Systems Engineering Analysis of Threat Reduction Systems Using a Collaborative Constructive Simulation Environment

NDIA Systems Engineering Conference
San Diego, CA
October 20-23, 2008

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Presentation Outline

- **Threat Reduction Analytic Objectives**
- **Original Long-Term Vision for the Constructive Simulation Environment**
- **Overview of Spiral Development / Analysis Approach**
- **Scenario Vignettes**
- **Nuclear Radiation Detection Modeling**
- **Behavior Module Characteristics**
- **Near-Term Plans**

The work presented herein was supported by the Defense Threat Reduction Agency (DTRA) under NAVSEA Contract N00024-03-D-6606, Task SG412.

Threat Reduction Analytic Objectives

Issues

- Many potential system solutions are being proposed for detection of materials important to Weapons of Mass Destruction (WMDs)
- System effectiveness evaluation requires analysis of system performance in operationally realistic tactical vignettes
- Material detection effectiveness is an element of broader campaign-level scenarios

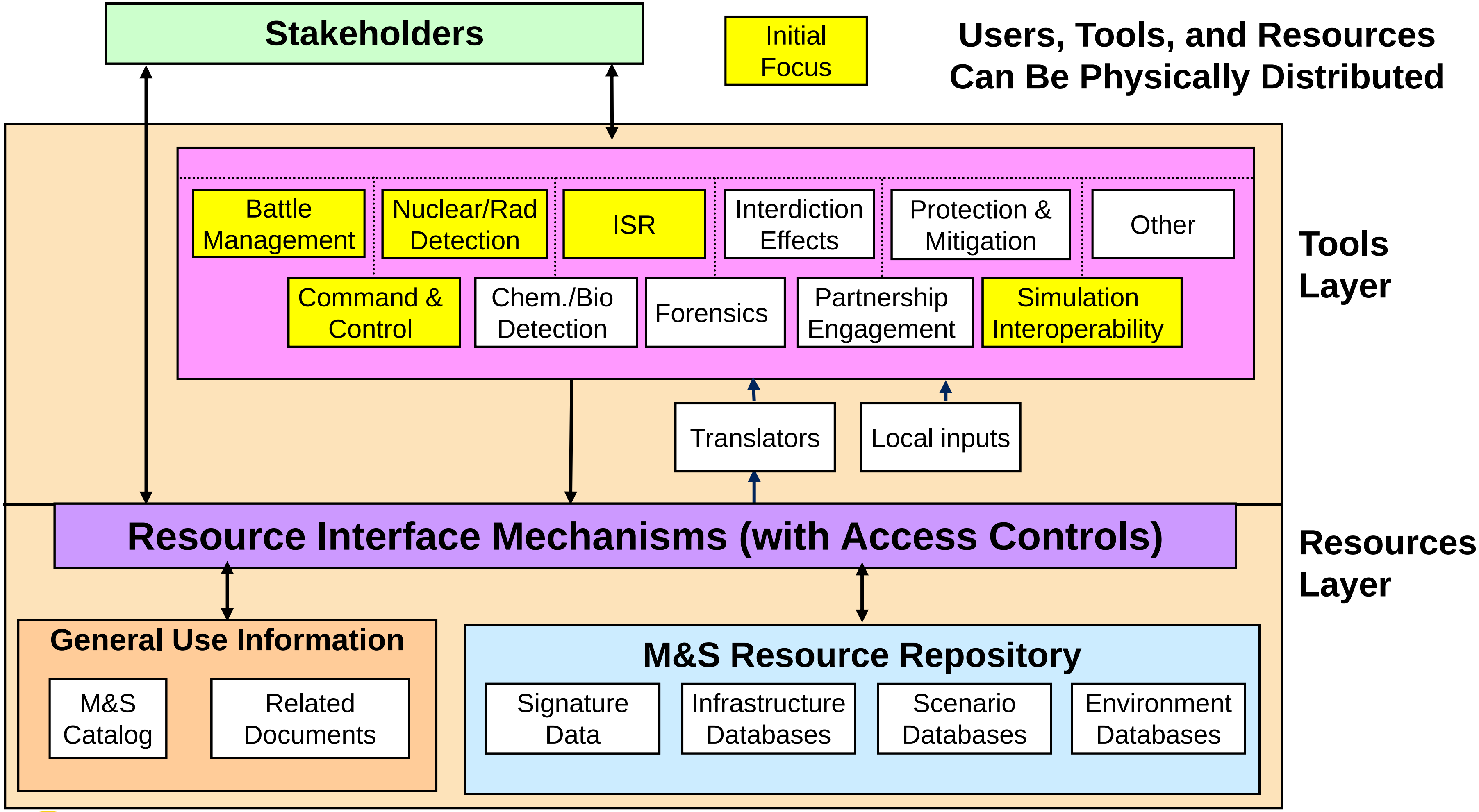
Overall analysis objective:

- To enable system acquisition decision-making by constructing an analysis-of-alternatives capability

Immediate analysis objective

- Construct an analysis-of-alternatives capability focused on detection of nuclear materials

Original Long-Term Vision for the Constructive Simulation Environment



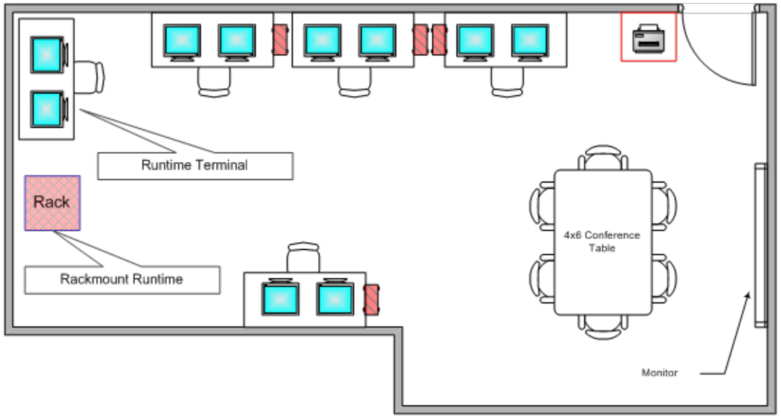
Overview of Spiral Development / Analysis Approach

