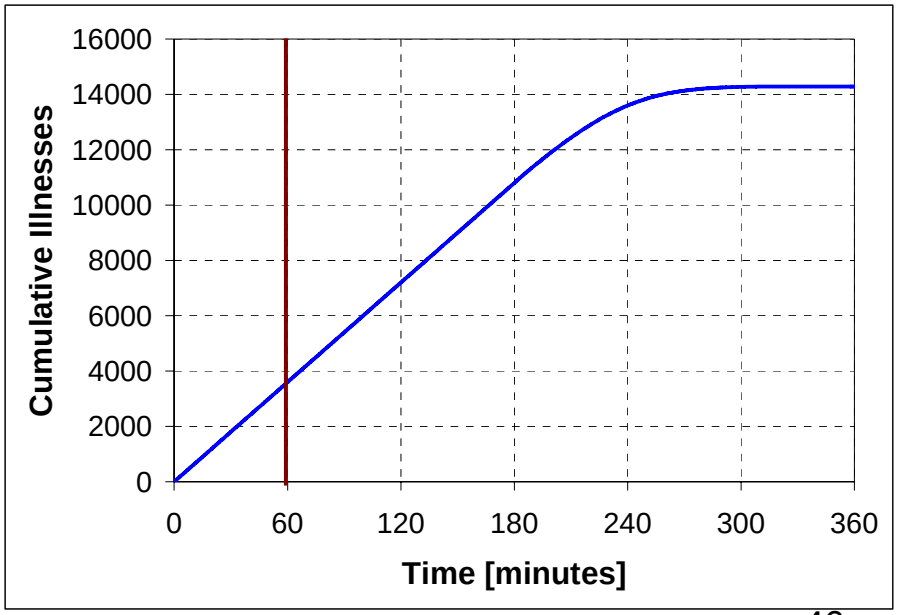




Residence Time

# Indoor Modeling Results (cont'd)

- Consequence Estimation
  - $ICt_{50}$ and probit slope are used to estimate the probability of illness for each exposure.
    - The probit slope is defined as the slope of the dose response curve where the x-axis is expressed as the log of the administered dose while the y-axis is expressed as the probability of illness or death.
  - Total illnesses are calculated for each exposure using the shopper population rates.



# Indoor Inhalation Modeling
# Single Zone Indoor Model

- Numerous surrogates (Target Types) considered.
  - Large Open Buildings
    - Enclosed Shopping Malls
    - Transportation Terminals
    - Entertainment, Religious, and/or Political Centers
  - Small Enclosures
    - Transportation Units
      - Subway Cars
      - Airplanes
  - Large Divided Buildings
    - Cruise Ships
    - Public / Private Buildings
      - Hospitals
      - Museums
      - Office Buildings

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# Indoor Inhalation Modeling Model Parameters and Scenarios

- The amount material that was effectively disseminated (MRE) relied on a number of scenario-driven parameters.
  - Method of Dissemination
    - Types of Dissemination considered
      - Foggers
      - Sprayers
      - IEDs
      - Mailed letters
    - Dissemination parameters determined other key factors such as:
      - Dissemination Efficiencies
      - Respirable Fractions
      - Active Fractions

# Indoor Inhalation Modeling Model Parameters and Scenarios

- A variety of methods were used to estimate the model parameters used in the 2006 DHS Bioterrorism Risk Assessment.
  - Some parameters were taken directly from literature and the internet.
    - Building volumes and square footages
    - Population data
  - Some parameters were estimated from data based on standards and rules of thumb (e.g. ASHRAE 6.2).
    - Removal Constant (Amalgamation of HVAC Parameters)
      - Outdoor Air
      - Recirculated Air
      - Filtration Efficiencies
  - Distributions were created for each of these parameters and sampled using a Monte Carlo analysis to produce the indoor inhalation model results for the 2006 DHS Bioterrorism Risk Assessment.

# Indoor Inhalation Modeling Discussion

- The indoor inhalation model represents a rough approximation of all possible buildings.
  - Does the model suitably approximate reality?

    *"All models are wrong. Some are useful"* - George E.P. Box
  - If one were to create a model to represent the wide range of targets considered how many zones would it have?
    - It is possible to make a detailed model of a specific building for a given scenario.
    - Doing so for "any" building and "any" indoor scenario is not.
      - By incorporating the details of a specific building, a model instantly becomes irrelevant to other specific buildings.
    - The central issue becomes a balance of detail versus applicability.

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# Foodborne and Waterborne Contamination Modeling

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# Foodborne Contamination - Vulnerabilities

- A number of vulnerabilities have been identified in the food supply system
  - Lack of resources within regulatory agencies
    - Frequently rely on passive system for detecting food contamination
  - Large-scale “factory” farming and processing
    - Centralized, with single access points affecting large amounts of food
    - High numbers of employees, and background checks difficult
    - Distribution systems cover a wide area, affecting a large population
  - Rising numbers of large-scale under-inspected imports and exports
    - Only a small percentage of foods are ‘inspected’, and these inspections usually involve paperwork verification rather than food assessment

# Foodborne Contamination– Scenario

- Agents considered
  - *B. anthracis, Y. pestis, C. botulinum, Cryptosporidium, Salmonella* Typhi*, E. coli O157:H7, S. dysenteriae* type 1*, F. tularensis, V. cholera,* SEB, Ricin, and BSE
- Vulnerable Foods
  - Produced in large volumes
  - Short shelf life (distributed and consumed quickly)
  - Processing not designed to remove/detect BW agents
  - Examples : **Milk** (liquid)**, Produce** (fruit and vegetables), **Ready-to-eat meats** [RTE] (deli meats)
- Production Step Opportunity
  - Milk storage silos
  - Produce in the field
  - RTE meats post lethality step

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# Foodborne Contamination – Scenario

- Ready to Eat Meat Contamination Scenario
  - *Agent* contaminated liquid emptied into chiller
  - No significant reduction step follows the chiller
  - Assume a significant portion is consumed prior to recall
  - Decay over time from contamination to consumption is considered
  - Detection at the scale proposed may eliminate the threat of many vegetative organisms.

- Different addition, washing, and storage solutions
- will significantly alter decay rates
- Toxins typically not assayed for immediately before packaging

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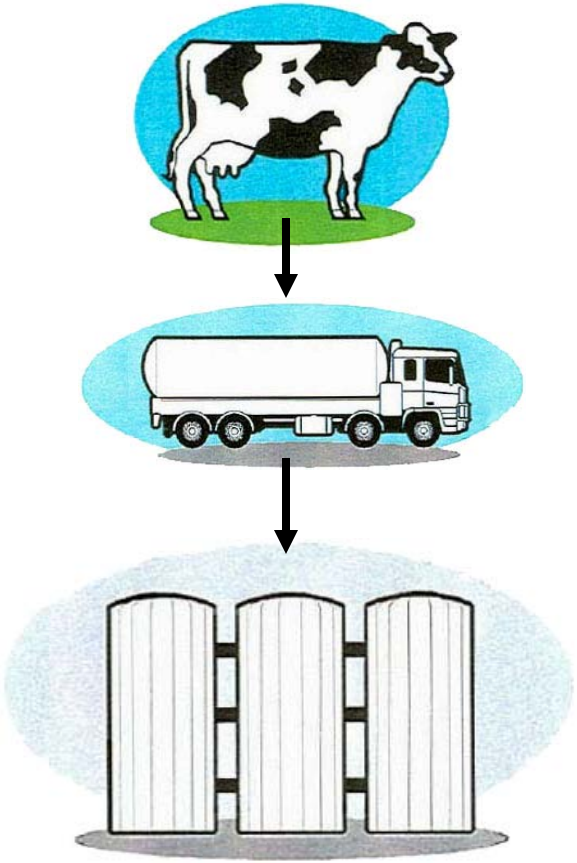
# Foodborne Contamination – Scenario

- Bulk Milk Contamination Scenario
  - *Agent* contaminated liquid emptied bulk milk storage tank (5000 gallon truck)
    - Milk is an ideal storage medium for many agents reducing normal decay. Many agents may actually increase.
  - Truck is emptied into storage silo of 20,000 to 50,000 gallons
    - Constant mixing thoroughly distributes agent throughout entire volume



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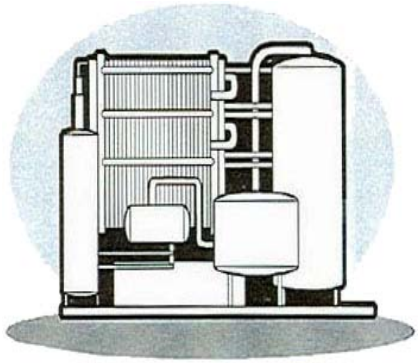
# Foodborne Contamination – Scenario

- Contaminated milk is pasteurized, packaged and distributed
  - Pasteurization does eliminate several agents however due to the desire for unaltered taste the process is not harsh enough for all agents.
  - Even after treatment milk has a constant microbial population (unless UHT treated) which may mask many agents
- Due to rapid consumption a significant amount of milk will be consumed before identification or recall.
- Each gallon is estimated to expose four people



# Foodborne Contamination – Scenario

- Produce (Lettuce) Contamination Scenario
  - Agent is sprayed upon (within protective leaves) produce within the field
    - This point affords a high degree of access from an outside influence as can be seen by the high turnover by low wage workers within the industry.
  - Amount contaminated estimated to equal one or multiple truck loads.
    - 9,410 kg based upon the capacity of an average refrigerated truck with a wood or aluminum floor rated at 22,000 lbs
  - Developing disinfection practices not considered.
  - To be further explored for future assessments

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# Foodborne Contamination – Model

- Incorporates the following variabilities
  - Amount of agent produced and amount capable of contaminating specific food
  - Mass contaminated based on access point proposed
  - Decay of agent due to processing and storage (shelf life)
  - Mass of food consumed based on amount contaminated, serving size, and when illness is detected (consumption stopped)
  - Number of illnesses based on the above and infectious dose
  - Number of deaths based on predicted mortality (number lost due lack of treatment or saved due to medical mitigation.
- Generates distributions of the number of people who develop an illness per mass of agent conditional on the agent mass (RI|MRE)
- Resulting distributions are used within the consequence calculation to determine number of illness (CI) as follows:

$$CI = MRE * (RI|PD)|MRE$$

MRE = mass of the agent
RI= number of illnesses

# Waterborne Contamination Summary

- A simplistic plug-flow model was used to simulate the fate and transport of several biological contaminants into the pipes of a water distribution system
- Overall, the risk for ingestion of contaminated residential water was assessed to be lower than risk from inhalation. Factors for this include:
  - High decay rate in tap water
  - High ingested infectious dose
  - Small percentage of contaminant actually consumed
- Agents
  - *B. anthracis, Y. pestis, C. botulinum* neurotoxin, *S. dysenteriae* type 1, *E. coli* O157:H7, *Salmonella* Typhi, *V. cholera, C. parvum*, and *F. tularensis*

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# Waterborne Contamination - Scenario

- Intentional backflow contamination
  - Required equipment and supplies: the agent, a pump that would boost pressure above 60 psi (typical pressure for most systems), tanks to contain the agent solution, a mixer to keep the solution in suspension, and miscellaneous plumbing supplies (i.e., hoses, fittings)
  - Procedure: agent suspension is added to the tanks, mixed, and fed to the pump with a hose. The pump discharge hose would then be attached to a typical faucet in an apartment building residence.
  - Assumes no backflow prevention on the distribution lines

# Water Network Model Distributional Assumptions

| Parameter | Units | 5th Percentile | 95th Percentile | Distribution |
|---|---|---|---|---|
| Volume of agent (V) | l | 24 | 2,400 | Lognormal |
| Pump rate (PR) | lpm | 10 | 50 | Normal |
| Pipe flow rate (FR) | lpm | 20 | 20000 | Logormal |
| Time to usage (TtU) | hrs | ~2.5 | 24 | Lognormal |

Notes:

1. Lognormal distributions are chosen when the 5th and 95th percentiles vary by orders of magnitude.

- Volume of agent derived from “Production, Processing, and Storage Factors” Appendix
- Pump rate was based on reasonable pump rates that could be used for pumps which could overcome water distribution pressures for a backflow attack
- Pipe flow rates derived from a small area network distribution model (KY Pipe), which had water distribution lines with diameters up to 16 inches. Maximum volume extrapolated by a factor of approximately four to accommodate for larger pipe diameters that may be present in a water distribution system.
- Time to usage was based over a 24 hour period, since many of the agents used in the assessment degrade relatively quickly in tap water.

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# Model Consumption Distributional Assumptions

| Parameter | Units | 50th Percentile [(a)] | 95th Percentile | Distribution |
|---|---|---|---|---|
| Serving Size (SS) | #/l | 4.35 | 8 | Lognormal |
| Percent Drinking Water | % | 1% | 3% | Lognormal |

(a) 50th percentile values were provided rather than 5th percentile values. These are equivalent to the median of the distribution.
(b) Assuming standard beverage serving of 8 ounces
(c) Derived from: 1) U.S. Environmental Protection Agency. 1997. *Exposure Factors Handbook*, *Vol I General Factors*. EPA/600/P-95/002Fa. 2) J.M. Montgomery. 1985. *Water treatment Principles and Design*. Wiley-Interscience, John Wiley & Sons, New York, NY.

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# Waterborne Contamination - Model

- Provided distributions of the number of people who develop an illness per mass of agent conditional on the agent mass
- Incorporated variability due to liquid volume injected, pump rate, water volume/flow at the injection site, variability in the percent drinking water, variability in the amount drunk by individuals (serving size), variability in the time to usage of contaminated water, and agent characteristics (stability in tap water, ingested infectious dose, concentration)
- Resulting distributions were used within the consequence calculation to determine number of illness (CI) as follows:

$$CI = MRE * (RI*PD)|MRE$$

MRE = mass of the agent
RI= probability of illness for an individual
PD = number of people exposed

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# Medical Mitigation and Epidemiological Modeling

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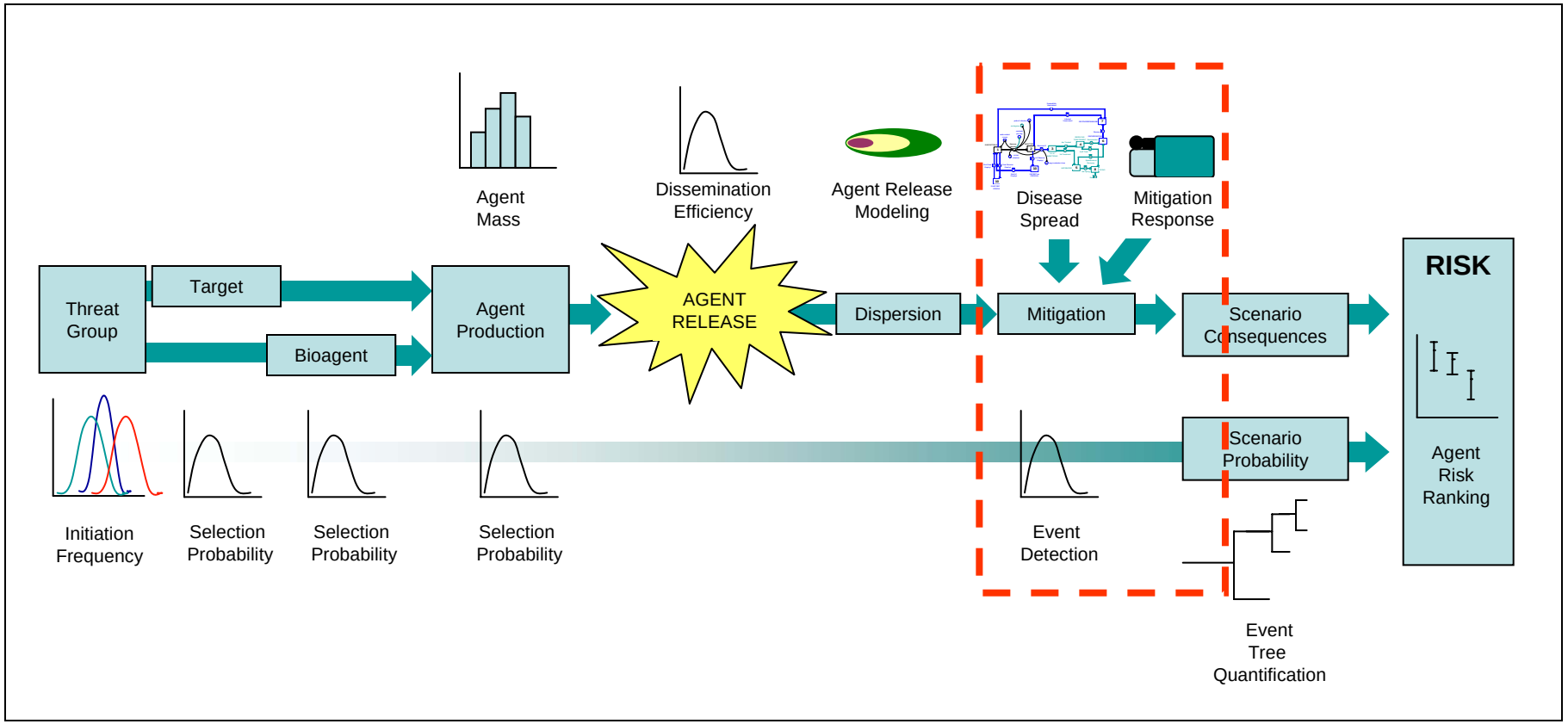
# Mitigation Modeling

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# Medical Mitigation Effectiveness

- Contributors to mitigation effectiveness
  - Time delay between exposure and initiation of treatment
    - Event identification
    - Transfer and distribution of treatment measures
  - Effectiveness of countermeasures
    - Antibiotic, vaccine, antiviral, antitoxin, supportive care
  - Mortality rates for treated and untreated diseases
    - Treatment alone does not guarantee survival
- Minor contribution based on number of persons exposed
  - Greater numbers exposed are assigned a greater likelihood of quicker diagnosis

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# Medical Mitigation Model Methodology

- Identified three potential scenarios to describe the time delay between exposure to treatment
  - Known/Announced
  - Biodetected
  - Clinical Identification
- Collected data regarding disease characteristics
  - Time to symptom onset
  - Duration of illness
  - Timeline for effective treatment
  - Treated/Untreated Mortality
- Calculated the effectiveness of treatment over each timeline for the three scenarios to determine the treatment of the population

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# Medical Mitigation Model Methodology

- Detection determines the time delay to medical mitigation – affects the medical mitigation factor
- Three scenarios of detection are considered
  - Event recognized as terrorist act – depends on dissemination mode
    - Probability of detection is based on mode of dissemination (refer to hypothetical data in table below)
  - Bioagent detected by monitor
    - Outdoor inhalation, agents included in BioWatch assigned detection probability reduced by likelihood of unmonitored targets and area coverage by sensors
    - Food detection – For monitored bioagents, assigned high likelihood of successful detection
  - Clinical identification – medical mitigation depends on timing of clinical diagnosis of index cases

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# Medical Mitigation Model Methodology

- Known/Announced Scenarios
  - Collect and transport samples to Laboratory Response Network (LRN), analysis and confirmation, approve release of treatment resources
- Biodetection Scenario
  - BioWatch detection system
    - In 2006, six agents were on the detection list
    - Collect and transport samples to laboratories, presumptive identification, CDC confirmation, approve release of treatment resources
  - Detection in food
    - Detection using standard assays in milk, meat, and produce
- Clinical Identification
  - Based on time to symptom onset, presumptive analysis based on collected patient samples, CDC confirmation, approval of release of treatment resources

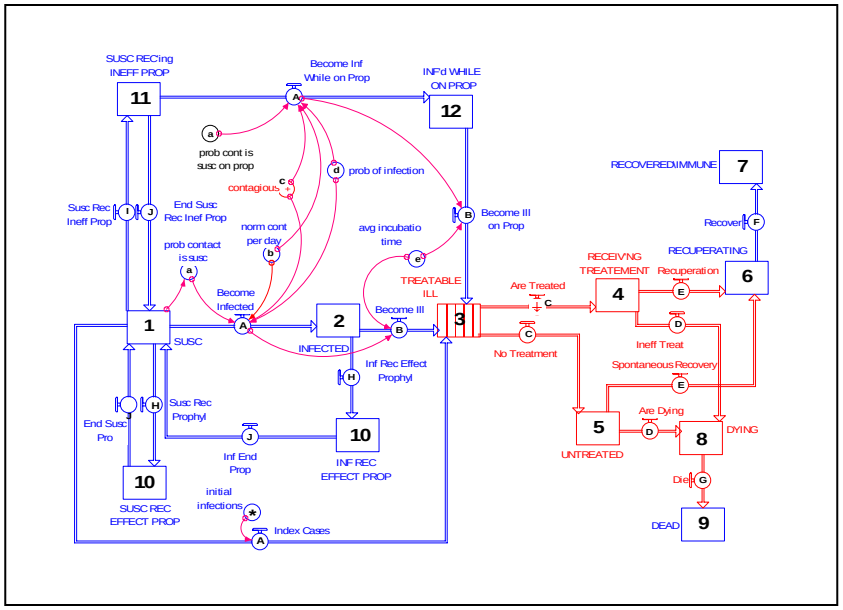
# Medical Mitigation Model Methodology

- All detection scenarios involve the authorization to release Strategic National Stockpile (SNS) resources, followed by time delays for transport and distribution to the appropriate population

- Strategic National Stockpile (SNS)
  - DHS worked closely with the CDC to identify the type and quantity of contents (model limited by type of treatments CDC indicated were available not quantity)
  - CDC provided probable distribution timelines to get stockpiled materials to affected cities
  - CDC also provided timelines to distribute treatments to public after receipt

# Medical Mitigation Model Methodology

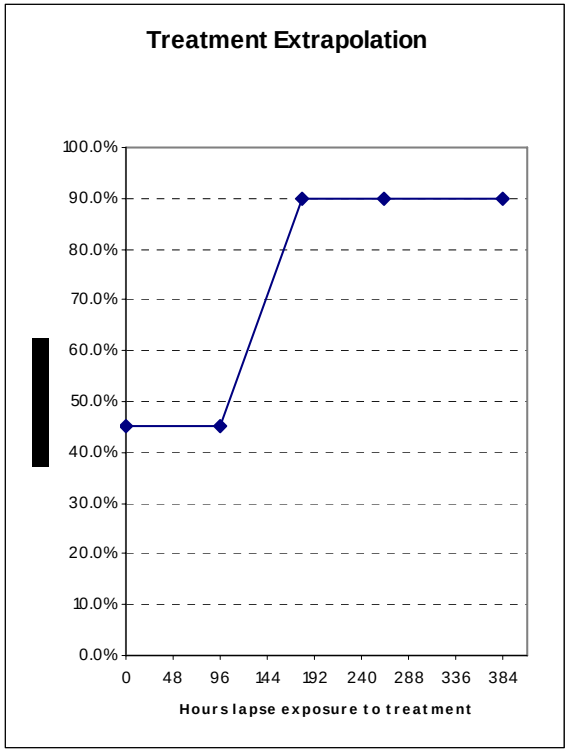
- Using STELLA software, an S-E-I-R (susceptible-exposed-infectious-removed) epidemic model was created which can be used to estimate the spread of contagious disease
- Incorporates factors such as contacts per day, rate of infection per contact, response behavior during outbreak
- In cases of contagious diseases (plague, VHFs, smallpox), epidemiological modeling is performed to calculate further consequences
- In this study, exposed populations increased by factors of 1 to 5 for contagious diseases



# Medical Mitigation Model Methodology

- In each detection scenario, the time between exposure and treatment is estimated
- The effectiveness of treatment over time is estimated

| Scenario | minimum | maximum |
|---|---|---|
| **Known Event** | | |
| Sampling and transport | 1 | 8 |
| Sample analysis | 1 | 24 |
| *Total* | 2 | 32 |
| **Biodetection Event** | | |
| Sample collection | 1 | 24 |
| Standard analysis | 10 | 14 |
| CDC confirmation | 0 | 10 |
| *Total* | 11 | 48 |
| **Symptom Identification** | | |
| Time to symptom onset | 24 | 168 |
| Initial anlaysis | 24 | 72 |
| CDC confirmation | 0 | 10 |
| *Total* | 48 | 250 |
| **Stockpile transfer and distribution** | | |
| Release and transfer | 1 | 12 |
| Distribution | 1 | 48 |
| *Total* | 2 | 60 |
| | | |
| **Total time from exposure to treatment** | | |
| Known Event | 4 | 92 |
| Biodetection Event | 13 | 108 |
| Symptom Identification | 50 | 310 |
| | | |
| **Revised total time** | | |
| Known Event | 4 | 92 |
| Biodetection Event | 13 | 108 |
| Symptom Identification | 50 | 290 |



# Medical Mitigation Model Methodology

- Total times calculated from exposure to treatment for each scenario are correlated with the plots to estimate the mortality rate anticipated at each timepoint

| | *Agent X* | | *Agent Y* | | Agent Z | | Agent T | |
|---|---|---|---|---|---|---|---|---|
| **Calculated Mortality Rate** | minimum | maximum | minimum | maximum | minimum | maximum | minimum | maximum |
| Known Event | 45% | 45% | 8% | 32% | 7% | 16% | 86% | 86% |
| Biodetection Event | 45% | 51% | 8% | 95% | 7% | 19% | 86% | 86% |
| Symptom Identification | 45% | 83% | 8% | 95% | 30% | 30% | 86% | 86% |

- These mortality rates are then associated with the probability of each event identification scenario, and a medical mitigation factor applied to the exposed population

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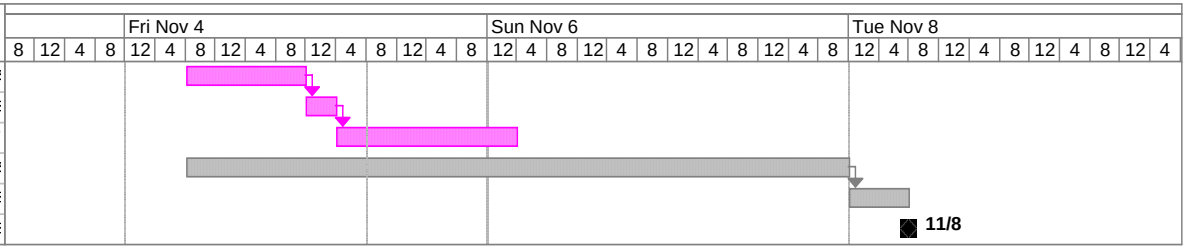
# Medical Mitigation Model Methodology

## Time Delay Between Exposure and Treatment for a Notional Agent

**(Median values selected for scenarios)**

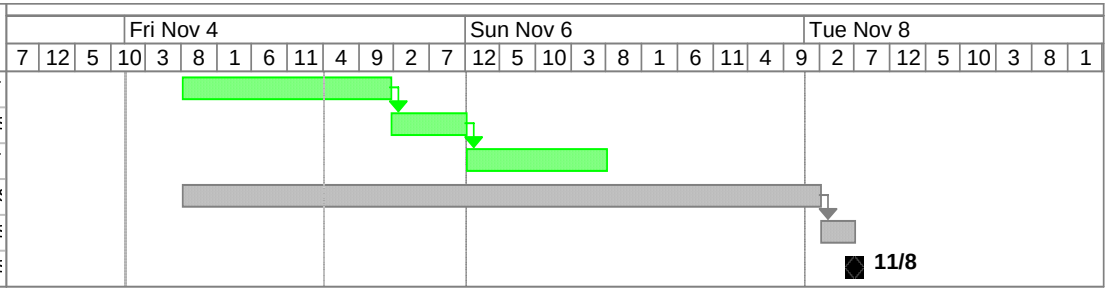
### Known Event

| ID | Task Name | Duration |
|---|---|---|
| 1 | Known Event | 17 hrs |
| 2 | Stockpile Release/Transf | 6 hrs |
| 3 | Stockpile Distribution | 24.5 hr |
| 4 | Optimal Treatment Timefi | 90 hrs |
| 5 | Limited Effectiveness | 6 hrs |
| 6 | Untreated | 0 hrs |



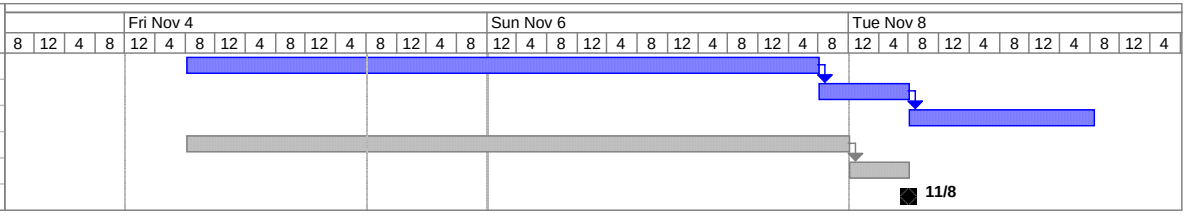

### Biodetected Event

| ID | Task Name | Duration |
|---|---|---|
| 1 | Unknown Event/Biodetec | 29.5 hr |
| 2 | Stockpile Release/Transf | 6 hrs |
| 3 | Stockpile Distribution | 24.5 hr |
| 4 | Optimal Treatment Timefi | 90 hrs |
| 5 | Limited Effectiveness | 6 hrs |
| 6 | Untreated | 0 hrs |




### Symptom Identification

| ID | Task Name | Duration |
|---|---|---|
| 1 | Unknown Event/Symptom ID | 84 hrs |
| 2 | Stockpile Release/Transfer | 12 hrs |
| 3 | Stockpile Distribution | 24.5 hrs |
| 4 | Optimal Treatment Timeframe | 90 hrs |
| 5 | Limited Effectiveness | 6 hrs |
| 6 | Untreated | 0 hrs |



