



SAND2014-1390C



Chemical Defense Model

Trisha (Hoette) Miller, Early Career LDRD Project
Sandia National Laboratories

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Project support: Greg Foltz, Luke Purvis & Nate Gleason
Sandia National Laboratories



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Outline

1. Introduction

- Chemical weapons and the chemical defense system
- LDRD Project: Modeling Chemical Defense

2. Structure and behavior of chemical defense

- Framework for analysis
- Tools for studying interactions and influences

3. Systems analysis questions

- Past, present and future of chemical terrorism
- Importance of chemical defense
- Detection in chemical defense
- Resource allocation

Chemical Terrorism and Defense

- **Chemical agents as weapons**

- Long history of lethal uses of chemical agents
- Use of chlorine in WWI marks a paradigm shift in the use of chemical weapons
- Illicit chemical activity is still taking place today

Picture from: *Collier's New Photographic History of the World's War* (New York, 1918)



- **Chemical terrorism and defense is a complex system**

- Social, political, physical, technological factors
- Intelligent antagonistic system (defense vs. adversary)
- Continuously evolving and emerging

- **Important distinctions for chemical weapons vs. other WMD:**

1. Rapid onset of toxicity
2. Chemical agents are dual-use and ubiquitous

LDRD Project -- Modeling Chemical Defense

- **Hypothesis:**

- Chemical defense is a multi-component system with complex, non-linear interactions
- Therefore current reduction approach to chemical defense is insufficient

- **Goal:**

- Develop an end-to-end model of the chemical defense system

- **Analysis approach:**

- Employ methods from Complex Adaptive System of Systems (CASoS) to analyze the structure and behavior of the chemical defense system

- **Results:**

- 2 year project (2009-2011)
- Developed an analysis framework for chemical defense
- Employed analysis tools to model complex interactions of the system
- The Chemical Defense Model is leveraged in a variety of projects for analysis of systems-level questions

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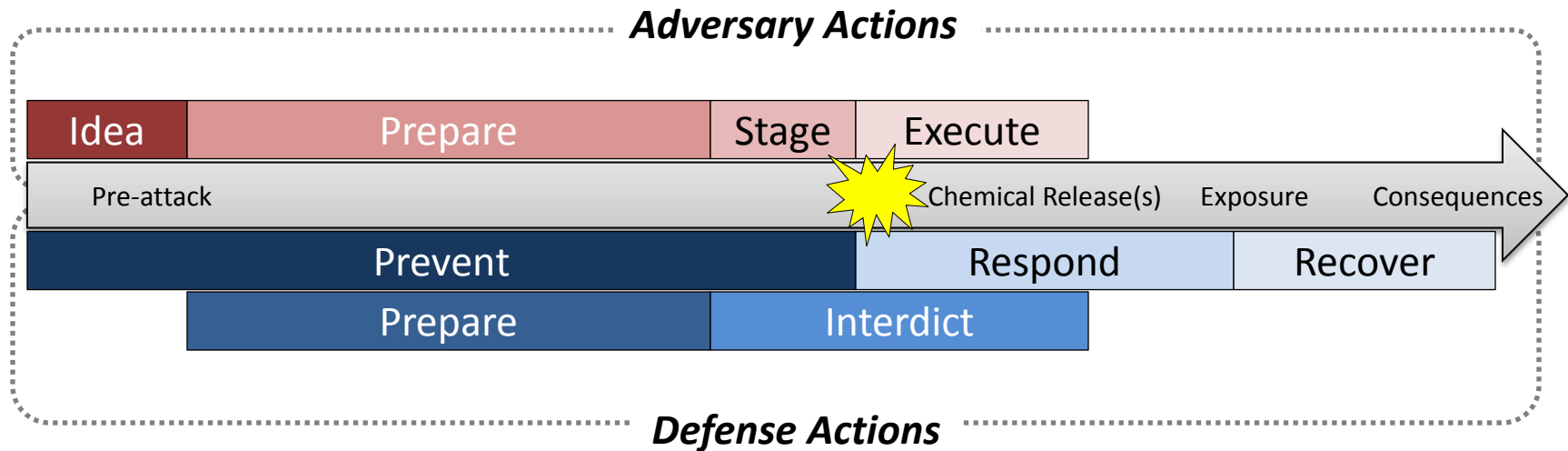
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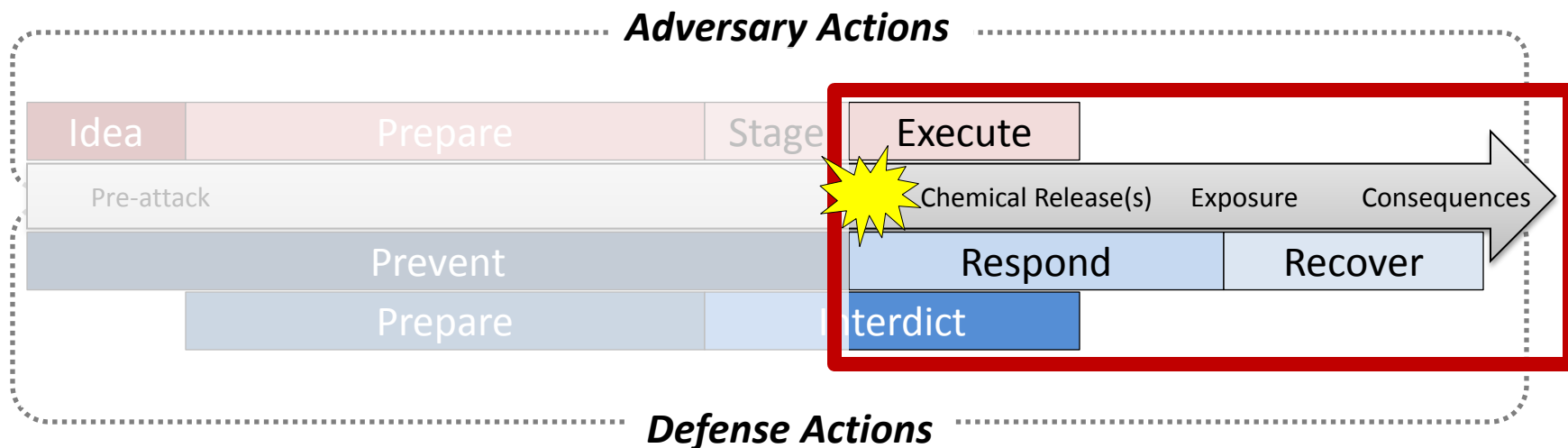
Chemical Defense Framework

- **What is the chemical defense framework?**
 - Structure of chemical terrorism system
 - Includes all factors and activities leading up to and following a chemical attack that impact the outcome



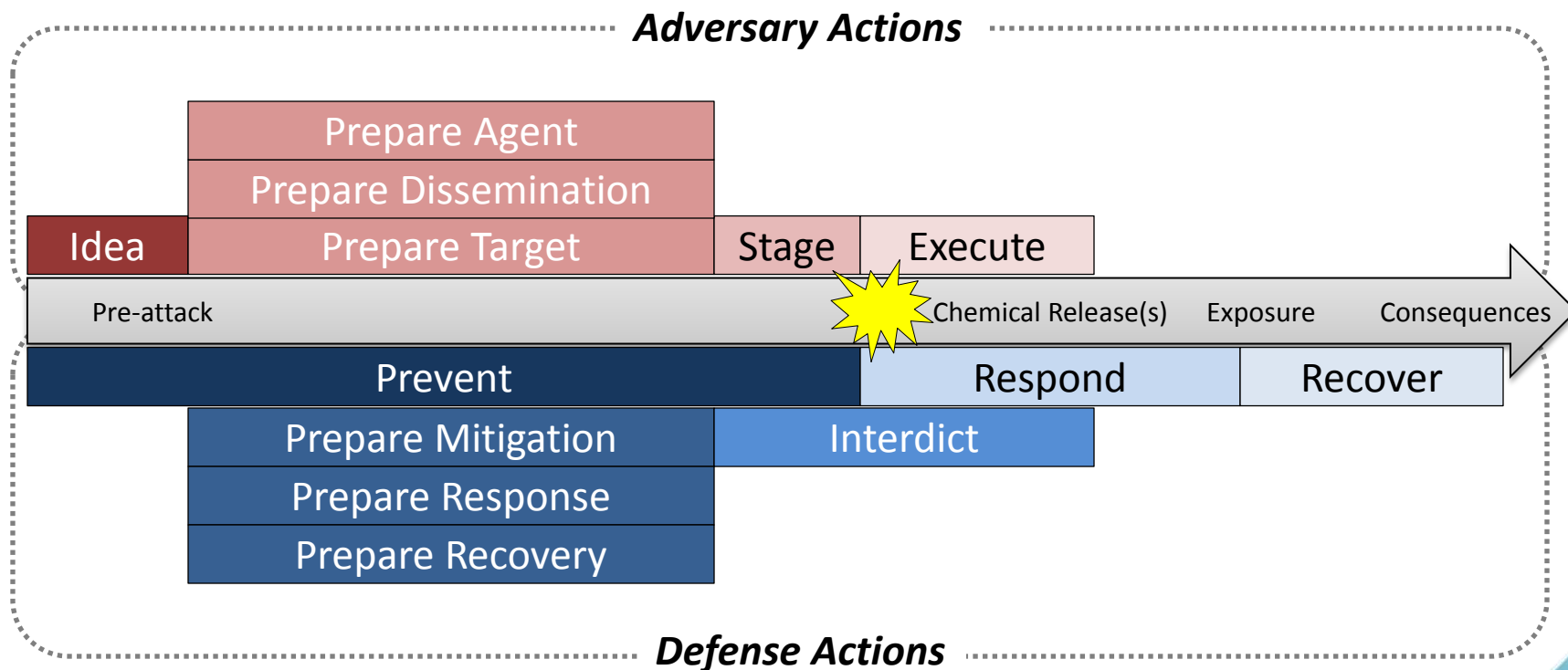
Chemical Defense Framework

- **Why do we need a framework for chemical defense?**
 - Often focus on scenario analysis
 - However, many factors contribute to the impact of chemical terrorism
- **Building a defense architecture on a broad framework will result in a more comprehensive and integrated chemical defense**



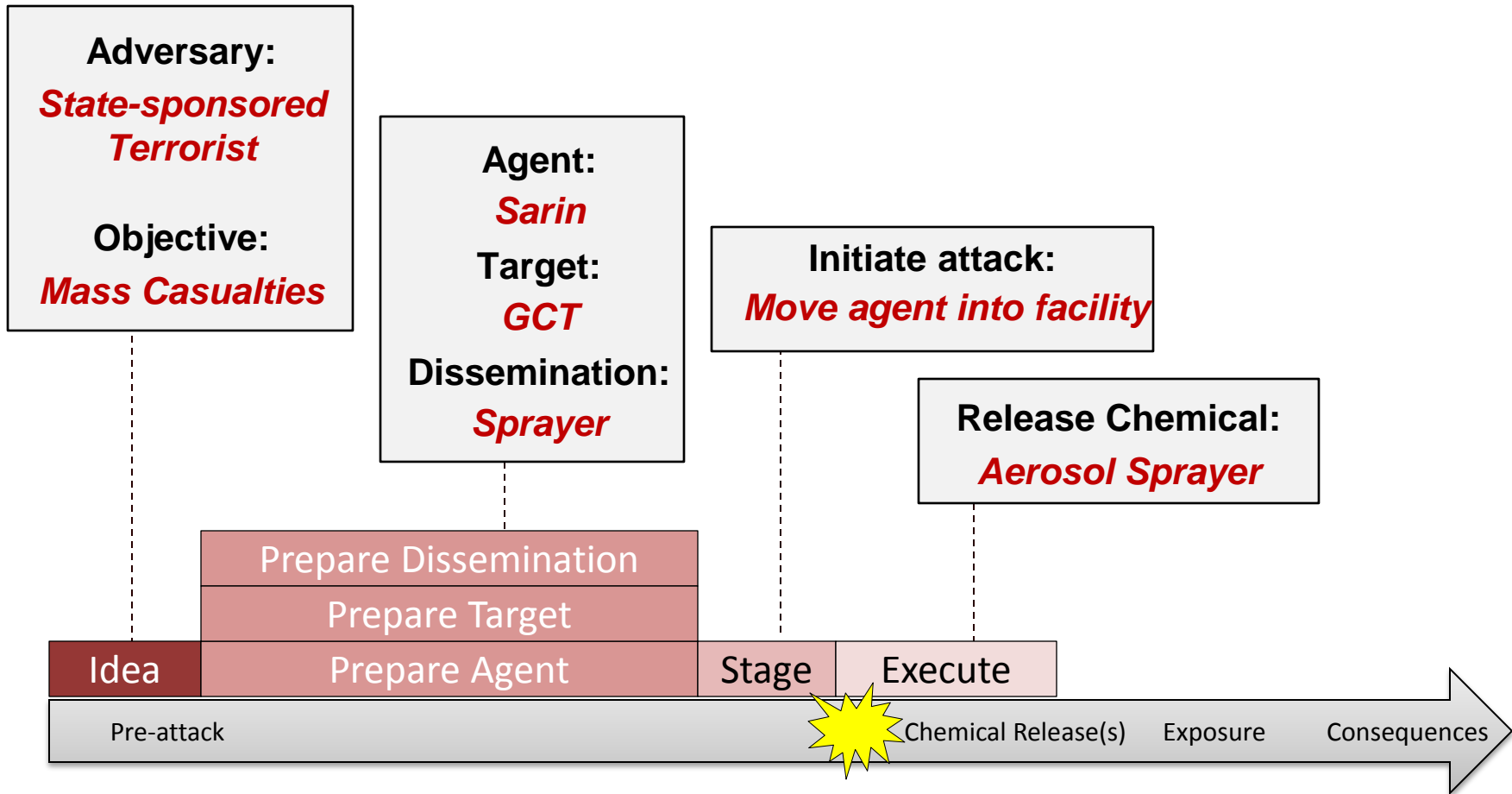
Chemical Defense Framework

- **Pre-attack activities are a significant source of complexity in the system**
 - How do defenses influence chemical attack preparation and vice versa?

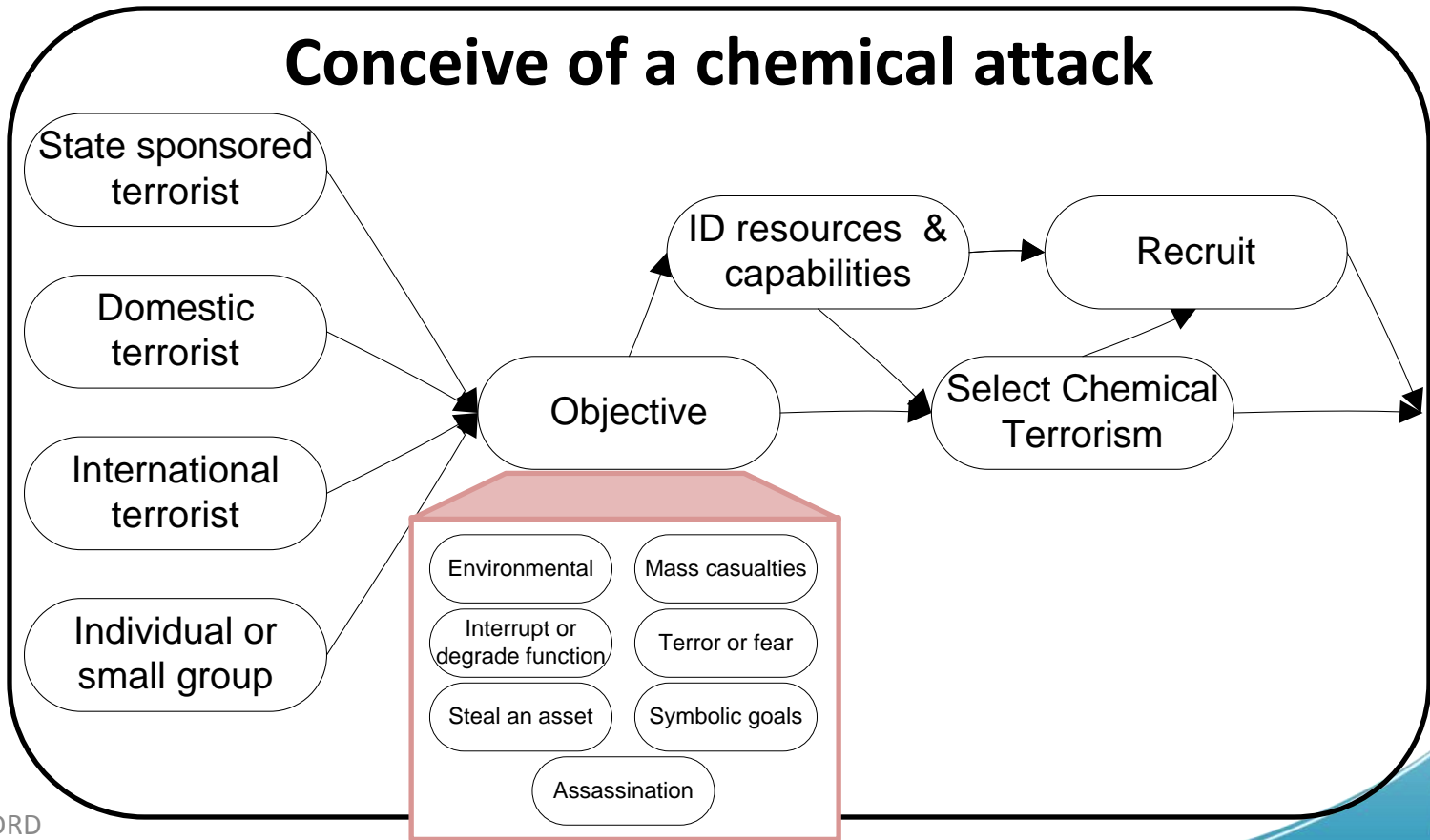
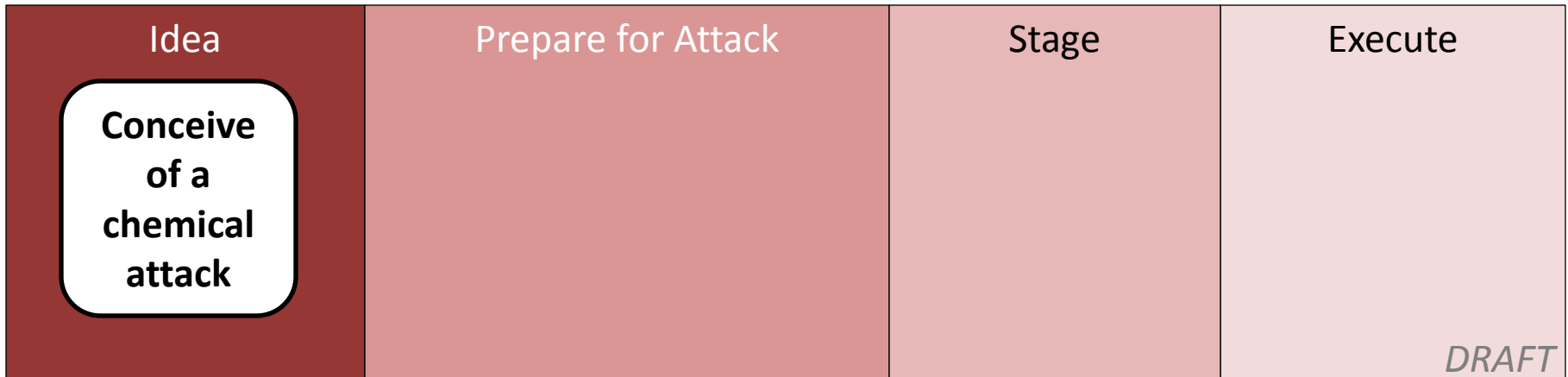