- Spiral 0 (April - July 2007)
  - Proof-of-concept use of Joint Semi-Automated Forces (JSAF) simulation for radiation detection in tactical vignette
- Spiral 1 (August 2007 – January 2008)
  - Setup of M&S laboratories at DTRA and JHU/APL
  - Development of checkpoint scenario vignettes
  - Development of higher fidelity JSAF radiation detection module and production of initial passive detection sensor performance
- Spiral 2 (February – September 2008)
  - Expansion of scenario vignettes, with 3D rendering
  - Development of Behavior Module linked with JSAF
  - Initial development of JSAF-embedded software for active concepts for nuclear material detection

Spiral 0 Activities (April - July 2007)

- Evaluated several alternatives, and selected JSAF as simulation of choice to model tactical vignette in selected “100 x 100 mi. box”
- Obtained / installed JSAF simulation
- Modified JSAF sensor module to model radiation detector
- Obtained terrain database for selected area
- Set up “land bridge” scenario vignette and checkpoint in JSAF
- Performed multiple JSAF executions to generate sensor performance estimates, including multi-sensor detections
- Tabulated sensor performance data in spreadsheet for use during table-top exercise

Spiral 1 Activities (August 2007 – January 2008)

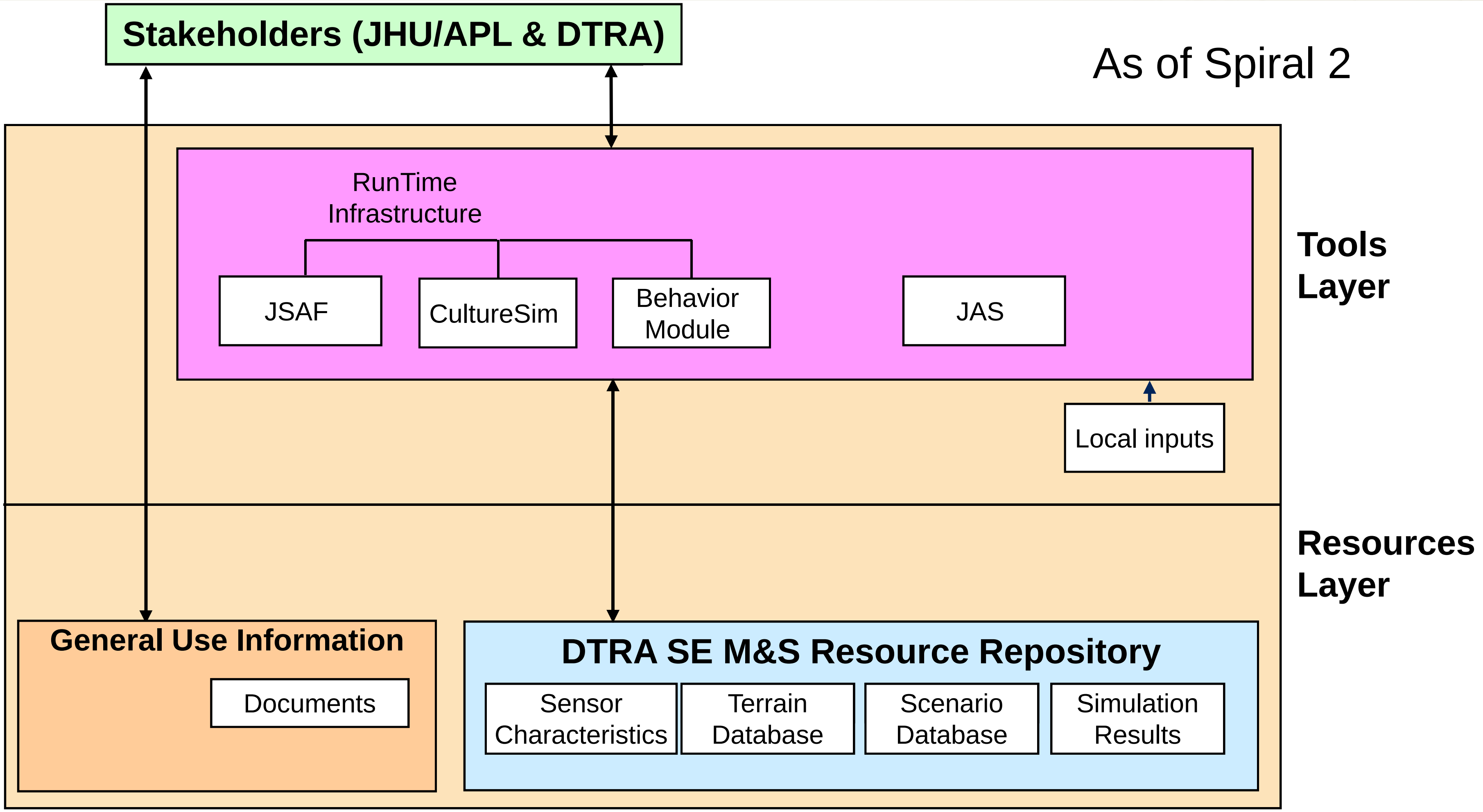


- Conducted trade-off study to determine most effective configurations of dual DTRA and JHU/APL systems engineering M&S laboratories
- Procured hardware and software for both M&S laboratories
- Instantiated three land-based scenario vignettes for checkpoints in JSAF, consistent with accepted campaign-level scenario
- Developed higher fidelity radiation detector module for JSAF
- Performed multiple short JSAF executions to get (preliminary) performance curves for a variety of passive radiation sensor types