# Medical Mitigation Summary

- The medical mitigation modeling is a crucial aspect of the risk assessment process – it allows for the performance of tailored assessments to evaluate the impact of numerous mitigation strategies
  - Risk reduction through decrease in response times
    - Agent identification in detection systems and laboratory analyses
    - Release, transport, and distribution of treatment resources
  - Risk reduction through increase in treatment efficacy and availability
    - Improvements in vaccine or antibiotic efficacy
    - Availability of stockpiled pharmaceuticals

# Risk Calculation Engine

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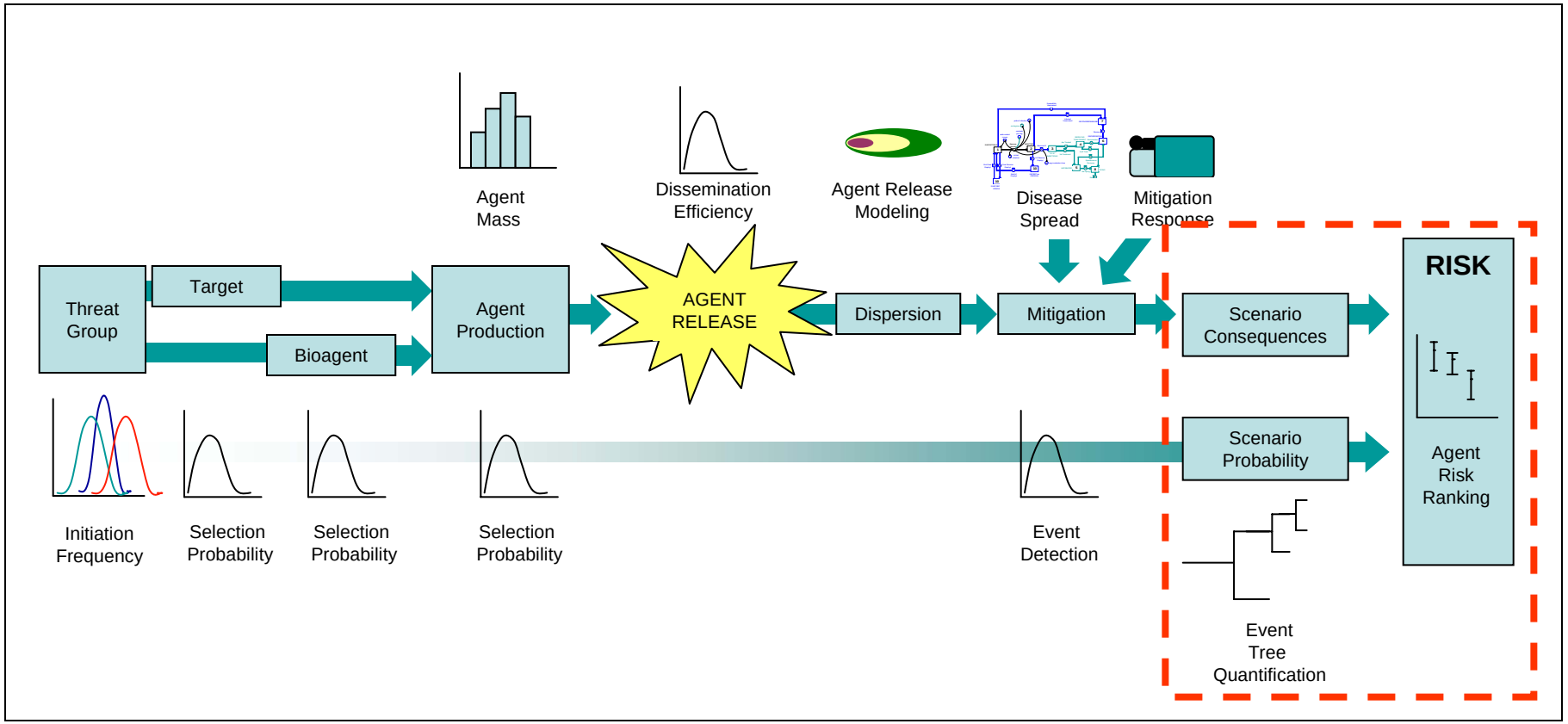
# Risk Calculations



# Risk Calculation Engine Outline

- Latin hypercube sampler
- Risk Tree Engine
- Consequence Calculator
- Risk Calculator

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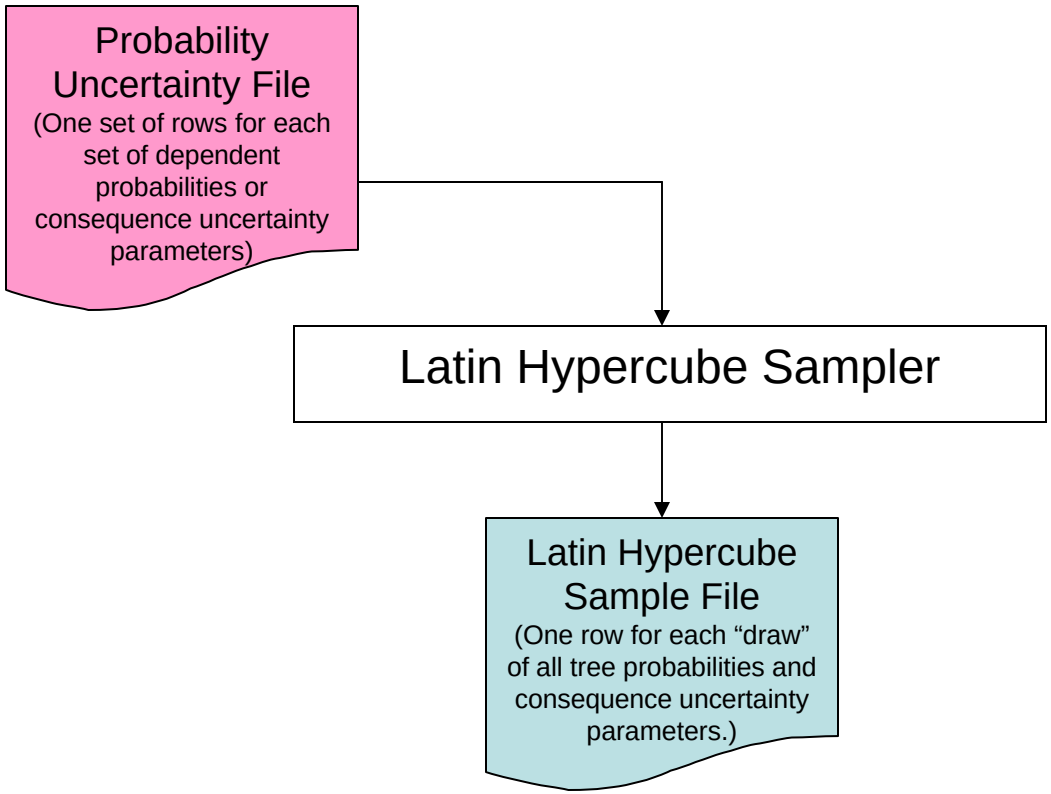
# Latin Hypercube Sampler

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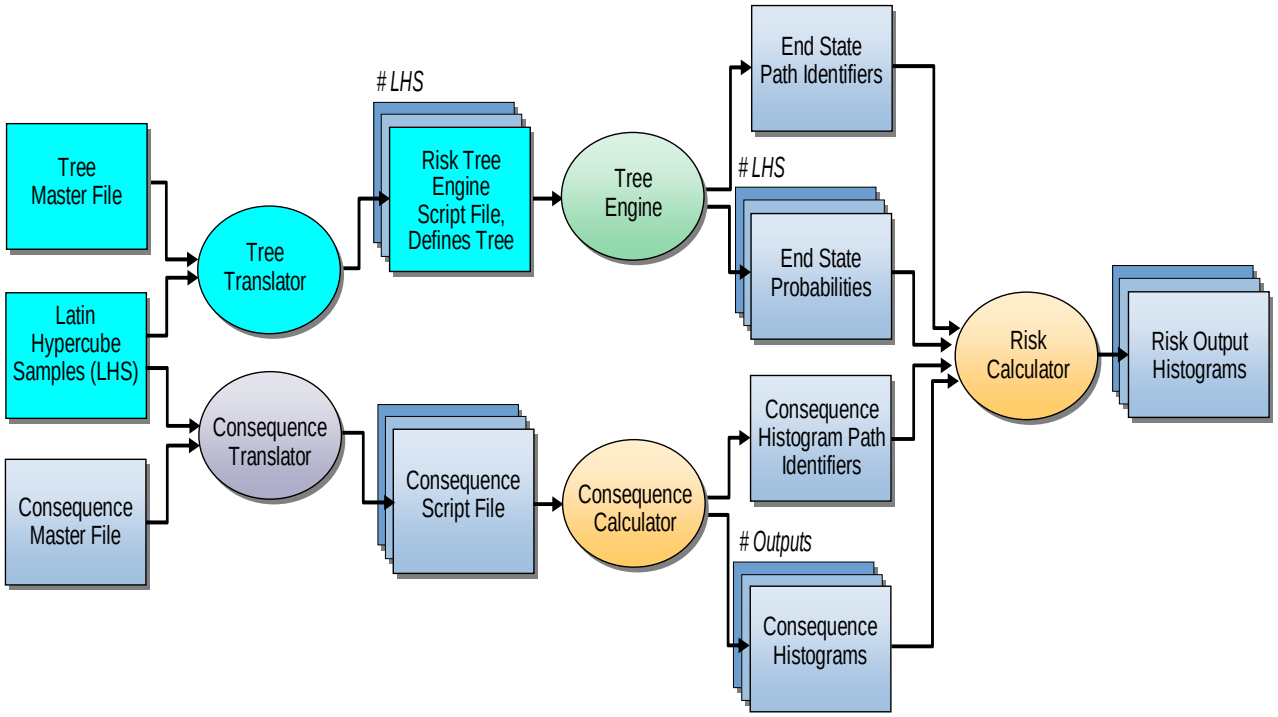
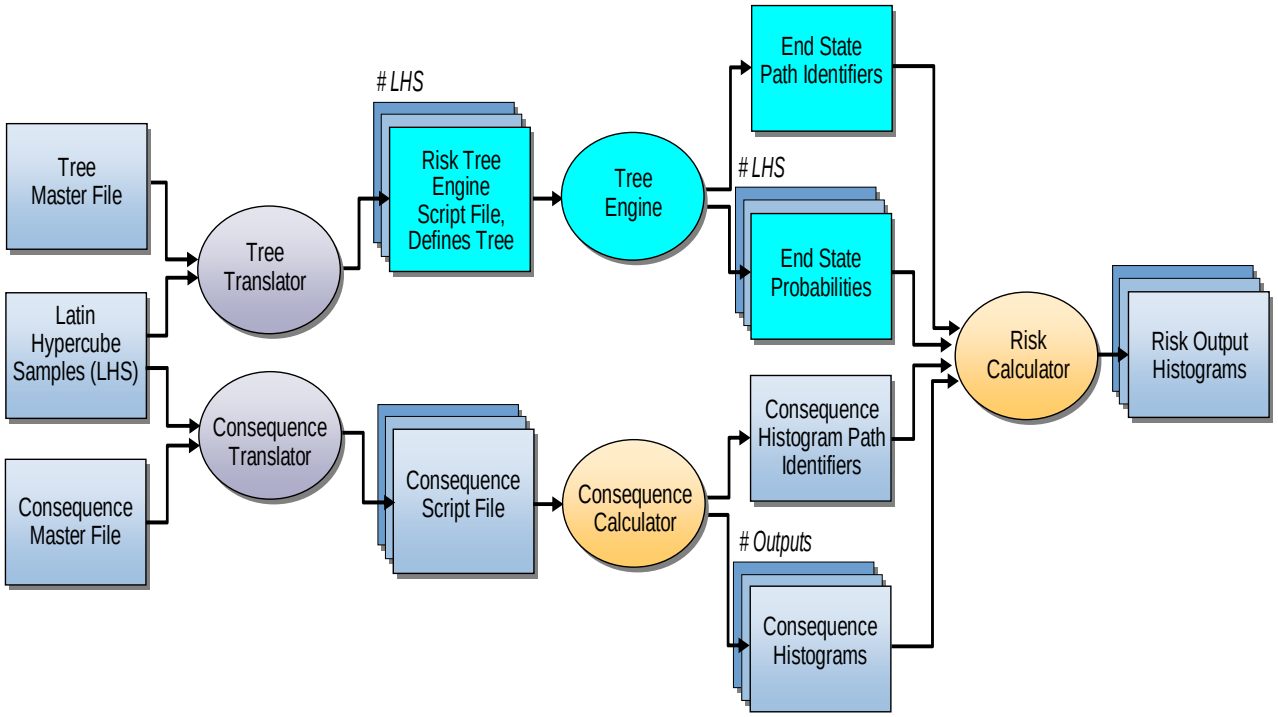
# Calculation Engine



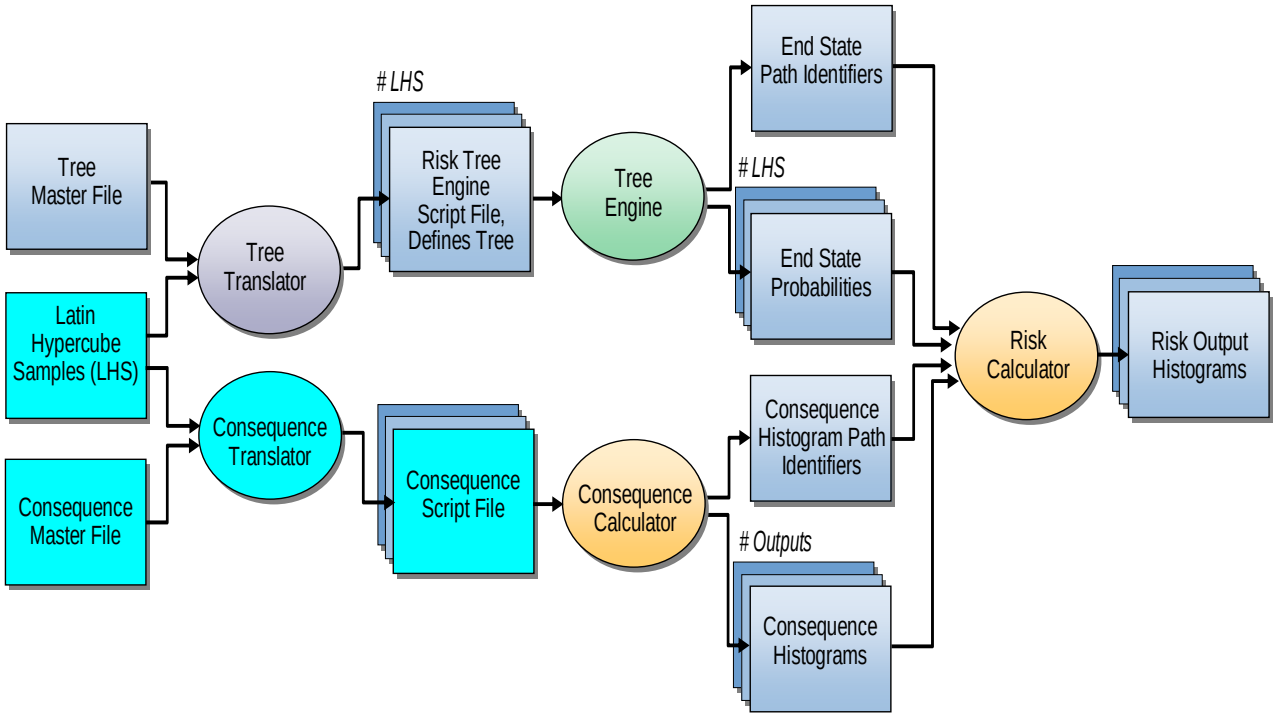

Calculation Engine

# Calculation Engine




Calculation Engine

# Calculation Engine




Calculation Engine

# Basic Consequence Equations (All Terms are Distributions)

- **MT = target mass**
  - MT distribution based on range of production time and production equipment
- **MR = MT * QF1 * QF2 * QF3 * QF4 * QF5**
  - MR = mass release
  - QF1 = production loss factor
  - QF2 = processing loss factor
  - QF3 = drying loss factor
  - QF4 = storage loss factor
  - QF5 = transportation loss factor

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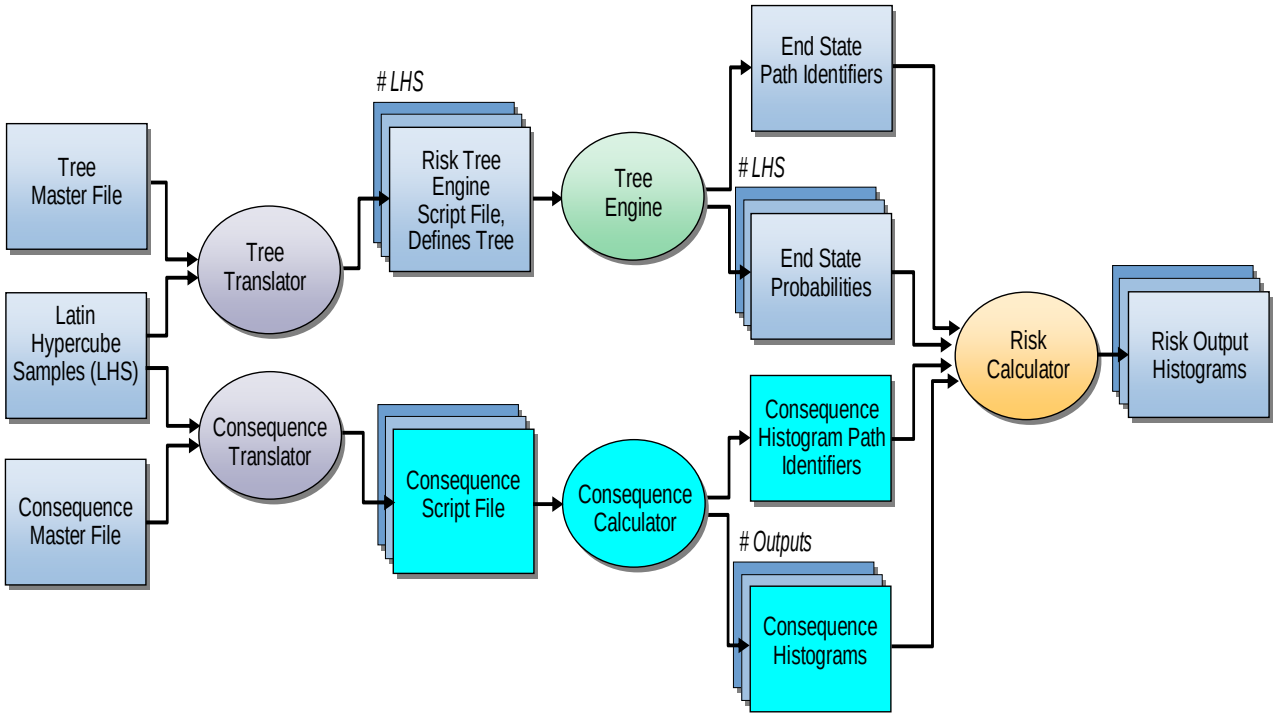
# Basic Consequence Equations

- **MRE = MR * QFA * QFR * QADD**
  - MRE = effective mass release
  - QFA = active fraction after dissemination (inhalation modes)
  - QFR = respirable fraction after dissemination (inhalation modes)
  - QADD = dry aerosol dissemination efficiency due to additives
- **CI = II|MRE * MEI|II**
  - CI = number of illnesses
  - II|MRE = index illnesses given effective mass released
  - MEI|II = epidemiological illness factor given index illnesses
- **CF = CI * RF|MRE * MFI**
  - CF = number of fatalities
  - RF|MRE = deaths per illness given effective mass release
  - MFI = medical mitigation/epidemiological factor
- **DEC|MRE**
  - Decontamination Costs given effective mass released

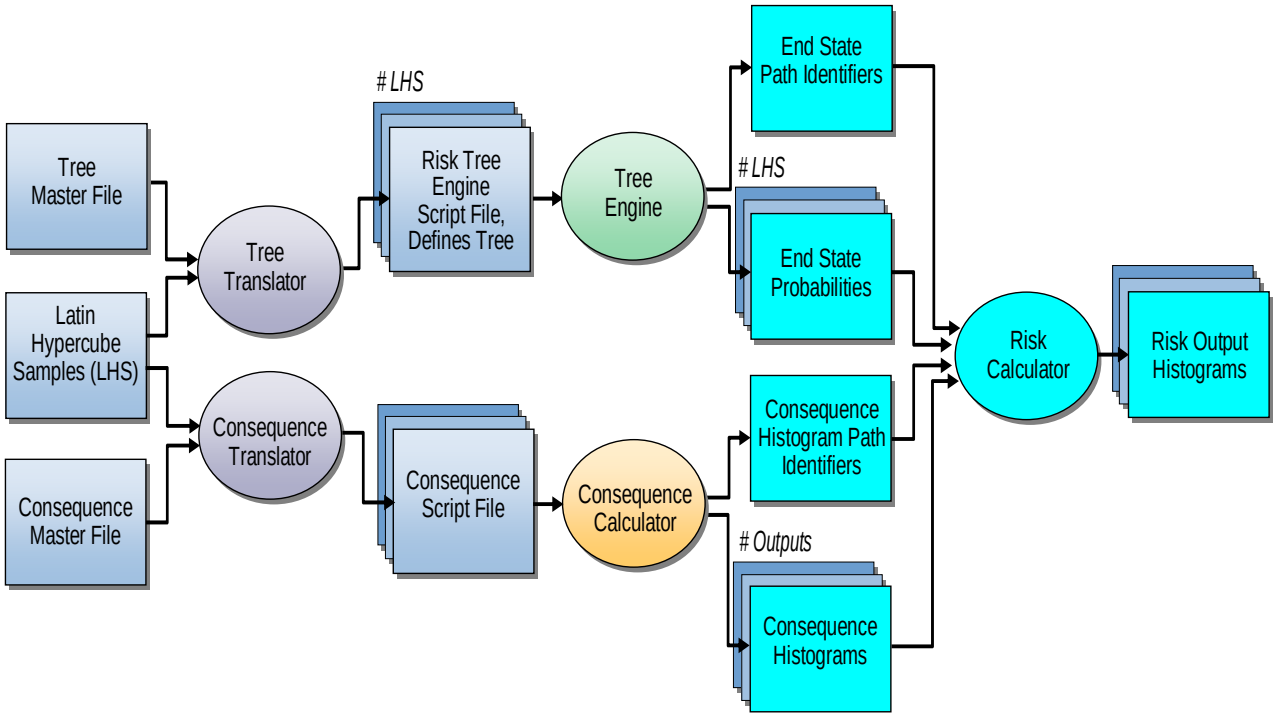
Homeland Security

# Calculation Engine




Calculation Engine

# Calculation Engine




Calculation Engine

# Computing Platform and Speed

- The Risk Engine is currently implemented on a Windows Platform with Xenon processors
  - Run time:
    - Risk Tree Engine ~ 20 min
    - Calculation Engine ~ 10 min (without consequence uncertainty)
    - Risk Calculator ~ 2:30
  - This does not include the hours of preprocessing included in the consequence models

# Attachment D

## Electronic mail exchange between Professor Stephen Pollock, Dr. Nancy McMillan, and Dr. Steve Bennett (provided by Dr. Bennett).

**Bennett, Steve**

**From:** Steve Pollock [pollock@umich.edu]
**Sent:** Friday, September 01, 2006 4:20 PM
**To:** McMillan, Nancy J
**Cc:** Weidman, Scott; gregory.parnell@usma.edu; Bennett, Steven P. (Federal); Hale, Traci L
**Subject:** Re: Relative vs. Normalized Risk

At 4:05 PM -0400 8/31/06, McMillan, Nancy J wrote:

> Dear Dr. Pollock,
>
> Thanks for your comments during the results presentation on Tuesday and even more for the additional explanation you provided after the 2008 planned improvements presentation. I think I finally get what you were telling me regarding our 'Relative Risk' metric. Clearly what we are calculating is a 'Normalized Risk' metric, not a 'Relative Risk' metric. I apologize for not catching on while we were talking; I was still recovering from presentation mode.

No need to apologize; indeed, perhaps I should be the one to do so, since in retrospect I seem to have unfairly jumped on you during the classified brief. However, since the main purpose of the NRC committee is to help you and your colleagues make use of the best possible methods and approaches, and then communicate these in order to effect rational decision making, I'm pleased to see that my question has prompted a re-thinking on your part.

I don't want to get too involved with the semantics of the terms "normalized" and "relative", but your observation that one should:

> ... define 'Relative Risk' to be the (percentage) contribution of a particular agent (or target or threat group) to total risk.."

is (excuse the irony) dead-on. That is, your proposal to:

> ... calculate each agent's (or target's or threat group's) contribution to total risk from **each** of the individual Latin hypercube samples and create our uncertainty intervals based on these.

is certainly what I would do. On the other hand, we are now running into one of the definitional issues raised earlier on the first day. That is, what you say is correct (or at least consistent) as long as you really mean (italics in red mine):

> calculate each agent's (or target's or threat group's) contribution to *the consequences (e.g., deaths)* from **each** of the individual Latin hypercube samples and create our uncertainty intervals based on these.

At the end of the briefings I was fairly well convinced that (whether advisable or not -- but that's another

issue) you have chosen to look at the relative contribution to total *consequences* (deaths or illness), and then *compared* the distributions of these (since they are random variables produced by the runs of the simulation) by using their means (as well-estimated by the sample averages, given your large sample sizes), and the uncertainties in these represented by sample fractiles.

In other words, I think you are saying that for every simulation run j =1,2,...N you observe (using modified LaTex notation) the random variables:

X_{i,j} = consequence due to agent i, i=1,2, ...28 on run j,

from which you compute

Y_{i,j} = percentage of total consequence on run j attributable to agent i

= \frac{ X_{i,j}{\sum_i{X_{i,j}}.

in which case

> This would produce 'Relative Risk' values that were (correctly) bounded below 1.

However, I am not sure that

> ... this would also decrease the variability in 'Relative Risk' estimates at least for the top category or two as total risk (the denominator) will be highly correlated with category risk (the numerator).

since this would depend on an the nature of the probabilistic dependence that might exist among agents, and therefore consequences. I wasn't all that clear about the method of eliciting critical event probabilities to see if it made possible assessments that would exhibit realistic dependences if they exist. If they are independent, you may be right (probably straightforward to prove).

In any event, you could do a quick back of the envelope calculation, using a pair of agents with a 2-D dependent joint Normal distribution of consequences (e.g. deaths), one with (say) a large mean and large s.d., and the other with mean and s.d. perhaps two orders of magnitude smaller, and see what results. This will involve the distribution of the ratio of two dependent normal variates, which as I recall involves a Cauchy distribution with some shifting of parameters.

In any event, I think you've identified the more informative (and supportable) way of doing things, and I look forward to seeing what the revised computations look like (perhaps at the next meeting if Greg thinks it worth going through again)

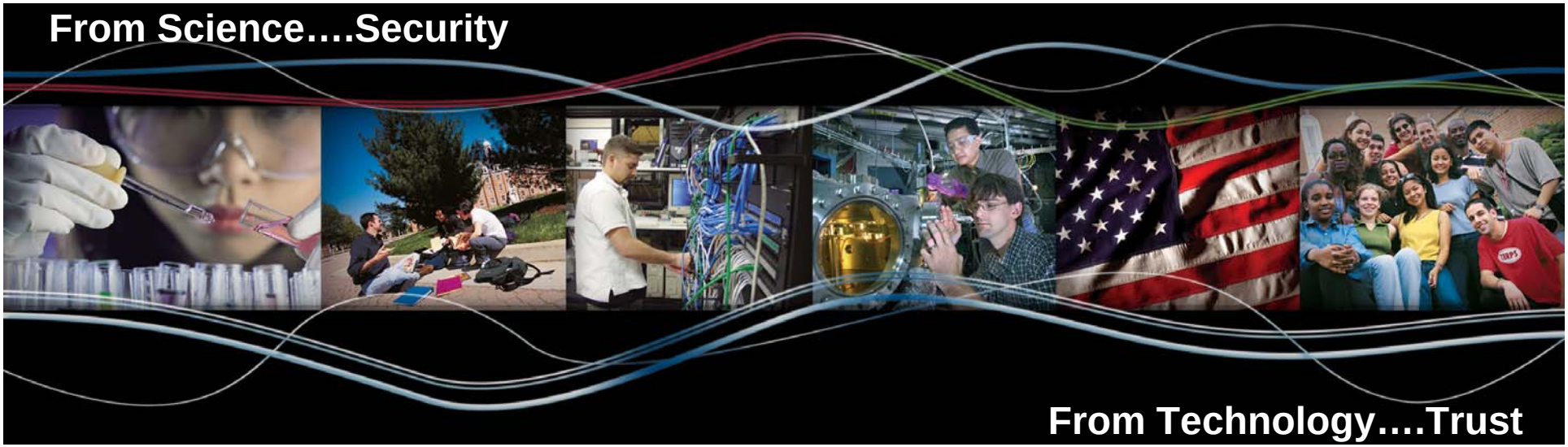
Hope you have (or at this point, *had*) a good Labor day weekend.