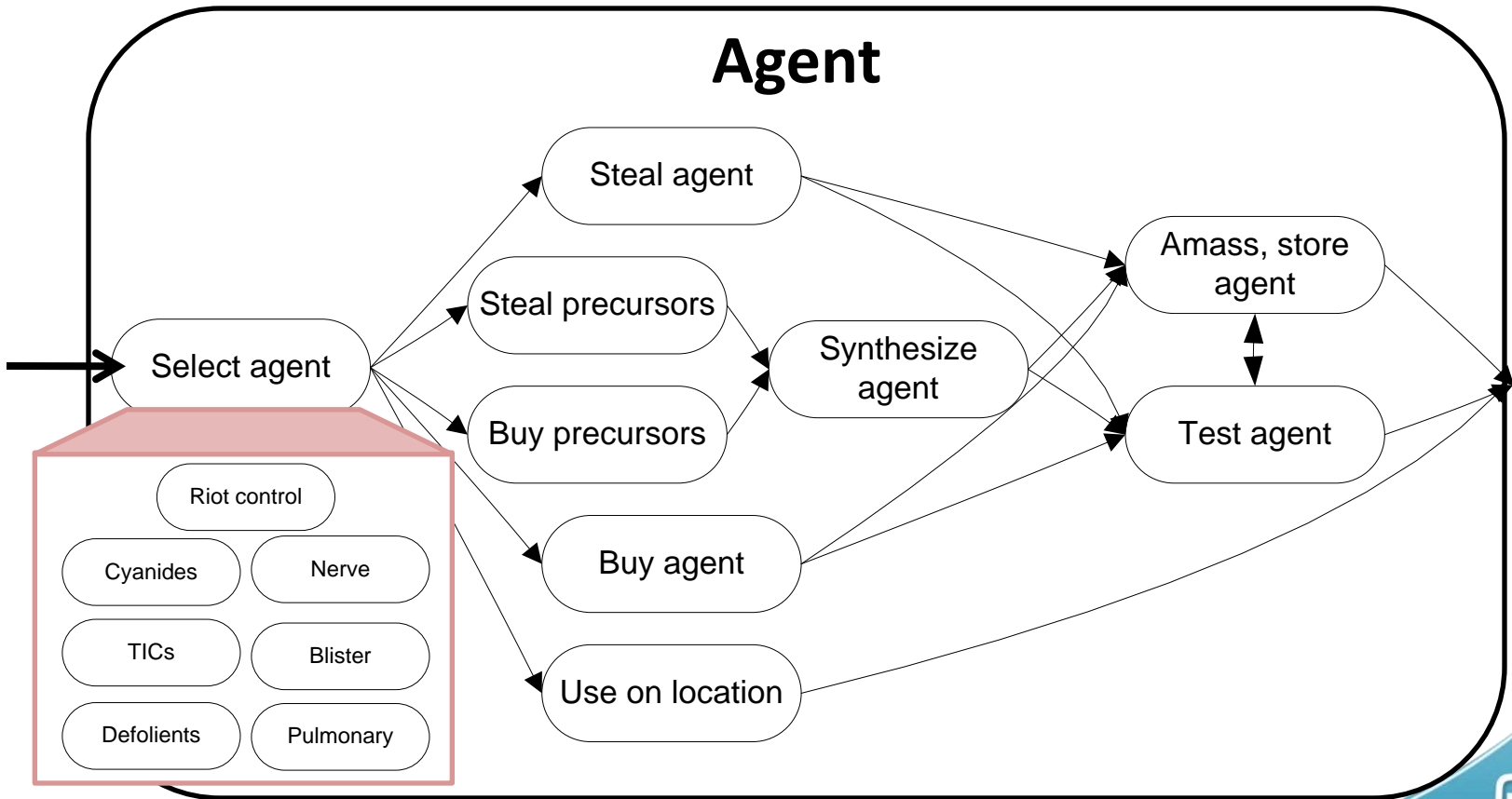
Adversary actions

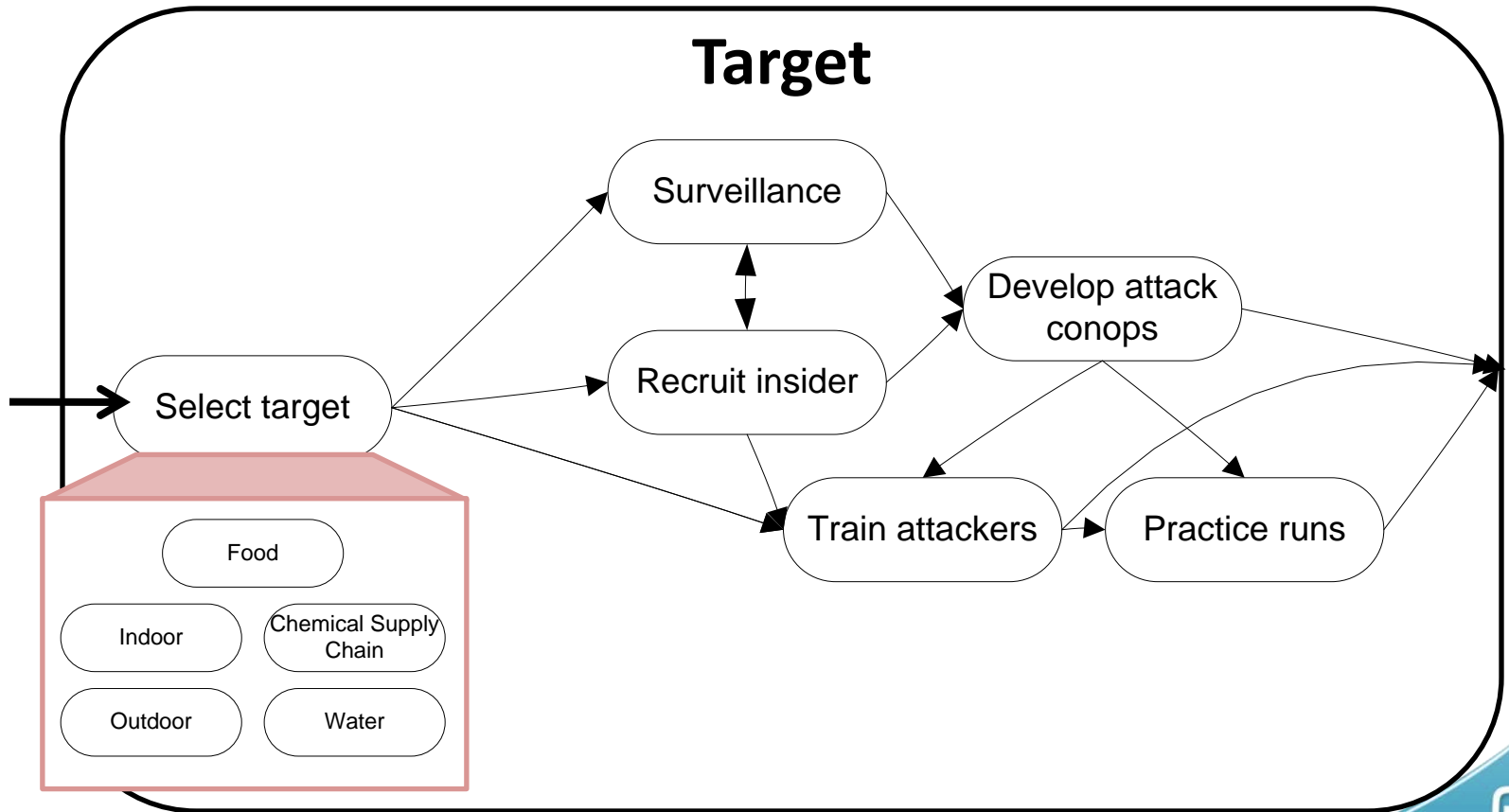
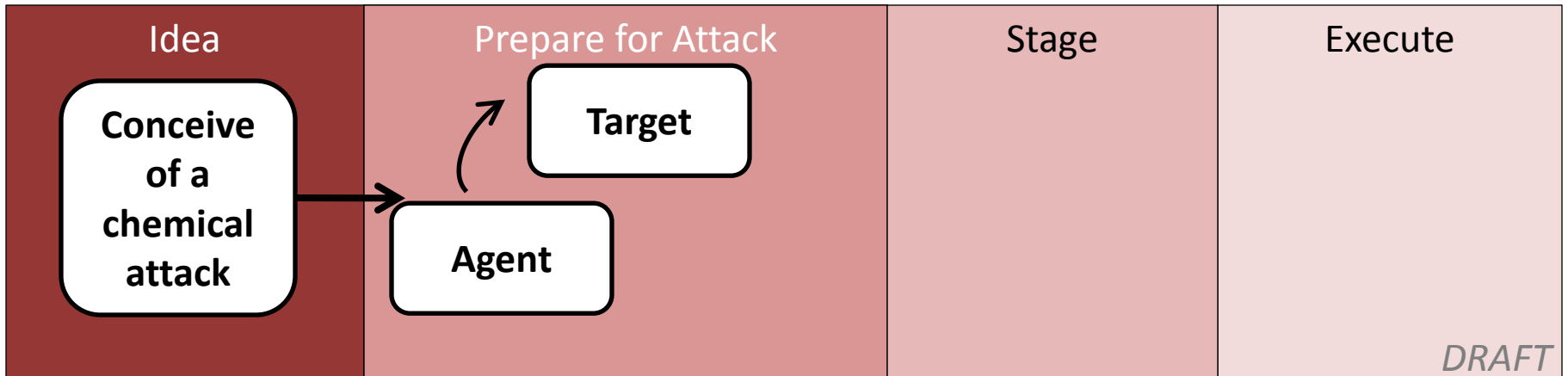
One attack scenario that an adversary might prepare and execute:

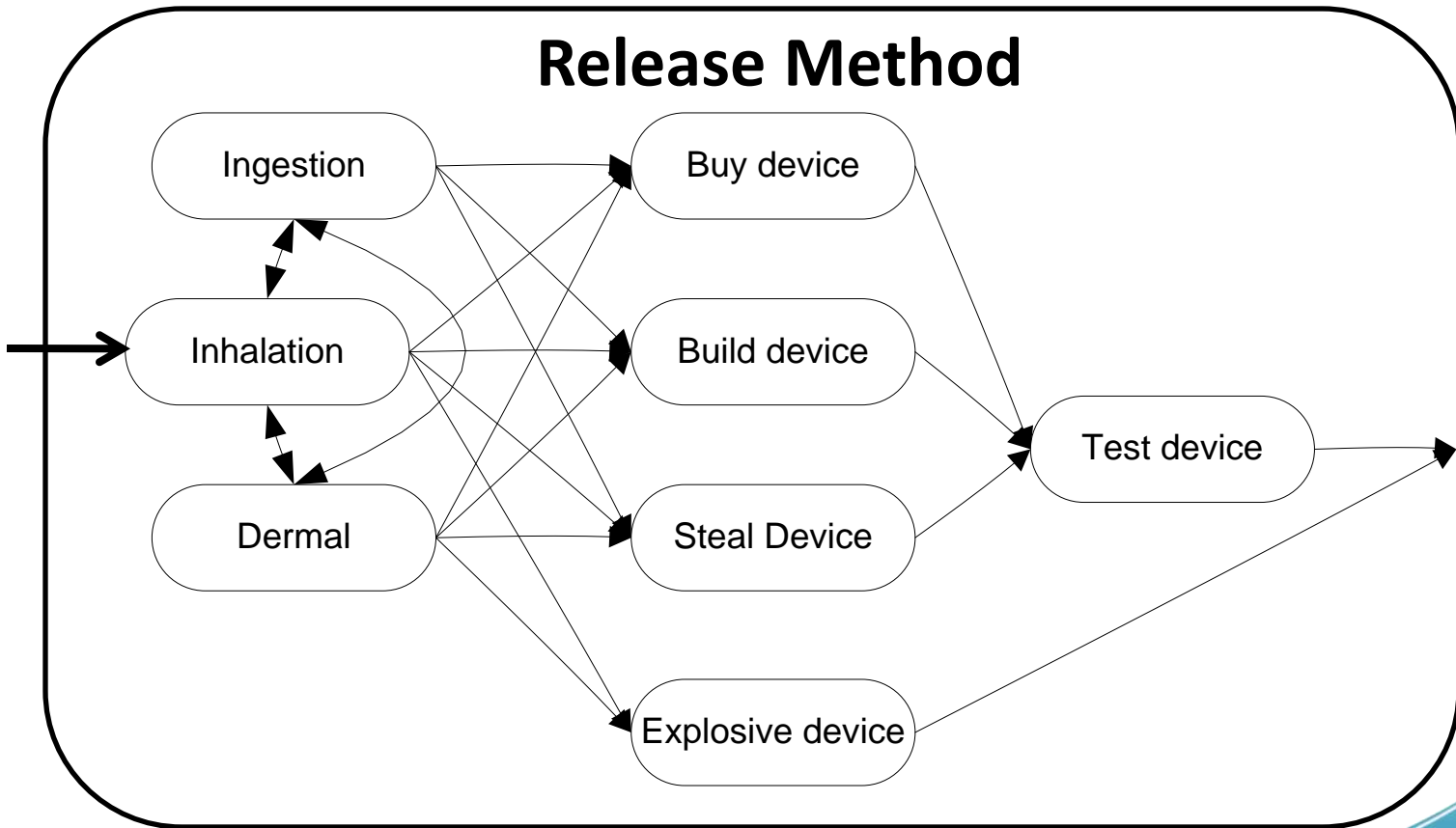
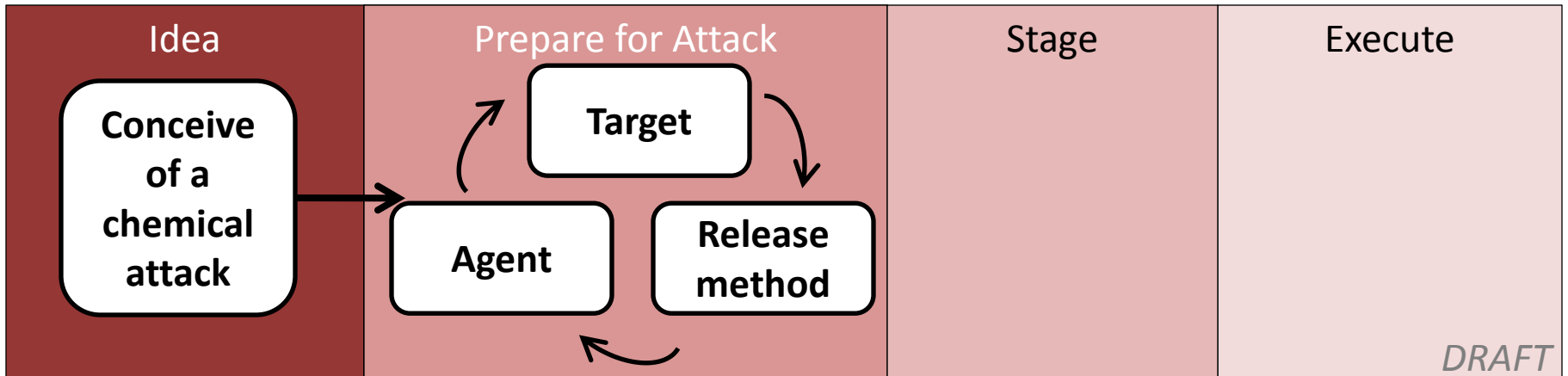