Spiral 2 Activities (February – September 2008)

- Instantiated five additional scenario vignettes in JSAF
- Incorporated 3D rendering of vignettes using JStealth, federated with JSAF
- Improved JSAF passive radiation detection module
- Developed a JSAF module to model active concepts for nuclear material detection
- Performed additional JSAF runs to explore the performance of selected combinations of sensors and to produce inputs for Joint Analysis System (JAS) campaign-level simulation executions
- Incorporated intelligent behavior for red and blue assets in JSAF
  - Federated new "Behavior Module" with JSAF, based on prior JHU/APL "commander federate" Independent Research and Development (IRAD) project
  - Incorporated tactics based on discussions with subject matter experts
- Developed a secure shared repository containing scenario information, sensor characteristics, and performance results from simulation executions

Constructive Simulation Environment Progress Toward Long-Term Vision



Scenario Vignettes (Three Types)

- Land-based checkpoints to detect mobile nuclear material
  - Rural / mountainous, limited road system
  - Rural / flatland, broader road system
  - Port area
- Land-based detection of stationary / hidden nuclear material
  - Rural hideout
  - Above-ground storage site
  - Underground facility
- Detection of mobile nuclear material in maritime environment
  - Straits
  - Open water

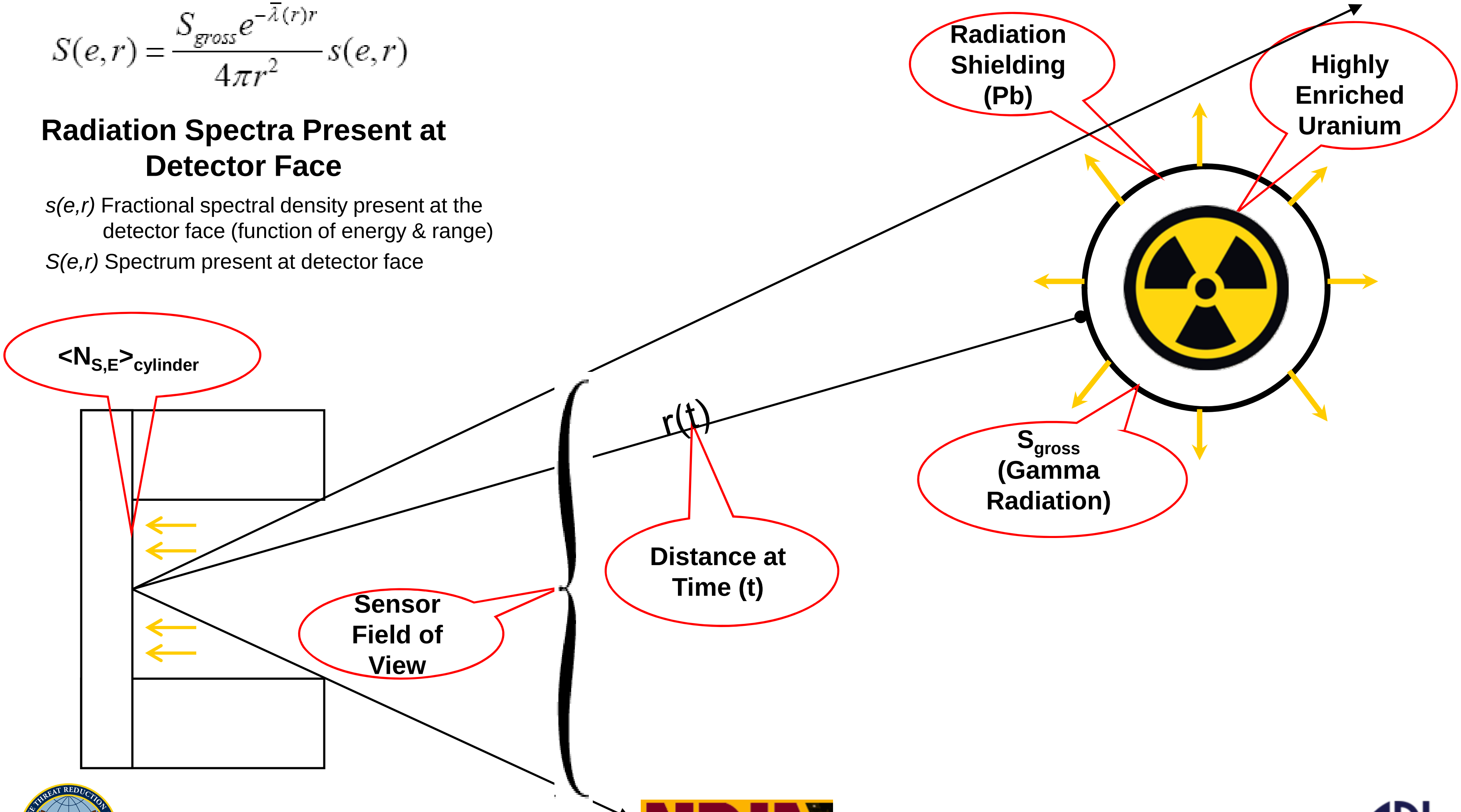
Nuclear Radiation Detection Modeling Source Signal to Detector

$$S(e,r) = \frac{S_{gross} e^{-\bar{\lambda}(r) r}}{4\pi r^2} s(e,r)$$

Radiation Spectra Present at Detector Face

s(e,r) Fractional spectral density present at the detector face (function of energy & range)

S(e,r) Spectrum present at detector face



Sensor Model Input Constants

Sensor Model - Input Constants

B_{gross} = Gross background count (counts/sec) – Assume constant

$\bar{\lambda}$ = atmospheric attenuation coefficient.