Steve Pollock

# Attachment E

# Cohen, Jay M. “NAS 2-8-07_Vitko.ppt”

# DHS Science & Technology:
# Enabling Technology to Protect the Nation




Homeland Security

Jay M. Cohen
Under Secretary
Science and Technology Directorate

# Outline of this presentation

- Overview of the new S&T structure
- Import of the Bio-Threat Risk Assessment (BTRA)
- Role & import of the current National Academy of Sciences (NAS) study

Homeland Security

# S&T Goals

## *Consistent with the Homeland Security Act of 2002*

- Accelerate delivery of enhanced technological capabilities to meet requirements and fill capability gaps to support DHS Agencies in accomplishing their mission
- Establish a lean and agile GS-manned, world-class S&T management team to deliver the technological advantage necessary to ensure DHS Agency mission success and prevent technology surprise
- Provide leadership, research and educational opportunities and resources to develop the necessary intellectual basis to enable a national S&T workforce to secure the homeland

Homeland Security

# S&T Realignment: First 180 Days

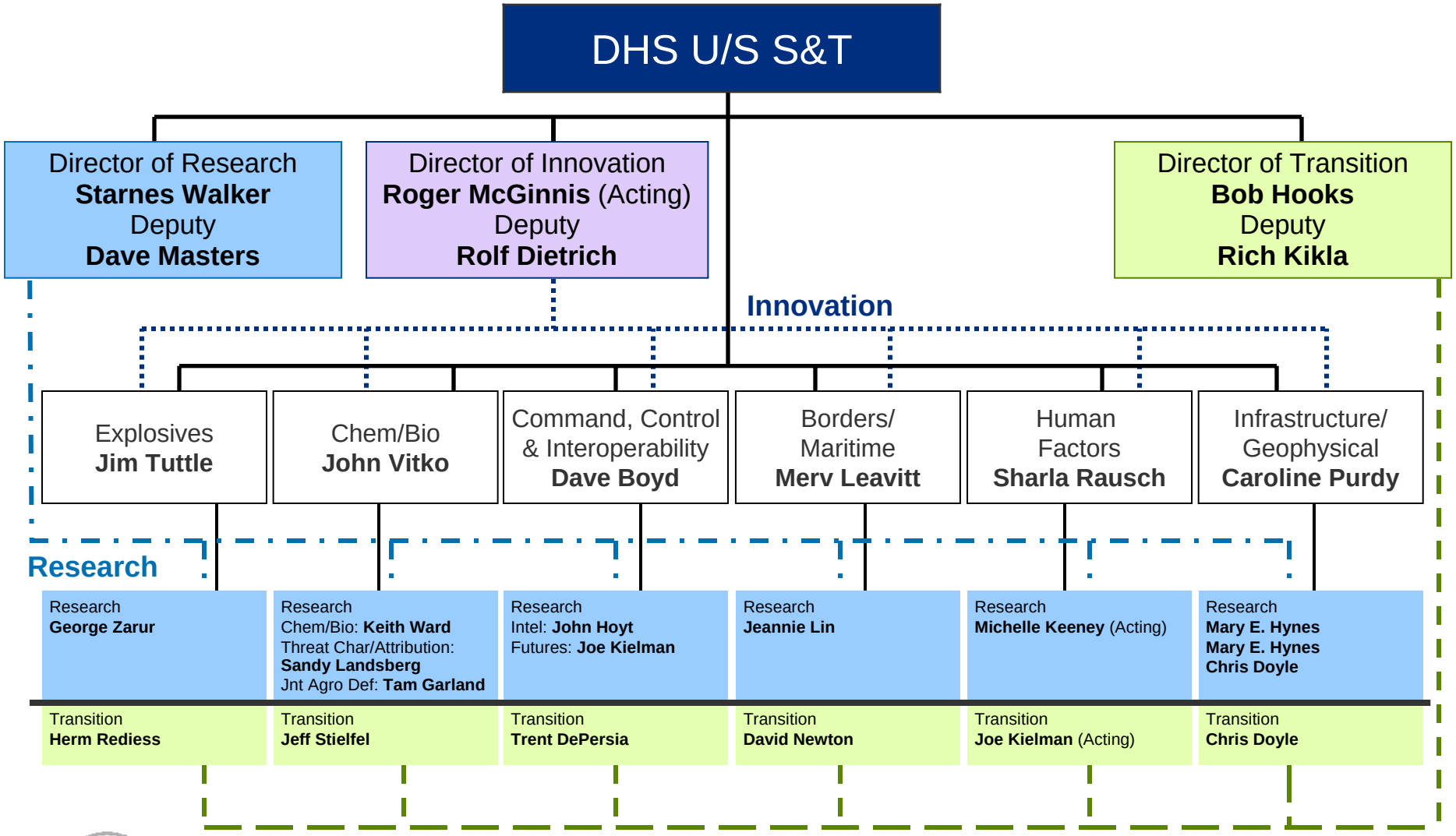
## Getting the People, Organization, Books & Content Right

***In Place:***

- ✓Framework for a customer-focused, output-oriented S&T management organization
- ✓Senior leadership team and key organizational components
- ✓6 Divisions and their Directors
- ✓3 Portfolio Directors: Research, Innovation and Transition
- ✓Directors of Test, Evaluation & Standards and Special Programs
- ✓S&T liaisons embedded in Europe, the Americas and Pacific/Asia
- ✓Corporate Communications Department
- ✓340 employees re-located to new working groups

Homeland Security

# S&T Organization

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Applications

# DHS S&T Investment Portfolio

## Balance of Risk, Cost, Impact, and Time to Delivery

| | |
|---|---|
| **Product Transition (0-3 yrs)**<br>▪ Focused on delivering near-term products/enhancements to acquisition<br>▪ Customer IPT controlled<br>▪ Cost, schedule, capability metrics | **Innovative Capabilities (1-5 yrs)**<br>▪ High-risk/High payoff<br>▪ "Game changer/Leap ahead"<br>▪ Prototype, Test and Deploy<br>▪ HSARPA |
| **Basic Research (>8 yrs)**<br>▪ Enables future paradigm changes<br>▪ University fundamental research<br>▪ Gov't lab discovery and invention | **Mandated Spending (0-8+ yrs)**<br>▪ Required by Administration (HSPDs)<br>▪ Congressional direction/law |

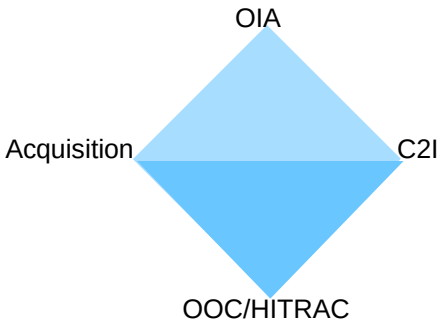
**Customer Focused, Output Oriented**

Homeland Security

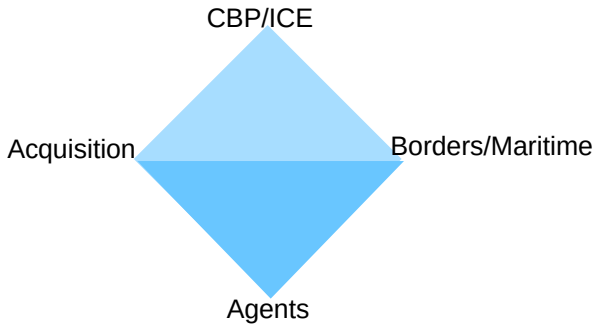
# DHS Requirements/Capability Capstone IPTs

## DHS S&T Product – "Enabling Homeland Capabilities" (EHCs)

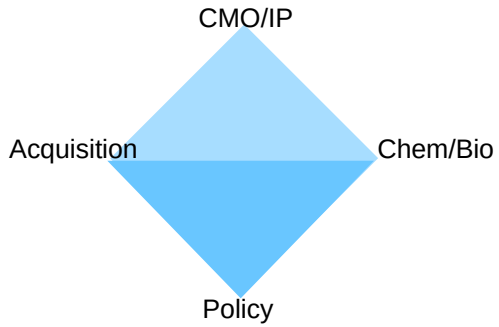
### Information Sharing/Mgmt



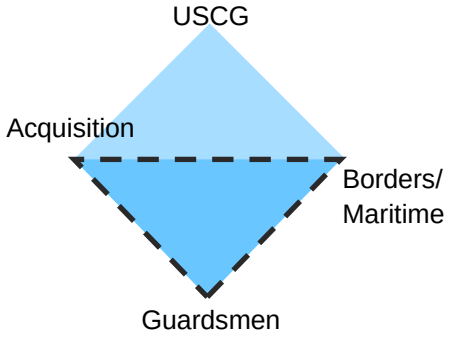

### Border Security



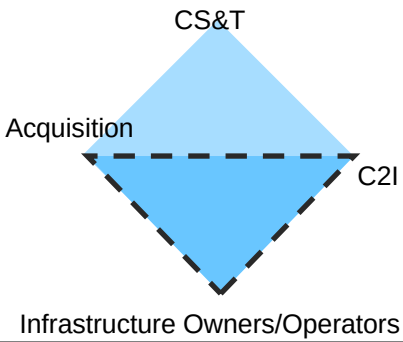

### Chem/Bio Defense



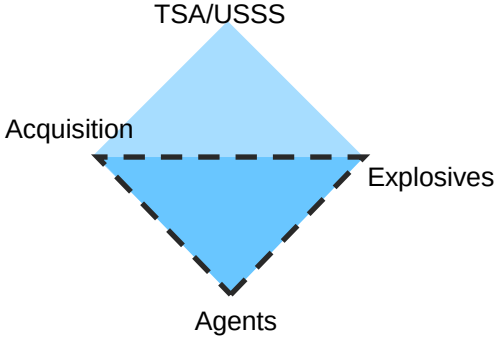

### Maritime Security



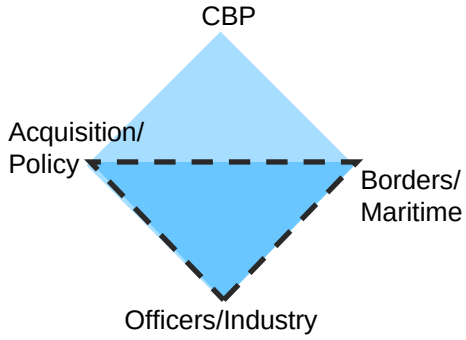

### Cyber Security



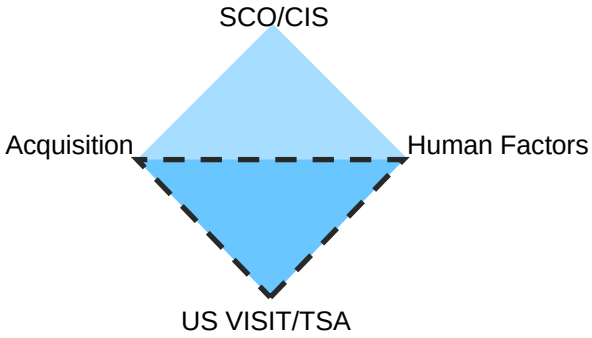

### Explosive Prevention



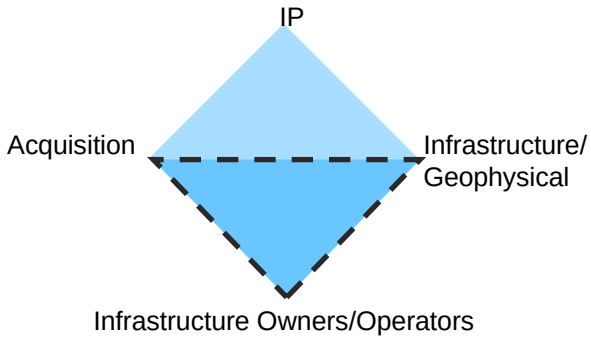

### Cargo Security



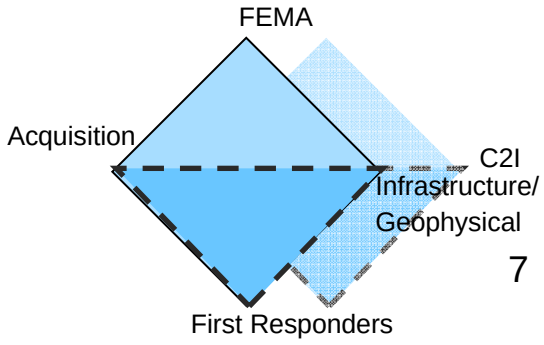

### People Screening




### Infrastructure Protection

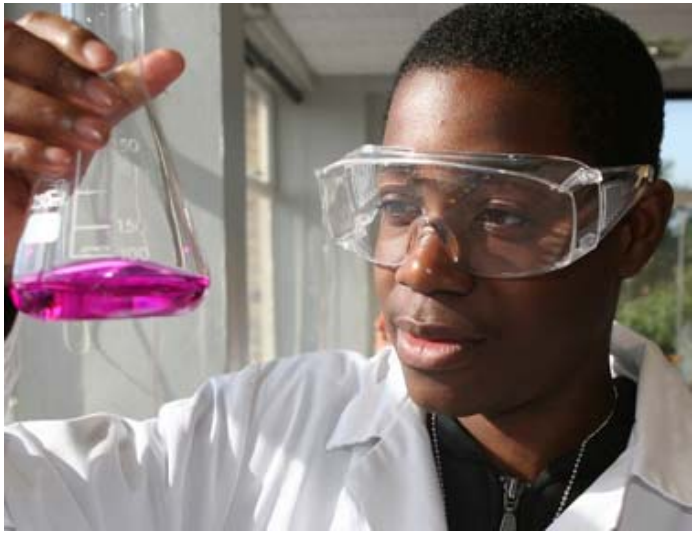



### Incident Management



# Homeland Security Centers of Excellence

- Seven university-based research centers established to date, each focused on a specific homeland security challenge
- Planning for four new Centers underway to address:
  - explosives detection, mitigation, and response
  - border security and immigration
  - maritime, island, and extreme/remote environment security
  - natural disasters, coastal infrastructure and emergency management
- **Broad Agency Announcements Released Feb. 5**
  Visit www.grants.gov for more information

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# The Bio-Terrorism Risk Assessment informs a range of "customers"

- HSC – on relative risks and vulnerabilities overall
- HHS – on medical countermeasures needs
- DHS/IP – on relative risks of different attack scenarios
- DHS/OIA – on high leverage intelligence needs
- DHS/S&T – on high leverage scientific gaps
- USDA & HHS – on food security
- EPA -- on water security
- USDA – has asked to include Ag agents in next round

**Building on this 1st BTRA, the new HSPD-18 calls for an integrated CRRN risk assessment**

Homeland Security

# Because of the import of the BTRA, it is important that the analysis be sound

- Sound methodology – reviewed by CREATE and NAS
- Valid/validated inputs
  - "intel" parameters from a panel of 12 senior intel analysts
  - Agent and human health parameters from HHS (NIAID & CDC)
- Extensive interagency vetting to help acceptance
  - Interagency working groups to inform scenarios, inputs, issues up front
  - Interagency vetting after the initial technical analysis
  - In depth follow-up and resolution of any surprising issues
- Careful communications to say just what the risk assessment does and does not do
- An on-going process – successive iterations will address limitations of previous rounds and update with new information

**The BTRA *informs* decision making – but other factors can also bear on decisions**

Homeland Security

# The NAS review is an important element in ensuring and improving the soundness of BTRA

- Ensure that there are “no fatal flaws” in the first generation BTRA
- Identify needed improvements for succeeding generations, especially for “round 2”
- DHS/S&T will consider all recommendations seriously

**Thank you for sharing your time & expertise!**

Homeland Security

# Attachment F

## Gisi, MR, *et al.* "NAS 020907 draft DHS – mg CAD tfh SPB.ppt"

# Systems Dynamic Approach to Modeling Public Health Response and the Spread of Infectious Disease

Michelle Gisi and Cheryl Dingus

Battelle Memorial Institute

National Academies' DHS Bioterrorism Risk Assessment Review Committee meeting

9 February 2007

# Medical Mitigation

- Purpose
  - To examine the effectiveness of public response measures, including the effects of pre-vaccination, prophylaxis, drug administration, and medical care, following a bioterrorism event
- Agents
  - Bacteria, viruses, toxins
  - Contagious and non-contagious
- Routes of Exposure
  - Inhalation and ingestion
- Types of Scenario Identification considered:
  - Known event (immediately suspected attack, e.g. an explosive dissemination)
  - Biodetection (based on air sampling)
  - Identification by symptoms (clinical diagnosis of ill)

Homeland Security

# Effectiveness of Medical Mitigation

- Consequences of interest
  - The number of illnesses generated from an event
  - The number of deaths resulting from illness
  - Economic consequences
  - These can all be reduced through the use of effective medical mitigation strategies
- Mitigation effectiveness is determined by:
  - Time delay between exposure and initiation of treatment
    - Clinical diagnosis / other means of detection
    - Transfer and distribution of treatment measures
  - Effectiveness of countermeasures
    - Antibiotics, vaccines, antivirals, antitoxins, supportive care
  - Disease-specific mortality rates for treated and untreated cases

Homeland Security

# Public Health Response Modeling

- Purpose
  - To estimate the number of deaths associated with a number of initial infections by a particular agent considering potential mitigating effects and epidemiological spread
- Compartmental model
  - **S**usceptible, **E**xposed, **I**nfectious, **R**emoved (SEIR)
  - Based on first-order ordinary differential equations
  - Use STELLA™ software (commercially available differential equation solver) as a platform for implementing the SEIR model

Homeland Security

# Why SEIR Modeling?

- Epidemiologic standard
- Dynamic
- Focuses on population systems
- Deterministic
- Ability to implement

- Reference: Koopman, JS. Compartment Model Analysis of Epidemiological Models. Available at: http://www.sph.umich.edu/~jkoopman/802Web/Course.htm. Accessed January 31, 2005.

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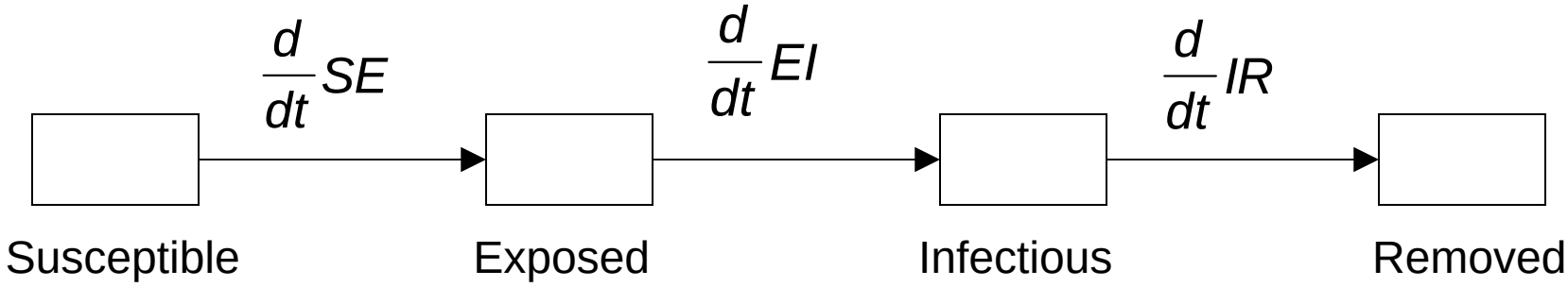
# SEIR Model Overview




- Size of each compartment given by:

$$Susceptible(t+1) = Susceptible(t) - \frac{d}{dt}SE$$

$$Exposed(t+1) = Exposed(t) + \frac{d}{dt}SE - \frac{d}{dt}EI$$

$$Infectious(t+1) = Infectious(t) + \frac{d}{dt}EI - \frac{d}{dt}IR$$

$$Removed(t+1) = Removed(t) + \frac{d}{dt}IR$$

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# SEIR Model Overview - Definitions

- **Susceptible** – population who is at risk of becoming infected by a disease if they are exposed to the infectious agent
- **Exposed/**Infected/Intoxicated – population who came in contact with the infectious agent
- **Infectious**/Ill – population who is infected, is showing symptoms, and is capable of spreading disease
- **Removed** – population who has recovered or died; is not returned to the susceptible population

- Infected – population who has been exposed and received an infectious dose of a bacterial or viral agent; may or may not be showing symptoms
- Intoxicated – population who has been exposed and received an infectious dose of a toxin; may or may not be showing symptoms

Homeland Security

# SEIR Model Overview

- Several commercially-available SEIR models exist
- STELLA™ was selected for this application
  - Ease of model construction - allows for ‘point and click’ construction
  - Visual representation of the model
    - Provides ability to draw flowcharts that represent the logic of the model
  - Flexibility
    - Capable of linking to Excel for parameter input
    - Natural mechanisms for conducting sensitivity analyses

Homeland Security

# Public Health Response Modeling

- Timeline Development
  - Detection timelines
    - Known, Biodectection, and Symptom ID events
  - Biodetection agent list for standard food analysis and Biowatch
  - Sample collection and lab analysis
    - Presumptive/Confirmatory identification tests and timelines
  - Information about treatment initiation time-points (following announcement of release, presumptive ID, confirmatory ID, etc.)

Homeland Security

# Public Health Response Modeling (cont.)

- Treatment Effectiveness Data
  - Effectiveness and availability of specific treatments
  - Consideration of rapid availability of non-stockpile drugs (local surge)
  - More accurate definition of surge capacity (satellite care)
  - Consideration of treatment of worried well, effect on public health system
  - Hospital beds can be re-used and hospital residence times are modeled

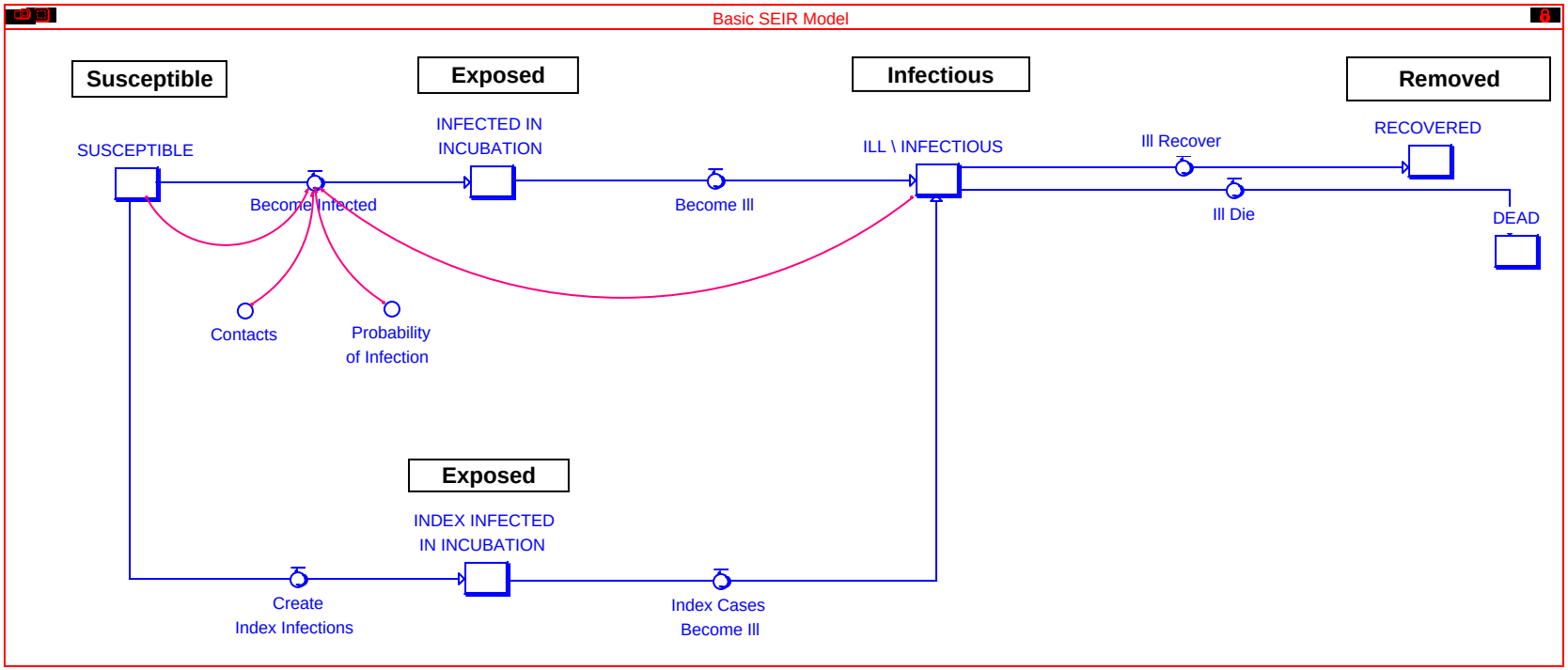
Homeland Security

# Model Review

- In progress
- Five base models
  - Contagious Inhalation, Non-contagious inhalation, Non-contagious ingestion, Toxin inhalation, Toxin ingestion
  - The base model will be tailored towards each specific agent
- Expert review to:
  - Provide input
  - Verify or revise assumptions
  - Verify or revise parameters
- Scheduled February 20-21, 2007

Homeland Security

# Basic SEIR Model in STELLA




- Epidemiological component
- Infectious population either recover or die – there is no intervention of that natural outcome
- Need to add Public Health Response (PHR)

Homeland Security

# Public Health Response – ILL and Facility Capacities

- ILL will seek treatment at symptom onset
  - May not seek care immediately
- Hospitals will be first source of treatment
  - Hospitals have limited capacity
- Other/Satellite care facilities will be set up to handle overflow
- Hospitals and satellite care facilities will accept ILL upon arrival
  - Delays possible
- Some ILL may choose not to seek treatment

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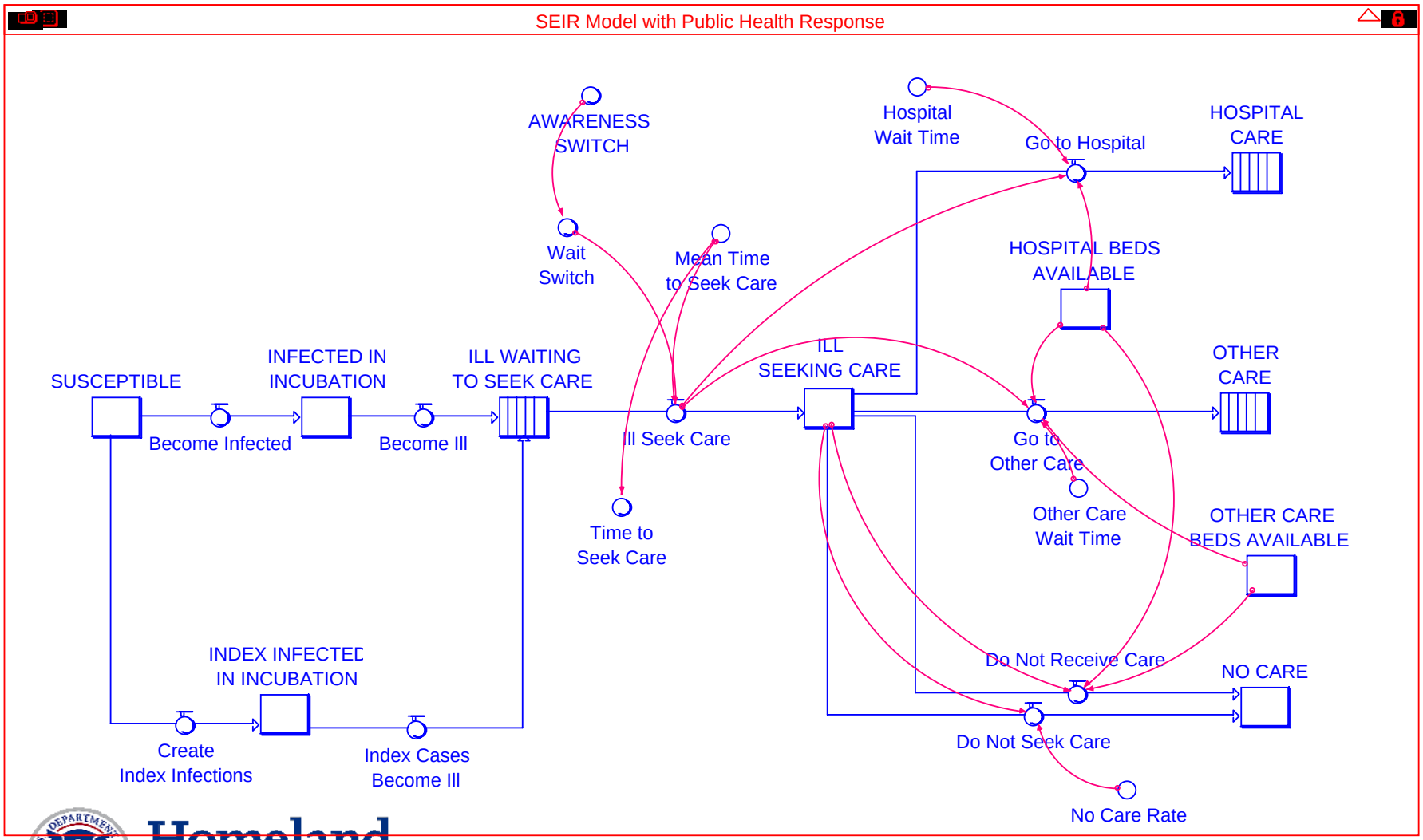
# PHR – ILL in STELLA