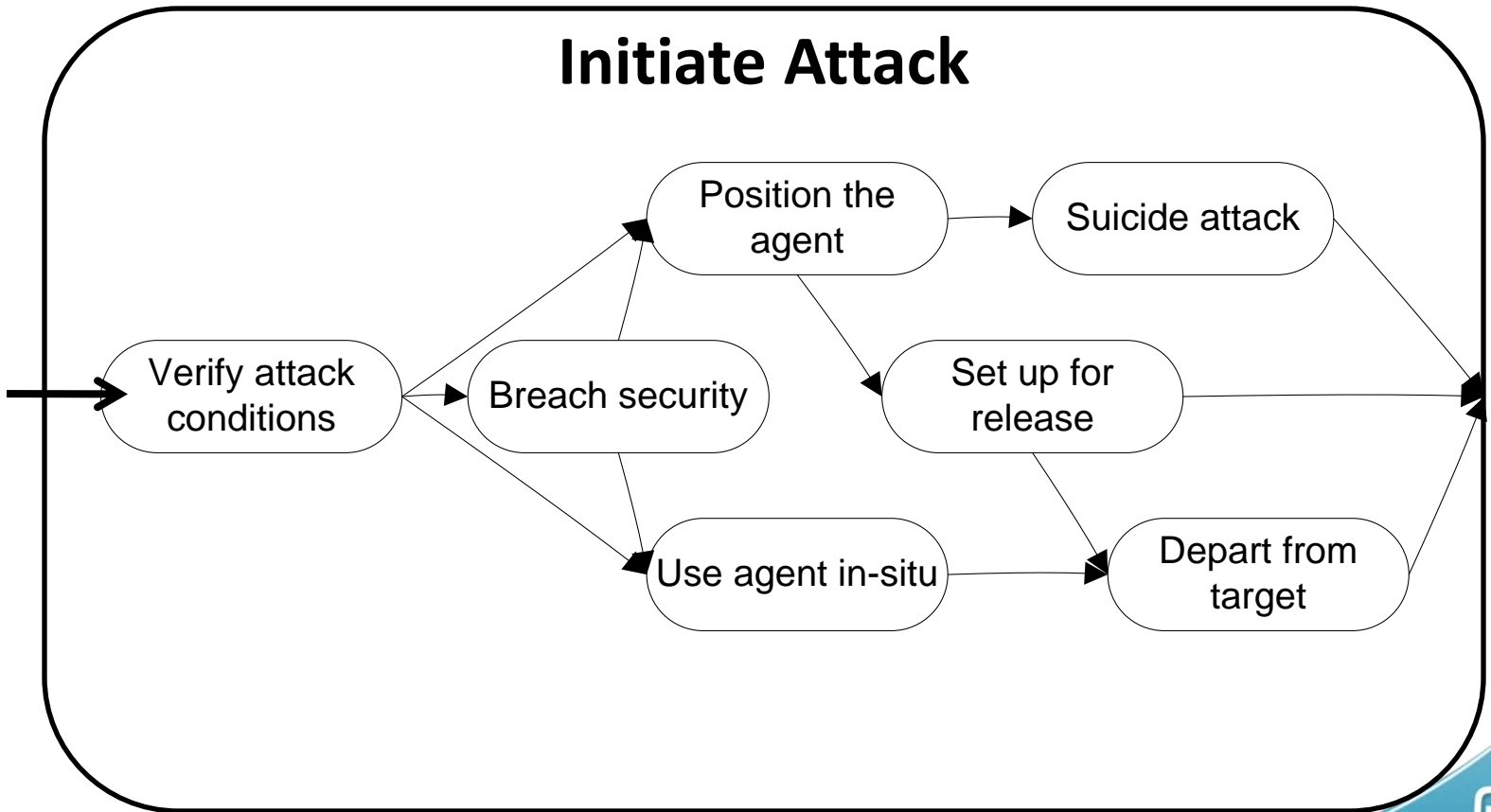
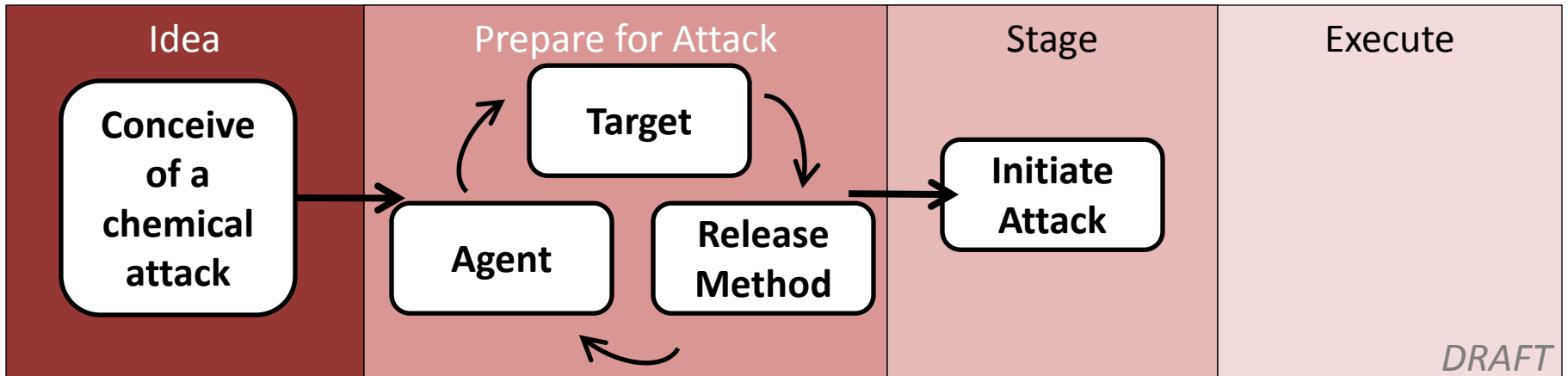
There are many “paths” for chemical terrorism

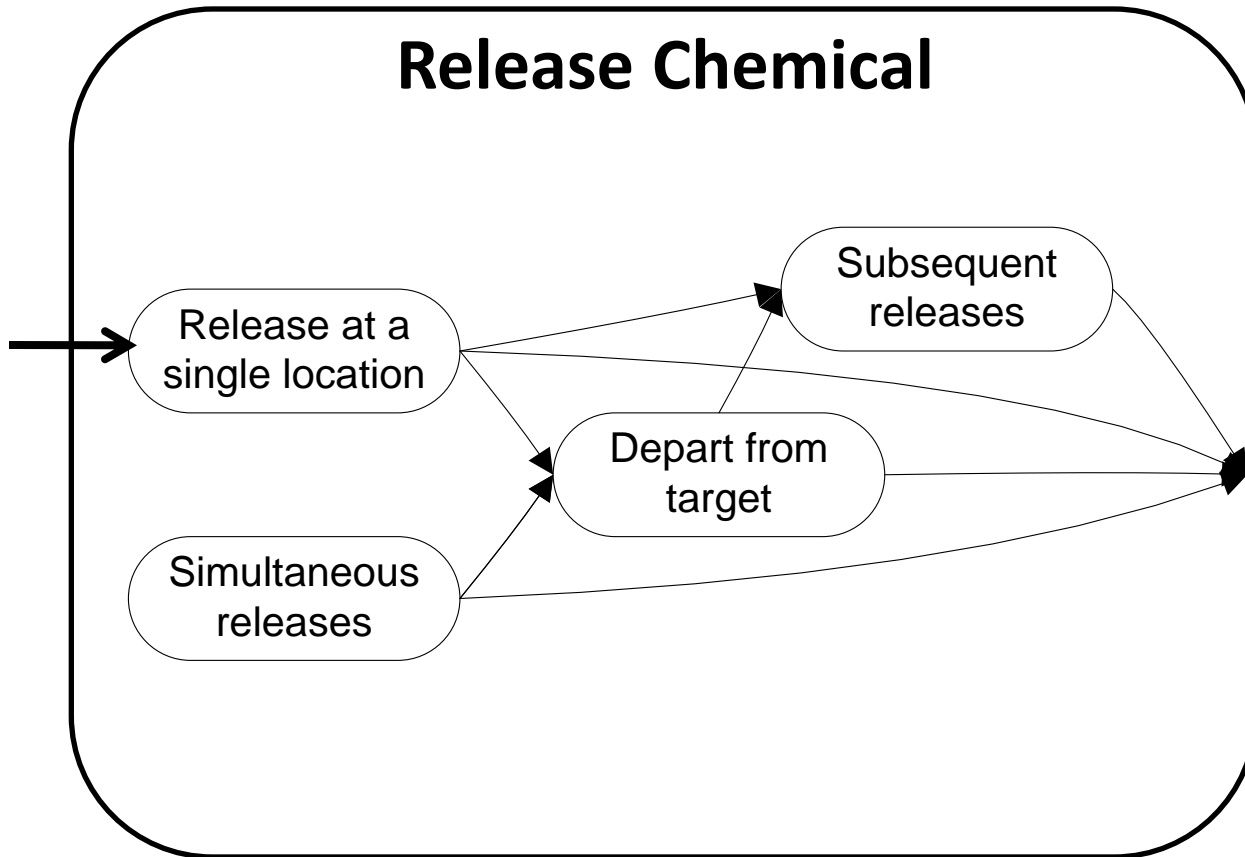
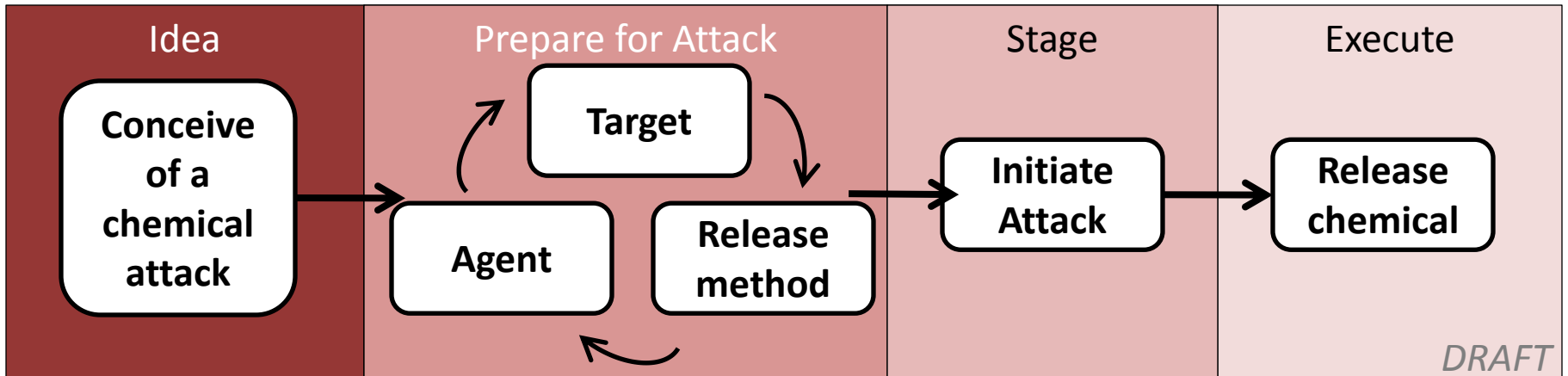