Properties dependent on detector type:

A_{sensor} = projected surface area of detector [m^2]

FOV = field of view of sensor [deg]

$\bar{\varepsilon}_B$ = Gross background count efficiency [unitless]

β_E = Fraction of gross background count in energy band E [unitless]

$\bar{\varepsilon}_S$ = Gross source count efficiency [unitless]

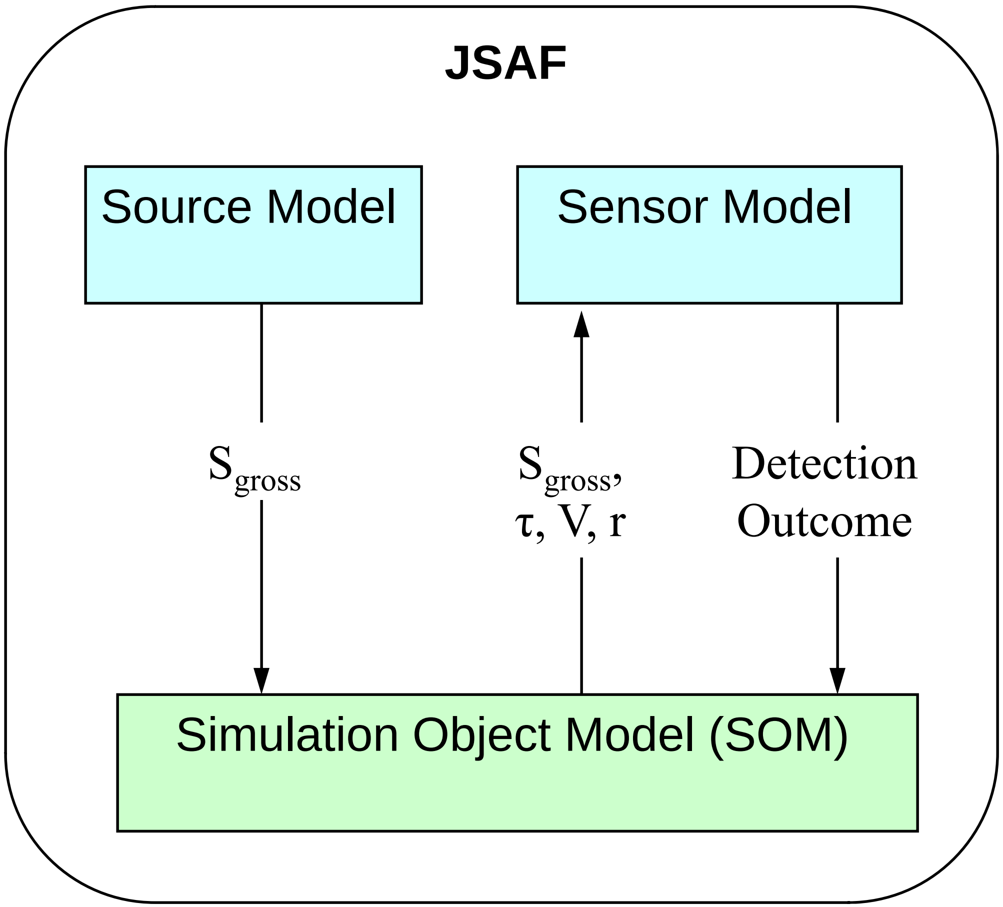
σ_E = Fraction of gross source count in energy band E [unitless]

Sensor Model Functions

Sensor Model - Functions

- Calculate background signal, $<N_{B, E}>$ (assume constant B_{gross})
- Calculate source signal, $<N_{S, E}>$
- Calculate signal-to-noise ratio (SNR)
- Calculate detection probabilities, P_D, P_{FA}
- Random draw for Detection Outcome

JSAF Source-Sensor Model Data Interactions



Where:

S_{gross} = Gross source count (counts/sec)

τ = integration time interval (sec)

V = Relative velocity of target (m/s)

r = Range of target (m)

and "Detection Outcome" can be one of:

-No detection

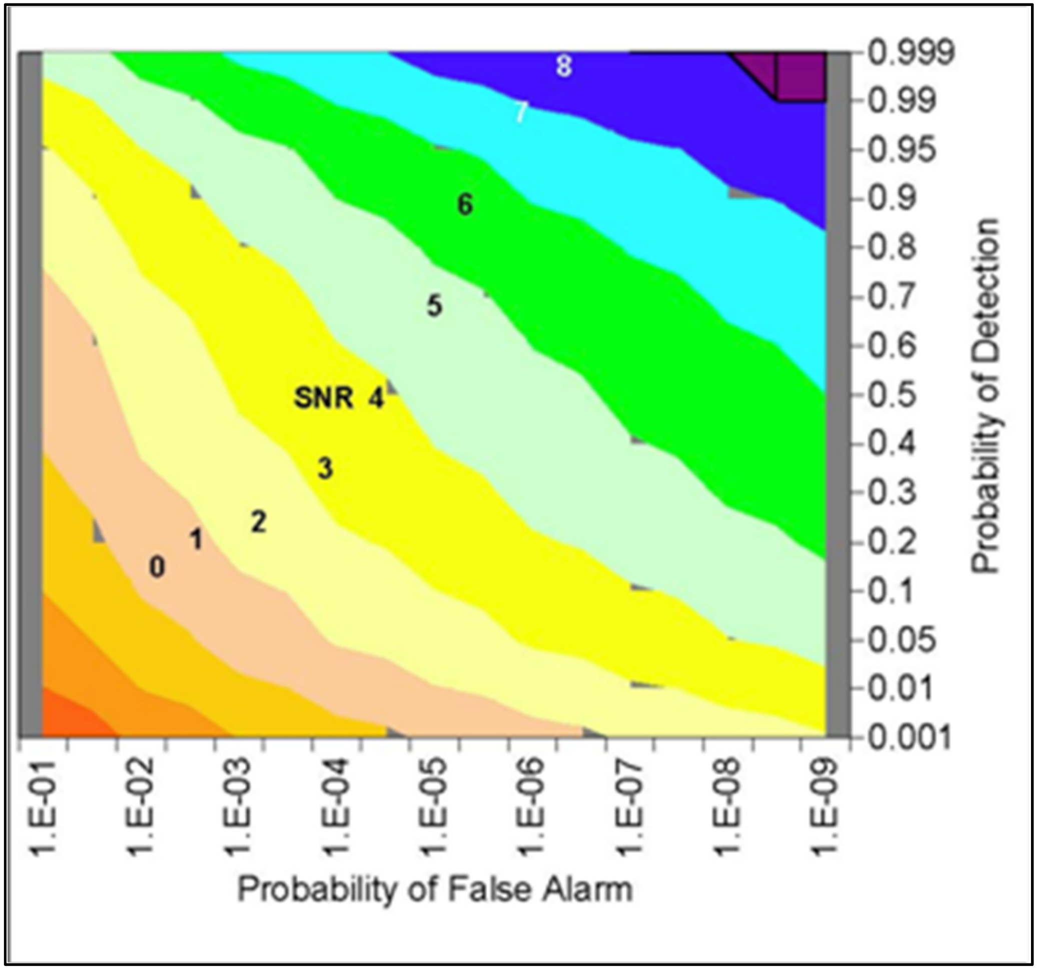
-Positive detection

-False positive detection

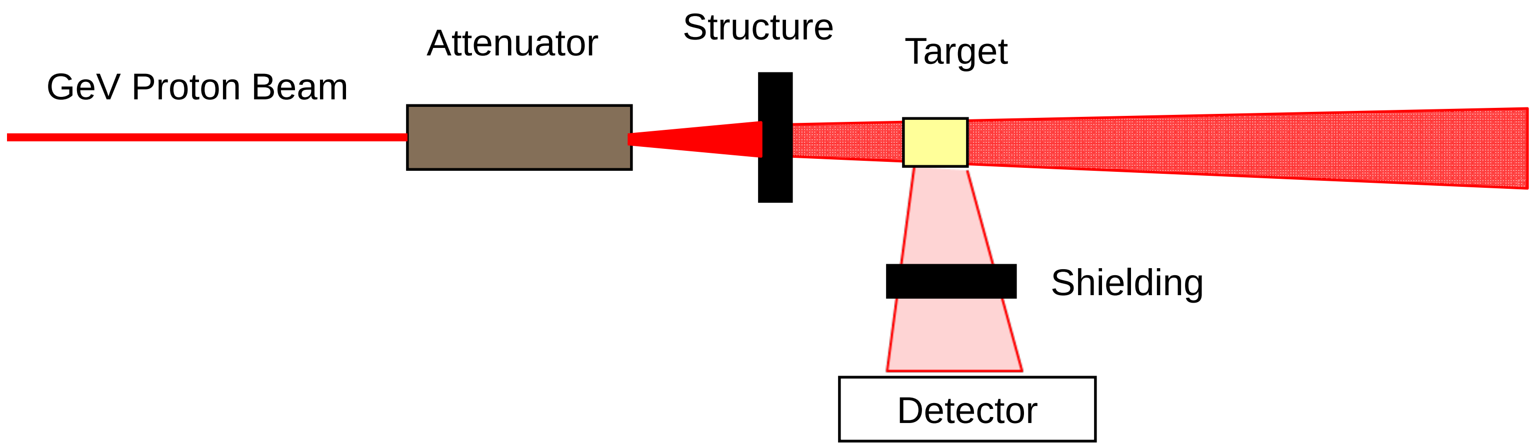
-Negative detection

-False negative detection

Sensor Signal-to-Noise Ratio vs. P_D, P_{FA}



Nuclear Radiation Detection Modeling Physics for Active Detection



Materials			
Attenuators	**Structures**	**Targets**	**Shielding**
Air, Graphite	**Iron, Steel, Aluminum**	**Uranium (235, 238), Lead, Tungsten, Carbon, Calcium, Silicon**	**Iron, Lead, Wood, Water**