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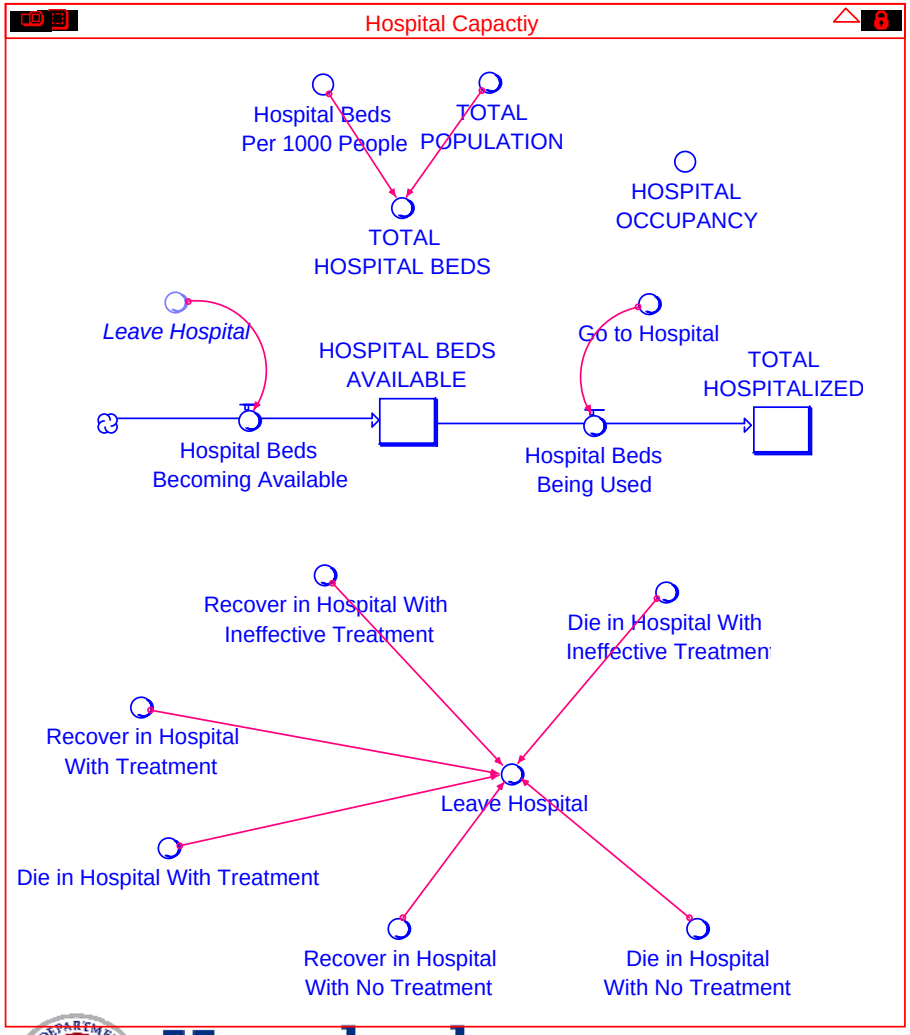
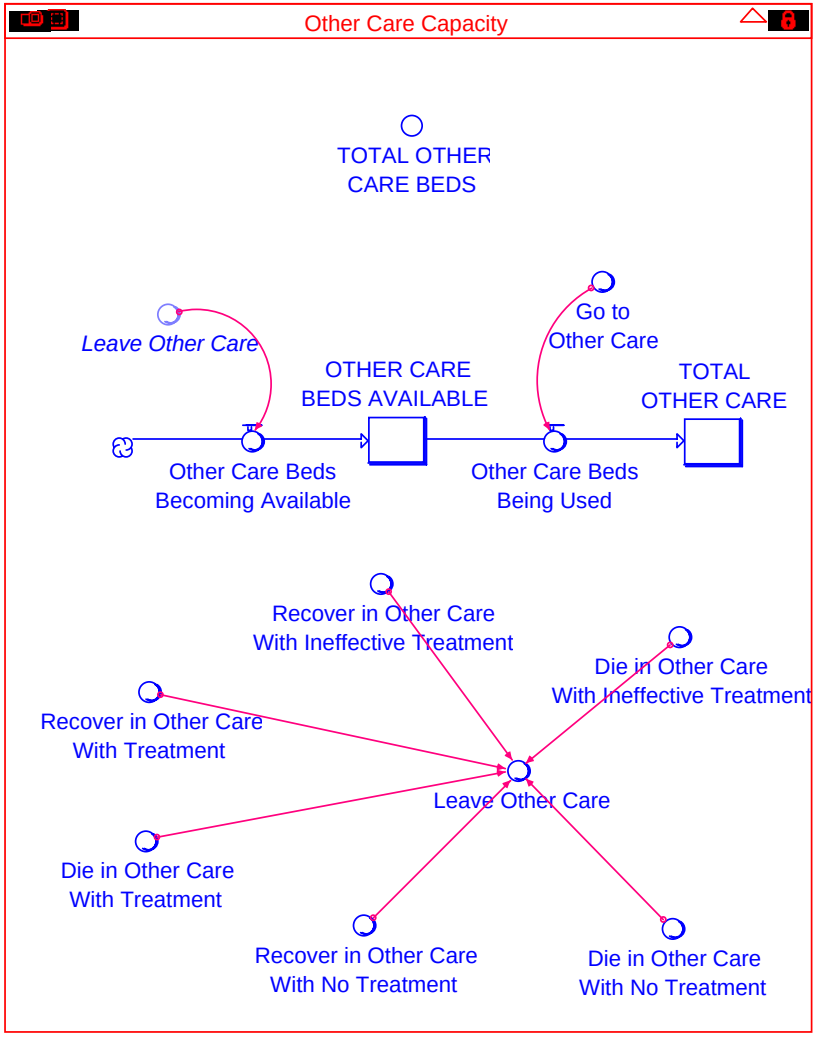
# PHR – Facility Capacities in STELLA

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# Public Health Response – Treatment Availability

- Local quantities of treatment may be immediately available
- Strategic National Stockpile (SNS) available after some period of time
  - Time to SNS availability depends on:
    - Time required to release and transport SNS materials to event site
    - Time to distribute SNS material to population
  - Times measures from event awareness/confirmation
- SNS is limited supply

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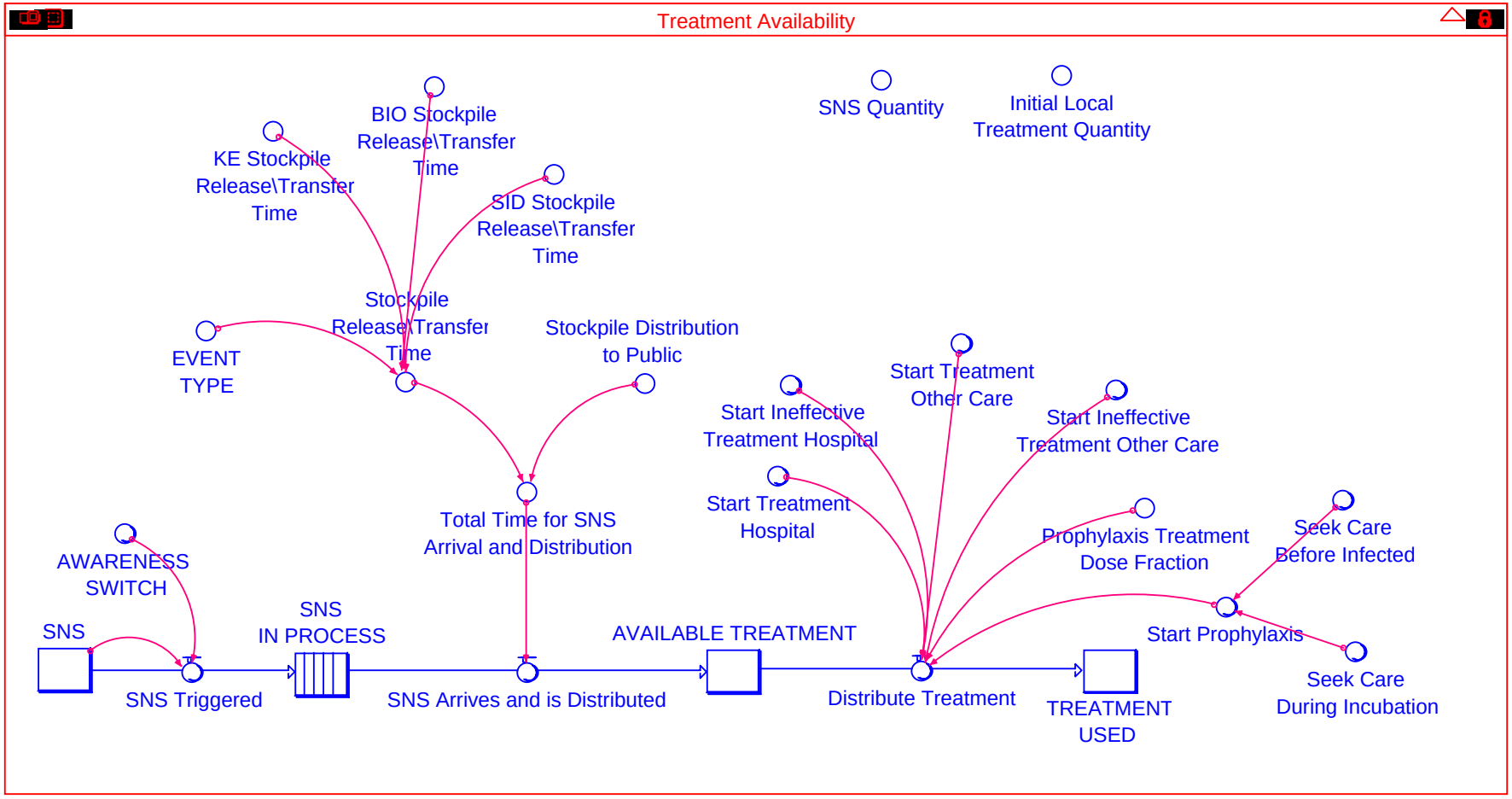
# PHR – Treatment Availability in STELLA

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# Public Health Response – Treatment

- Treatment is assumed to be effective if received within specified time after symptom onset
- Treatment is assumed to be provided if outside the treatment window, but is assumed to be ineffective
- Treatment is assumed to be equally available at hospitals and satellite care facilities
- Treatment is assumed to be equally effective at hospitals and satellite care facilities

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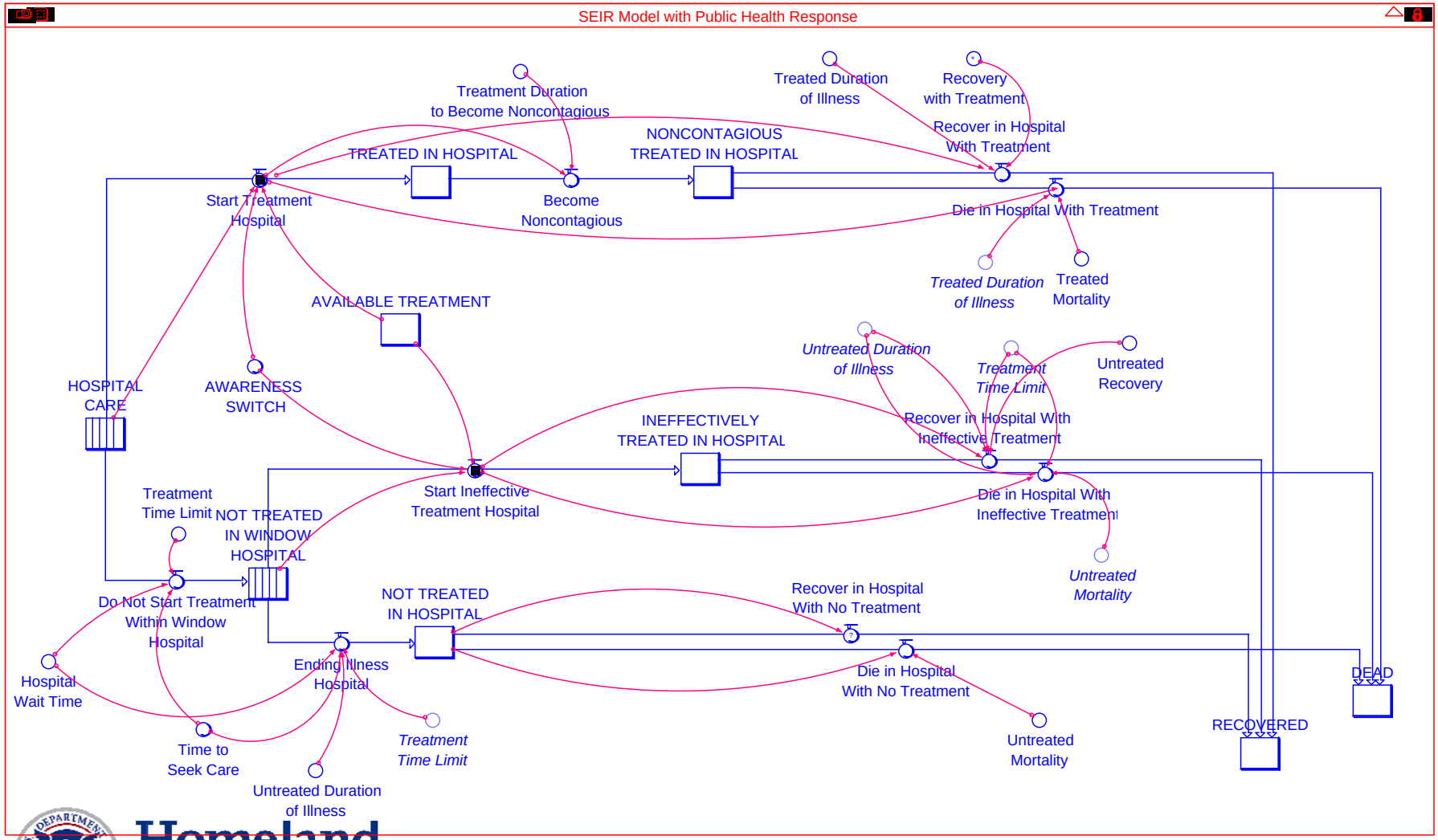
# PHR – Treatment in STELLA



# Public Health Response - EXPOSED

- Following public announcement some EXPOSED will seek treatment
  - Here, treatment = Prophylaxis
- Prophylaxis is assumed to be out-patient
  - EXPOSED who are not symptomatic do not occupy hospital or satellite care beds
- Prophylaxis is not 100% effective
  - Some EXPOSED become ILL despite prophylaxis
- Effective prophylaxis lasts for a specified amount of time after which EXPOSED return to SUSCEPTIBLE

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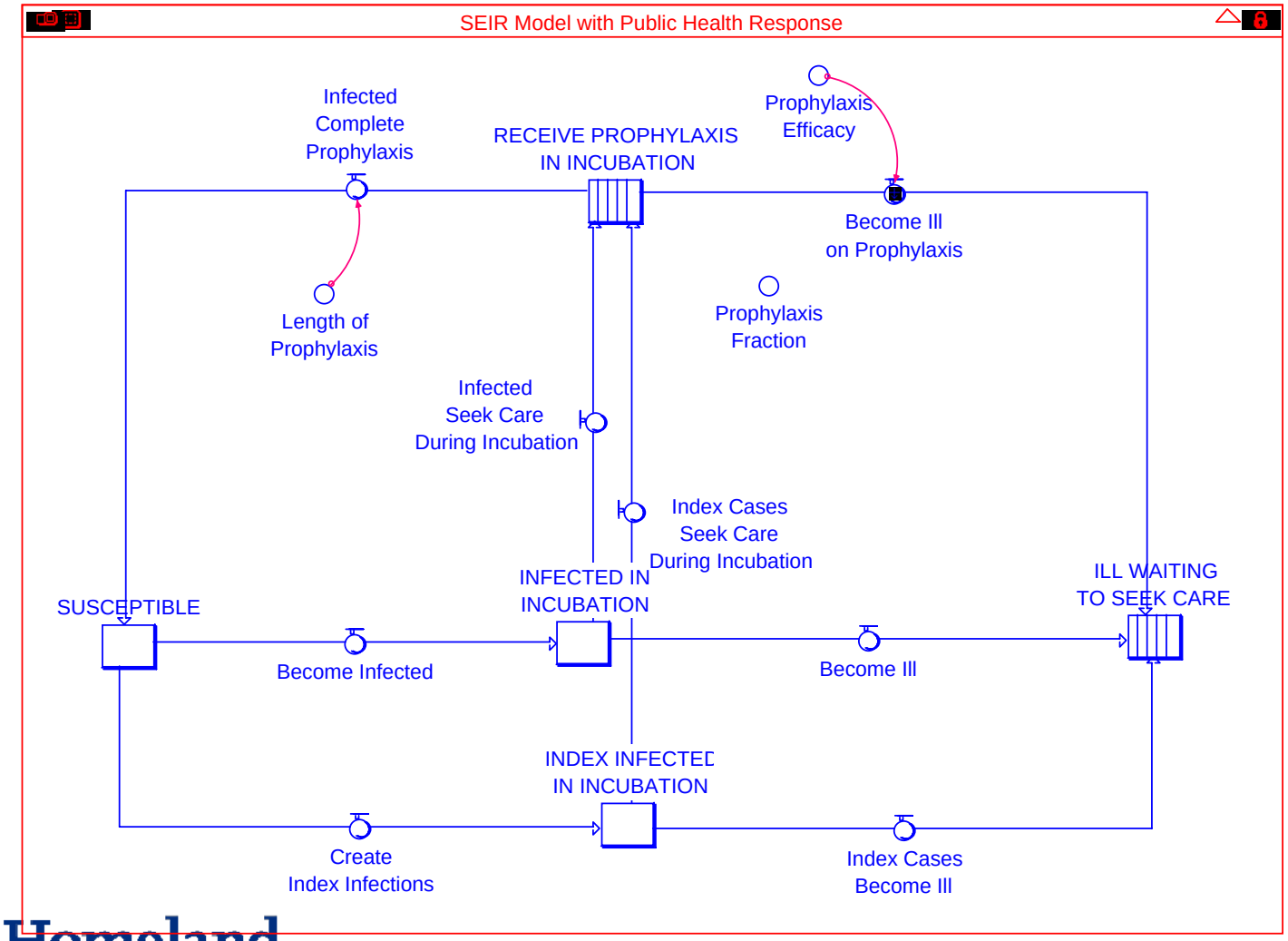
# PHR – EXPOSED in STELLA

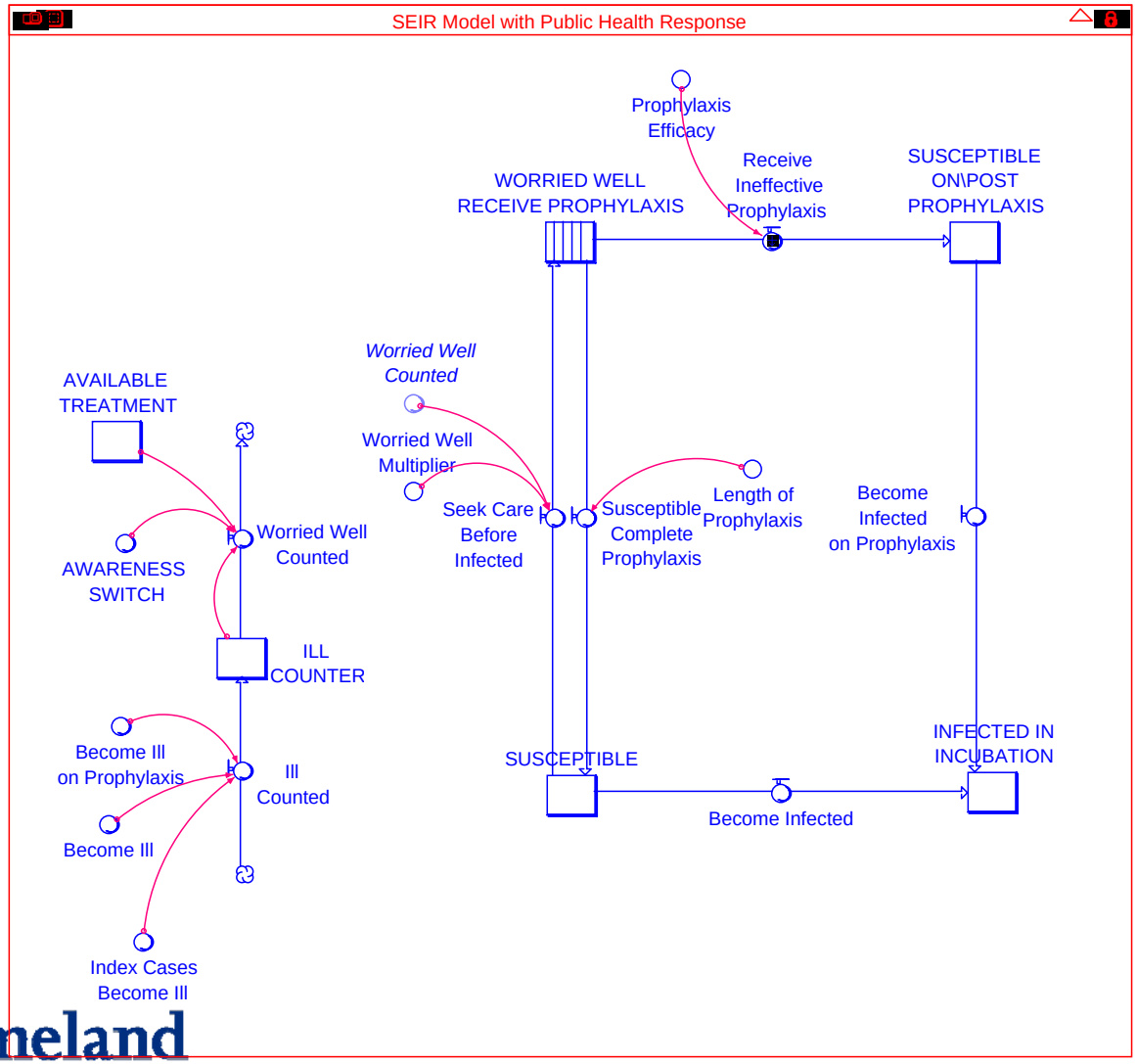


# Public Health Response - SUSCEPTIBLE

- Following a public announcement some SUSCEPTIBLE will seek treatment
  - "Worried Well"
  - Again, here, treatment = Prophylaxis
- Prophylaxis is assumed to be out-patient
- Prophylaxis is not 100% effective
  - Some SUSCEPTIBLE become EXPOSED while on prophylaxis
- Effective prophylaxis lasts for a specified amount of time after which EXPOSED return to SUSCEPTIBLE

Homeland Security

# PHR – SUSCEPTIBLE in STELLA

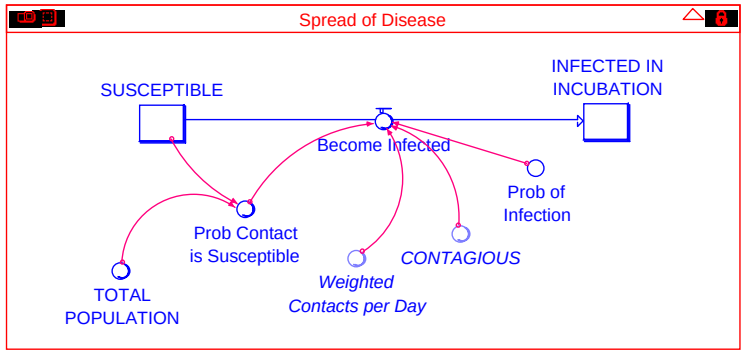


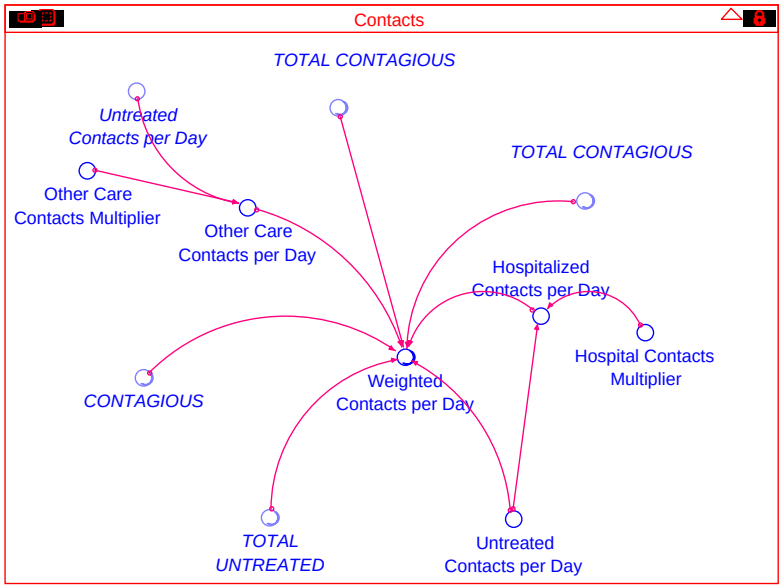
# SEIR Model – Spread of Disease

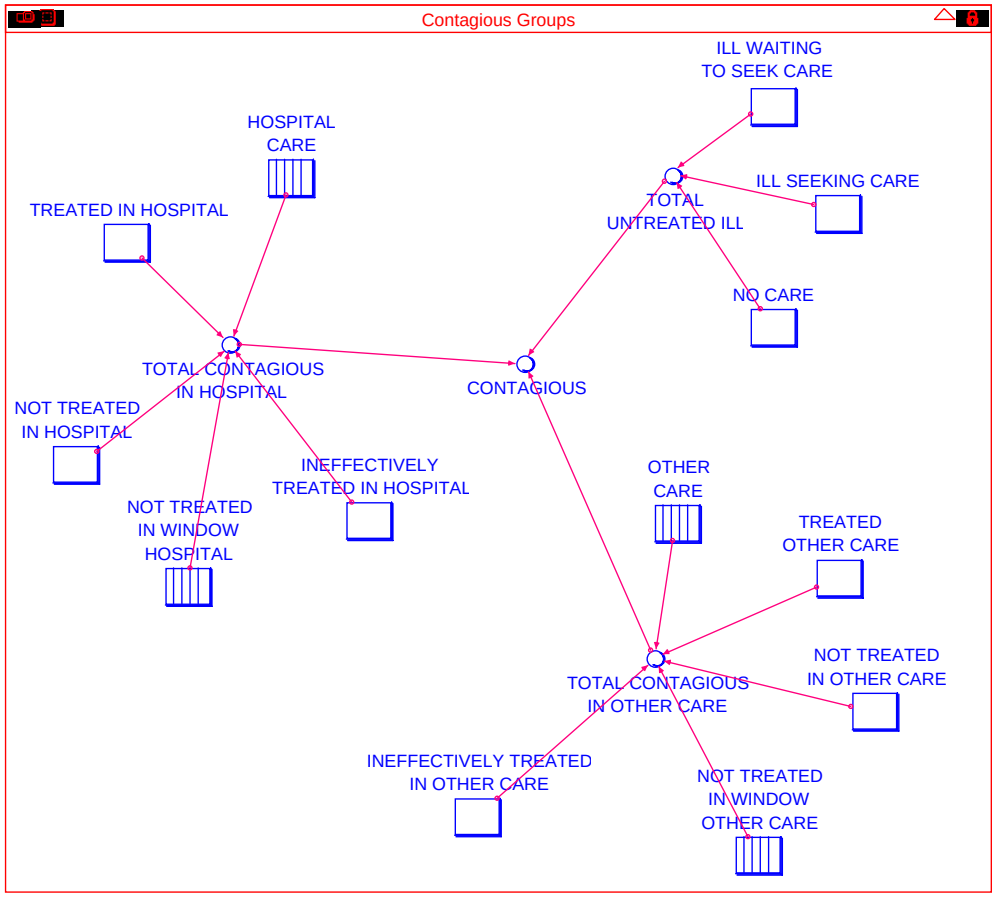
- SUSCEPTIBLE become EXPOSED through contact with INFECTIOUS
- Homogeneous mixing of population with random contacts
- Fixed number of contacts/day outside of hospital and satellite care
- Number of contacts/day reduced in hospital (95%) and satellite care (90%)

Homeland Security

# SEIR Model – Spread of Disease in STELLA

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# Types of Scenario Identification

- The particular mechanism by which an attach scenario is identified determines critical elements of the subsequent medical mitigation such as:
  - The available time remaining to release and transport SNS material such that it will have a positive effect
  - The available time to initiate treatment
  - The available time to release a public announcement of event (at event confirmation) such that it will have a positive effect
- Monte Carlo simulation of each component of the event timelines is conducted
  - Exception: Time to preliminary symptom ID is determined based on specified number of people arriving in hospital for treatment