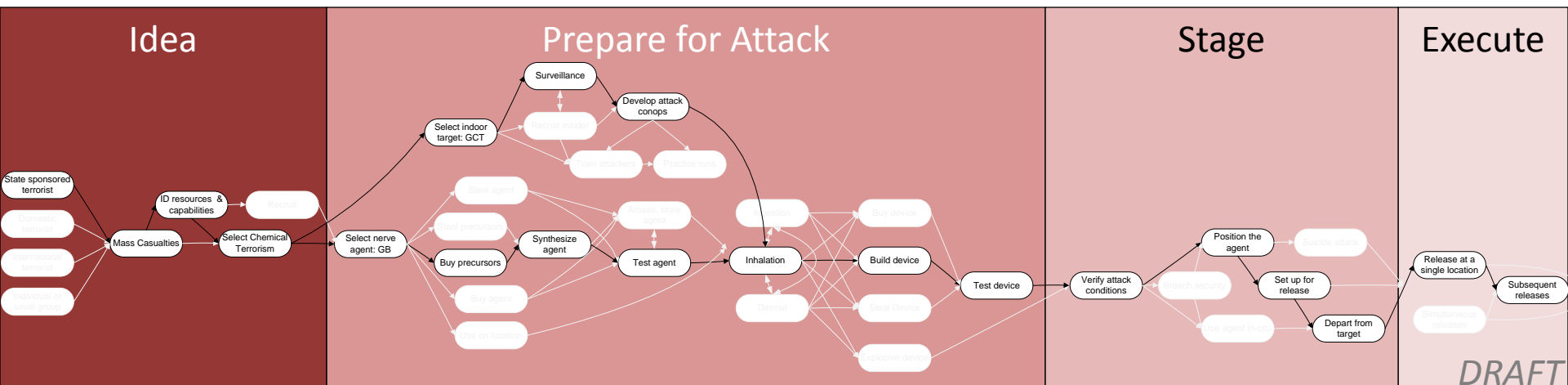




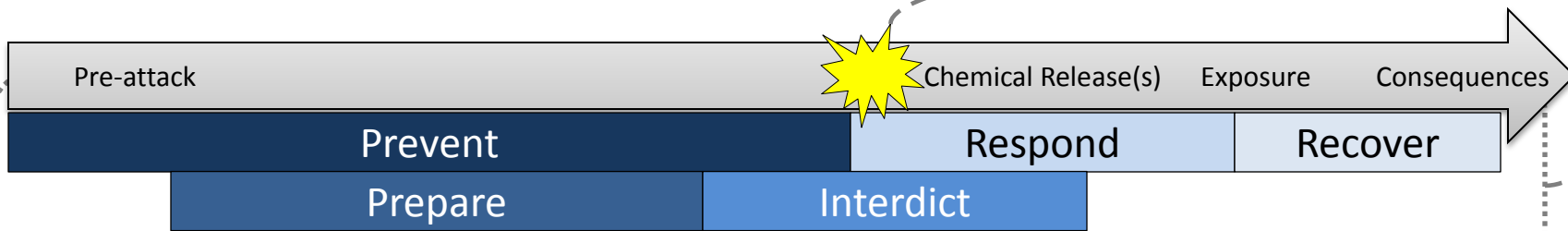






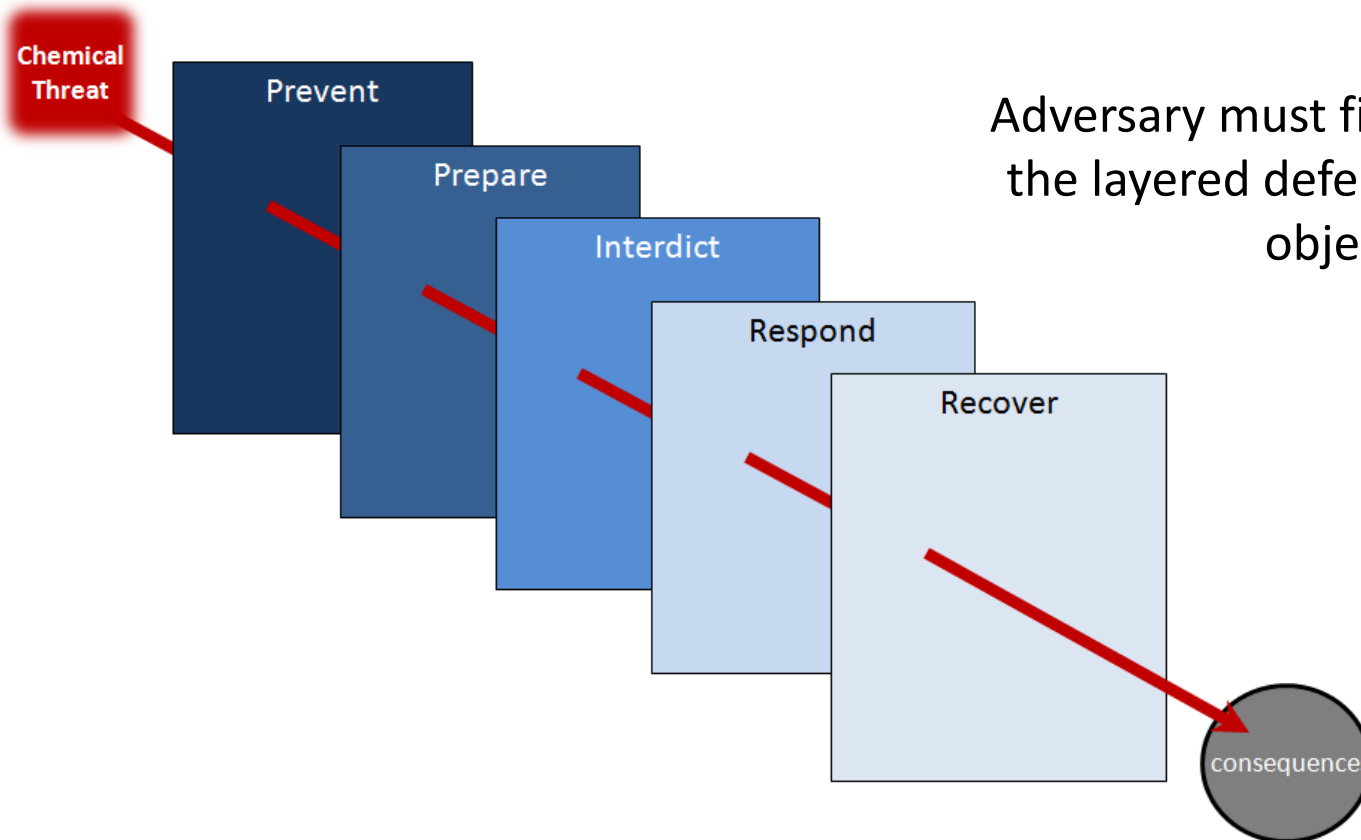
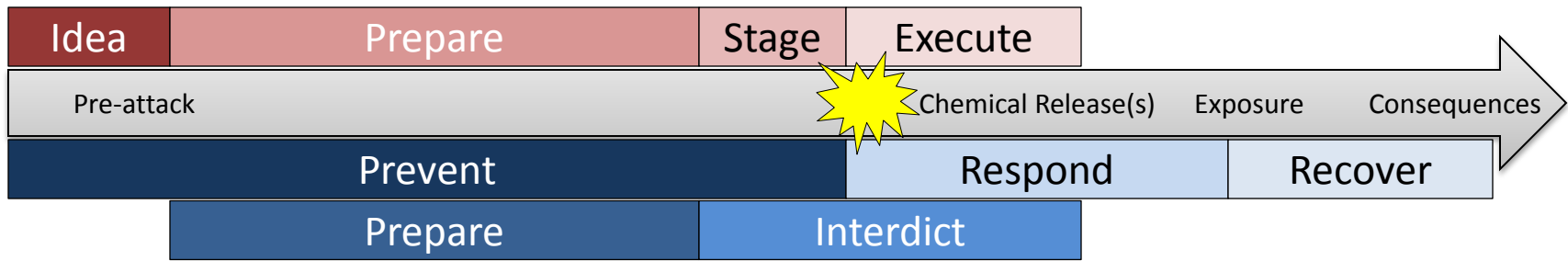


- Is this a direct pathway? What about feedback loops?
- How does the defense influence the scenario pathway?



Defense Actions

Defense actions



Adversary must find a path through the layered defense to achieve his objectives

Defense actions

Prevent: defense measures that interfere with the adversary's attack preparation, i.e. stop them from assembling resources/capabilities for attack

Prevent

- Counterterrorism
- Physical security in chem supply chain
- Policies & regulations on toxic chemicals
- Inherently Safer Technologies
- Operational security
- Deterrence

Prepare

Interdict

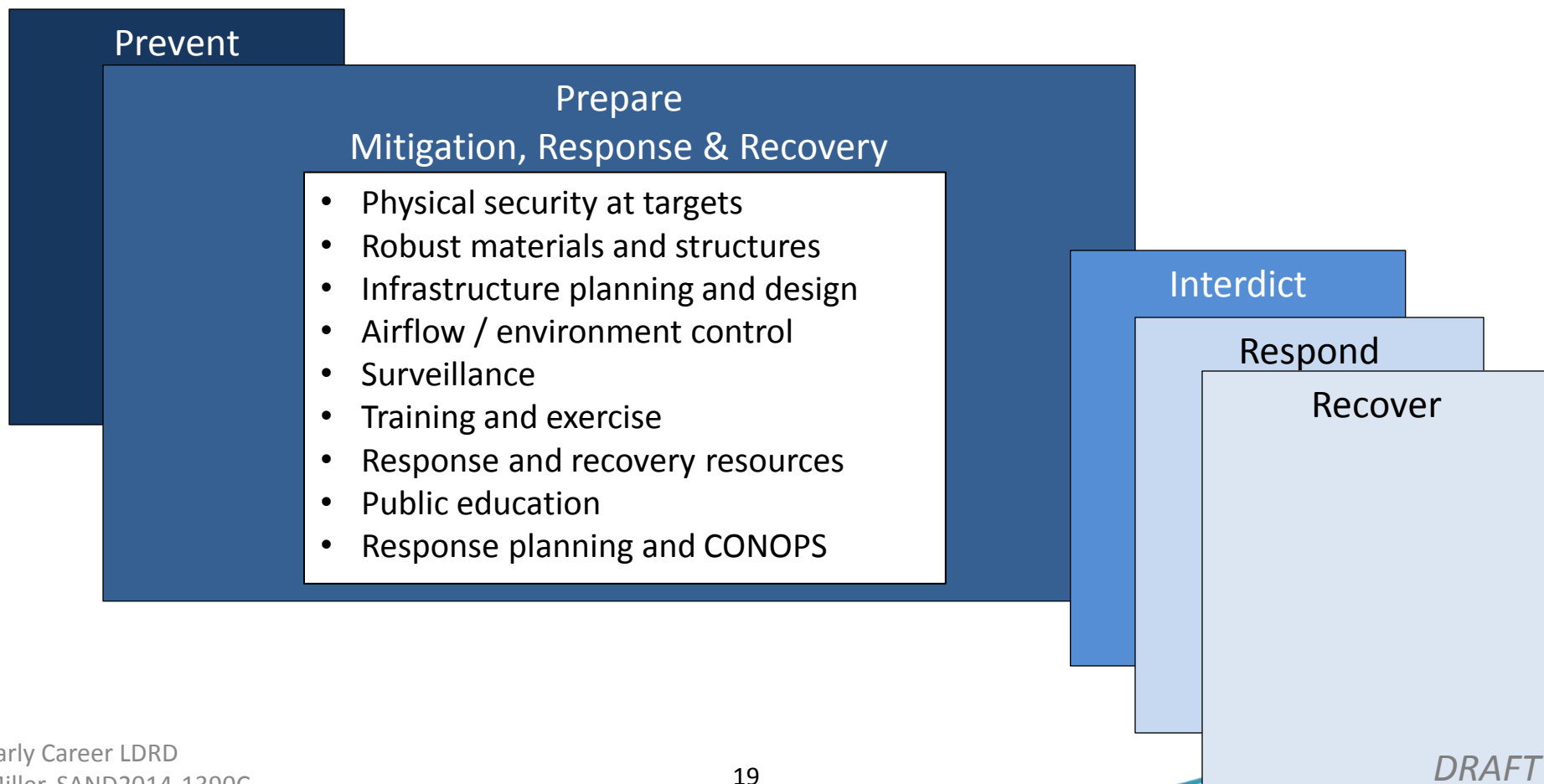
Respond

Recover

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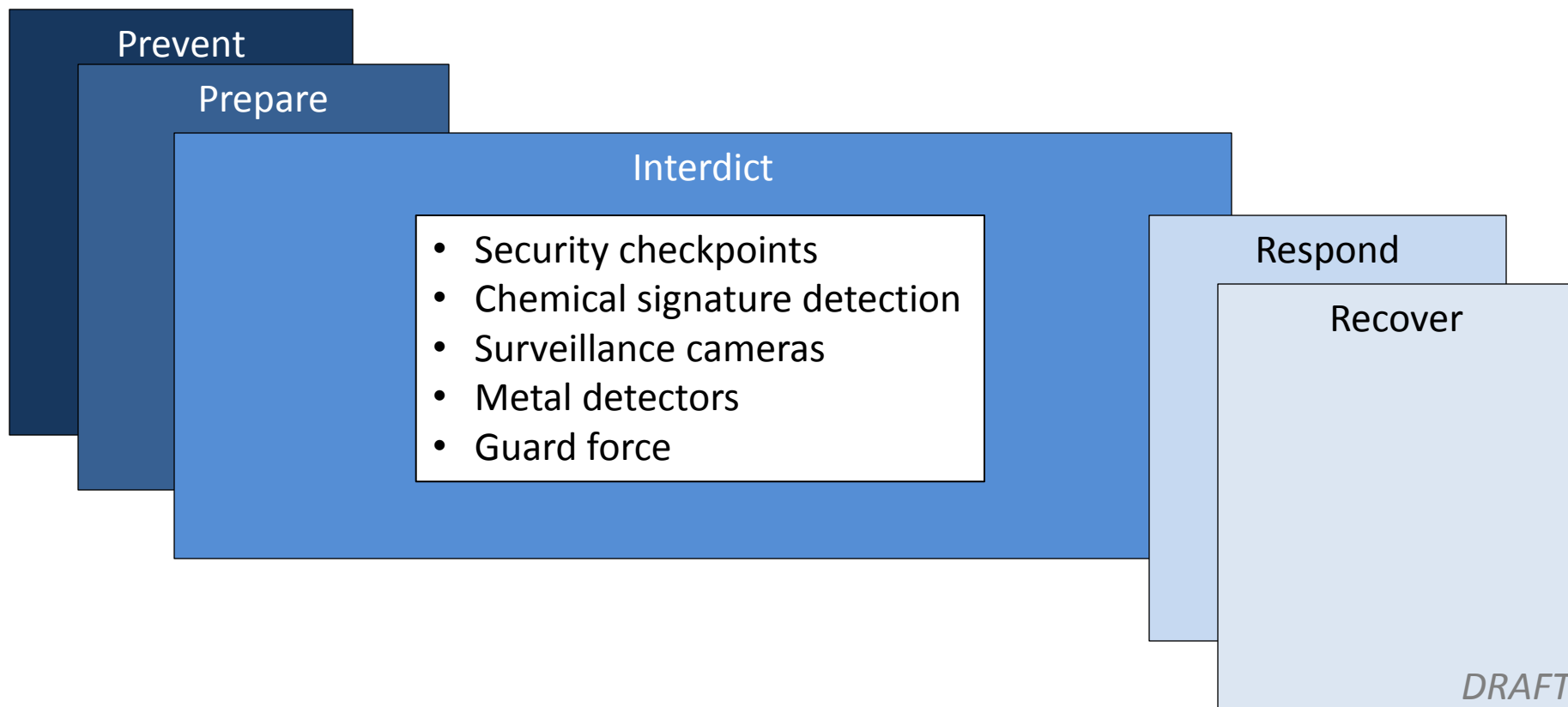
Defense actions

Prepare: defense measures that alleviate the consequences, either passively or actively, of an attack that has been executed



Defense actions

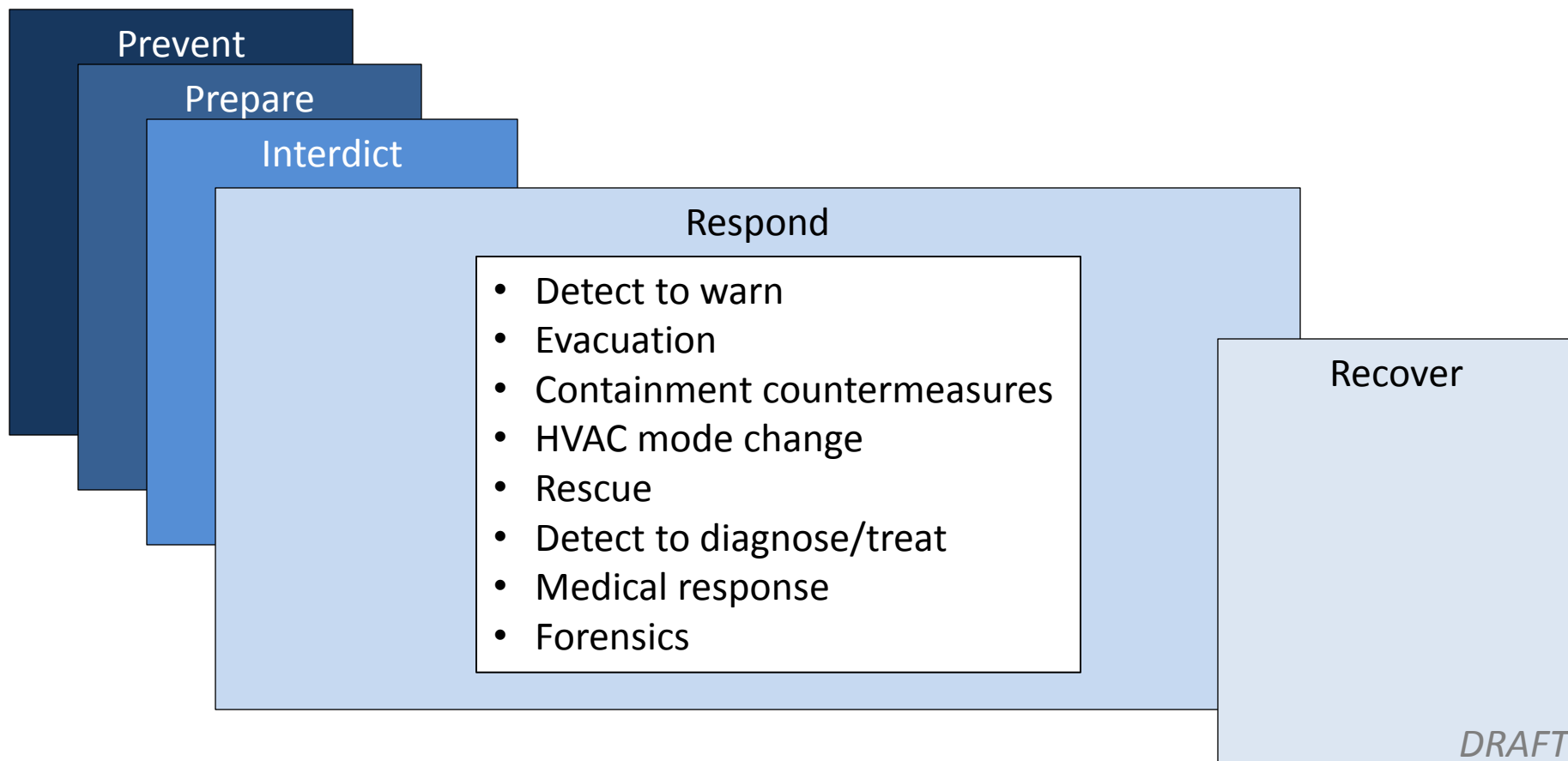
Interdict: defense measures that interrupt the adversary during staging or execution of the attack



Defense actions

Respond: defense measures initiated after the release to mitigate the impact of the attack