Motivation for the Behavior Module

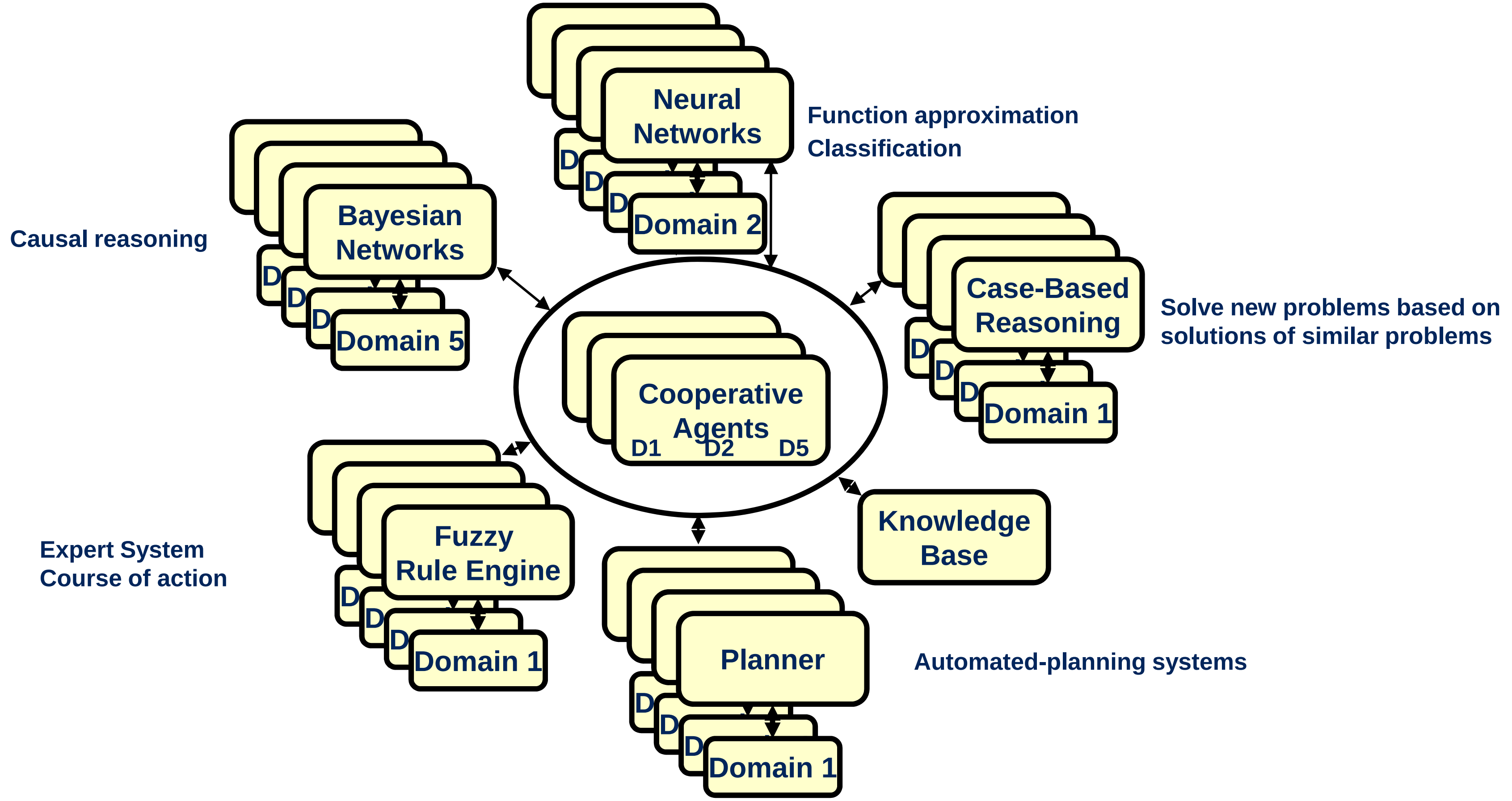
Issue

- Standard scripting for Red and Blue CONOPS in scenario vignettes in JSAF attributed insufficient reactive behavior to humans involved
  - For example, drivers of vehicles carrying nuclear materials simply proceeded to known checkpoints, were scanned, and detained

Behavior Module needed to

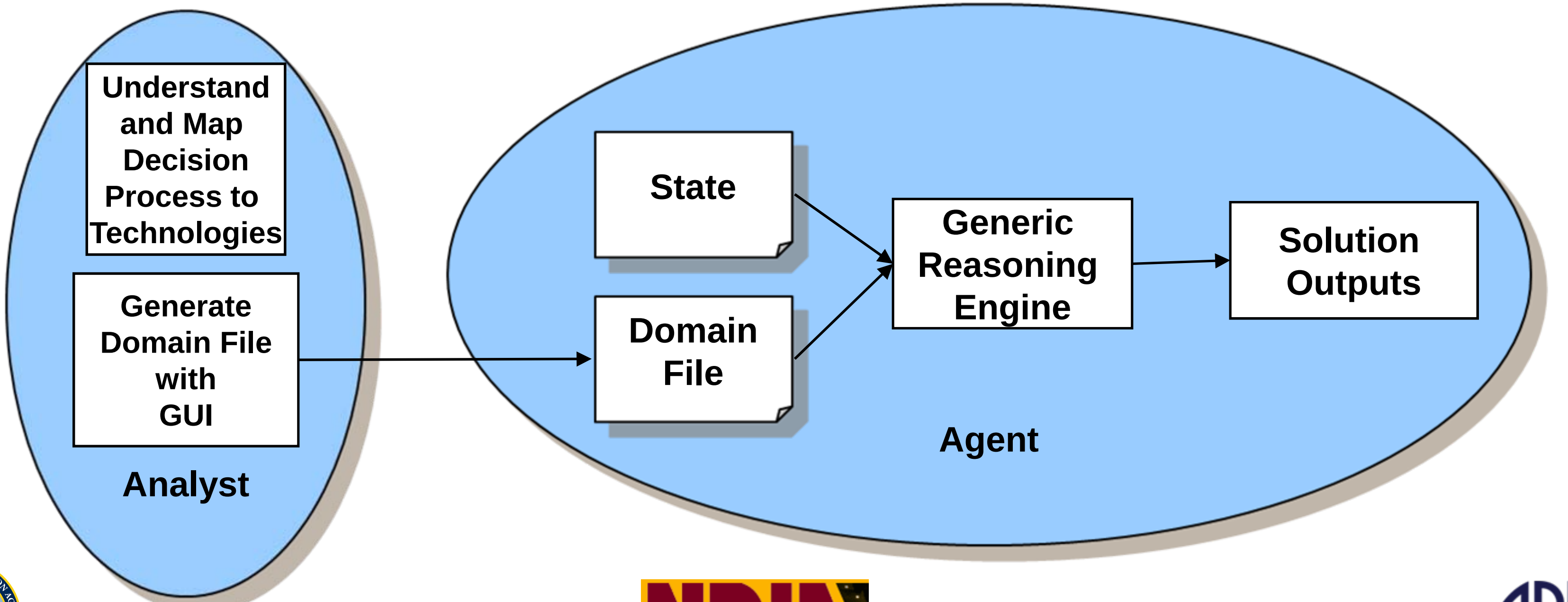
- Provide reactive CONOPS for Red and Blue assets, and background behaviors for Green entities
- Enable analysis of effectiveness of Blue CONOPS using various sensors in opposition to Red CONOPS, together with Green background activity
- Enable trades between CONOPS and sensor investment decisions
  - For example, given a sensor's maximum probability of detection, can an adjustment of resources to execute a CONOPS improve the ability to detect and interdict the nuclear material?