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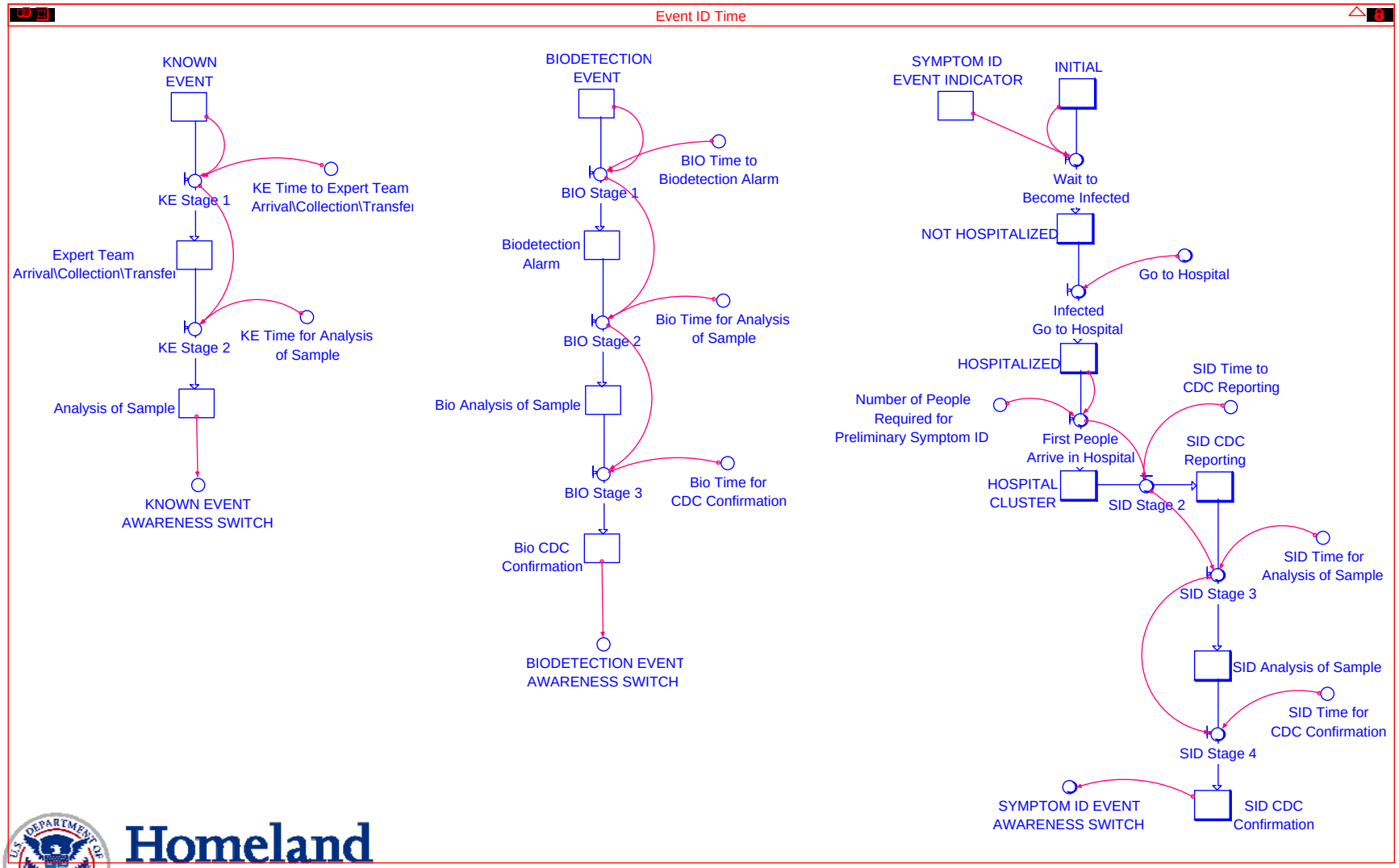
# Identification Event Scenarios in STELLA

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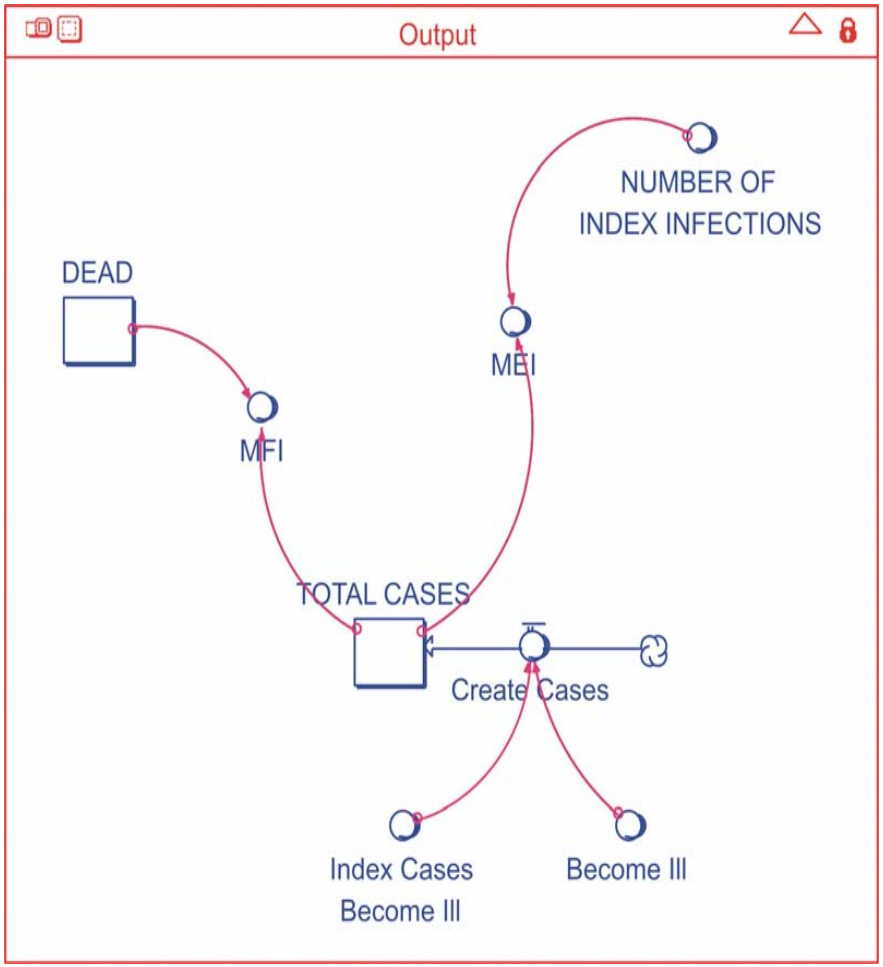
# Model Output

- MFI:
  - $$\frac{\textbf{Total DEAD}}{\textbf{Total Cases ILL}}$$
- MEI:
  - $$\frac{\textbf{Total Cases ILL}}{\textbf{Total Index Cases EXPOSED}}$$

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# Model Parameters

- Complete model illustrated here
- Uncertainty parameters
  - Treated and untreated mortality
  - Worried Well
  - Prophylaxis Fraction
  - $R_0$
- Variability parameters
  - Identification Event timelines (ex – stockpile release/transfer time, sample collection and analysis times,etc)
  - Duration of illness, duration to become noncontagious
  - Prophylaxis Efficacy
  - Hospital Occupancy
- Model includes parameters for sensitivity analysis
  - Examples: No Care Rate, Hospital Wait Time, Other Care Wait Time, Total Other Care Beds, local pharmaceutical cache
- Sensitivity parameters will be fixed for main risk assessment

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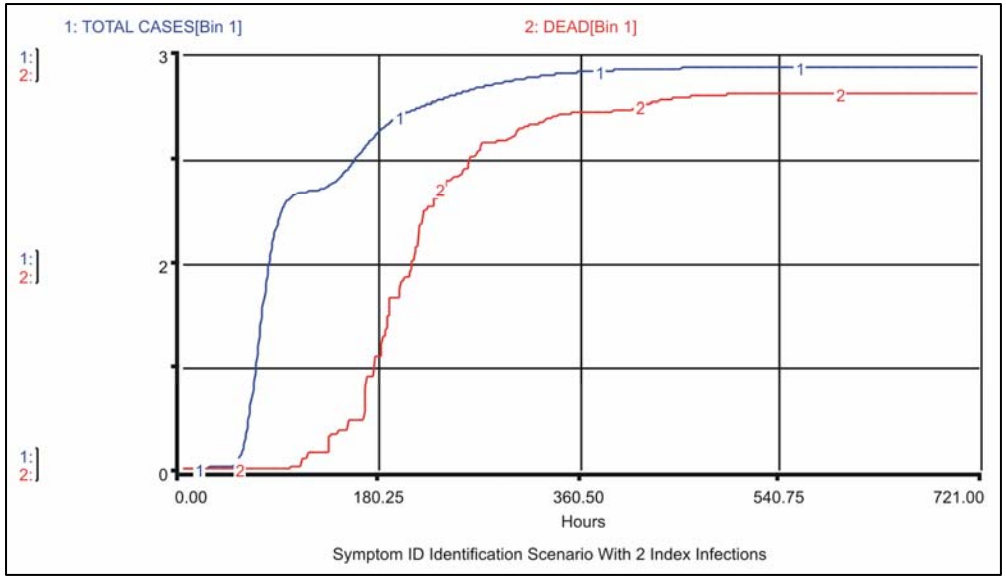
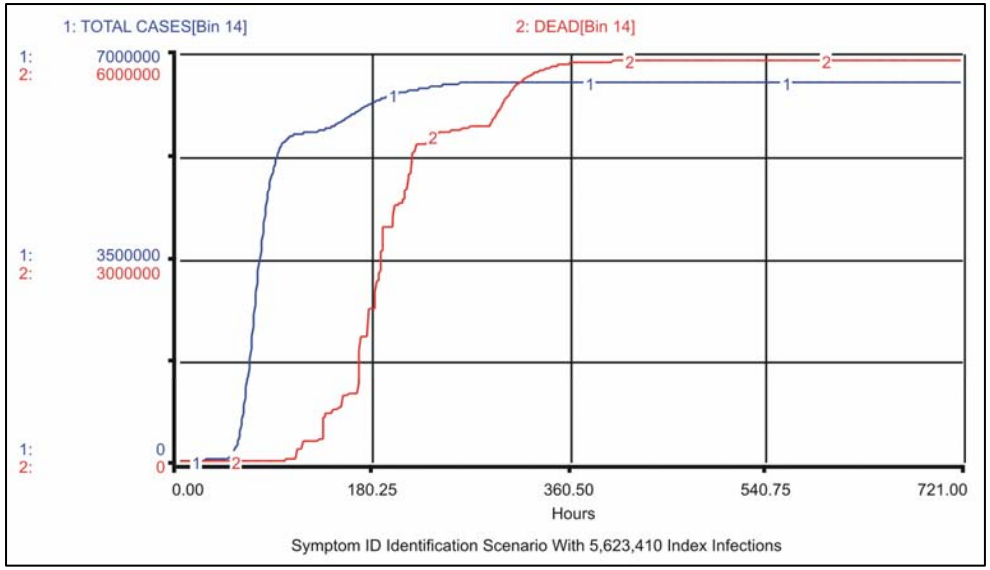
# Notional Agent Results: SEIR

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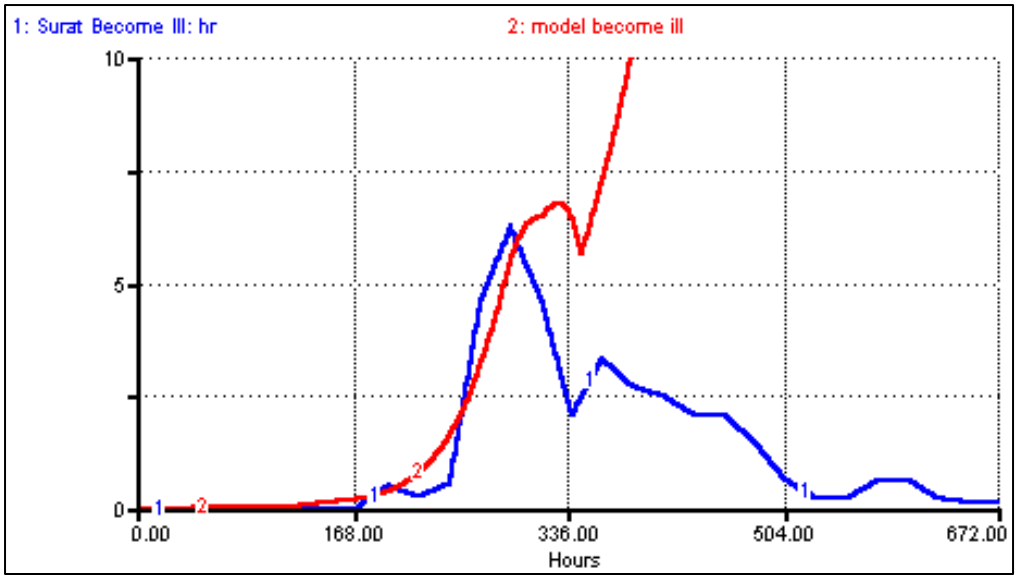
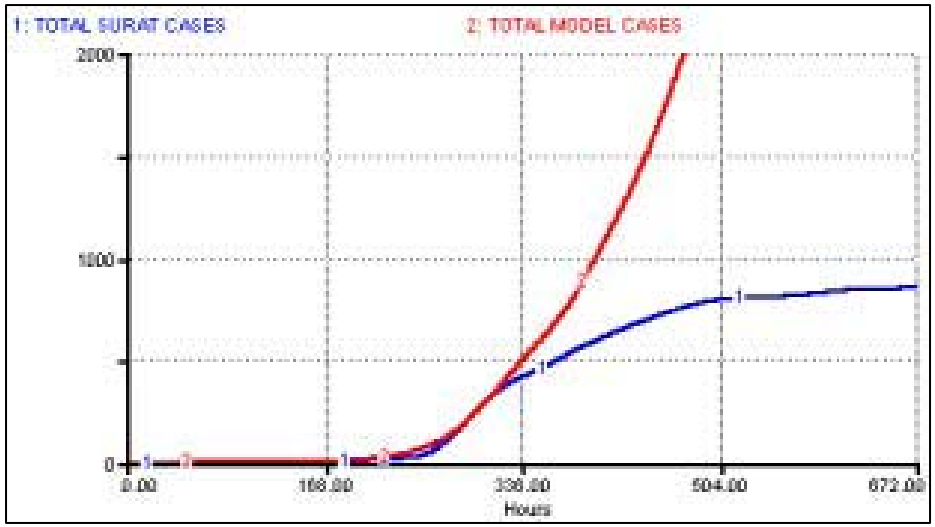
# CIESD Results




Actual Surat data and model predictions of the rate of new cases (top panel)
and the cumulative cases (bottom panel) for models in which antibiotics are provided and used with 60% efficiency and in which approximately 30% of the population flees in the first 48 hours following announcement of the presence of plague in Surat.




Reference: Potash PJ and Heinbokel JF. Modeling Human Behavior as a Factor in the Dynamics of an Outbreak of Pneumonic Plague. Presented at 21st International System Dynamics Conference. New York, New York. July 2003.

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# Attachment G

## Electronic mail exchange between Dr. Neal Glassman and Professor Marc Lipsitch (provided by Dr. Glassman).

Dear Neal:

Thank you for the opportunity to speak at the NAS/NRC Review Committee Meeting on the DHS bioterror risk assessments on 9 February.

As you know, I was present for most of the presentation by representatives of Battelle on the transmission dynamic model they propose to use for assessing the impact of an introduction of various infections on the select agent lists. As I indicated verbally, I was rather disappointed in the quality of the presentation. Here are some more specific reflections (noting, of course, that I have had only an hour's exposure to the work). I do not mind having my name used in connection with these comments.

1. The scope of the task is too large to do well with a reasonably-sized team in a reasonable amount of time, at the level of detail being undertaken. Soon after 9/11/2001, several of the world's most prominent infectious disease modelers undertook studies of the likely magnitude of smallpox epidemics under various response scenarios. Despite the availability of excellent data from smallpox epidemics in recent years, there was considerable disagreement about the likely adequacy of various reponses (particularly targeted/traced vaccination). It took several years, multiple articles, letters, discussions, and other interactions to clarify that the crux of disagreement was about the timing of transmission relative to symptoms and to the likely speed of public health response (Cooper B. Poxy models and rash decisions. Proc Natl Acad Sci U S A. 2006 Aug 15;103(33):12221-2.) The availability of evidence for smallpox is greater than that for nearly any other Category A-C agent. Hence the likelihood of making accurate estimates of the key parameters for the more obscure diseases on the list especially is small.

2. The complexity of the model is too great for the data and resources available. The model presented by Battelle at the meeting contains dozens of compartments and dozens of parameters. These parameters were not easily identified for smallpox (largely, though not only, because it had never been observed spreading in an unvaccinated but industrialized setting); it is wishful thinking to expect to identify these for hemorrhagic fever viruses, Yersinia pestis, or several of the vector-borne agents on the Select Agent lists. The large number of parameters in the model will obscure the basic question that is at issue: will public health measures be able to control the spread of the infection (meaning that only a small fraction of the population will be infected) or will they fail (meaning that a fraction dependent on R0 and other parameters of the pathogen in our population will be infected)? As I noted in my talk, I believe that a reasonable way to characterize the likely impact of each agent would be a probability distribution among three order-of-magnitude outcomes: (1) a number of infections of order similar to the number initially infected; (2) a number of infections of order larger than the number initially infected but much smaller than the population size; (3) a number of infections of order of the population size (10% - 100% attack rate). Outcome (1) would occur if the infection had R0<1 in the US population in the absence of any response or under basic nonspecific public health measures; outcome (2) would occur if the infection had R0>1 initially in the US population but was readily controlled by timely public health

measures; and outcome (3) would occur if control measures were ineffective.

I emphasize that the use of a complex model when adequate data are unavailable is not just inappropriate, but is likely strongly detrimental to the quality of conclusions. It will be impossible to elicit sensible estimates, uncertainty ranges, and correlations in the uncertainty for all of these parameters from subject matter experts. Hence the uncertainty coming out of the model will likely be misspecified. Furthermore, the complexity of the model makes it extremely difficult to use intuition or simpler models to check its outputs (see below).

3. Based on the meeting on 9 February, I do not believe the Battelle team is adequately qualified to undertake these studies. As noted above, I believe that making estimates of the likely magnitude of an epidemic of a novel agent under likely scenarios of response is an extremely difficult task in which results have been controversial when some of the world's most experienced researchers in the field have undertaken it for a well-studied pathogen; it is all the more so for the less-well-understood agents on the Select Agent List. Given the magnitude of this task, it is almost laughable to entrust it to a team for which, as best I can ascertain, no individual member has published a peer-reviewed paper on any of the infections being considered, epidemic control, or mathematical modeling of transmission dynamics. Two of the comments by the Battelle team were particularly telling. First, the graphs on slide 33 of their presentation show an infection which ultimately infects approximately 1.4 x the initial number infected, over a range of 2 to >5x10^6 initial infections. This is a classic behavior for an infection with a basic reproduction number R0<1. The Battelle team insisted that this "notional agent" had a basic reproduction number R0>1. This is not plausible, and would be a disappointing response if I heard it from a first-year master's student looking at simulation output. Second, a panel member asked about their ability to look at parameter variation using a "dashboard" or "sliders." The Battelle speaker responded that this had not been set up. This is something that can be set up within minutes and is a basic part of debugging a model in a program like Stella, which they are using. In summary, the work that was presented, had I received it as a term paper in my graduate class on mathematical modeling, would have received a poor grade. If this work is to form the basis of decisions, it needs far more input from both subject matter (disease-specific) and modeling experts.

As these comments indicate, I see the work that was requested by DHS and for which Battelle has contracted as a daunting task. There are only a few hundred to perhaps a few thousand people in the United States who have any exposure to infectious disease modeling, of whom perhaps a few dozen have the level of experience and intuitive understanding of the process to judge the validity of a model's output. For most of the select agents, I would venture to guess that there are between 0 and 5 people who are knowledgeable about the epidemiology of the particular agent and have any familiarity with modeling transmission. For this reason, it seems to me that the approach taken here, with a highly complex model and many parameters, is unlikely to generate meaningful predictions. In particular, I have seen over and

over that complex models used without intimate knowledge of the subject matter (and especially when used also without a simpler model that can reproduce the key features of the behavior) tend to produce artifactual results that escape detection as such. Hence it is a case where greater “realism” truly leads to worse predictions and to inadequate skepticism of these predictions.

For these reasons, I would advocate scrapping this approach altogether. I would replace it with carefully structured discussions, for each agent individually, that include experts in (1) the pathogenesis and epidemiology of the agent in question; (2) public health response, and in particular the rapidity and capacity of responses to particular types of contagious diseases; (3) the vector species where appropriate; (4) the likely routes of introduction of the agent if used by bioterrorists, as well as possible modifications of the agent by same; and (5) transmission dynamics - i.e. experienced modelers. If appropriately constructed, a day’s worth of discussion by such individuals would produce, in my opinion, a far more trustworthy probability distribution over the three outcomes specified at the outset than this modeling exercise.

Short of such an approach (or other approach different from the current one) I would place little or no weight on the magnitudes estimated by the Battelle project as presented on 9 February.

I hope that these comments are useful.

Sincerely,

Marc Lipsitch, D.Phil.
Professor of Epidemiology
Harvard School of Public Health

**ADDED LATER**

Dear Neal

I had meant to add one more thing but neglected to. Please append to my comments in some way:

An additional complexity in all of these models is that of spatial and temporal scale. It appears (though I am not certain) that the current models, like many models used for policy, assume a single introduction of the pathogen (maybe by more than one primary case, but only one time of introduction) into a closed population (e.g. the US). In reality, a pathogen may be introduced into more than one country, and/or on more than one occasion (the concept of "reload" formulated by former Navy Secretary Danzig). If so, the model assumptions may underestimate the magnitude of the problem. For example, controlling one introduction is much easier than maintaining control such that, regardless of spread in other countries and possible reintroductions from those countries, we do not have significant spread in the US. Likewise, controlling one introduction may require a large mobilization that would be harder to repeat on multiple occasions. References for this concept include
Danzig R (2003) Catastrophic bioterrorism: What is to be done? Washington (D. C.): Center for Technology and National Security Policy,

National Defense University. 30 p.; and C. Mills et al., PLoS Medicine 2006 (http://medicine.plosjournals.org/perlserv/?request=get-document&doi=10.1371/journal.pmed.0030135)

This may be a very important limitation of the models. In addition, because it is an issue of model structure (how do we consider introductions and how do we consider interaction between our population of primary interest and spread of the infection in the rest of the world), it is an example of how exclusive focus on uncertainty about parameters within a fixed model, as proposed by Battelle (and as is standard in many analyses) may vastly underestimate the uncertainty about the actual outcome. For this problem more generally see Brisson M, Edmunds WJ. Impact of model, methodological, and parameter uncertainty in the economic analysis of vaccination programs. Med Decis Making. 2006 Sep-Oct;26(5):434-46.

# Attachment H

## Electronic mail exchange between Dr. Neal Glassman and Dr. Steve Bennett (provided by Dr. Bennett).

## Bennett, Steve

**From:** Glassman, Neal [NGlassman@nas.edu]
**Sent:** Monday, February 26, 2007 9:30 AM
**To:** Bennett, Steven P. (Federal)
**Cc:** Parnell, G. DR SE
**Subject:** Some comments from Marc Lipsitch
**Attachments:** Lipsitch.doc

Steve:

I've received some lengthy comments from Marc Lipsitch--he spoke on the spread of epidemics at our February meeting. They are significant enough that I thought that you would want to see them. Please note that they are his comments and not those of the committee.

Neal

Neal Glassman
Senior Project Officer
Board on Mathematical Sciences and their Applications
The National Academies
Keck 976
500 5th Street NW
Washington DC 20001
Tel: 202-334-3855
Fax: 202-334-2422
Email: nglassman@nas.edu

# Attachment I

## Bennett, SP. “ResponseToInterimReport_02-10-07.ppt”

# 2008 DHS Bioterrorism Risk Assessment:
## Thoughts and Impressions from the NAS Interim Report

Committee on Methodological Improvement to the Department of Homeland Security's 2006 Bioterrorism Risk Assessment

10 February 2007

# NAS Review and Report

- On August 28-29, the NRC Committee on Methodological Improvements to the Department of Homeland Security's Biological Agent Risk Analysis was briefed on the PRA approach implemented in the 2006 DHS Bioterrorism Risk Assessment
  - "The implementation of the selected PRA framework appears, for the most part, to be consistent with well-accepted practice in other fields of risk analysis such as nuclear reactor safety and chemical safety."
  - "…the committee's main concerns are about the overall purpose and directions of DHS's risk analysis, the challenges involved in structuring and predicting the actions of determined adversaries, and the need to provide policy makers with a sound foundation for DHS's ongoing risk analyses."
- Recommendation 1: DHS should establish a clear statement of the long-term purposes of its bioterrorism risk analysis
- Recommendation 2: DHS should improve its analysis of intelligent adversaries
- Recommendation 3: DHS should increase its risk analysis methodology's emphasis on risk management

Homeland Security

# Recommendation 1

*A clear statement of the long-term purposes of the bioterrorism risk analysis is needed to enunciate how it will support risk assessment, risk perception, and especially risk management decision making.*

- The intended use and purposes of the BTRA is expressed by the primary customer, the Homeland Security Council, in HSPD-10. Since HSPD-10 is a broad statement, we have and continue to pursue the next level of detail with the HSC now that they have a product and toolset to work from.

Homeland Security

# Recommendation 1

*DHS should actively solicit the opinions of its stakeholders to ensure that communication on issues of risk analysis is two-way*

- DHS recognizes that this assessment will be most useful to stakeholders if they participate throughout the process
- Inter Agency Bioterrorism Risk Assessment Working Group (IBRAWG)
  - CDC, NIH, FDA, USDA, EPA, intelligence community
  - Provide guidance to the risk assessment, assist DHS in identifying agents and scenarios, provide technical review of input and assumptions, serve as a source of technical expertise and forum for reviewing and vetting data and results as they are generated
- Biological Threat Intelligence Support Working Group (BTISWG)
  - Senior Intelligence Community members
  - Provide classified intelligence information and data to the risk assessment
  - Assign probability concerning terrorist decisions
- HHS collaboration
  - Modeling coordination
  - Input/assumption validation
- DHS University Centers of Excellence
  - National Consortium for the Study of Terrorism and Responses to Terrorism (START)
  - CREATE

Homeland Security

# Recommendation 1

*Future iterations of the methodology should consider enhanced, emerging, and advanced agents in addition to traditional biological threat agents*

- A single 'test' enhanced agent was incorporated into the 2006 risk assessment (a multi-drug resistant bacterium)
- Inclusion of additional enhanced agents (with altered infectious dose, mortality rate, transmissibility, and other parameters) is planned
- The inclusion of advanced agents (such as *de novo* synthesized agents within a laboratory) will be considered, although we are still determining whether that analysis should be part of the overall results, or rather presented as a separate analysis

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# Recommendation 1

*Determination of how DHS should incorporate new information into its analyses. DHS issues 'tailored assessments' to respond to unscheduled requirements, and it must be able to incorporate new intelligence information or technological change in these analyses*

- Two approaches are currently implemented to incorporate new information and data
  - Replace previous value or distribution with new value or distribution
  - Update previous distribution in a Bayesian manner, treating the previous distribution as a prior and the new information as data
  - During the HHS review of the 2006 data and results, both approaches were exercised
- More profound 'structural' changes, such as additional attack scenarios, can be accomplished through modification of the Event Tree and Consequence Calculations
- The impact of any change can be generated relatively quickly and provided via a Tailored Risk Assessment report – ***new information need not wait for a biennial update to be included and analyzed in the risk assessment.***

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# Recommendation 1

*DHS should use a standard lexicon, clarify risk concepts, and treat time explicitly in terms of number of events within a specified time period.*

- DHS recognizes that consistency in the lexicon is necessary. A document has been drafted and is being provided today for NAS review today which includes:
  - A common set of terminology
  - A mathematical description of the expression of risk as the probability of events of different magnitude within a specified time interval
  - Method of numerically calculating risk using the calculation engine
  - Approach to displaying results
- Issues in standardizing terminology
  - Lack of consensus among technical experts
  - Difficulty in conveying complex issues to a lay person in a manner that is both comprehensible and technically accurate
- Agreement on common terminology from this NAS committee would be of substantial benefit both to the bioterrorism risk assessment effort and to DHS S&T as a whole.

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# Recommendation 2

*In order to better understand the sources of uncertainty and to plan for their reduction, any analysis resulting from the PRA model should include a data-quality matrix with a qualitative assessment of the sources and quality of the data and quantitative indications of the confidence and precision associated with current estimates.*

- Limited data quality matrices were developed during the 2006 DHS Risk Assessment
  - An assessment was made of the quality of the data source (low/medium/high) from which the data were obtained
  - Infectious dose and mortality rate were the only agent parameters included in the 2006 data quality matrix
- Per committee recommendations, more extensive data quality matrices are being developed for the 2008 DHS Risk Assessment
  - Uncertainty distributions are being placed on the selected parameters
  - Scope of the parameters included in the matrices is being expanded
    - New agent-specific parameters, e.g., probit slopes, reproduction number, aerosol stability factors
    - New scenario specific parameters, e.g., worried-well and prophylaxis fraction
- Single parameter sensitivity analyses will be performed to generate tornado diagrams including each uncertainty parameter
- These data quality matrices will be provided to the IBRAWG to facilitate interagency vetting of all input data and assumptions

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# Recommendation 2

*Alternative risk analysis techniques, including attack-preference, decision tree, attack tree, or attack graph models, can complement or replace probability elicitation. Consideration should be given to the roles of affect, emotion, and bias on the decision-making processes of individuals or groups.*

- Due to budget, schedule, and HSPD-10/18 requirements, the 2008 assessment will be based on the PRA approach, although DHS agrees that alternatives are important to consider for the long-term.
  - Elicitation of subject matter experts is an accepted approach
- Analysis of terrorists' decision-making processes are being improved for the 2008 assessment via discussions and formal elicitations of experts in the psychology of terrorism (CREATE, University of Hawaii)
- Agree that greater consideration should be given to tools that have been developed to examine the interplay between attacker and defender to improve the validity of input to the current approach
- Agree that DHS should consider alternatives to PRA as input to risk management to determine the sensitivity of risk management decisions to different perspectives

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# Recommendation 2

*DHS should consider decision-analytic methods for dealing with issues such as attitudes toward likelihoods and consequences, the role of affect and emotion, biases in judgment, and the types of rules used by individuals and groups in choosing between alternatives*

- In the 2008 assessment, there is increased emphasis placed on incorporating the likely response of individuals and groups to a bioterrorism event
  - Worried well drain on resources in the medical mitigation modeling
  - Indirect economic impacts resulting from behavior; changes in spending due to fear

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# Recommendation 2

*A small number of well-chosen red teams to provide input for what-if scenarios can help confirm and expand the current state of understanding and model validation and can complement expert opinion*

- While there are currently no plans to create specific red teams during this program, the participation of the IBRAWG, BTISWG, START members and other experts provides a similar opportunity for guiding the assessment decision-tree and modeling structure, and vetting data and scenarios.
- Use of red-teams is certainly possible outside the scope of the existing working groups and other panels should the committee find these working groups insufficient for the perceived requirement.