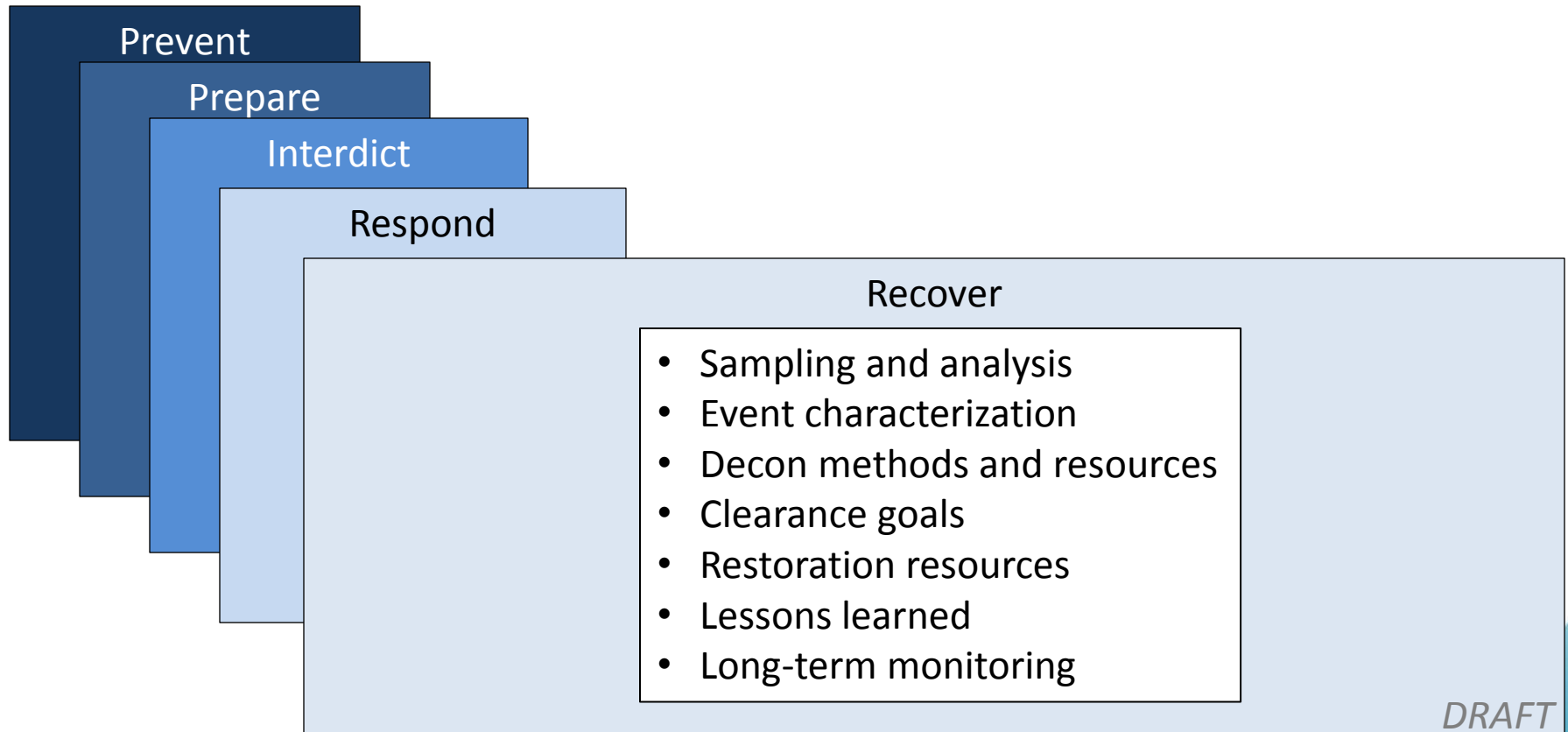
- resources and capabilities are prepared pre-attack



Defense actions

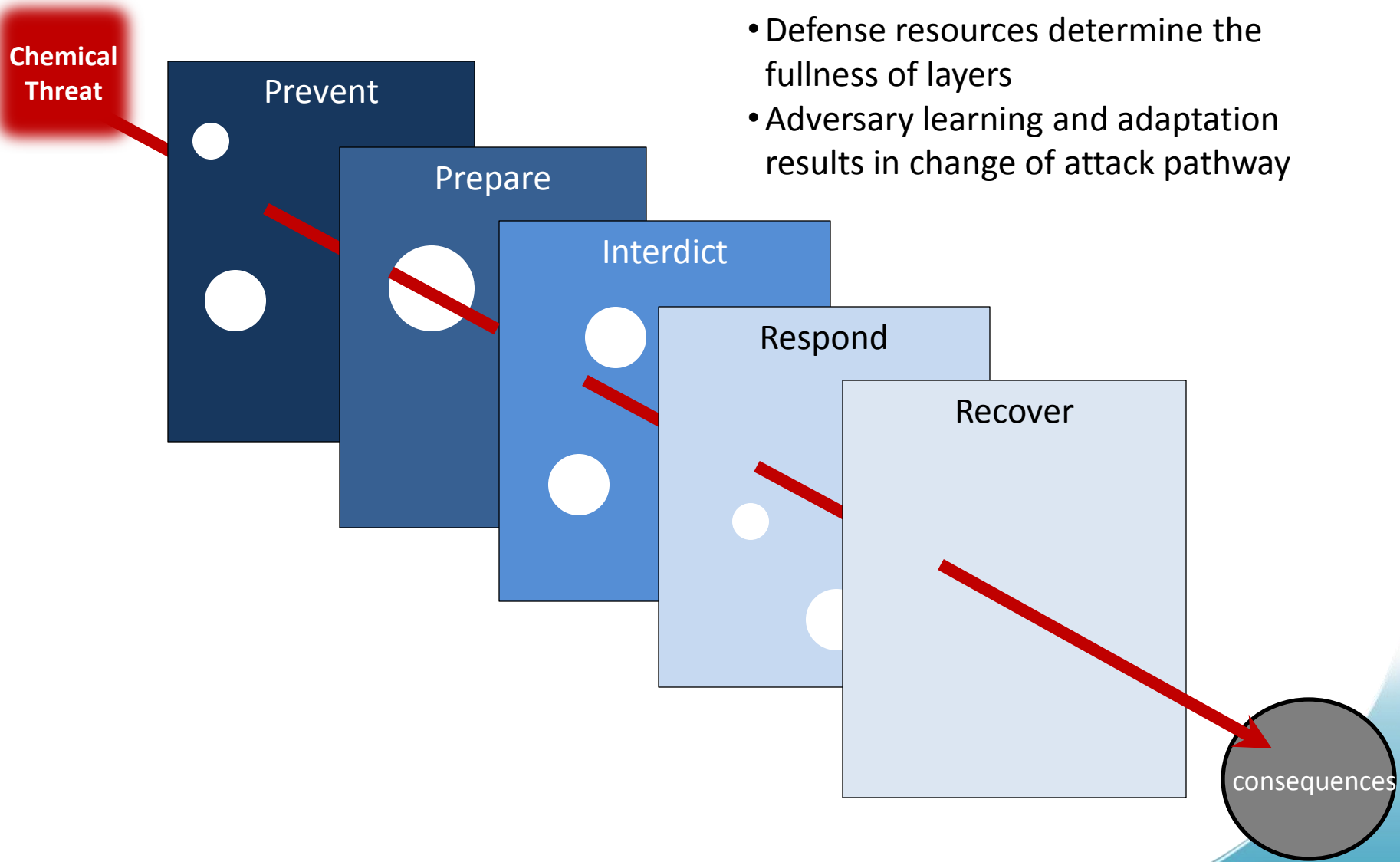
Recover: measures taken to return a target to normal operations and provide for long-term monitoring of the venue and victims

- resources and capabilities are prepared pre-attack and enhanced post-attack



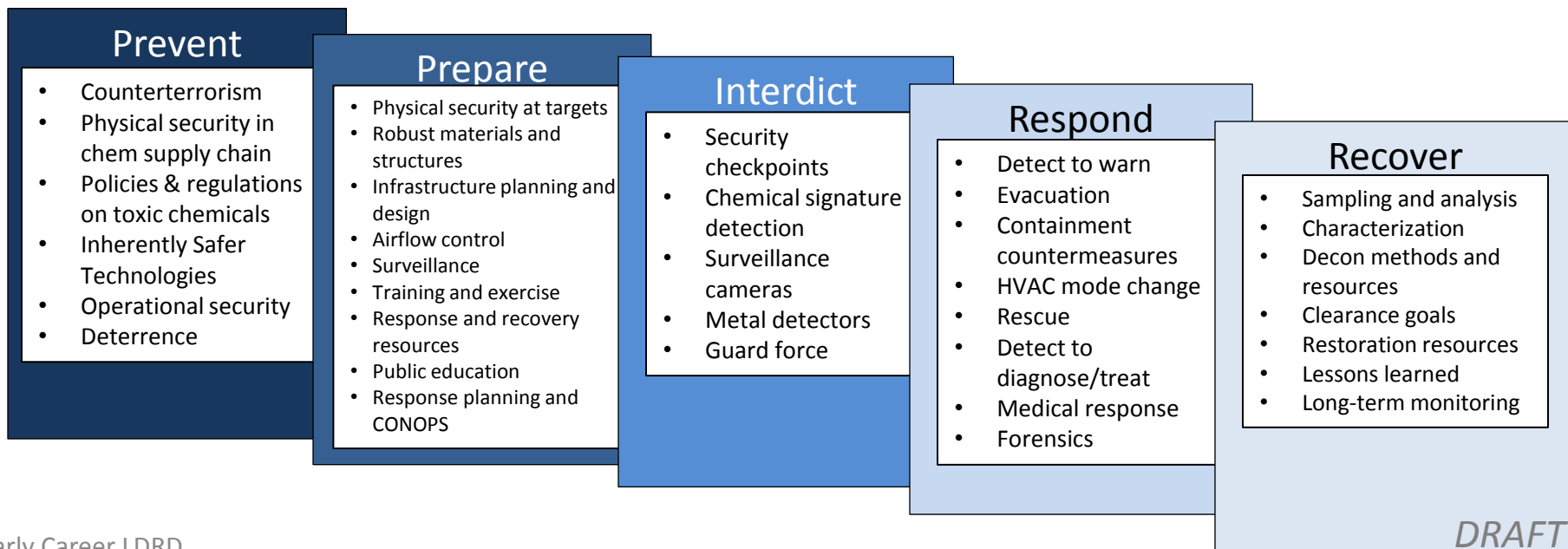
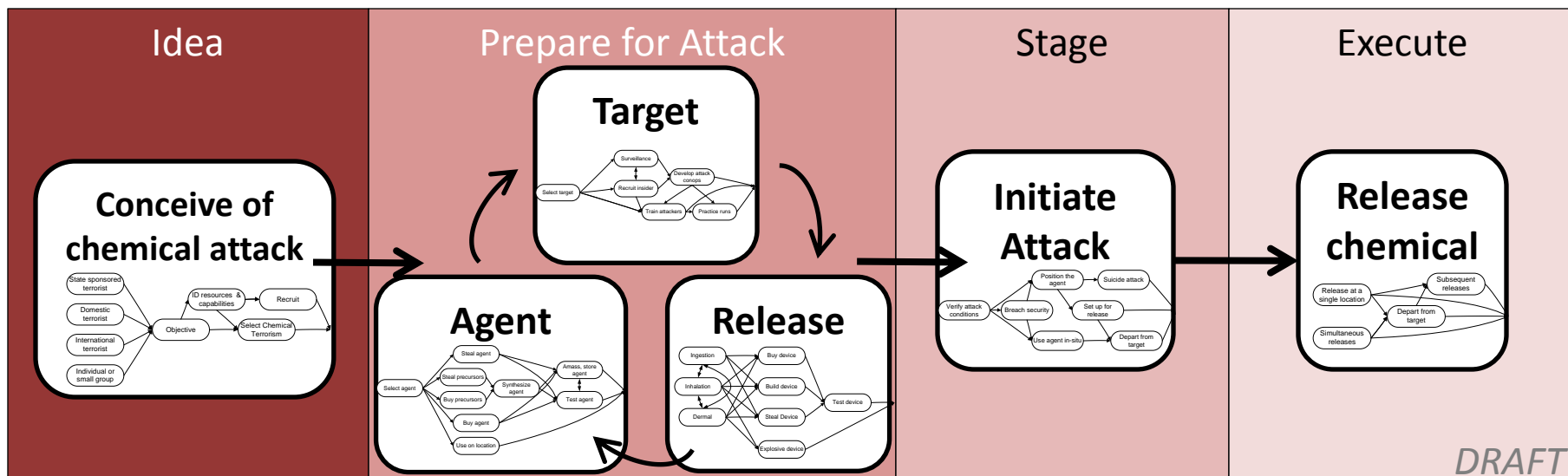
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Chemical Defense Framework

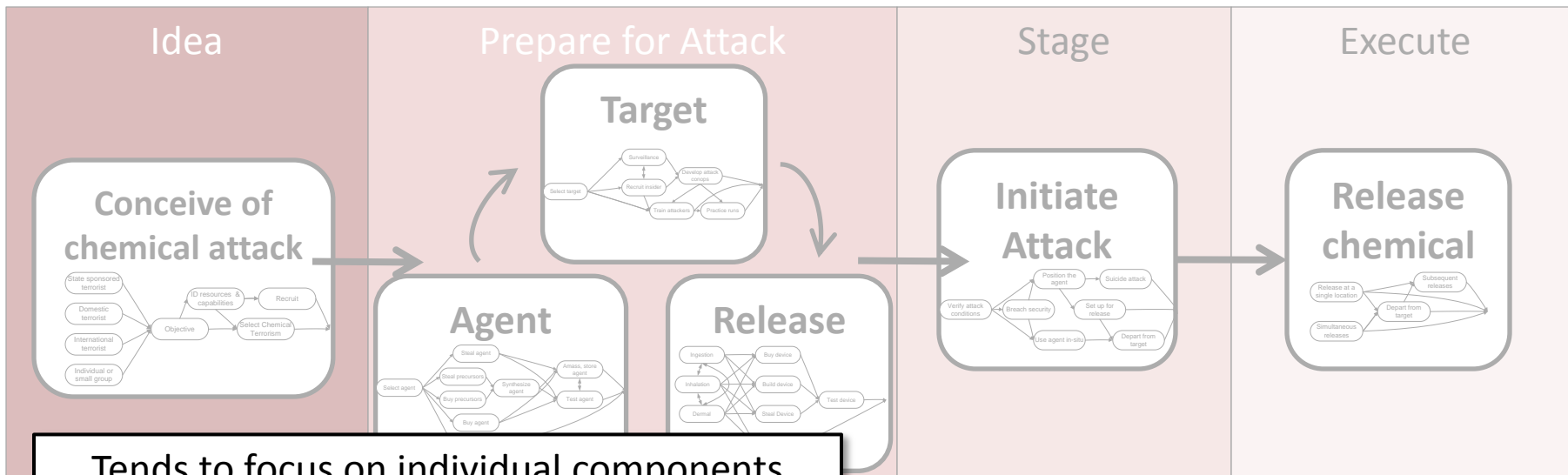


- Defense resources determine the fullness of layers
- Adversary learning and adaptation results in change of attack pathway

Chemical Defense Framework



Chemical Defense Framework



Tends to focus on individual components rather than integrated system.

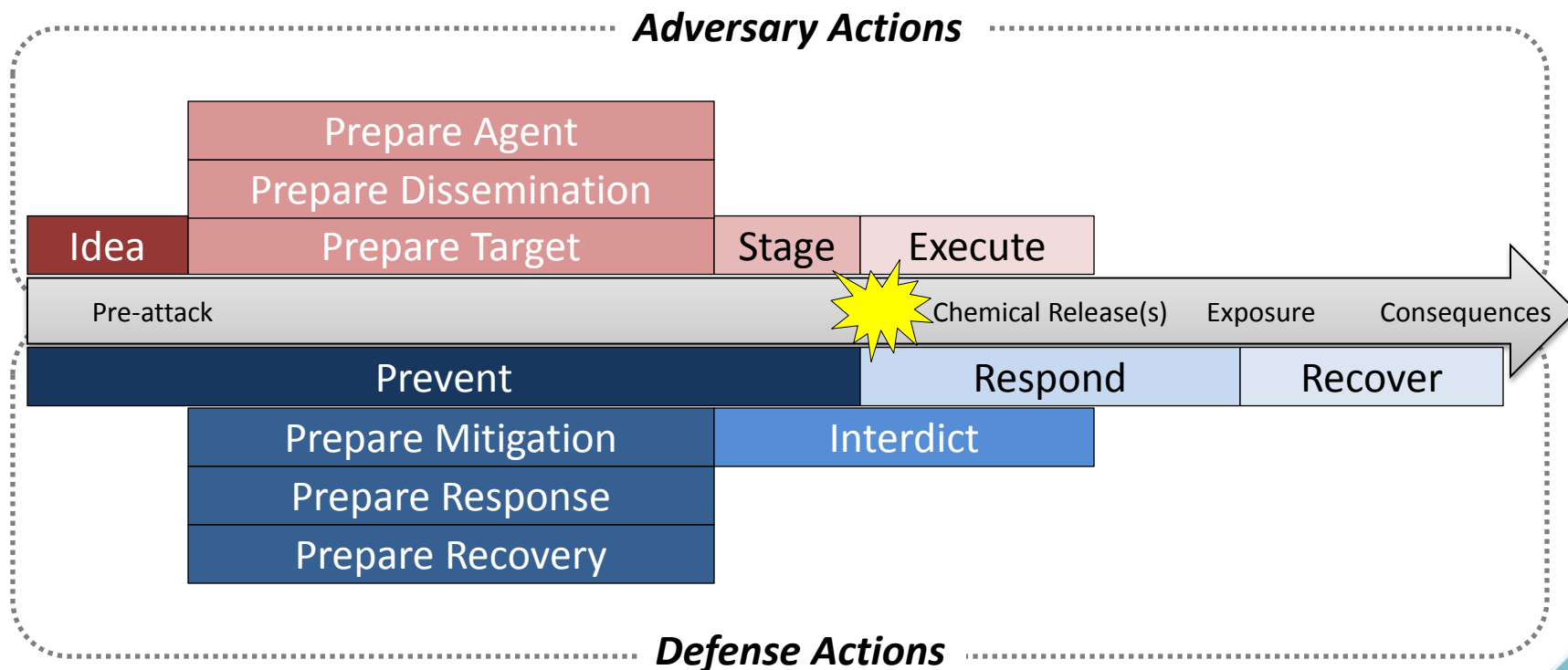
Prevent	Prepare	Interdict	Respond	Recover
<ul style="list-style-type: none"> Counterterrorism Physical security in chem supply chain Policies & regulations on toxic chemicals Inherently Safer Technologies Operational security Deterrence 	<ul style="list-style-type: none"> Physical security at targets Robust materials and structures Infrastructure planning and design Airflow control Surveillance Training and exercise Response and recovery resources Public education Response planning and CONOPS 	<ul style="list-style-type: none"> Security checkpoints Chemical signature detection Surveillance cameras Metal detectors Guard force 	<ul style="list-style-type: none"> Detect to warn Evacuation Containment countermeasures HVAC mode change Rescue Detect to diagnose/treat Medical response Forensics 	<ul style="list-style-type: none"> Sampling and analysis Characterization Decon methods and resources Clearance goals Restoration resources Lessons learned Long-term monitoring

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Chemical defense is more than the sum of its parts!!!