Technology Basis for Behavior Module: Hybrid Reasoning Technology Framework

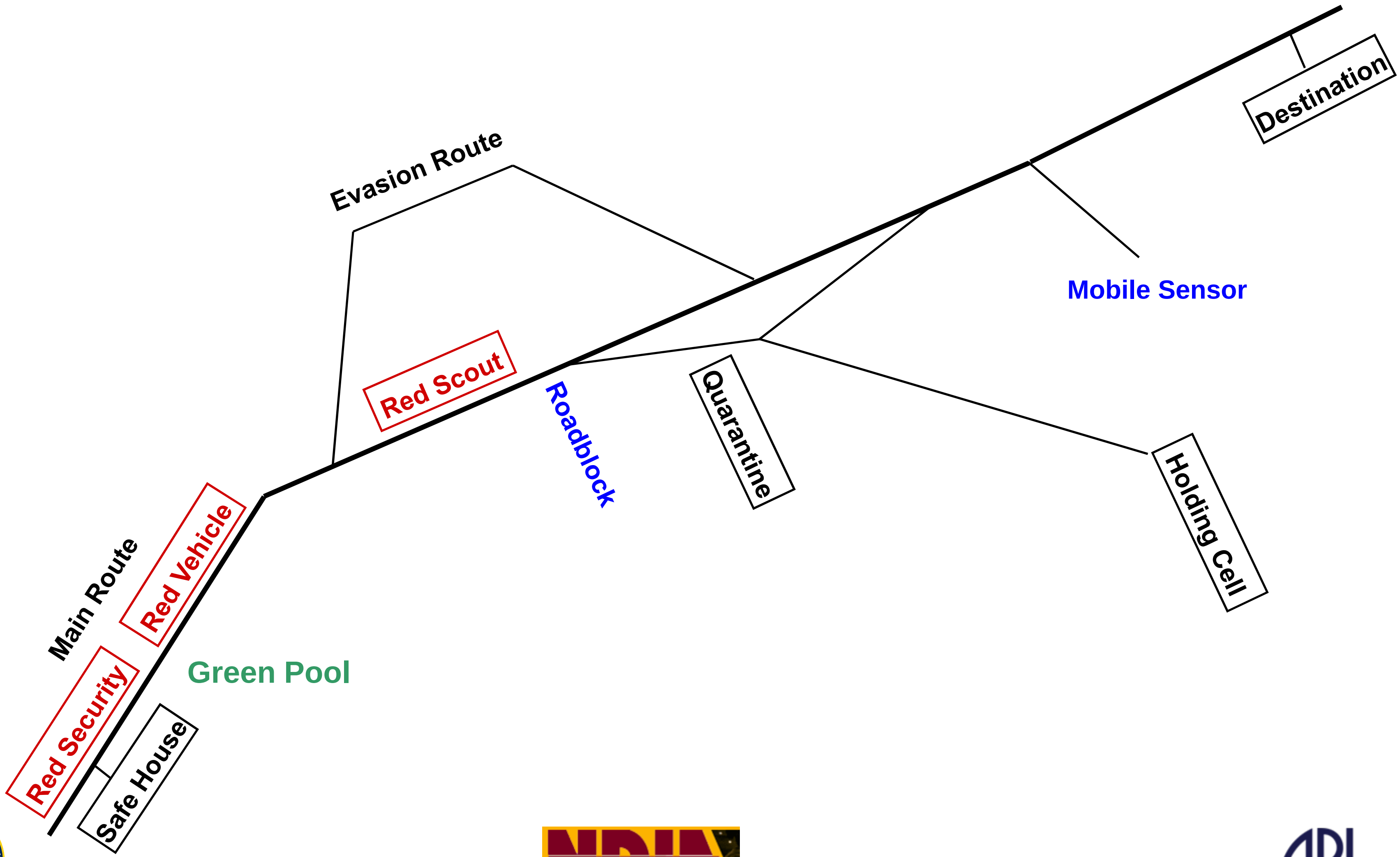


Hybrid Reasoning Framework Preparation and Use

- Analyst gains understanding of the decision process to be simulated
- Analyst maps appropriate reasoning technologies to the decision process
- Analyst creates a domain-specific file using reasoning software GUI editor and exports the domain-specific file for agent's future use
- Agents load domain-specific files as needed for their function, provide problem specific inputs (state), and use appropriate generic engines to create solution outputs



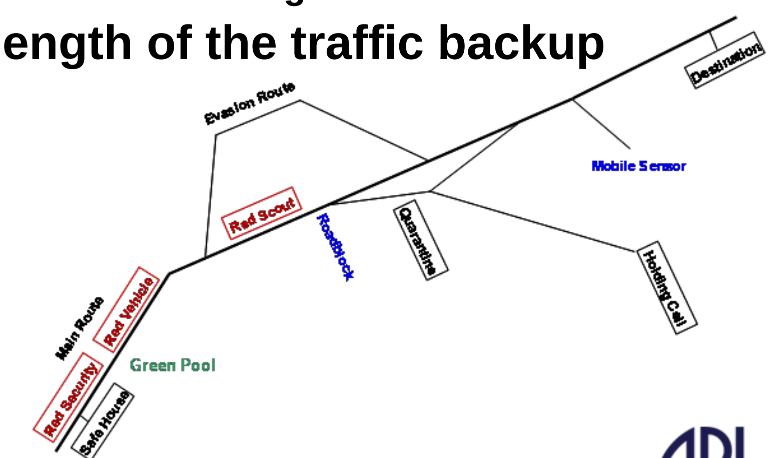
Baseline Concept for Enhanced Checkpoint Scenario Vignette Using Behavior Module