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# Recommendation 2

*Improved consequence modeling of higher fidelity and resolution is unwarranted*

- The validity of risk management decisions depends as much on the consequences of the scenarios as their probabilities. Even experienced subject matter experts cannot generate meaningful estimates of consequences without performing complex dispersion analyses within the context of realistic scenarios (in short, the details matter for many components of the consequence calculations).
- As pointed out by the NAS committee, the level of detail in which the scenarios are analyzed must be in sufficient depth to be able to discriminate between alternative risk management strategies. This is the focus of the planned modeling improvements. We agree that level of detail beyond this is not necessarily warranted.
- Additionally, the epistemic uncertainty in the consequence modeling tools will be better characterized in the 2008 assessment, and incorporated in the uncertainty bands on risk results.

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# Recommendation 3

*Risk managers should be able to explore the impact of different investment strategies on the effects they might have on the attacker. The current DHS event tree cannot determine which portfolio of investments if most effective and how potential attackers are likely to respond.*

- While technically true, the DHS capability gets a good part of the way to that end currently:
  - Risk Assessment – identifies key risks
  - Risk Mitigation Strategy Evaluation – platform to test the affects on risk of different potential strategies or policies (provides measure of the amount of risk reduction achieved for a given program, policy, or strategy)
- The last piece to needed to provide guidance relevant to the 'portfolio problem' is the cost/benefit analysis that provides measure of 'risk reduction per unit of resource' results. As Admiral Cohen mentioned, HSI is currently doing some of this type of analysis for S&T.

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# Recommendation 3

*It is unclear how the current approach supports DHS' design and evaluation of alternative risk management strategies. The computational engine does not permit, let alone encourage, risk managers to explore scenarios of 'if resource allocation, then probable consequence' scenarios for evaluating alternative risk mitigation strategies.*

- While the current tools do not permit the complete connection between resource allocation and risk reduction, it is certainly true that the current approach does provide the capability mentioned in the first sentence, and indeed supports the design and evaluation of alternative risk management strategies as described earlier.

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# Recommendation 3

- An interface and visualization component is needed to display results and limitations of this very complex model and improve transparency.

- Several activities are underway to make visualization of results and conduct of tailored risk assessments more accessible and transparent.
  - Improved interfaces to the Calculation Engine
  - Compartmentalizing results so that tailored risk assessments can be performed more quickly
- Other options which are planned but not currently being implemented for 2008 include:
  - Developing a GUI for visually exploring the risk assessment results (a key goal for 2010)
  - Developing a desktop version of the risk assessment software that can perform some tailored assessments based on partially pre-calculated results (a key goal for 2010)

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# Recommendation 3

*In evaluating alternative risk management strategies, DHS should take into account all significant benefits that result from any strategy, beyond just those benefits that directly impact the risk of bioterrorism attacks.*

- While it is true that the risk reduction effected by counterterrorism activities and improved response capabilities can provide benefit outside the security arena (such as naturally-occurring/emerging infectious diseases), the mission and scope of the DHS Bioterrorism Risk Assessment Program is limited both by HSPD-10 and by internal DHS requirements to consider risk from intentional release.
- Where it is observed that a particular 'dual-benefit' exists for a given strategy, the BTRA report highlights these synergies, but does not explicitly model the benefits of any particular strategies beyond those related to terrorism.

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# Attachment J

## Hale, TL. “NAS_Review__08-29-06___2008improvement--UNCLASS_v2.ppt”

# 2006 DHS Bioterrorism Risk Assessment: Planned Improvements for the 2008 Risk Assessment

**Traci Hale**
Battelle

Committee on Methodological Improvement to the Department of Homeland Security's 2006 Bioterrorism Risk Assessment

29 May 2006

# General overview of plans

- The 2008 Risk Assessment will include:
  - An expanded list of agents to be assessed (to include anti-agricultural, engineered, and emerging agents)
  - An expansion of scenarios for each target-type and associated revisions to the Event Tree
  - Review and improvement of all consequence models
  - Improved data regarding mitigation strategies, and improved medical mitigation models
  - Improved calculation engine to decrease run times and simplify configuration files
  - Implementation of formalized elicitation process to obtain SME judgments in specific subject areas
  - Expansion of economic modeling to include indirect costs as well as additional direct costs
  - Expansion of tailored risk assessments and sensitivity studies

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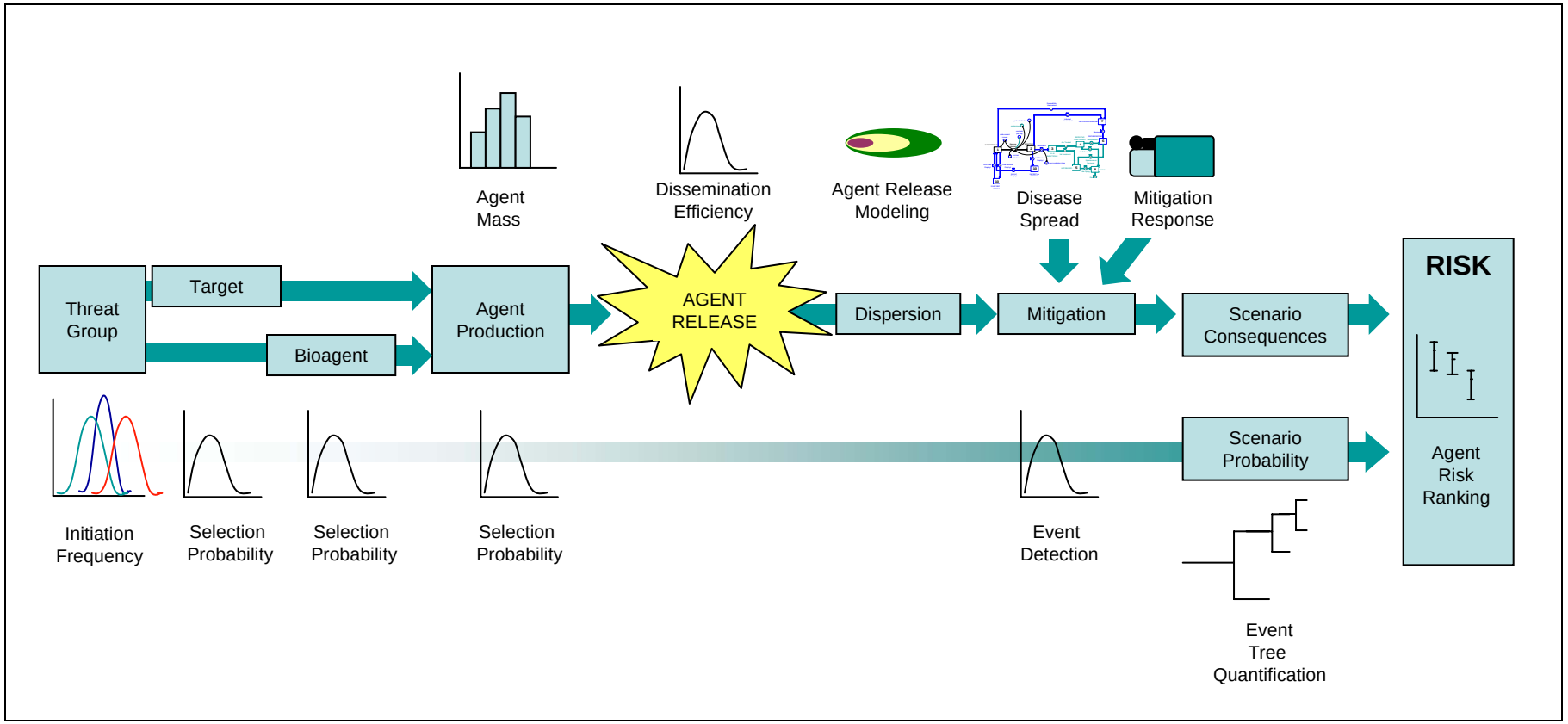
# Scenario Analysis and Consequence Modeling

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# Branch Probabilities and Uncertainty Management

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# Consequence Uncertainty

- Consequence uncertainty was calculated for some agents by sampling from a multiplicative uncertainty parameter representing the uncertainty in consequences due to modeling and the infectious dose uncertainty.
  - MRX = MRE * UID * UIM
    - MRX: Mass Released with Uncertainty
    - MRE: Effective Mass Released
    - UID: Uncertainty in the Infectious Dose
    - UIM: Uncertainty in modeling

- Instead of adding uncertainty as an external multiplicative term in the mass released equations, important parameters (such as the infectious dose) will be sampled from appropriate distributions in the Latin hypercube and consequences will be calculated for each sample in the calculation engine during processing.

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# Atmospheric (Outdoor) Dispersion Modeling

# Summary of Planned Expansion/Improvements for 2008 Risk Assessment

- Modes of dissemination improvements
  - More accurate representation of slurries
  - Increased accuracy for small quantity disseminations
  - Improved approach for additives
- Outdoor modeling improvements
  - Automated batch processor
  - More contours
  - Improve model for fitting HPAC results for risk engine
- Indoor modeling improvements
  - More detail for divided buildings

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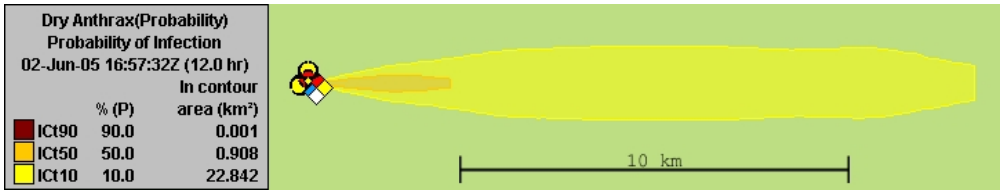
# Modes of Dissemination

- More accurate representation of slurries
  - Slurries previously modeled using a single solids concentration and agent concentration for each agent
  - Real slurries would have significant variability in these values
  - Will work to develop an approach to characterize applicable range of possible solids concentrations and agent concentrations for each method of production
- Increased accuracy for small quantity disseminations
  - Since many tree pathways result in very small quantities of agent being produced, some additional devices more appropriate to that scale should be considered and included into the determination of consequence modeling variables for the various modes of dissemination
- Improved approach for additives
  - Prior assessment involved presence/absence of a single additive type. The 2008 assessment involves the use of several different additive types, which could potentially impact dissemination as well as storage stability

# Outdoor Modeling

- Automated Batch Processor
  - Previously each HPAC case had to be run by hand (very time consuming)
  - A Batch Processing module will be developed to speed up the process of generating HPAC data
- Improve contours
  - Only three contours were originally used to estimate consequences (10%, 50%, and 90%)
  - Propose to increase the number of contours modeled
  - Will lead to more accurate modeling of “low” impact scenarios
  - Consider tracking plume dimension
- Improve HPAC model fitting
  - Because all agents are subject to the same diffusion and transport mechanisms, it is possible that one single statistical model could be used to estimate consequences for all agents.
  - Possible increase in the number of HPAC cases used to fit the statistical model

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# Indoor Aerosol Dispersion Modeling

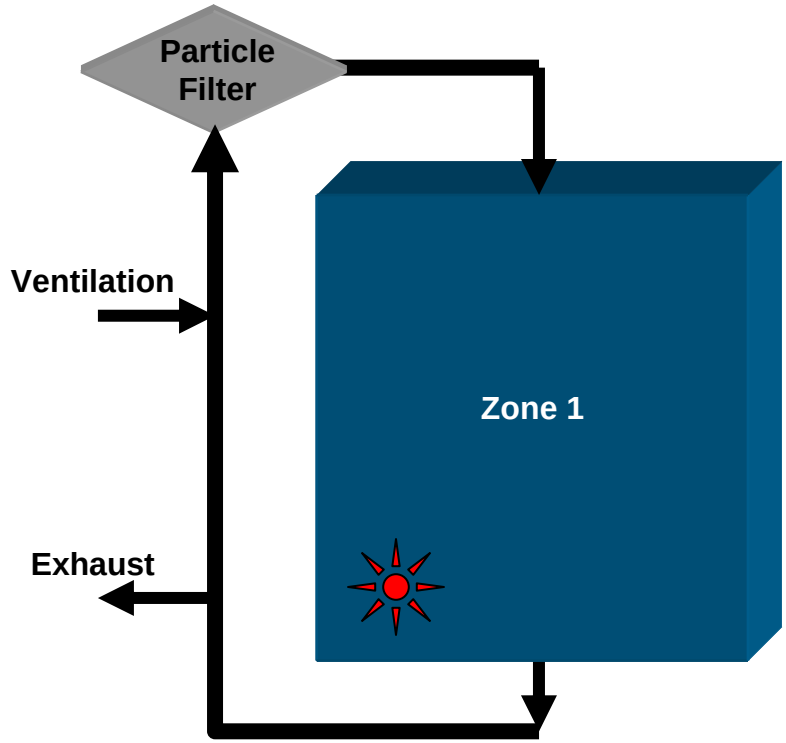
Homeland Security

# Summary of Planned Expansion/Improvements for 2008 Risk Assessment

- The key improvement/change to the indoor inhalation modeling is the introduction of a multi-zonal modeling approach, when applicable based on scenario-driven details.
    - Provides three 'contours' of results (more resolution than 1 zone model), with flexibility to apply to numerous scenarios
- The 2008 Assessment uses three types of indoor models
    - 1 Zone Model for large indoor volumes (1Z)
        - e.g. Release in a Shopping Mall or Indoor Arena
    - 3 Independent Zone Model for releases in large areas within a larger building (3IND)
        - e.g. Release in the Lobby or Atrium of an Office Building
        - e.g. Release into an HVAC System which feeds a large area of the building
    - 3 Zone Model with 2 Linked Zones for releases in a standard size room (3DUO)
        - e.g. Release in a Single Office within an Office Building

# Indoor Inhalation Modeling
# 1 Zone Model – 1Z

- A Single Zone Indoor Inhalation Model

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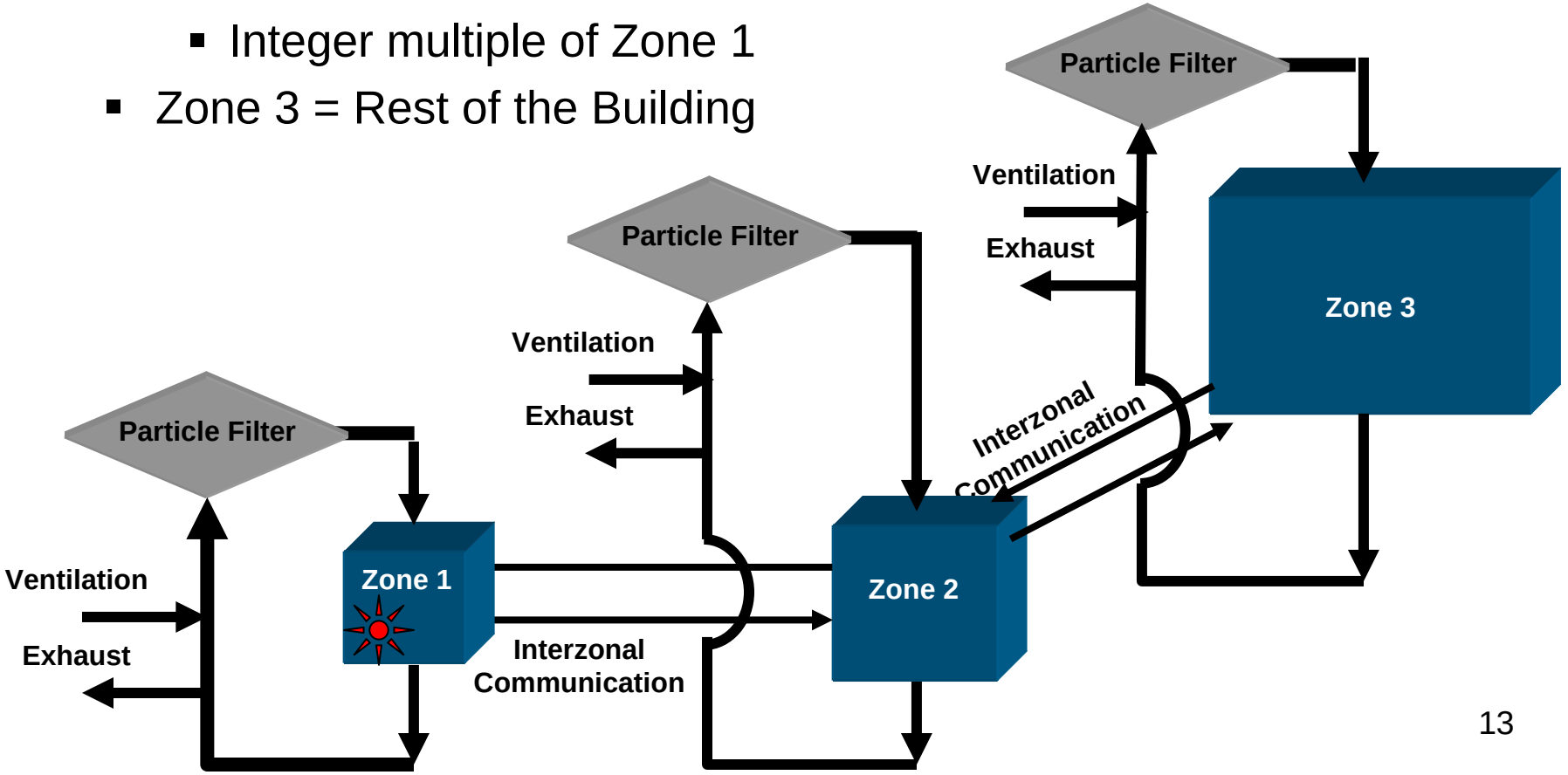
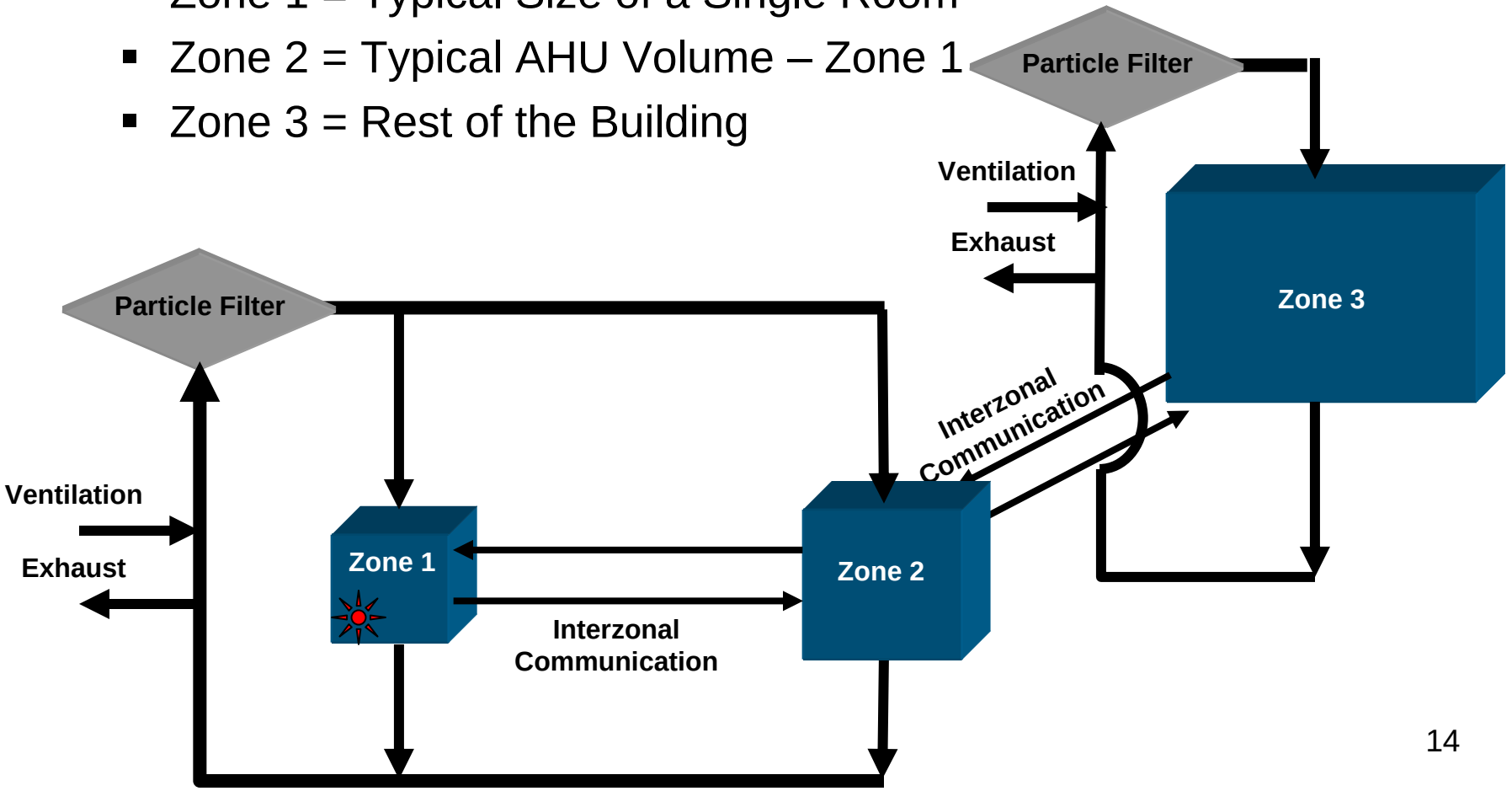
# Indoor Inhalation Modeling
# 3 Zone Models – 3IND

- 3 Independent Zones Connected by “Unplanned Flow”
  - Zone 1 = Lobby or Atrium
  - Zone 2 = Volume Adjacent to Zone 1
    - Integer multiple of Zone 1
  - Zone 3 = Rest of the Building



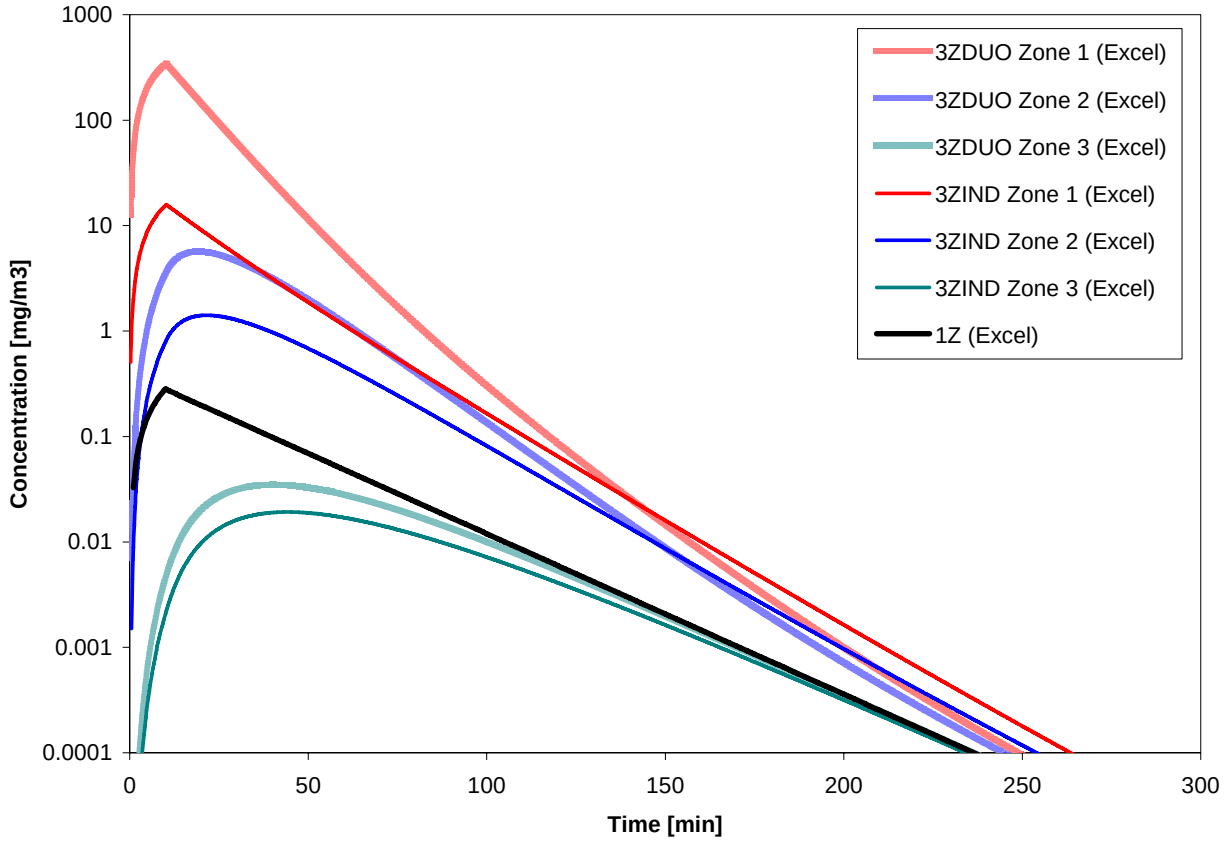
# Indoor Inhalation Modeling
# 3 Zone Models – 3DUO

- 2 Linked Zones and 1 Independent Zone
  - Zone 1 = Typical Size of a Single Room
  - Zone 2 = Typical AHU Volume – Zone 1
  - Zone 3 = Rest of the Building



# Indoor Inhalation Modeling
# 3 Zone Models – Illustrative Results

- Large Building: Considering population gets divided up proportionally with volume, the 1Z approximation was more reasonable than one might initially expect.




**1Z Model**

V=1,291,000 $m^3$

**3IND Model**

$V_1$=21,100 $m^3$ (1.6%)
$V_2$=42,200 $m^3$ (3.2%)
$V_3$=1,227,700 $m^3$ (95.2%)

**3DUO Model**

$V_1$=850 $m^3$ (0.06%)
$V_2$=20,200 $m^3$ (1.6%)
$V_3$=1,269,950 $m^3$ (98.4%)

Interzonal Flow = 1.4 ACH
Filter Efficiency=40%
Flushing Constant=4.0 ACH
Removal Constant=2.1 ACH

430g released over 10 min

# Indoor Inhalation Modeling

- The 3 zone model approach outlined in this presentation combines a reasonable increase in the technical difficulty with a significant improvement in the resolution of the exposure results.
  - A reasonable increase in calculational load.
  - A reasonable increase in the parameters required for the risk assessment.
    - Unplanned, Interzonal Flow
    - Volume fed by an AHU
    - Scenario Type
  - A significant improvement in the resolution of individual exposures.
    - Illustration that the single zone model was not an unreasonable first approximation.

Homeland Security

# Foodborne and Waterborne Contamination Modeling

Homeland Security

# Summary of Planned Expansion/Improvements for 2008 Risk Assessment

- Food and Water Contamination Assessment
  - Working with interagency partners such as EPA, USDA, and FDA to
    - Expand number of agents assessed
    - Expand scenario set
      - Identify agents and scenarios (vulnerable foods)
  - Identify and obtain best available data
    - Agent ingestion dose
    - Decay rates in various food types and tap water
    - Detection rates and recall effectiveness data
  - Review and select most appropriate food distribution and consumption model
    - Review of BT Safety model and compare with 2006 assessment model
  - Review water distribution model and revise

Homeland Security

# Food and Water Agents

Possible agents to add in 2008

- *Burkholderia pseudomallei*
- *Burkholderia mallei*
- *Brucella* (*B. Suis*)
- *Vibrio parahaemolyticus*
- *Vibrio vulnificus*
- *Clostridium perfringens*
- *Clostridium difficile*
- *Enterococcus* spp.
- *Bacteroides fragilis*
- *Yersinia enterocolitica*
- *Yersinia pseudotuberculosis*
- *Campylobacter jejunis*
- *Helicobacter pylori*
- *Citrobacter freundii*
- *Salmonella (*non-typhoidal*)*
- *Streptococcus* spp.
- *Staphylococcus* spp.
- Enterovirulent *Escherichia coli* group (EEC group)
- *Listeria* spp.
- *Giardia lamblia*
- Noroviruses, Rotavirus, Adenovirus
- Hepatitis (A and E)
- Mycotoxins
- Abrin
- Saxitoxin
- Tetrodotoxin
- Coxiella
- Toxoplasma

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# Food Contamination Scenarios

- Food Assessment
  - Foods under consideration
    - Different Meat Products (possibly commercial gravy and stocks)
    - Cream, Ice Cream (including specialty types) , Artificial Cream, and Cheeses
    - Pasteurized Liquid Eggs and Egg products
    - Shellfish and other Seafood
    - Leafy vegetables and produce in which the skin is typically eaten
    - Infant formula (liquid and dry)
    - Frozen juice concentrates and fresh squeezed juices
    - Bottled water
    - Commercial ice



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# Food Contamination Scenarios

- Data Acquisition for Food Assessments
  - Accounting for variability within the industry
    - Types of Ready-to-eat foods and differing processing equipment
    - Pasteurization times and temperatures
    - Quality control and storage of produce
  - Proprietary, and therefore guarded, methods which are not available to those outside the industry
  - Varying degrees of access/security
  - Frequency and focus of detection
    - Large scale production farms have begun implementing pathogen detection methods due to arising problems.