Chemical Defense Framework

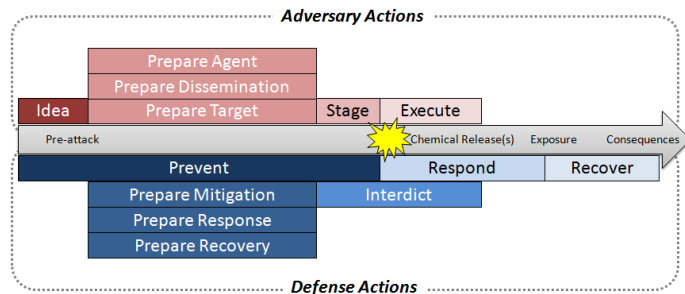
How to should we model the structure and behavior of the chemical defense system?



Chemical Defense Model

- **Why do we need a model?**

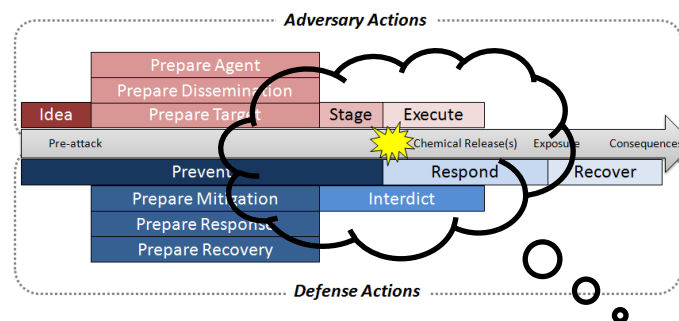
Our “mental model” of the chemical defense system cannot utilize all required information at once



Chemical Defense Model

Why do we need a model?

Our “mental model” of the chemical defense system cannot utilize all required information at once



Need a model that describes complex structure & behavior

Begin with the chemical defense framework

Describe influences and interactions within the system



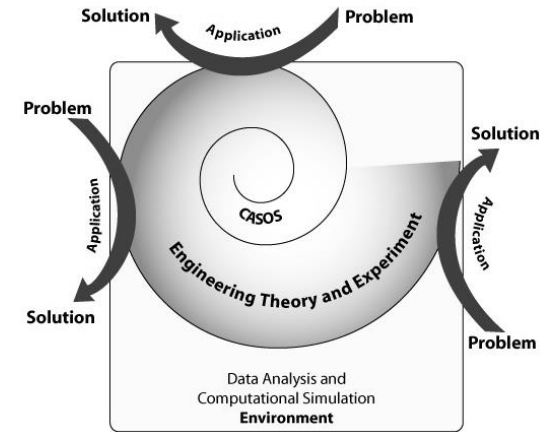
Chemical Defense may be modeled as a Complex Adaptive System of Systems (CASoS)

Complex Adaptive Systems of Systems (CASoS)



“CASoS are vastly complex ***physical-socio-technical systems*** which we must understand to design a secure future for the nation and the globe.”

→ **CASoS Engineering Initiative**
Glass, R. J. *et al.* SAND 2008-4651



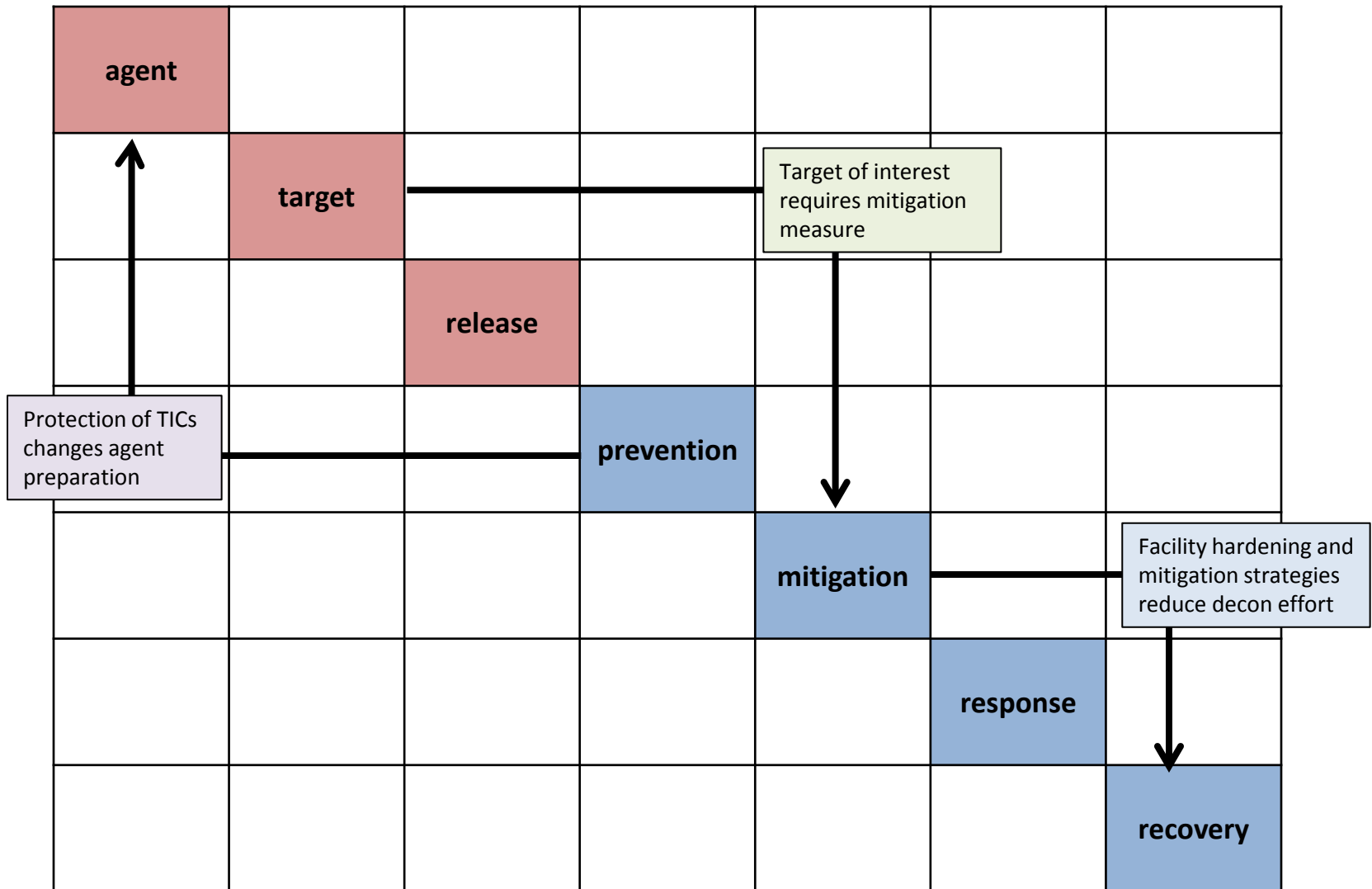
Moving away from the blindfolded men and the elephant...

CASoS Engineering provides an integrated research approach:

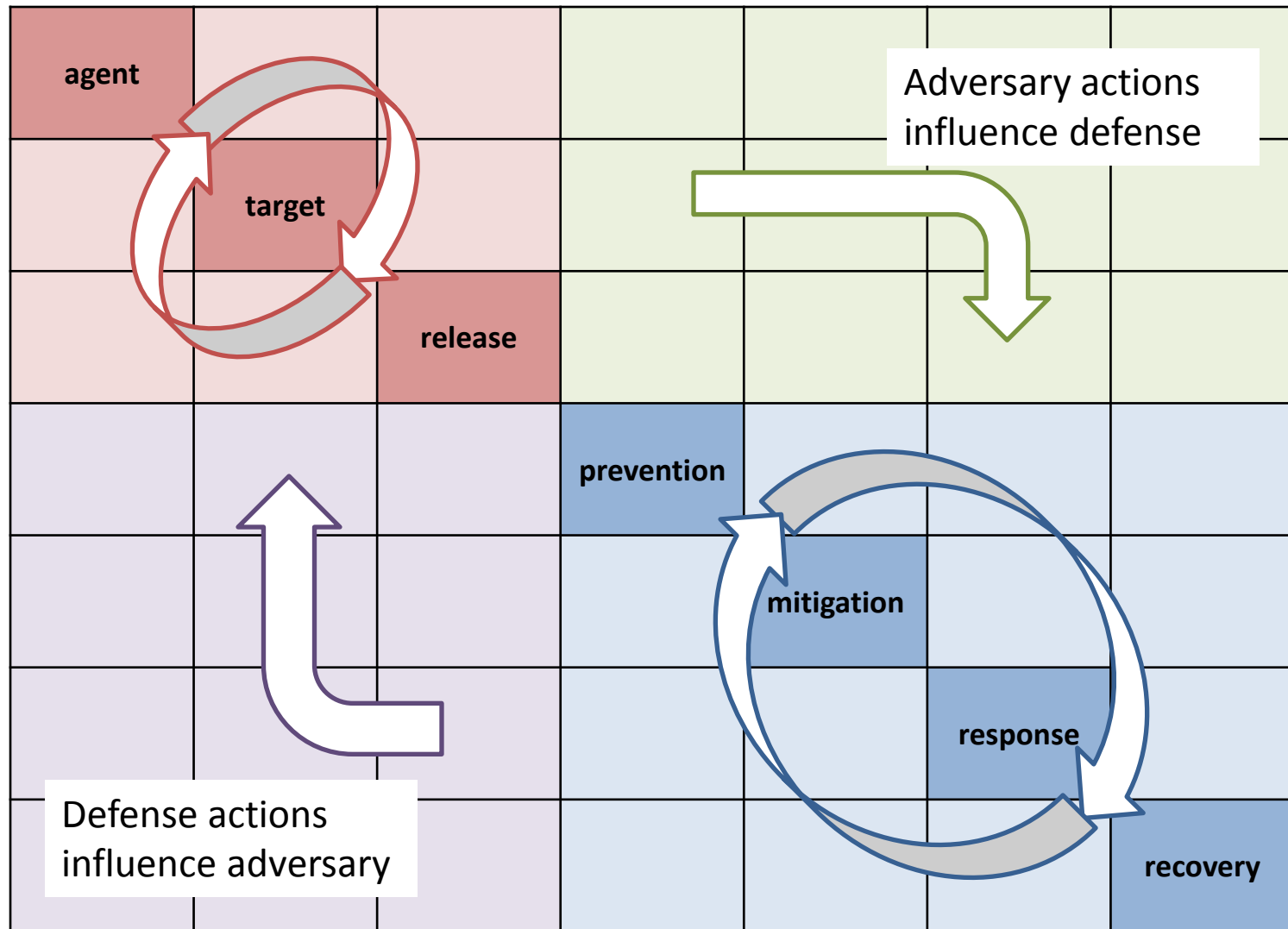
- Multi-disciplinary tool boxes
- Conceptual modeling and representation
- Analysis and computational simulation

Influence Matrix

A tool to diagram interactions between system components

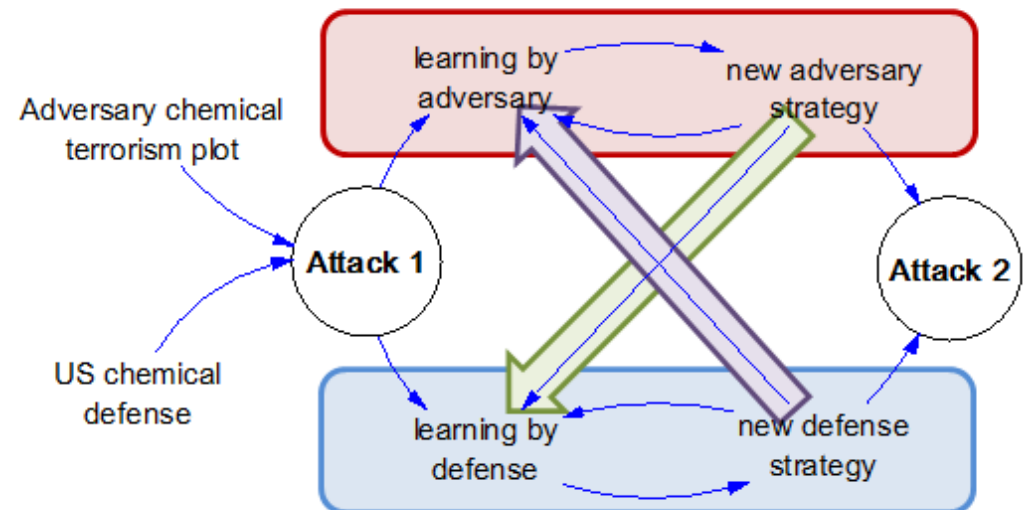
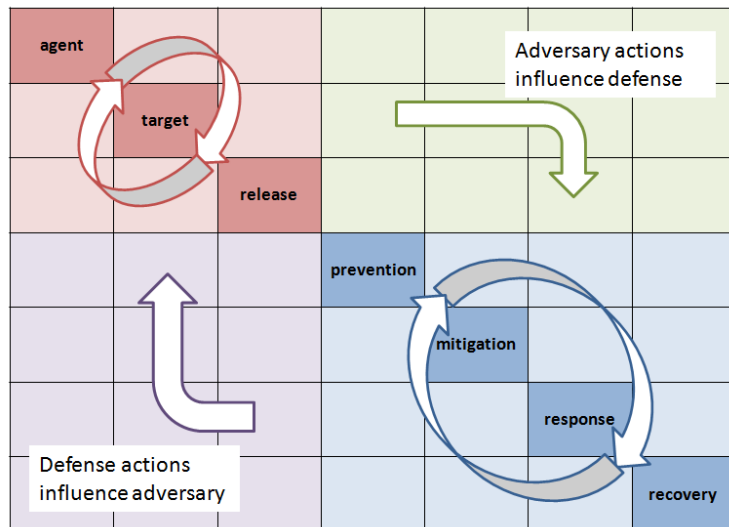