Behavior Module
Current Blue Checkpoint Behaviors

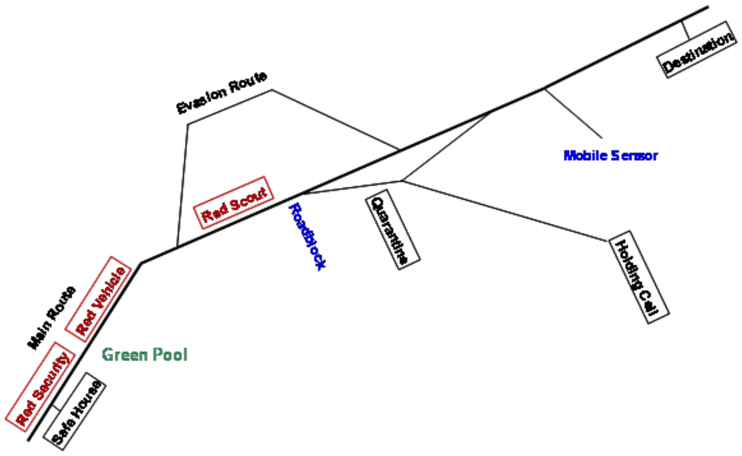
When a Red or green vehicle reaches a checkpoint, a roadblock prevents passage in one direction until the sensor reports

- If the reading is negative, the roadblock raises and allows the vehicle to pass
- If the reading is positive,
  - The vehicle is sent to a quarantine location
  - A mobile sensor platform is tasked to report to the quarantine location to conduct a second reading
    - If the second reading is negative, the vehicle is allowed to continue its journey
    - If the second reading is positive, the vehicle is sent to a holding location.
- Blue adjusts the roadblock to manage the length of the traffic backup
- Certain types of vehicles are randomly selected for checks. If the checkpoint queue gets too long, Blue communicates to the Blue selection point in order to reduce the percentage selected until the queue length is satisfactory.



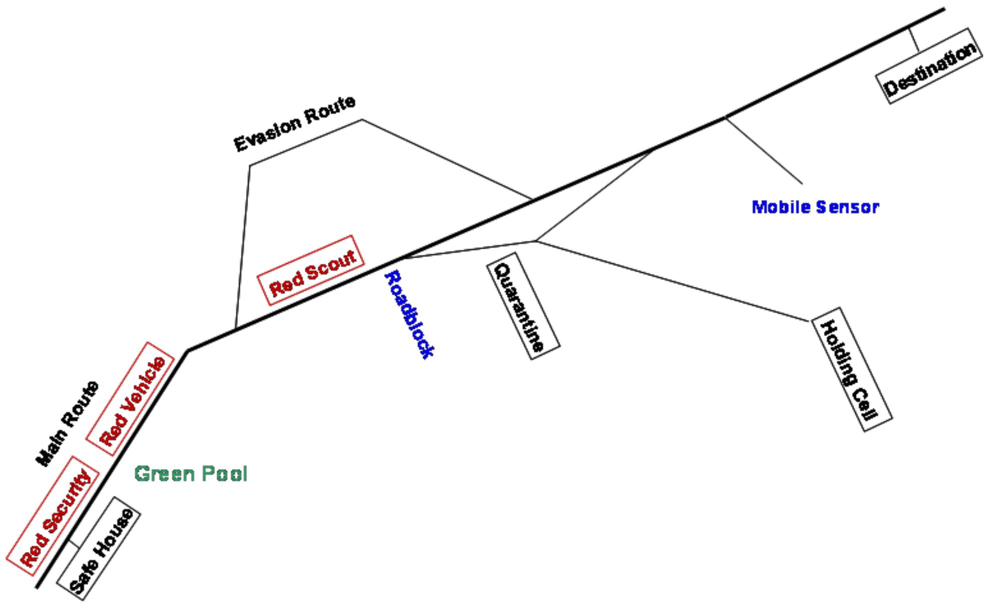
Behavior Module
Current Red Checkpoint Behaviors

- **Red vehicle starts at safe house and travels to destination over existing roads**
- **Red vehicle is informed by a Red "scout" vehicle that a checkpoint is ahead so that the Red vehicle with weapons grade nuclear material either aborts or evades**
- **When a Blue checkpoint is seen, Red has option to:**
  - **Stop and pull over at the roadside for ten minutes to consider either aborting or continuing**
  - **Continue journey**
  - **Evade around checkpoint if possible**
  - **Abort and return to starting location**
- **Red either diverts or aborts if progress along the current route is too slow.**



Behavior Module
Current Green Checkpoint Behaviors

- **Background traffic without any nuclear sources**
- **Several green vehicles with medical nuclear sources are dispatched at random intervals to add to congestion at checkpoints**



Near-Term Plans
Spiral 3 (October 2008 – September 2009)

- Enhance passive nuclear detection modeling
  - Spectroscopic capability for source and sensor
  - Gamma imaging capability for sensor
  - Passive fast and thermal neutron imaging for source and sensor
  - Thermal neutron directional / imaging capability for sensor
  - Fast neutron imaging for sensor
- Add fidelity to active nuclear detection concept modeling
  - Introduce active interrogation sources
  - Modify targeted material behavior
  - Modify passive sensor as needed to support active concepts
- Add behaviors to Behavior Module (selected based on perception of Red capabilities)
  - Blue – downstream checkpoints, traffic funneling to checkpoints, vehicle tagging and tracking, CONOPS variation based on nature of Blue forces
  - Red – Red security vehicle follower, bribery, rush-hour exploitation, peaceful demonstration, traffic accident diversion, limited attacks, etc.