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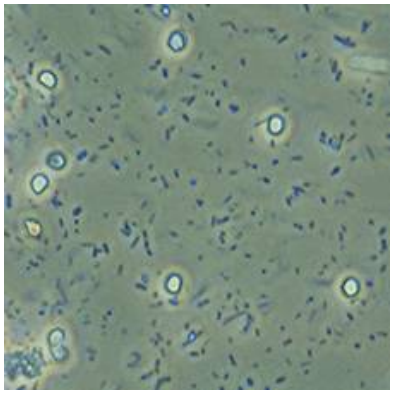
# Summary of Planned Expansion/Improvements for 2008 Risk Assessment

- Water Assessment
  - Expanded scenario set
    - Backflow (piped distribution, large commercial building)
    - Finished water storage facilities for large commercial building
  - Expanded number of agents assessed
    - EPA: *Burkholderia pseudomallei, Coxiella burnetti, Toxoplasma gondii*
    - Virus (e.g. Noroviruses, Rotavirus, Adenovirus)
  - Identify and obtain best available data
    - Agent ingestion dose
    - Chlorine-induced decay rates in tap water



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# Summary of Planned Expansion/Improvements for 2008 Risk Assessment

- Water Assessment
  - Review and select most appropriate water model
    - EPA NHSRC, and key water security experts concurred that the 2006 model was a good approach
    - Currently performing comparison with software model to determine if 2006 model should be used with some adjustments or indicates that it is inadequate
    - PipelineNet
      - Geographic Information System (GIS)-based software tool with integrated database capability that can be used to model the flow and concentration of contaminants in a city's drinking water pipeline infrastructure
      - Pipe network hydraulic model (EPANET)

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# Medical Mitigation and Epidemiological Modeling

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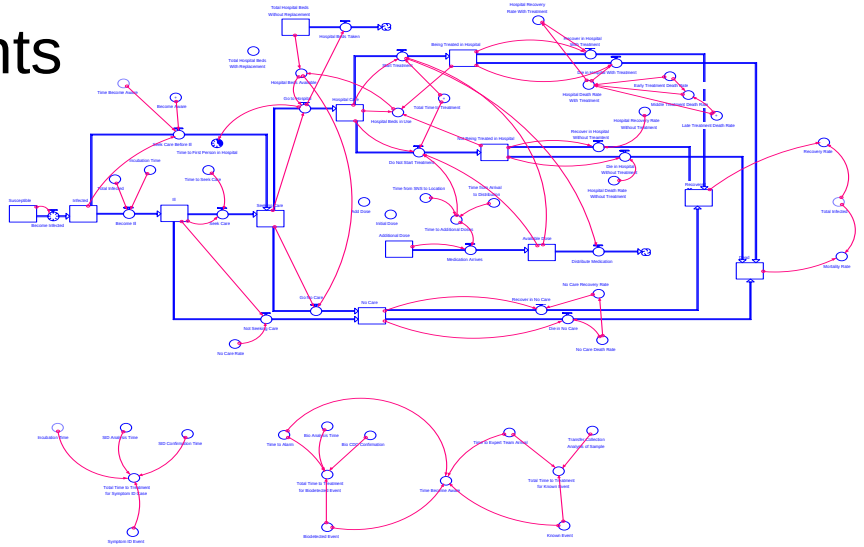
# Summary of Planned Expansion/Improvements for 2008 Risk Assessment

- Major areas of planned improvement include:
  - Data Acquisition
    - Detection and Testing
    - Treatment
  - Modeling Improvements



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# Medical Mitigation Modeling

- Detection/Testing Data Acquisition
  - Biodetection timelines
  - Biodetection agent list for standard food analysis and Biowatch
  - Confirmatory identification tests (0-10 hr CDC confirmation)
  - Presumptive identification tests and timelines
  - Information about treatment initiation timepoint (following announcement of release, presumptive ID, confirmatory ID, etc.)
  - Exposure dose correlation with severity of disease and response to treatment

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# Medical Mitigation Modeling

- Treatment Effectiveness Data Acquisition
  - Effectiveness and availability of specific treatments
  - Consideration of rapid availability of non-stockpile drugs (define local surge)
  - Addition of supportive care treatment value
  - Better definition of the importance treatment with regard to disease progression time-point
  - More accurate definition of surge capacity
  - Review of current response plans, discussion with response experts regarding transport of ill
  - Consideration of treatment of worried well, effect on public health system

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# Medical Mitigation Modeling

- Application of STELLA (differential equation solver) as a framework for the complete medical mitigation model
  - Benefits
    - Improved graphical representation of approach that provides visual overview that is easier to grasp
  - Preliminary evaluation
    - Comparison against previous R code model
    - Demonstration of equivalent results with potential for enhanced input parameters

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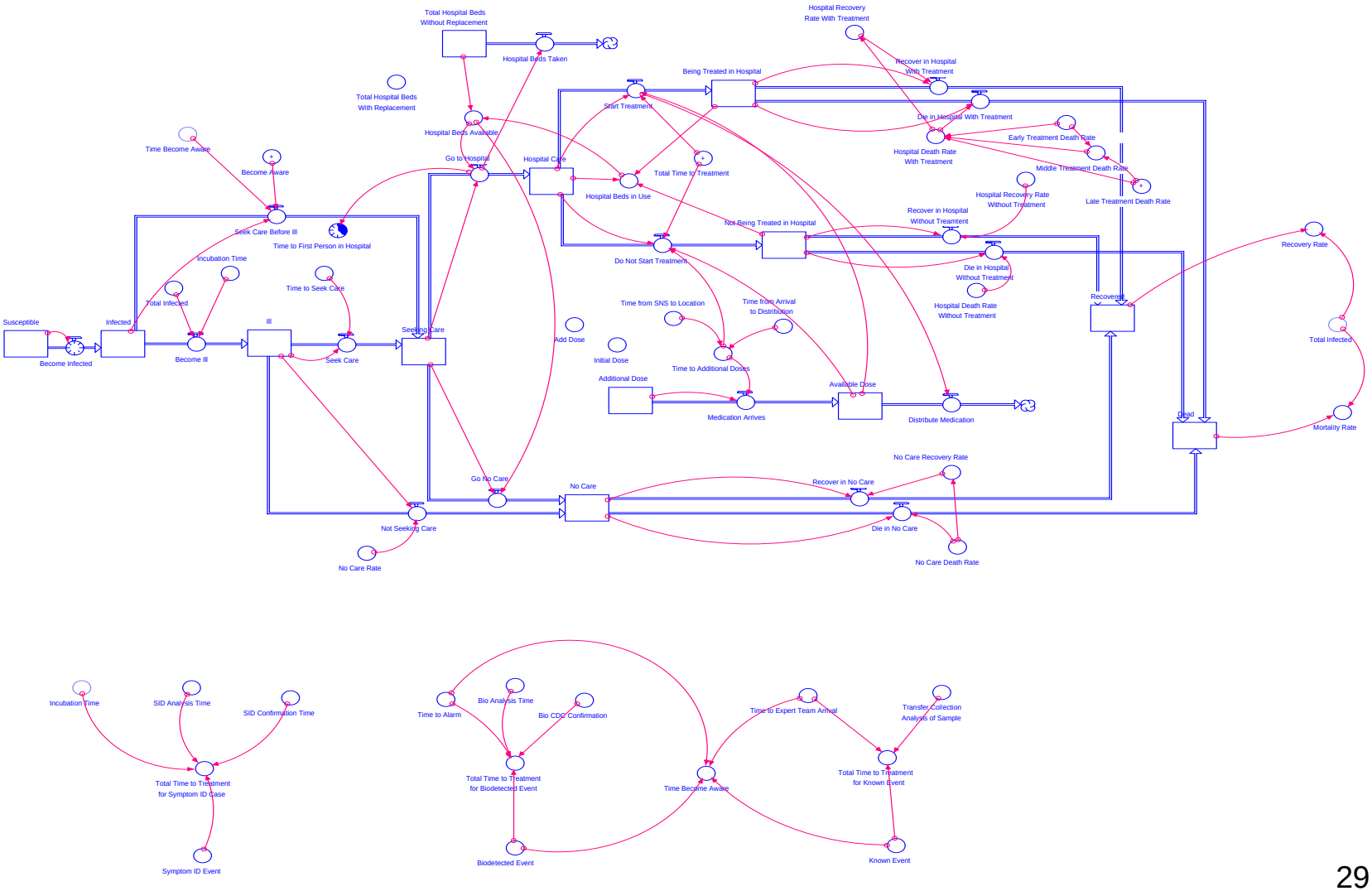
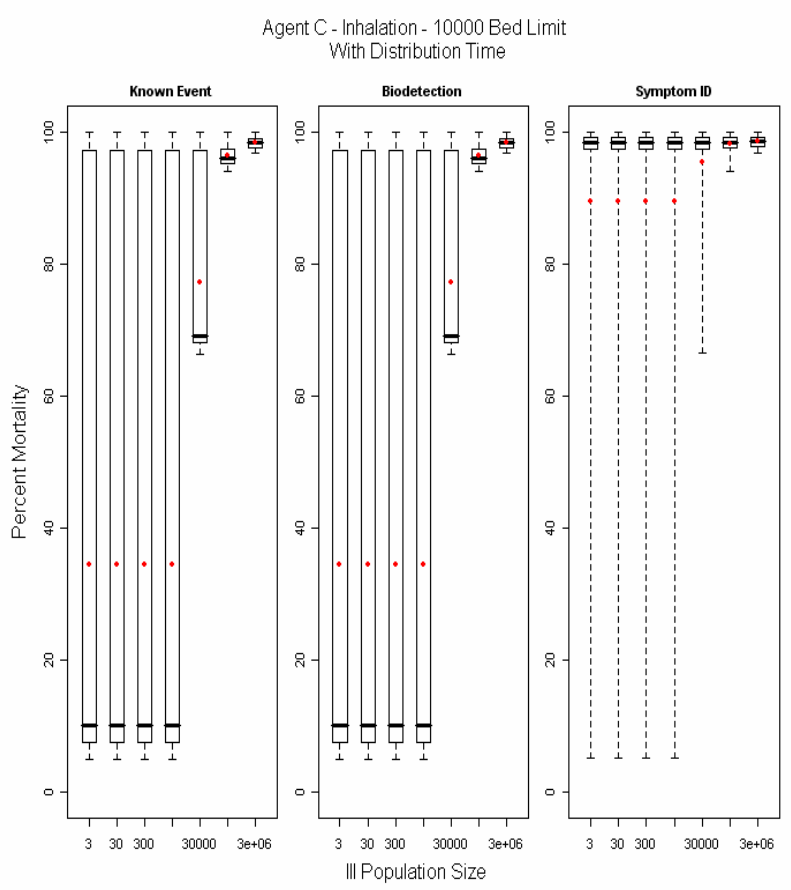
# Basic Medical Mitigation Model in STELLA

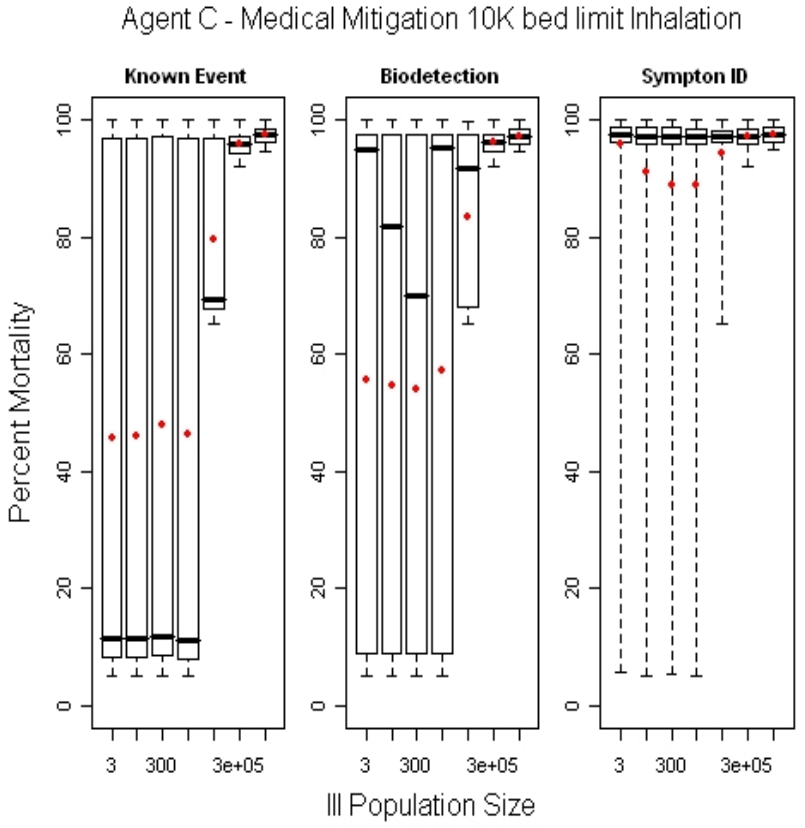


# Notional Agent Result: STELLA vs. R

- STELLA Model




- R Model

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# Improvements in STELLA

- Include subpopulations of differing susceptibility (e.g. young, old, pregnant)
- Different rates
  - Within subpopulations
  - Across subpopulations
- Satellite care
- Track time
  - Example: Track time from symptom onset to treatment availability
  - Rates can depend on time between events

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# Improvements in STELLA

- Treatment limitations
- Differentiate SNS and other federal support from local treatment capacity
- Ability to include varying treatment efficacies
- Hospital bed re-use
- Different levels of treatment (e.g. supportive care)

- All proposed improvements depend on availability of data to set parameters

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# Risk Calculation Engine

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# Summary of Planned Expansion/Improvements for 2008 Risk Assessment

- 2008 Assessment will be implemented on a Linux Cluster, rather than on a single computer.
- The Risk Engine is highly parallelizable and is expected to experience speed increase roughly proportional to the number of nodes in the cluster.
- The Risk Engine was originally written in C#, but is being converted to C/C++ for use in the parallel environment. This conversion is also expected to increase the speed of the engine.

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# Summary of Planned Expansion/Improvements for 2008 Risk Assessment

- Many preprocessing steps will be moved into the calculation engine as user routines
  - Outdoor inhalation consequences
  - Indoor inhalation consequences
  - Latin hypercube sampling
- With the preprocessing steps built into the calculation engine, a better characterization of consequence uncertainty can be performed.

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# Subject Matter Expert Elicitation

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# Summary of Planned Expansion/Improvements for 2008 Risk Assessment

- A formalized elicitation process based on the NUREG 1150 process will be instituted for the use of Subject Matter Expert judgments in the topic areas of terrorist motivations, capabilities, and resources
  - NUREG 1150 is an accepted approach for SME elicitation of quantitative but uncertain information developed for PRA nuclear applications
- With the assistance of the CREATE team, Battelle is formulating a formal, defensible process for the elicitation of these judgments
- Planned elicitations include members of the START center, as well as representatives of the IC

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# SME Elicitation Process

- The process involves a minimum of two sessions, separated by a span of time (likely 1-2 weeks)
  - Session 1: discussion of elicitation topic, process, and goals; sharing of information among SMEs; training
  - Intervening time: SMEs identify and study additional information in the relevant topic area
  - Session 2: SMEs share new data/information identified since Session 1, then break into individual elicitations
- During each elicitation, SME judgments of branch probabilities will be analyzed and presented to the SMEs in real-time as Dirichlet distributions
- SMEs will be able to review and revise their judgments throughout the session
- Upon completion of the elicitations, the compiled statistical results are provided to the SMEs for joint discussion and revision
- This process will allow for a rigorous, well-documented process to incorporate SME judgment

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# Anti-agricultural Scenarios

# Summary of Planned Expansion/Improvements for 2008 Risk Assessment

- Identify appropriate agents
- Correlate relevant animal populations for each disease
- Ascertain possible introduction scenarios and dissemination modes
- Determine most appropriate model for each disease
  - LLNL (MESA)
  - FAZD (AusSpread)
- Obtain relevant data
  - Production, dissemination, economic impact
- Identify data gaps

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# Economic Analysis

# Summary of Planned Expansion/Improvements for 2008 Risk Assessment

- 2006 assessment included selected direct costs
  - Funeral, Hospitalization, Decontamination costs
- 2008 assessment will include estimates of other direct costs (e.g., medical mitigation, emergency response, clean-up, and business loss) as well as indirect and induced effects on the economy
- With support from DHS Center for Risk and Economic Analysis of Terrorism Events, Input-Output (I-O) models will assess economic ripple effect of events
- I-O modeling provides upper-bound estimates of economic consequences since they do not explicitly consider resiliency
- CREATE-developed Computable General Equilibrium (CGE) models provide lower-bound estimates
- Plan to perform selected scenarios with CGE modeling and generate a factor which can be applied to I-O result to estimate a lower bound

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# Economic Modeling

- IMPLAN software to be used to run I-O models
  - I-O modeling is a linear approach to estimating indirect costs of an event
  - IMPLAN is a PC-based regional economic analysis system which draws on national and state level data to create the social accounting matrices needed for I-O modeling
  - Impacts applied to Total Production and Final Demand
- DHS risk assessment team is developing scenario-specific impact estimates for direct cost areas

| Direct Costs | Shopping Mall Event |
|---|---|
| Decontamination | x sq. ft. |
| Emergency Response | evacuation |
| Medical/Illness | # ill, medical cost |
| Fatalities | # killed |
| Lost Business | Local effect? Broad impact from fear of exposure? |

For each cell, need to consider:

- How to estimate cost
- What is the impact estimate ($)
- What industry/sector is the charge applied to

# Economic Modeling

- Other considerations:
- IMPLAN utilizes demand-side I-O model that captures upstream impacts, i.e. the inputs into impacted sectors/products
  - Does not capture all downstream effects (e.g., effect on grocery stores of cattle loss) unless impacts are applied downstream
- For certain scenarios, investigate use of custom supply-side I-O model that better captures impact of missing inputs
- Limited number of CGE models that better account for substitution and resiliency will allow adjustments to I-O model estimates

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# Tailored Risk Assessments, Sensitivity Studies, and Knowledge Gaps

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# 2008 Tailored Risk Assessments and Sensitivity Studies

- Increased capacity for tailored assessments and sensitivity studies
  - Faster computing through hardware upgrades and software improvements

- Example tailored assessments requested
  - Use of high $R_o$ agent, similar to measles
  - Injection of high expertise terrorists

- Example sensitivity studies under consideration
  - Impact of additional modeling detail
    - Water modeling using a hydraulic simulation of a public water system versus the analytical model

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# 2008 Prioritization of Knowledge Gaps

- The previous assessment prioritized bioagent knowledge gaps based on risk weighted uncertainty
- For 2008, the contribution of individual parameters to risk uncertainty will be calculated
- The calculation of this contribution, in conjunction with the risk weighting, will be used to prioritize knowledge gaps

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# Summary of the 2008 Bioterrorism Risk Assessment Planned Improvements

- Number of improvements involving
  - Event tree structure
  - Probability judgments
  - Consequence models
  - Data acquisition
  - Faster calculation tool

- Will permit more accurate assessment of more agents and more scenarios, as well as an improved ability to perform tailored risk assessments to evaluate the impact of various mitigation strategies

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# Attachment K

# “AllegedMathematicalErrors_v5.doc”

# Discussion of the Allegations of Mathematical and Statistical Errors in the 2006 BTRA

Throughout the NRC Final Report (ES-2, 13; ES-4, 23; ES-5, 20; p1-9, 14; Appendix H Comments by Dr. Alan Washburn) the NRC Committee claims that there are mathematical and statistical errors in the 2006 BTRA implementation as well as unnecessary complexity in the methodology. Review of the report identified several alleged mathematical and statistical errors and unnecessary complexities. These issues are discussed in this document. The alleged unnecessary complexities discussed in this document are only those related to the risk assessment methodology itself. Complexity in the models employed to assess consequences are discussed elsewhere.

Most of the alleged mathematical and statistical errors identified in the NRC Report were discussed with an NRC subcommittee (Dr. Neal Glassman, Professor Greg Parnell, and Professor Gerald Brown) and the BTRA team during the course of the NRC review. In the course of these discussions, additional documentation of the 2006 BTRA methodology was generated and provided to the subcommittee, including

1. Terminology and Formalism v1.doc (Feb 2, 2007)
2. Example of Risk Assessment Calculations.doc (February 26, 2007)
3. Response to Gerry Brown 20070309.doc
4. Lexicon with Example 20070409.doc
5. Lexicon with Example 20070415.doc
6. Lexicon with Example 20070427.doc
7. Classified 'Agent Trace Through' PowerPoint presentation (provided via Dr. Steven Bennett April 2007)
8. Lexicon-Formalism 20070427.doc
9. DHSResponseWashburn_v0.doc (May 14, 2007)
10. DHSResponseTwoFindings_v1.doc (May 14, 2007)
11. 2006 Sensitivity Studies.doc (provided via Dr. Mike Kuhlman in May 2007)

This document draws mainly on this documentation from those interim discussions with the NRC subcommittee to illustrate that the NRC allegations of mathematical and statistical errors and unnecessary complexity are not supported. NRC did identify one error in the calculations, which was discussed with the committee during the spring of 2007 and shown to not affect the results of the BTRA. Documentation previously provided to the committee is presented in this document in text boxes with the document from which the text is drawn indicated as a header for the text box.

**Alleged mathematical and statistical errors:**

1. It is claimed that DHS samples probabilities for multi-way splits incorrectly because DHS samples marginal probabilities for each branch according to a beta distribution, leading to a set of multi-way split probabilities that do not sum to 1. (p3-13, 9)

DHS addressed this comment in a conference call on April 16, 2007 for which DHS sent advance materials including the lexicon document and responses to a number of specific questions (Lexicon with Example 20070415 (2).doc provided to the committee by e-mail

from Dr. Steve Bennett on April 16, 2007) and in the response to Dr. Alan Washburn's comments entitled DHSResponseWashburn_v0.doc sent to the committee by e-mail from Dr. Steve Bennett May 14, 2007.

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**Lexicon with Examples 20070415 (2).doc – provided to committee April 16, 2007**

Figure C4 *(of the BTRA final report)* describes the process used to draw the relative frequencies for a *singe multi-way split*. This process is used many times to generate the conditional probabilities that are described in this document starting with Equation 9 *(of the Lexicon document)*. In the process described in Figure C4, the branch relative frequency means, $\mu_i$, and variances,$\sigma_i^2$, $i=1,...,N$ are known. The following text, extracted from an earlier, unclassified version of the (*BTRA 2006 final*) report is inserted here for ease of discussion. It has some minor adjustments to improve clarity.

> The conversion of a multi-way tree into a series of binary splits is shown in Figures D-3 and D-4 *(of the BTRA final report)*. These figures, their formulas, and accompanying text assume that the user has picked means ($E[A_k]$) and variances ($V[A_k]$) for a multi-way split. At each binary split a beta distribution was assigned. A beta distribution is a unimodal (or bimodal if the variance is large) probability distribution on the domain [0,1] and is useful in situations where the random variable of interest is a probability. The beta distribution is defined by two parameters, and the functional form is a variant of the quadratic function f(x) = x (1-x). In particular the probability density function for the beta distribution is
>
> $$f(x,\alpha,\beta) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} x^{\alpha-1}(1-x)^{\beta-1}$$
>
> where $\alpha > 0$ and $\beta > 0$.
>
> The mean and variance of the beta distribution are computed with the equations:
>
> $$E(x) = \frac{\alpha}{\alpha+\beta}$$
>
> $$V(x) = \frac{\alpha\beta}{(\alpha+\beta)(\alpha+\beta+1)}$$

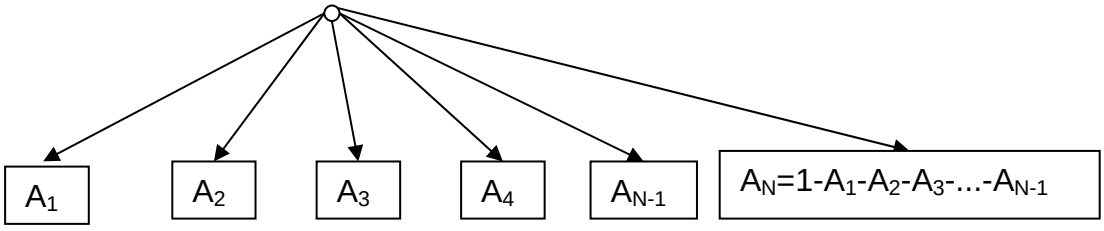


**Figure D-3. A Multi-way Split in a Tree**

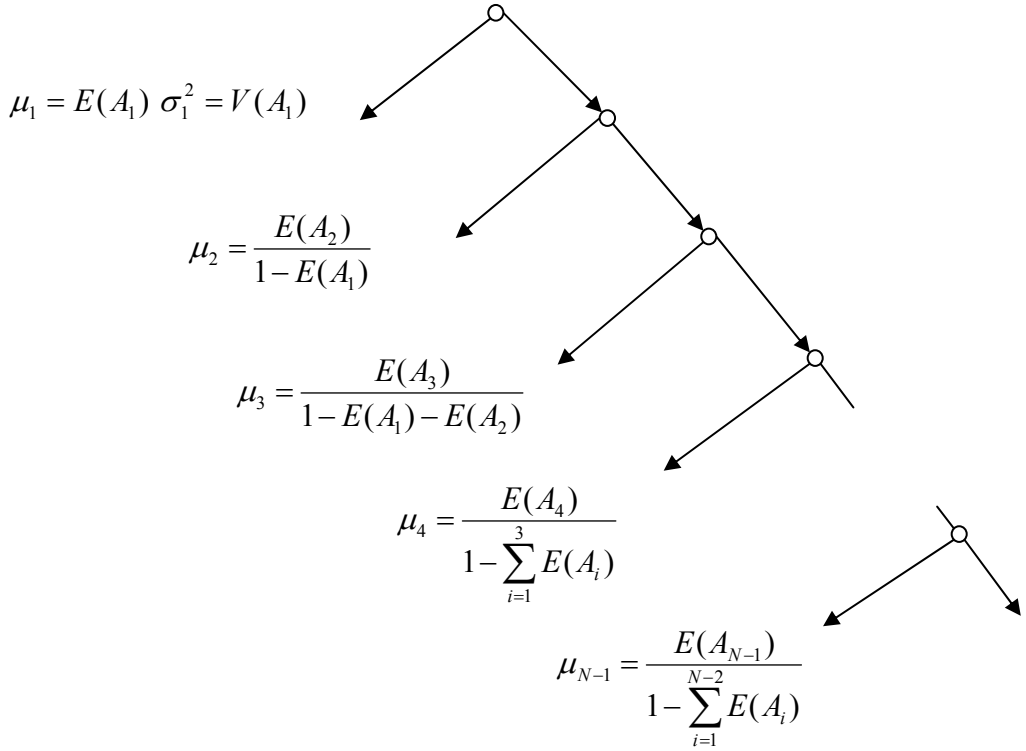


**Figure D-4. The Multi-way Split Converted to a Series of Binary Splits**

Figure D-4 shows a multi-way split expressed as series of binary splits and illustrates how the means of the binary splits, $\mu_k$, must be scaled so that the rolled up multi-way split (Figure D-3) has the correct mean, $E[A_k]$. Similarly, but in a more complex manner, the variances must be adjusted. The formula for this adjustment is

$$\sigma_k^2 = \frac{V(A_k) - \mu_k^2 \sigma_{12..k-1}^2}{\sigma_{12..k-1}^2 + \prod_{i=1}^{k-1}(1-\mu_i)^2} \qquad \sigma_{12..k}^2 = \sigma_{12..k-1}^2 \sigma_k^2 + \left[\prod_{i=1}^{k-1}(1-\mu_i)^2\right]\sigma_k^2 + (1-\mu_k)^2 \sigma_{12..k-1}^2$$

.

Note that in the binary split configuration, the split to the right is always 1 minus the split to the left as each split must sum to one. Necessarily, the last distribution in the series is already determined once the rest of the distributions are determined.

The binary tree gives a set of conditional probabilities. Thus at each binary split the probability is conditional on all the splits that have come before. Rolling up the binary representation into a multi-way split is a process of multiplying the probabilities along each segment of a branch.