Influence Matrix



System Dynamics

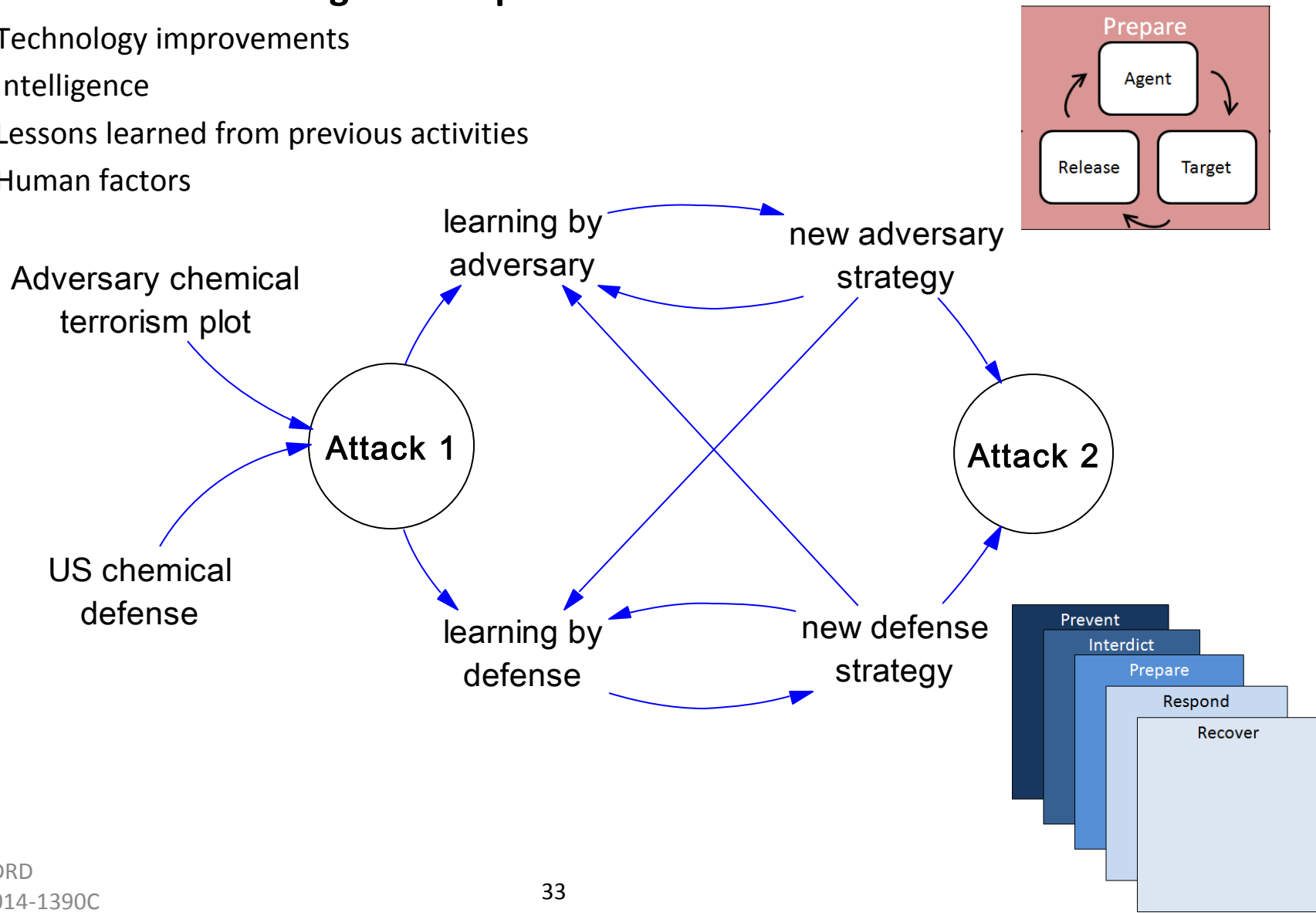
- Influence Matrix is a static representation of system interactions
- Advantages of System Dynamics modeling:
 - System behavior over time
 - Resolution can be high-level detailed technical
 - Feedback & Delays
 - Perception vs. Reality
- Simple, top-level model of system behavior



System Dynamics

- **Model includes learning and adaptation:**

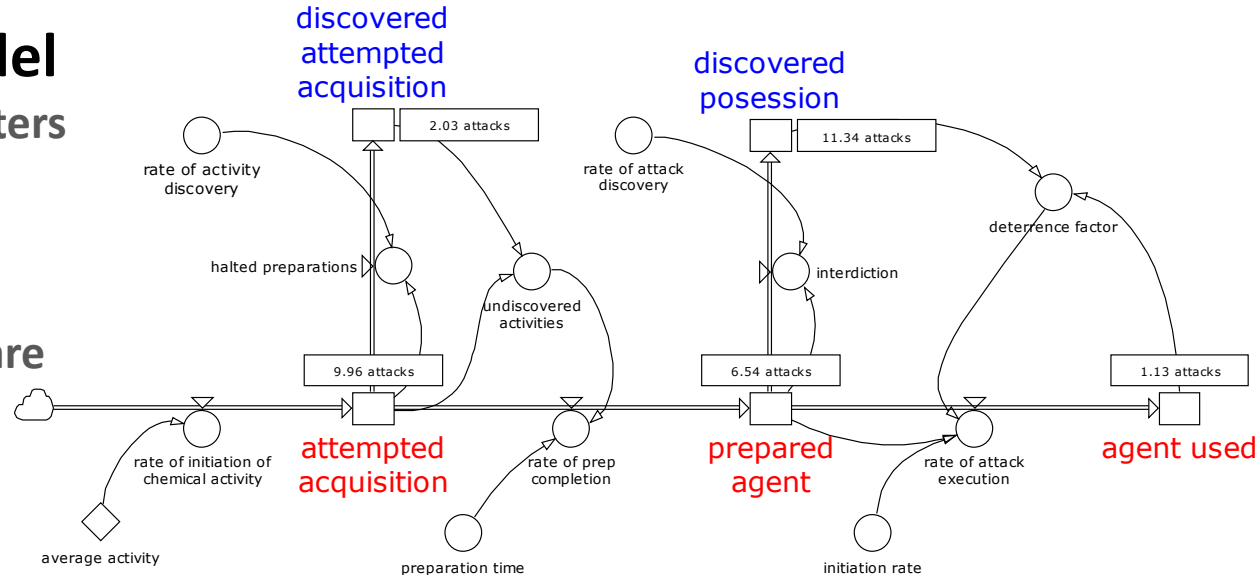
- Technology improvements
- Intelligence
- Lessons learned from previous activities
- Human factors



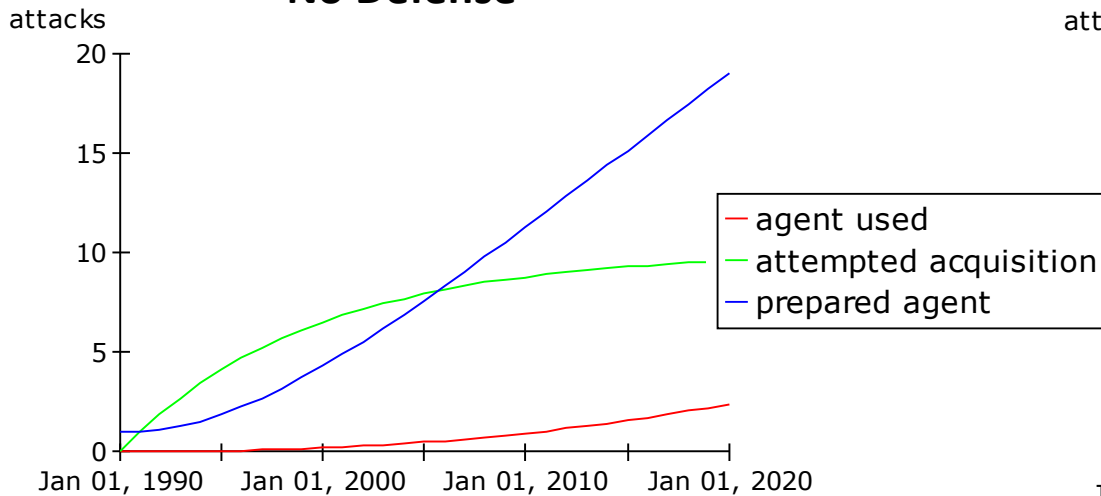
System Dynamics

• Attack pipeline model

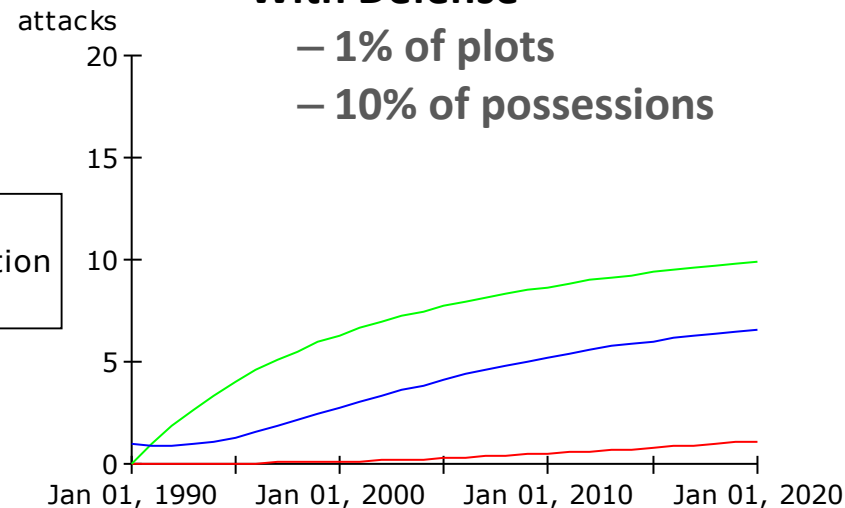
- 1 adversary per year enters into chemical activity
- 10% of acquisition attempts are successful
- 1% of prepared agents are actually used (terrorist attack is executed)



No Defense



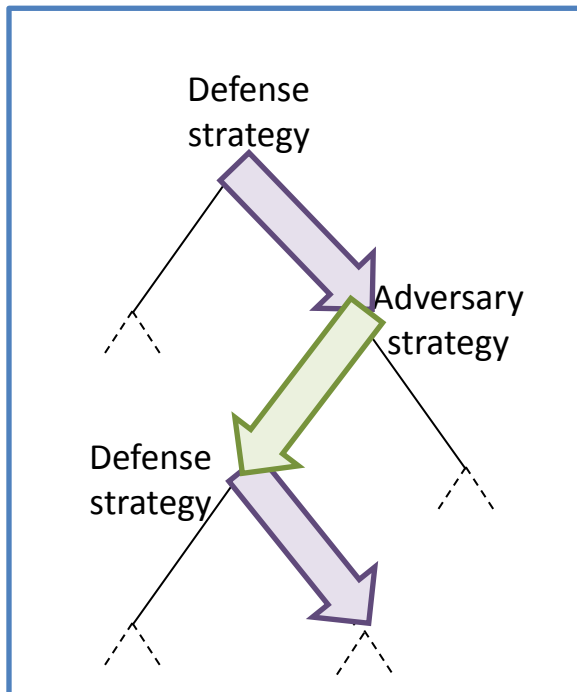
With Defense



Game Theory

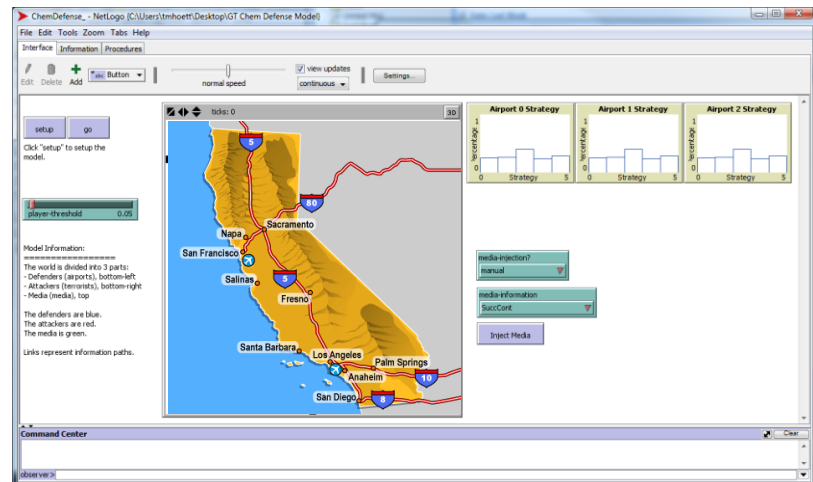
- Adversary vs. Defense
- Use Game Theory to model iterative decision making between adversary and defense
 - Each player makes decisions based on their opponent's previous decision
 - May be useful for predictive defense

Extensive Form Game Tree

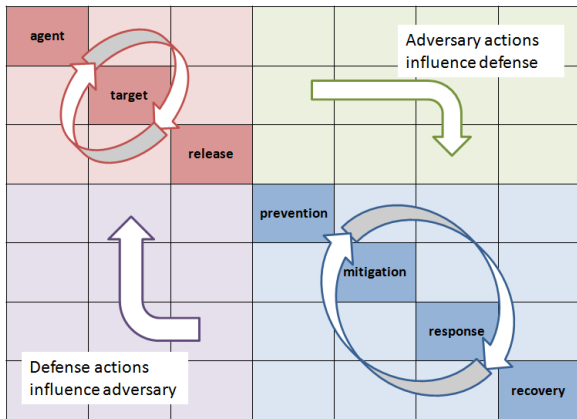


Antagonistic, multi-agent system model (w/ Andrew Smith)

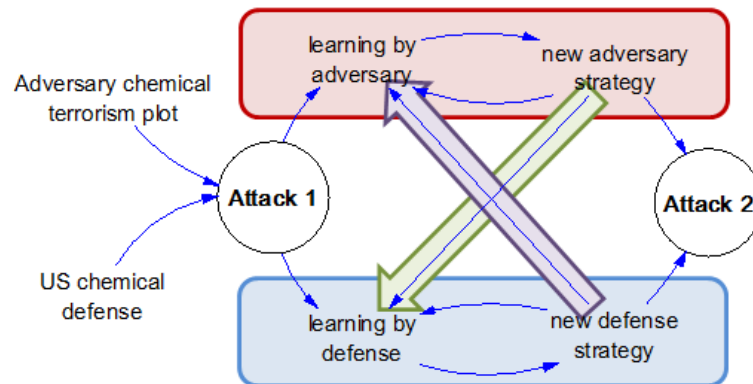
- Airport, terrorist, and media agents
- Utility calculations feed adaptive decision-making by agents



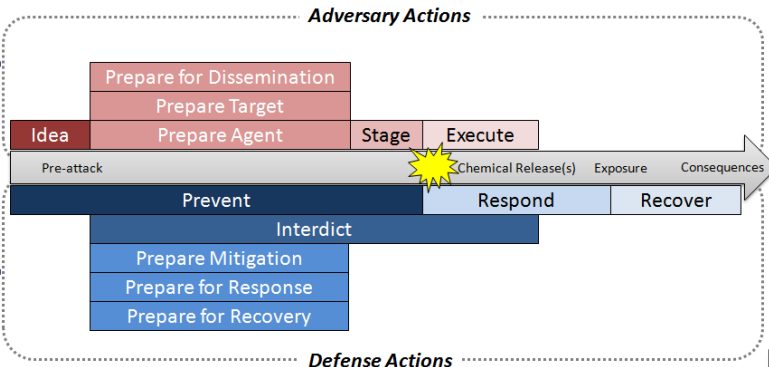
Chemical Defense Model (CDM)



Influence Matrix



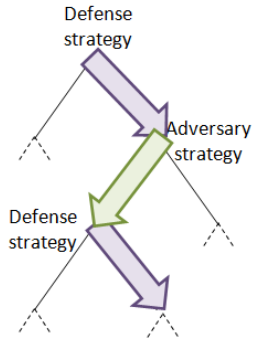
System Dynamics



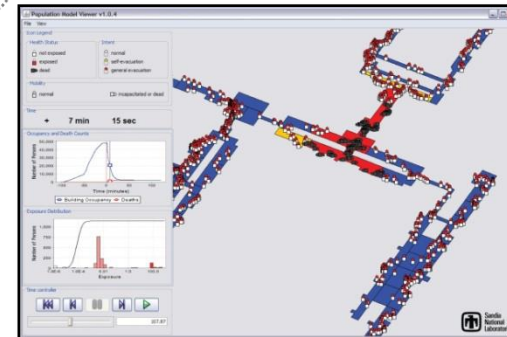
Defense Actions

Game Theory

Extensive Form Game Tree



Scenario Modeling



Within the Chemical Defense Model, system interactions are studied using multiple techniques to develop a more complete picture of the chemical defense system

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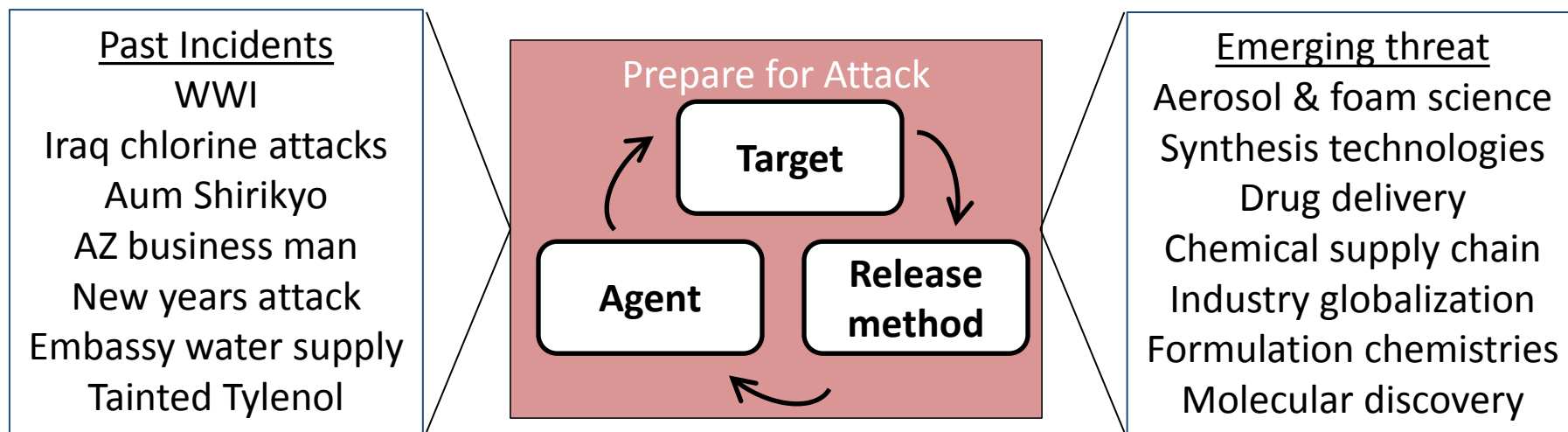
3. Systems analysis questions

- Past, present and future of chemical terrorism
- Importance of chemical defense
- Detection in chemical defense
- Resource allocation
- Application to CBRN

Systems analysis questions that can be investigated with the CDM

- **How is the chemical threat evolving?**
- **How does the defense influence adversary decisions?**
- **How should we allocate defense resources across the architecture?**
- **What is the best way to deploy defense resources and technologies (e.g. detection)?**
- **How does the Chemical Defense Framework compare to other WMD systems?**

Scenario Elements Analysis



- **Three elements define a chemical attack scenario**

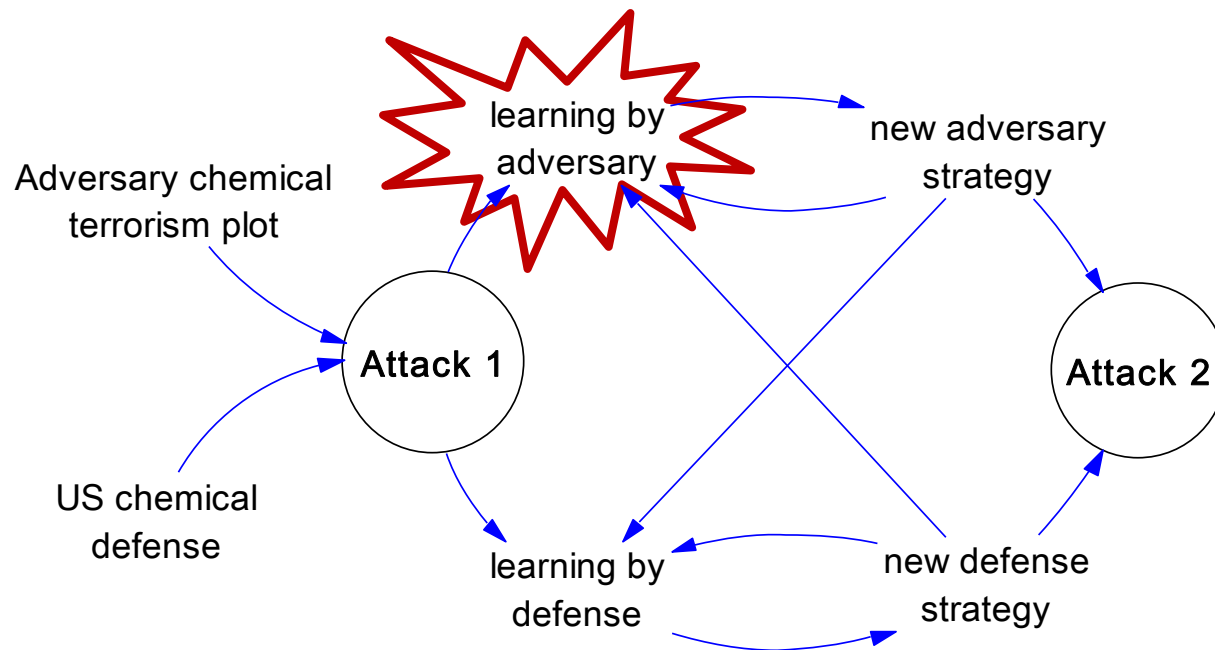
- Efficacy of each element is dependent on the character of the other two elements
- These elements together determine the agent transport and population exposure

- **Conclusions:**

- Low levels of technical expertise needed to prepare and execute a chemical attack
 - *Entry into chemical activity is facile*
- Adversaries learn from both successes and failures
- New S&T can potentially enhance each element and the overall chemical threat

Systems Analysis Questions

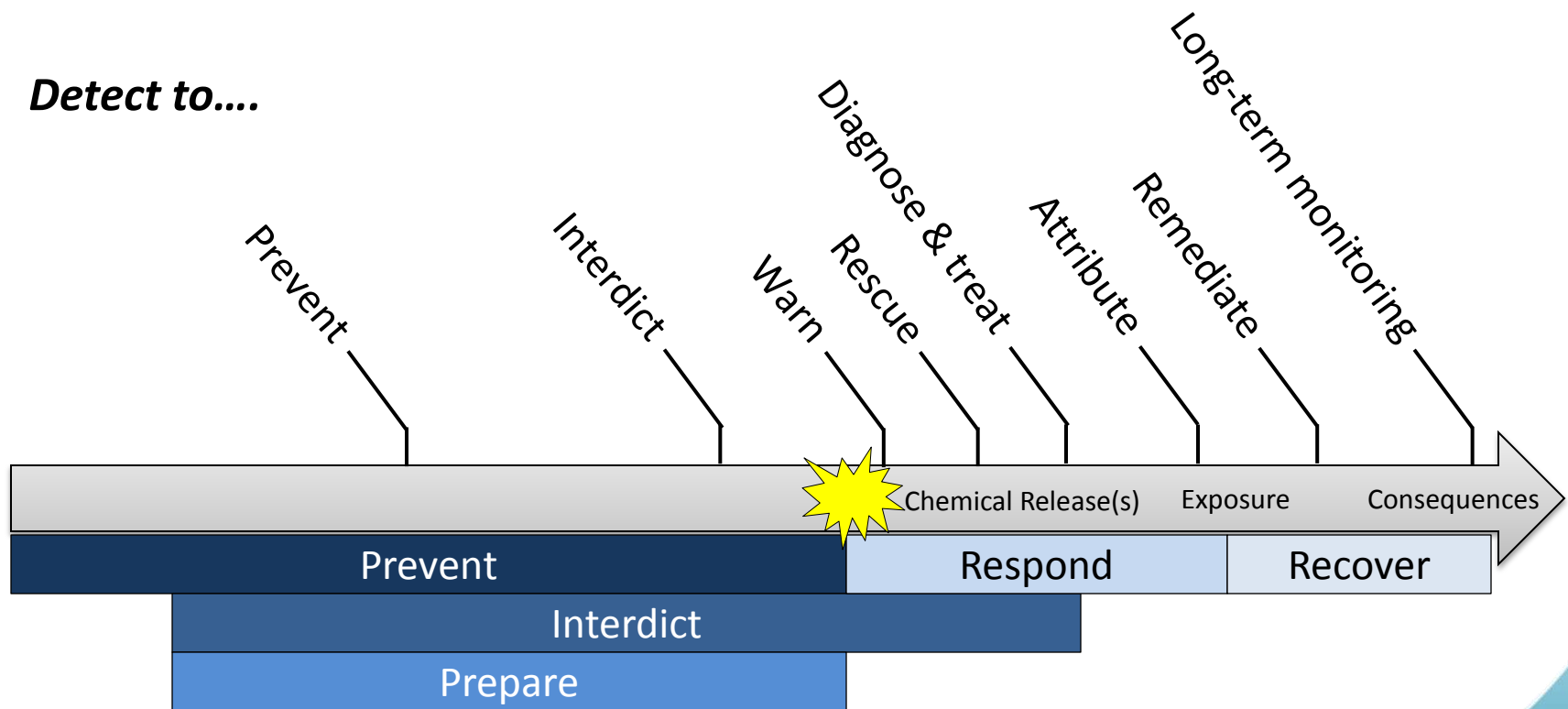
- **Is chemical defense an important problem to address?**
- **Risks:**
 - Precedent for adversary interest in chemical terrorism
 - Emerging technologies may enhance adversary capability
 - Chemical hazards of interest are dual use



Systems Analysis Questions

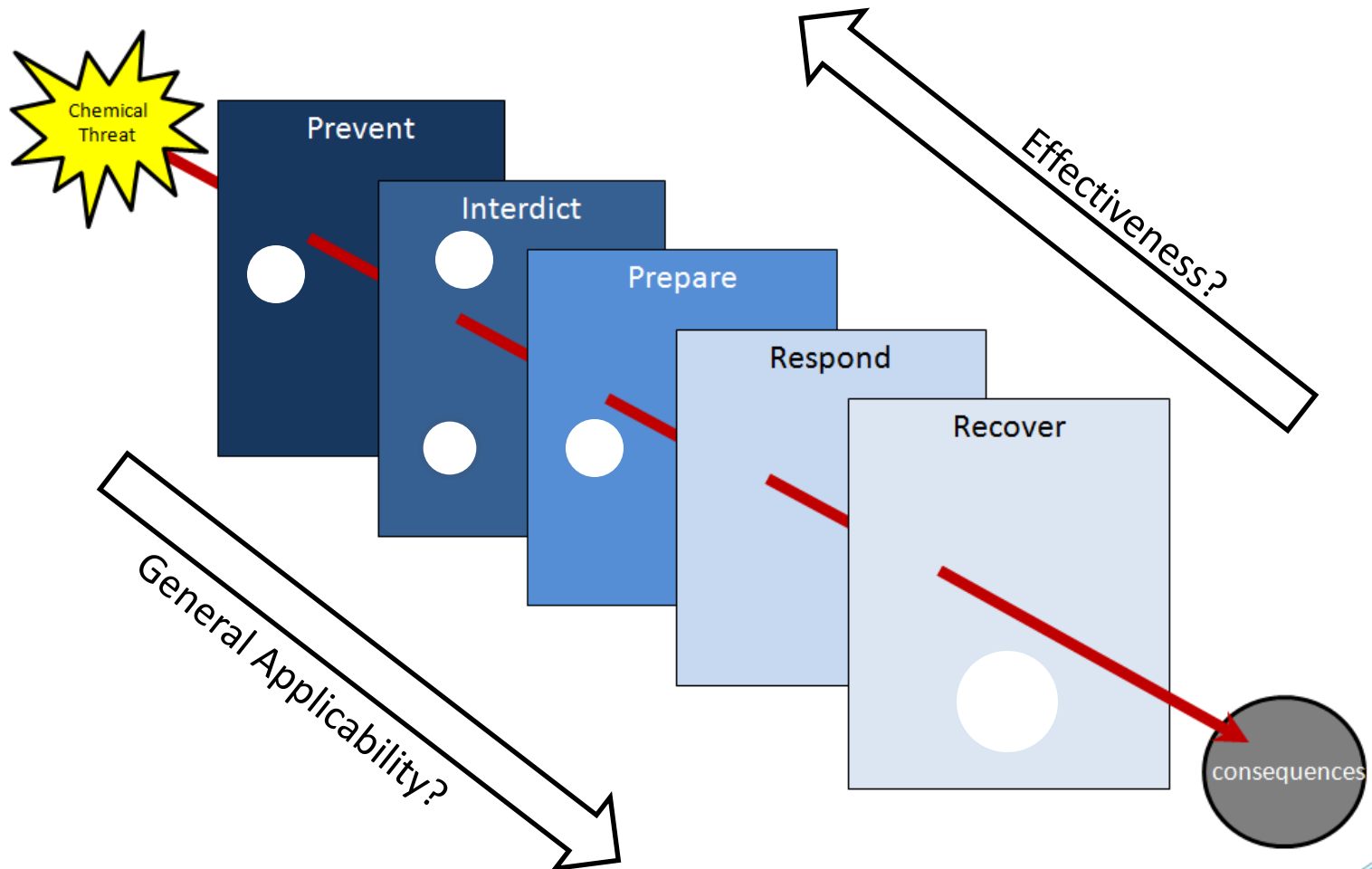
- **Where can detection add value in chemical defense?**
 - May potentially improve primary defense measures
 - Detection alone is not a defense

Detect to....



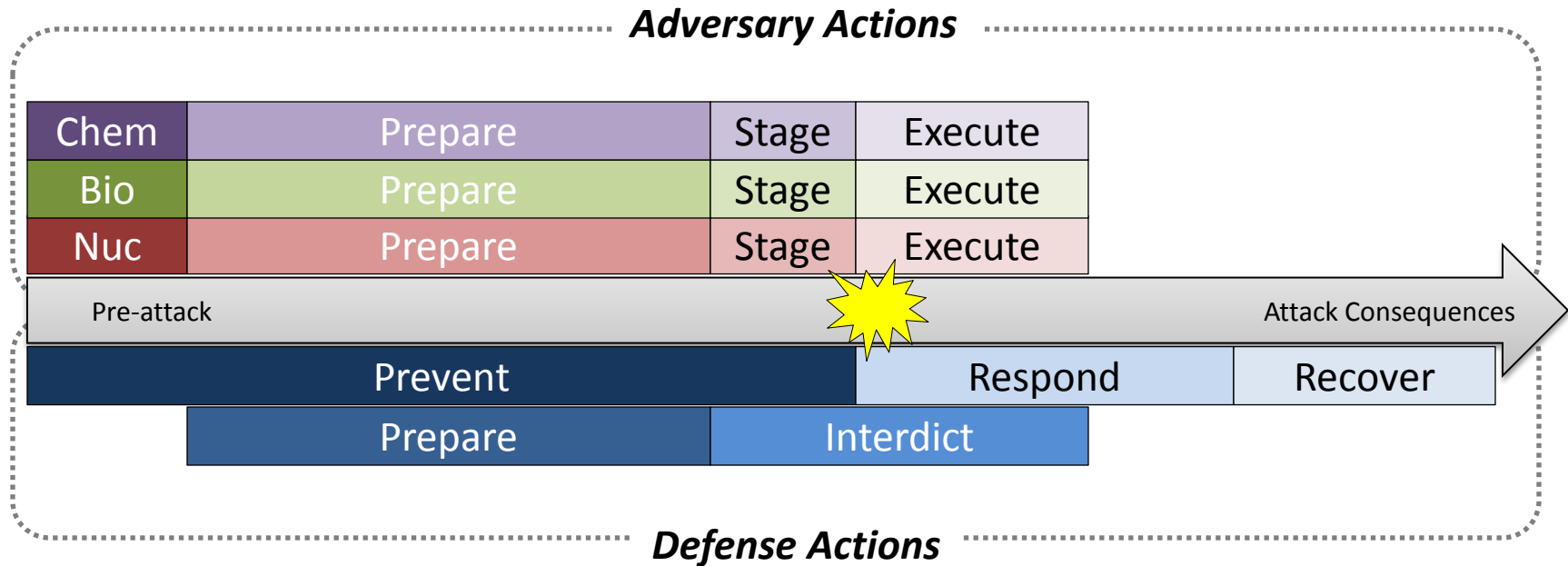
Systems Analysis Questions

- How should we allocate our resources across our defense?



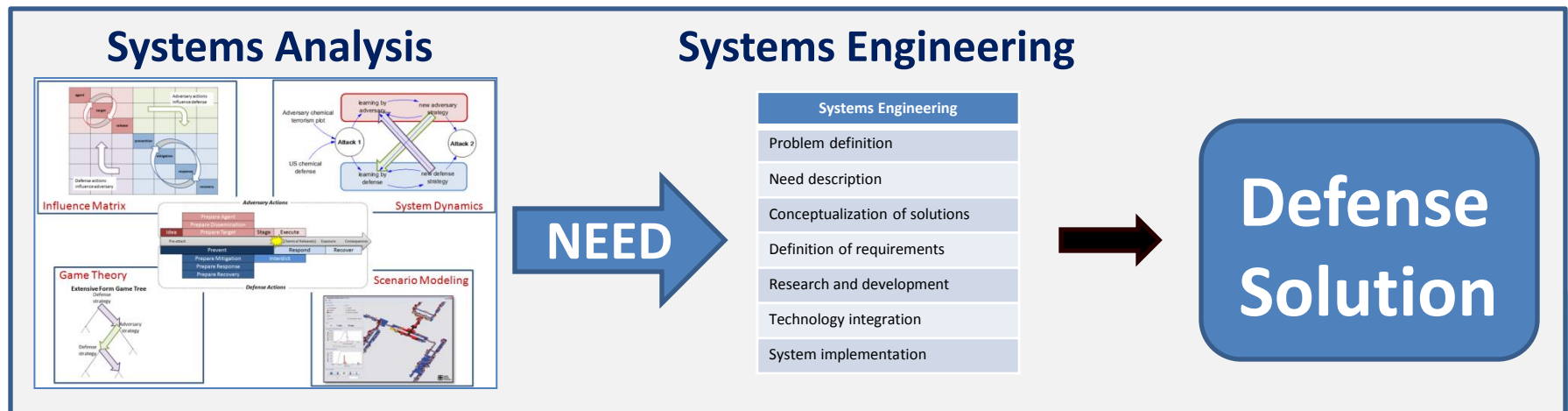
WMD Defense Framework

- **Can the Chemical Defense Framework be extended?**
 - Identify and implement cross-cutting defenses
 - Strategic WMD defense resource allocation across



Vision for the Future

- Use systems analysis to assemble Chemical Defense Model
 - Informs subsequent systems engineering process
- Systems engineering tools to guide strategic development of new defense capabilities
- Chemical Defense Model:
 - Provides a shared conceptual model
 - Facilitates thinking about the complex dynamic system



For more information contact:
Trisha H. Miller
millert@sandia.gov
Systems Research and Analysis
Sandia National Laboratories



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