The means ($E[A_k]$) and variances ($V[A_k]$) for the multi-way split are specified. Based on these, the means ($\mu_k$) and variances ($\sigma_k^2$) for the binary splits are calculated. The parameters for a beta distribution with the binary split means and variances are calculated ($\alpha_k$, $\beta_k$). The first N-1 sets of beta parameters are used to generate N-1 independent beta random variables with the respective sets of parameters, $y_1,\ldots,y_{N-1}$. The randomly drawn multi-way split fractions are calculated as $A_k = \prod_{j=1}^{k} y_j$ for $k=1,\ldots,N-1$ and $A_N = 1 - \sum_{j=1}^{N-1} A_j$

---

**NRC Chapter 3 asserts that outcome probabilities should have a joint distribution that captures the dependencies, the most important being that the probabilities sum to 1. This is exactly the result of the procedure described above and used in the 2006 BTRA for sampling the outcome probabilities. There is no sampling of marginal beta distributions. If that fact was not entirely clear from the report section cited above, the teleconference with the NRC subcommittee clarified this on April 16, 2007. DHS is unclear why this misunderstanding remains in the Final Report.**

**DHSResponseWashburn_v0.doc – provided to committee May 14, 2007**

*To be clear: full distributions for each marginal probability were **not** provided by SMEs. SMEs provided expected relative frequencies for each branch (which summed to one) and sometimes (for internally elicited SMEs) $5^{th}$ and $95^{th}$ percentiles of relative branch frequencies.*

*In 2006, we converted the multi-way split to a series of conditional binary splits; the binary splits were modeled as beta distributions. We determined the parameters of the beta distributions that, when rolled up to a multi-way split, produced the 'right' mean relative frequencies (as specified by the SMEs), and, to the degree possible, matched the SME indicated variability. When variability was not specified by the SME, we set variability of the relative frequencies to be approximately proportional to p(1-p) where p is the mean of the branch relative frequency specified by the SME and in a manner to ensure each of the beta distributions was unimodal rather than multimodal.*

*DHS did not allow the SMEs to define meaningless distributions and made use of the fact that the final branch in the set is defined by the previous branches. This was discussed in detail during the April 16 conference call related to the lexicon/formalism document. Beta distributions were not assumed for the marginal branch relative frequency distributions in the 2006 BTRA; only marginal means and variance of branch relative frequencies were set.*

*The process used produces a random sample for the multivariate quantity $(p_1,p_2,\ldots p_n)$ where each $p_i$ is a branch relative frequency, such that the sum of the components from each sample is 1 and the marginal relative frequency means set by the SME are met. Rarely was sufficient information provided to set marginal variances based on SME input. In these cases, we set the marginal variances such that the resulting distributions were unimodal, maximizing variance with the constraint that the unimodal shape was maintained. This in effect "errs" in the direction of more variance rather than less.*

*For the 2008 BTRA, we are moving toward drawing the relative frequencies from **generalized Dirichlet** distributions, because the **"ungeneralized" Dirichlet** is not flexible enough to capture the relative frequency variability judgments of the SMEs, especially when the opinions of multiple SMEs are combined.*

2. It is claimed that DHS' philosophical approach to consecutive attacks and its implementation of that approach are incorrect.

DHS addressed comments on consecutive attacks twice: first in response to comments provided by Dr. Alan Washburn (apparently an external reviewer of the 2006 BTRA employed by the Committee) in a document entitle DHSResponseWAshburn_v0.doc which was provided to the committee on May 14, 2007 by e-mail from Dr. Steve Bennett and again in a document entitled DHSResponseTwoFindings_v1.doc which was provided to the committee on May 14, 2007 by e-mail from Dr. Steve Bennett. Dr. Washburn and the TwoFindings.doc document both correctly identified a mistake in the calculation of number of consecutive attacks, which DHS acknowledged in the response. However, as indicated in the DHSResponseTwoFindings.doc document, the calculation of consecutive attacks as implemented in the 2006 BTRA did not affect results because all results were reported as normalized risk. In our response to NRC, DHS calculated the impact of the error that would have been observed in absolute risk had it been reported (an over-estimation of risk of a factor of approximately 2), which is quite different than the order of magnitude error anticipated by the committee.

**DHSResponseWashburn_v0.doc – provided to committee May 14, 2007**

*We concur that this is the right expectation of number of attacks – there was an error in the formula used to produce the 2006 results. Further, there was a typographical error in the report regarding this formula. If we continue to treat multiple serial attacks in the same manner, the correct formula will be used in the 2008 assessment. As for the 2006 BTRA, the multiple attack term effectively multiplies the initiating event frequency. If a terrorist organization chooses to undertake multiple consecutive attacks, the multiplier would be half as large using the formula recommended by the NRC review committee versus the formula actually used. Thus, in absolute risk, the values would be approximately one-half the values obtained in the 2006 study. However, because all agents are treated the same with regards to the multiple attack factors, the normalized values of the risk results presented in the study are completely unaffected.*

**DHSResponseTwoFindings_v1.doc – provided to committee May 14, 2007**

*The first equation cited in your comments ($f_1$) was a typographical error in the report and not used in any calculations. Battelle agrees that the expectation used in analysis ($f_2$) is incorrect and the correct estimate is the one given in your equation ($f_3$). The result of the error was an overestimate of risk for each agent. However, because the results reported were normalized using total mean risk and because the interdiction probabilities were the same across agents, the error had no effect on the reported relative risk. This error is not expected to have changed the agent ranking or the main conclusions of the report.*

*The three interdiction probabilities that impacted the value of λ' were interdiction during production, interdiction during transport and storage, and interdiction during attack. Of these interdictions, only interdiction during transport and storage had a dependency on other levels of the tree; interdiction during transport and storage was dependent on location of production and processing. The mean λ' value, when production was domestic was 0.64. The mean λ' value, when production was international was 0.56. This makes the ratio of $f_2$ to $f_3$ approximately (1+4.94)/(2.78)=2.14 and (1+2.89)/(2.27)=1.71 for domestic and international production respectively (which are both substantially less than the order of magnitude differences in the example at the end of the second committee recommendation).*

The Report further claims that the philosophical approach to estimating the number of consecutive attacks was also incorrect because consecutive attacks were given the same interdiction probabilities as the first attack, even though it is recognized that surveillance would increase dramatically if there were a successful first attack. However, the 2006 BTRA model does in fact incorporate increased probability of interdiction. Probability of zero interdiction (that is, success) was decreased from the original attack value at each of three interdiction events by a factor of 0.9, leading to a factor of 0.7 reduction in probability of successful attack for subsequent attacks.

For the 2008 BTRA, number of successful consecutive attacks has been directly elicited from Intelligence Community (IC) analysts. This approach leverages their knowledge of the increased security and surveillance activities that would result following a successful bioterrorism attack. These analysts also provide judgments on frequency of initiation based on their classified knowledge of the historic rate of known initiations and their information on terrorist organizations interest in initiating a bioterrorism attack. In our interactions with the IC analysts, information was captured about the importance of including consecutive attacks in the assessment.

## Discussion of the Allegations of Mathematical and Statistical Errors in the 2006 BTRA

Both Dr. Washburn and the NRC Report further report that consecutive attacks should have been treated by computing convolutions of the consequence distributions, which the 2006 BTRA does not do. DHS' response to this comment was provided in DHSResponseWashburn_v0.doc on May 14, 2007. While computing convolutions of consequence distributions would have been one way to account for the risk from consecutive attacks, the BTRA treats each of the consecutive attacks as an additional terrorist attack initiation in which the same attack scenario is executed. Thus, the BTRA adjusts risk curves (CCDFs) by increasing the frequency of attack (y-axis) rather than computing convolutions of risk distributions. Our rationale for modifying the risk curve frequency rather than the consequence is discussed in the mathematical formalism/lexicon document provided to the committee multiple times during the spring of 2007.

**DHSResponseWashburn_v0.doc – provided to committee May 14, 2007**

*The E(X) calculation is used as a multiplier on the frequency of initiation, not as a multiplier on the consequences of a single attack. We agree that the (X+1)-fold convolution is the right way to compute the consequence distribution if we in fact interpreted that distribution to be across all attacks. Instead, we interpret the consequences to be of a single attack and the frequency of attacks to be increased. Again, the lexicon/formalism document developed by DHS and the committee in April discusses the convolution issue for the related situation when there are multiple initiations and our decision to maintain the consequence distributions as the consequences of a single attack. As the reviewer has indicated, the mean or consequence averaged risk estimates are the same regardless of how the afterattacks are handled. When considering the complementary cumulative distribution functions, the afterattacks are an adjustment to the y-axis (frequency of initiation) not the x-axis (consequences).*

*We are currently discussing how to handle simultaneous attacks in 2008 in a situation where it is more direct to calculate the number of simultaneous attacks within the consequence calculations. We have not, however, determined how to deal with the impact of scaling consequences based on number of simultaneous attacks without increasing the variability in scenario consequence distributions by a factor of N, where N is the number of simultaneous attacks. The variance of the scaled up consequences is* $N^2 Var(Y)$ *whereas the variance of the sum of independent consequences would be* $NVar(Y)$. *As the reviewer has pointed out, convolution is a complicated operation.*

**The NRC has identified a flaw in the calculation of consecutive attacks that has *no impact on risk results as reported.* The NRC has misunderstood the use of this**

**calculation, which was an adjustment to frequency of attacks, not consequences. The NRC has misunderstood the model assumptions behind the consecutive attacks calculation.**

3. LHS not proven to provide advantage

DHS addressed Dr. Alan Washburn's comments on Latin hypercube sampling in a document entitled DHSResponseTwoFindings_v1.doc which was provided to the committee on May 14, 2007 by e-mail from Dr. Steve Bennett. DHS believes the committee has removed their original criticism from the main report instead focusing on what DHS provided at the end of this response, i.e., that DHS have not proven our sample is large enough to ensure negative correlation.

**DHSResponseTwoFindings_v1.doc – provided to committee May 14, 2007**

*Latin hypercube sampling is performed as described in McKay et. al. 1979. In this paper, it is shown that LHS is unbiased for estimating the empirical distribution function. Using the notation of the comments provided by Dr. Alan Washburn on this topic, we define $Y_a$ to be the consequence associated with agent a and θ to be the parameters sampled in the LHS. In the 2006 BTRA, we estimate the empirical distribution function of $E(Y_a|\theta)$ and report the 5th and 95th percentiles. Specifically, we draw a LHS from the distribution of $\boldsymbol{\theta}$:*

$$\boldsymbol{\theta}_1,\ldots\boldsymbol{\theta}_{500} \sim g(\boldsymbol{\theta})$$

*This is not an i.i.d. sample. We are interested in the quantity*

$$\boldsymbol{\Psi}(\boldsymbol{\theta}) = E[Y_a|\,\boldsymbol{\theta}],$$

*which is consequence-averaged risk. We estimate* $E[\boldsymbol{\Psi}(\boldsymbol{\theta})]$ *with*

$$\hat{\boldsymbol{\Psi}}(\boldsymbol{\theta}) = \frac{1}{500}\sum_{i=1}^{500}\boldsymbol{\Psi}(\boldsymbol{\theta}_i)$$

*We understand the reviewers point that the variance of this estimate,* $\mathrm{var}(\hat{\boldsymbol{\Psi}}(\boldsymbol{\theta}))$ *, does not have the usual relationship with* $\mathrm{var}(\boldsymbol{\Psi}(\boldsymbol{\theta}))$ *because of the non-i.i.d. nature of our* $\boldsymbol{\theta}$ *sample. This is described in Stein 1987, Equation 3. However, we contend that this is not a problem for the 5th and 95th percentile estimates reported in the 2006 BTRA because those estimates were constructed using an unbiased approach. We use the usual approach to estimating a cumulative distribution function. Let*

$$D_{\boldsymbol{\Psi}}(\boldsymbol{y}) = \begin{cases} 1 & \boldsymbol{\Psi} \le \boldsymbol{y} \\ 0 & otherwise. \end{cases}$$

*We estimate the distribution of* $\boldsymbol{\Psi}(\boldsymbol{\theta})$ *using*

$$\hat{D}_{\boldsymbol{\Psi}}(y) = \frac{1}{500}\sum_{i=1}^{500} D_{\boldsymbol{\Psi}(\boldsymbol{\theta}_i)}(y)$$

*As indicated in McKay et. al. 1979, this is unbiased. We report the 5th and 95th percentiles of consequence-averaged risk using the inverse empirical cumulative distribution function as*

$$\hat{D}_{\boldsymbol{\Psi}}^{-1}(0.05)$$

*and*

$$\hat{D}_{\boldsymbol{\Psi}}^{-1}(0.95),$$

*respectively. Thus, the 5th and 95th percentiles are percentiles of the distribution of* $\boldsymbol{\Psi}$*, not percentiles of* $\hat{\boldsymbol{\Psi}}(\boldsymbol{\theta})$.

*We understand that LHS has an effect (because of unknown covariance between* $E(Y_a|\theta_i)$ *and* $E(Y_a|\theta_j)$*) on the variability of estimates (*$\text{var}(\hat{\boldsymbol{\Psi}}(\boldsymbol{\theta}))$*). As discussed above, we do not believe it has a biasing effect on the quantities we are interested in, i.e., the mean and fractiles of the sample distribution. If the covariance is positive, variance in the mean estimate is inflated; if it is negative variance is reduced. We are interested in this effect because we are using LHS to reduce variability in our mean estimate, but the 5th and 95th percentile estimates are for the distribution of* ***risk*** *not* ***mean risk****. Our intention was to have negative covariance. While this is guaranteed to happen asymptotically as the size of the LHS gets large (Stein 1987), we have not verified that N is sufficiently large in our sample. The number of samples we are drawing (500) is not really large compared to the dimension of the LHS we are drawing.*

4. The NRC Report questions the allegedly high complexity introduced by treating the relative frequencies of branches as random variables and capturing uncertainty in these quantities using distributions. In the terminology of the Report, event tree outcome probability assessment is unnecessarily complex. This criticism has an appendix of its own (NRC Report Appendix C), with computer code illustrating how the mean scenario probabilities could be calculated exactly if DHS wasn't specifying distributions for outcome probabilities. The NRC Report also claims that conducting the calculations in this manner would not cost anything, since the NRC asserts that the BTRA does not use the family of risk curves that are generated by treating outcome probability as an uncertain quantity.

**DHS agrees that the mathematics presented in Appendix C of the NRC Report is correct in that the mean scenario probabilities could be calculated directly if DHS simply propagated mean outcome probabilities down the tree to calculate scenario probabilities. However, doing this would grossly overstate our confidence in risk**

**results, ignoring all of the uncertainty in these estimates. Typically, distributions elicited from the Intelligence Community and other experts are quite wide, revealing significant uncertainty that DHS has an obligation to report in some form to the decision maker in the risk results. These uncertainties are in fact the source of the wide band of risk curves displayed on each CCDF and the large uncertainty bands displayed for each biological agent in the summary figures of the assessment. These "error bars" were instrumental in assessing which biological threat agents could be said to have different risk from the others, i.e., the tiering process requested by senior Government leadership.**

5. Normalization

The committee made a number of comments about normalized risk at the 28 and 29 August 2006 briefings. At that time, the BTRA referred to the normalized risk estimates as "relative risk." In the course of the August 2006 discussions, the Committee pointed out that there is a difference between the dimensionless quantities obtained in the 2006 BTRA normalization process, in which absolute risk measures are divided by the total mean risk and what the Committee defined as formal relative risk. An e-mail exchange followed between the BTRA team and Dr. Stephen Pollock regarding how our normalization process should be revised to convert into true "relative risk."

**From:** McMillan, Nancy J
**Sent:** Thursday, August 31, 2006 4:05 PM
**To:** pollock@umich.edu
**Cc:** Weidman, Scott; gregory.parnell@usma.edu; Bennett, Steven P. (Federal); Hale, Traci L
**Subject:** Relative vs. Normalized Risk

Dear Dr. Pollock,

Thanks for your comments during the results presentation on Tuesday and even more for the additional explanation you provided after the 2008 planned improvements presentation. I think I finally get what you were telling me regarding our 'Relative Risk' metric. Clearly what we are calculating is a 'Normalized Risk' metric, not a 'Relative Risk' metric. I apologize for not catching on while we were talking; I was still recovering from presentation mode.

Would you define 'Relative Risk' to be the (percentage) contribution of a particular agent (or target or threat group) to total risk? We could calculate each agent's (or target's or threat group's) contribution to total risk from each of the individual Latin hypercube samples and create our uncertainty intervals based on these. This would produce 'Relative Risk' values that were (correctly) bounded below 1. I think it is likely that this would also decrease the variability in 'Relative Risk' estimates at least for the top category or two as total risk (the denominator) will be highly correlated with category risk (the numerator).

Thanks again for your many constructive comments Monday and Tuesday.

Nancy

Nancy McMillan
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cell: (614) 527-1305

# Discussion of the Allegations of Mathematical and Statistical Errors in the 2006 BTRA

**From:** Steve Pollock [pollock@umich.edu]
**Sent:** Friday, September 01, 2006 4:20 PM
**To:** McMillan, Nancy J
**Cc:** Weidman, Scott; gregory.parnell@usma.edu; Bennett, Steven P. (Federal); Hale, Traci L
**Subject:** Re: Relative vs. Normalized Risk
At 4:05 PM -0400 8/31/06, McMillan, Nancy J wrote:
Dear Dr. Pollock,

Thanks for your comments during the results presentation on Tuesday and even more for the additional explanation you provided after the 2008 planned improvements presentation. I think I finally get what you were telling me regarding our 'Relative Risk' metric. Clearly what we are calculating is a 'Normalized Risk' metric, not a 'Relative Risk' metric. I apologize for not catching on while we were talking; I was still recovering from presentation mode.

No need to apologize; indeed, perhaps I should be the one to do so, since in retrospect I seem to have unfairly jumped on you during the classified brief. However, since the main purpose of the NRC committee is to help you and your colleagues make use of the best possible methods and approaches, and then communicate these in order to effect rational decision making, I'm pleased to see that my question has prompted a re-thinking on your part.

I don't want to get too involved with the semantics of the terms "normalized" and "relative", but your observation that one should:

... define 'Relative Risk' to be the (percentage) contribution of a particular agent (or target or threat group) to total risk.."

is (excuse the irony) dead-on. That is, your proposal to:

... calculate each agent's (or target's or threat group's) contribution to total risk from **each** of the individual Latin hypercube samples and create our uncertainty intervals based on these.

is certainly what I would do. On the other hand, we are now running into one of the definitional issues raised earlier on the first day. That is, what you say is correct (or at least consistent) as long as you really mean (italics in red mine):

calculate each agent's (or target's or threat group's) contribution to *the consequences (e.g., deaths)* from **each** of the individual Latin hypercube samples and create our uncertainty intervals based on these.

At the end of the briefings I was fairly well convinced that (whether advisable or not -- but that's another issue) you have chosen to look at the relative contribution to total *consequences* (deaths or illness), and then *compared* the distributions of these (since they are random variables produced by the runs of the simulation) by using their means (as well-estimated by the sample averages, given your large sample sizes), and the uncertainties in these represented by sample fractiles.

In other words, I think you are saying that for every simulation run j =1,2,...N you observe (using modified LaTex notation) the random variables:

X_{i,j} = consequence due to agent i, i=1,2, ...28 on run j,

from which you compute

Y_{i,j} = percentage of total consequence on run j attributable to agent i

= \frac{ X_{i,j}{\sum_i{X_{i,j}}}.

in which case

This would produce 'Relative Risk' values that were (correctly) bounded below 1.

However, I am not sure that

... this would also decrease the variability in 'Relative Risk' estimates at least for the top category or two as total risk (the denominator) will be highly correlated with category risk (the numerator).

since this would depend on an the nature of the probabilistic dependence that might exist among agents, and therefore consequences. I wasn't all that clear about the method of eliciting critical event probabilities to see if it made possible assessments that would exhibit realistic dependences if they exist. If they are independent, you may be right (probably straightforward to prove).

In any event, you could do a quick back of the envelope calculation, using a pair of agents with a 2-D dependent joint Normal distribution of consequences (e.g. deaths), one with (say) a large mean and large s.d., and the other with mean and s.d. perhaps two orders of magnitude smaller, and see what results. This will involve the distribution of the ratio of two dependent normal variates, which as I recall involves a Cauchy distribution with some shifting of parameters.

In any event, I think you've identified the more informative (and supportable) way of doing things, and I look forward to seeing what the revised computations look like (perhaps at the next meeting if Greg thinks it worth going through again)

Hope you have (or at this point, *had*) a good Labor day weekend.

Steve Pollock

**It is surprising that one NRC Committee member would recommend an improvement to the normalization approach, while the NRC Report with which this member has concurred concludes that any approach that does not report absolute risk results is a fatal flaw of the 2006 BTRA. Based on this e-mail exchange with Dr. Pollock, the 2008 BTRA followed what DHS believed to be Committee direction, presenting results using Professor Pollock's recommended approach for "relative risk" rather than normalized risk. At an October 2006 site visit (where Committee members visited the facility in Columbus Ohio where BTRA calculations are carried out), a new plot of 2006 BTRA results, presented using Professor Pollock's relative risk approach was presented to the Committee. This new figure was discussed and the Committee deemed it to be an appropriate representation of relative risk. DHS remains unclear as to why there is a significant disconnect from what the Committee has instructed DHS to do in this area over the last year, and what appears in the Report.**

# Attachment L

# “DHSResponseTwoFindings_v1.doc”

To avoid any misunderstanding, the following is a recitation of facts as the committee has found them.

1. Latin hypercube sampling.

BTRA randomly samples 500 sets of branch probabilities for each agent event tree using a Latin hypercube sample design[1], a sampling technique applied earlier to probabilistic risk analysis of nuclear safety. Documentation presented to this committee contains no detail of this, so we merely refer to this as a random sample. However, the committee warns that this sampling design produces an unbiased estimate of the mean, but not of the variance, or quantiles. Further, see Stein[1], page 144, equation (3). Note that the variance may be decreased *or increased* by this design, depending on the covariance among the distributions sampled. Presumably there is some covariance, for otherwise this technique has no influence at all on the variance of results. So, either we have no covariance, and the Latin hypercube sampling scheme has no function, or we do have covariance, and thus the 5-th and 95-th percentiles reported for the sample distributions do not come from the epistemic distribution.

*Latin hypercube sampling is performed as described in McKay et. al. 1979. In this paper, it is shown that LHS is unbiased for estimating the empirical distribution function. Using the notation of the comments provided by Dr. Alan Washburn on this topic, we define $Y_a$ to be the consequence associated with agent a and $\theta$ to be the parameters sampled in the LHS. In the 2006 BTRA, we estimate the empirical distribution function of $E(Y_a|\theta)$ and report the 5th and 95th percentiles. Specifically, we draw a LHS from the distribution of $\boldsymbol{\theta}$:*

$$\boldsymbol{\theta}_1,\ldots\boldsymbol{\theta}_{500} \sim g(\boldsymbol{\theta})$$

*This is not an i.i.d. sample. We are interested in the quantity*

$$\boldsymbol{\Psi}(\boldsymbol{\theta}) = E[Y_a|\,\boldsymbol{\theta}],$$

*which is consequence-averaged risk. We estimate* $E[\boldsymbol{\Psi}(\boldsymbol{\theta})]$ *with*

$$\hat{\boldsymbol{\Psi}}(\boldsymbol{\theta}) = \frac{1}{500}\sum_{i=1}^{500}\boldsymbol{\Psi}(\boldsymbol{\theta}_i)$$

*We understand the reviewers point that the variance of this estimate,* $\mathrm{var}(\hat{\boldsymbol{\Psi}}(\boldsymbol{\theta}))$ *, does not have the usual relationship with* $\mathrm{var}(\boldsymbol{\Psi}(\boldsymbol{\theta}))$ *because of the non-i.i.d. nature of our $\boldsymbol{\theta}$ sample. This is described in Stein 1987, Equation 3. However, we contend that this is not a problem for the 5th and*

[1] Stein, M., 1987, "Large Sample Properties of Simulation Using Latin Hypercube Sampling," Technometrics, 29(2) pp. 143-151.

*95th percentile estimates reported in the 2006 BTRA because those estimates were constructed using an unbiased approach. We use the usual approach to estimating a cumulative distribution function. Let*

$$D_{\Psi}(y) = \begin{cases} 1 & \Psi \le y \\ 0 & otherwise. \end{cases}$$

*We estimate the distribution of* $\Psi(\theta)$ *using*

$$\hat{D}_{\Psi}(y) = \frac{1}{500}\sum_{i=1}^{500} D_{\Psi(\theta_i)}(y)$$

*As indicated in McKay et. al. 1979, this is unbiased. We report the 5th and 95th percentiles of consequence-averaged risk using the inverse empirical cumulative distribution function as*

$$\hat{D}_{\Psi}^{-1}(0.05)$$

*and*

$$\hat{D}_{\Psi}^{-1}(0.95),$$

*respectively. Thus, the 5th and 95th percentiles are percentiles of the distribution of* $\Psi$*, not percentiles of* $\hat{\Psi}(\theta)$.

*We understand that LHS has an effect (because of unknown covariance between* $E(Y_a|\theta_i)$ *and* $E(Y_a|\theta_j)$*) on the variability of estimates (*$\mathrm{var}(\hat{\Psi}(\theta))$*). As discussed above, we do not believe it has a biasing effect on the quantities we are interested in, i.e., the mean and fractiles of the sample distribution. If the covariance is positive, variance in the mean estimate is inflated; if it is negative variance is reduced. We are interested in this effect because we are using LHS to reduce variability in our mean estimate, but the 5th and 95th percentile estimates are for the distribution of* ***risk*** *not* ***mean risk****. Our intention was to have negative covariance. While this is guaranteed to happen asymptotically as the size of the LHS gets large (Stein 1987), we have not verified that N is sufficiently large in our sample. The number of samples we are drawing (500) is not really large compared to the dimension of the LHS we are drawing.*

2. Estimating number of multiple attacks

Given a successful attack, PRA tree stage 16 presents an opportunity for the terrorist to mount more such attacks. The probability for succeeding at each additional attack is given as $\lambda'$, and the expected number of attacks before interdiction is given in the original BTRA report and Powerpoint presentation to our committee as

$$f_1(\lambda') = 1 + \frac{\lambda'}{(1+\lambda')^2}.$$

This expectation is *multiplied* by the consequence distribution for such attacks.

During a site visit to Battelle, Columbus, Ohio, in October, 2006, the committee pointed out that this must be in error, suggesting a Feinman test with $\lambda' = 1$, where the expected number of re-attacks would go to infinity, but for which $f_1(\lambda' = 1) = 0$.

Subsequent briefing materials (ca. 27 March 2007)[2] feature a new expectation:

$$f_2(\lambda') = 1 + \frac{\lambda'}{(1-\lambda')^2}.$$

This expectation is also wrong.

Given one successful attack, the total number of successful attacks before an interdiction with probability of success for each additional attack $\lambda'$ is

$$f_3(\lambda') = 1 + E[n \mid \lambda'] = 1 + \sum_{n=0}^{\infty} n(\lambda')^n(1-\lambda') = 1 + \frac{\lambda'}{1-\lambda'} = \frac{1}{1-\lambda'}.$$

Figure 4-9 shows these expressions as a function of $\lambda'$. This has significant influence on the expected consequences of multiple attacks. For $\lambda' = 0.9$, $f_1(0.9) = 1.25$, $f_2(0.9) = 91$, and the correct expectation $f_3(0.9) = 10$. *The two BTRA expectations respectively under- and over-estimate consequences by an order of magnitude.*

> *The first equation cited in your comments ($f_1$) was a typographical error in the report and not used in any calculations. DHS agrees that the expectation used in analysis ($f_2$) is incorrect and the correct estimate is the one given in your equation ($f_3$). The result of the error was an overestimate of risk for each agent. However, because the results reported were normalized using total mean risk and because the interdiction probabilities were the same across agents, the error had no effect on the reported relative risk. This error is not expected to have changed the agent ranking or the main conclusions of the report.*
>
> *The three interdiction probabilities that impacted the value of λ' were interdiction during production, interdiction during transport and storage, and interdiction during attack. Of these interdictions, only interdiction during transport and storage had a dependency on other levels of the tree; interdiction during transport and storage was dependent on location of production and processing. The mean λ' value, when production was domestic was 0.64. The mean λ' value, when production was international was 0.56. This makes the ratio of $f_2$ to $f_3$ approximately (1+4.94)/(2.78)=2.14*

[2] Battelle Columbus Operation, 2007, "*Detailed Single Scenario Analysis* (U)," prepared for National Biodefense Analysis and Countermeasures Center, 27 March.

*and (1+2.89)/(2.27)=1.71 for domestic and international production respectively (which are both substantially less than the order of magnitude differences in the example at the end of the second committee recommendation).*

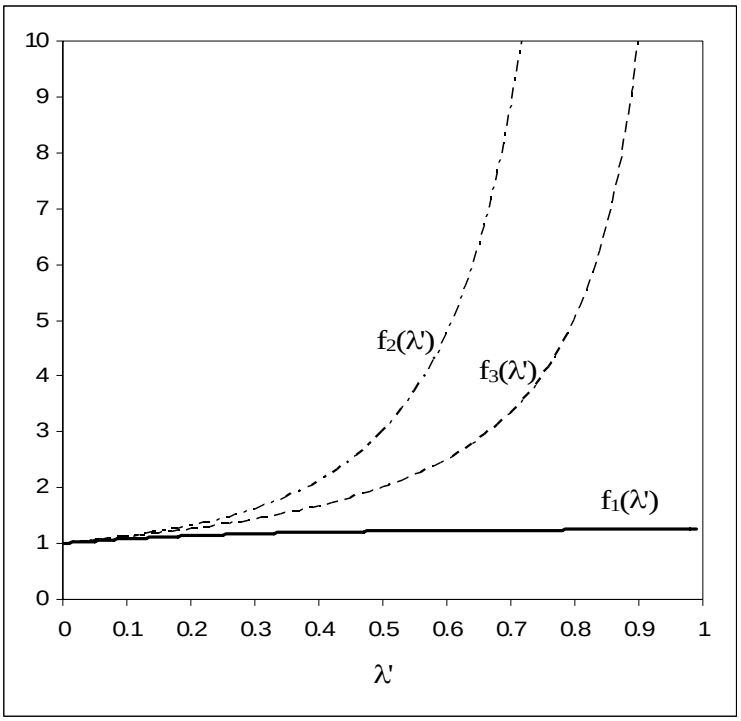


**Figure 4-9. Expected number of attacks before interdiction, given a first successful attack and that continued attacks each evade interdiction with probability $\lambda'$. $f_3(\lambda')$ is the expected number of attacks before interdiction. $f_1$ is the BTRA expression, and $f_2$ is the expression offered with a complete numerical example[2]. For $\lambda' = 0.9$, $f_1$ under-estimates by an order of magnitude, and $f_2$ over-estimates by an order of magnitude. This expectation is multiplied by the single-attack distribution of consequences, so these errors have major influence.**