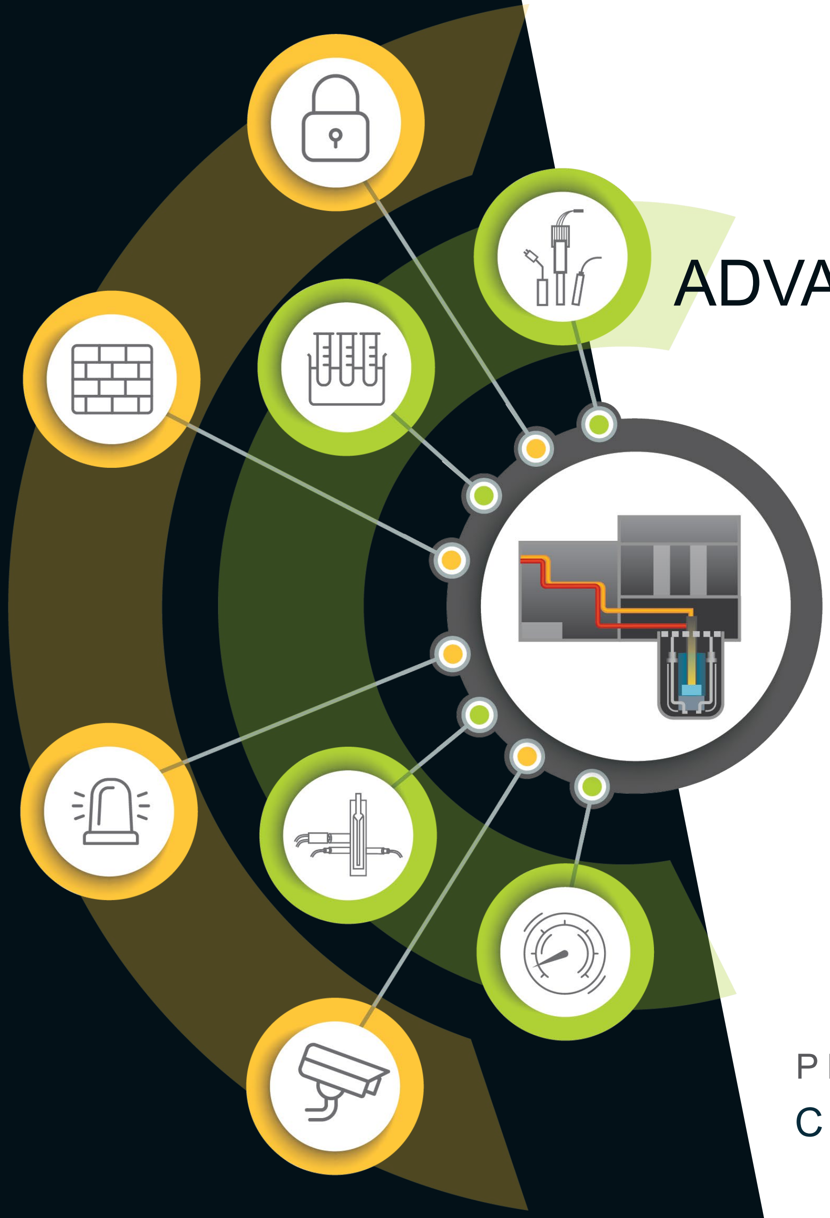


ADVANCED REACTOR SAFEGUARDS

Scenario Exploration and Timeline Analysis for Advanced Reactors

PRESENTED BY

Curtis Smith, Director, Nuclear Safety and Regulatory Research

October 2022

Idaho National Laboratory | U.S. DEPARTMENT OF ENERGY

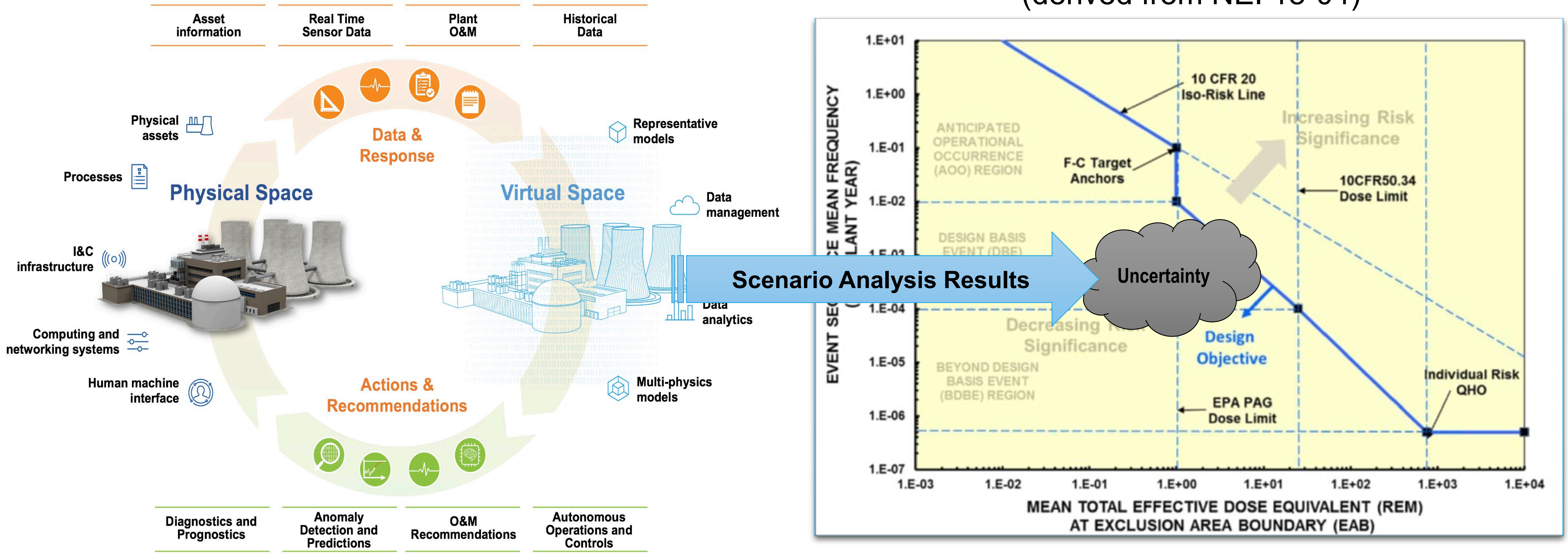
Motivation on Scenario and Uncertainty Research and Development

- Advanced reactors will be able to use risk insights for many design aspects
  - Example risk-informed approach is found in the Nuclear Regulatory Commission's SECY-19-0117
  - Probability is widespread through the guidance via a safety case
  - Probabilistic concepts are built into metrics, such as the frequency-consequence curve
- We need realistic scenarios for input into the licensing basis safety-case
  - These scenarios must include timing and physics
- We need to understand inherent uncertainty
- We need to automate the safety-case creation as much as possible

 Curtis.Smith@inl.gov

Advanced Reactor Design Attributes have Links to Frequency-Consequence Metrics

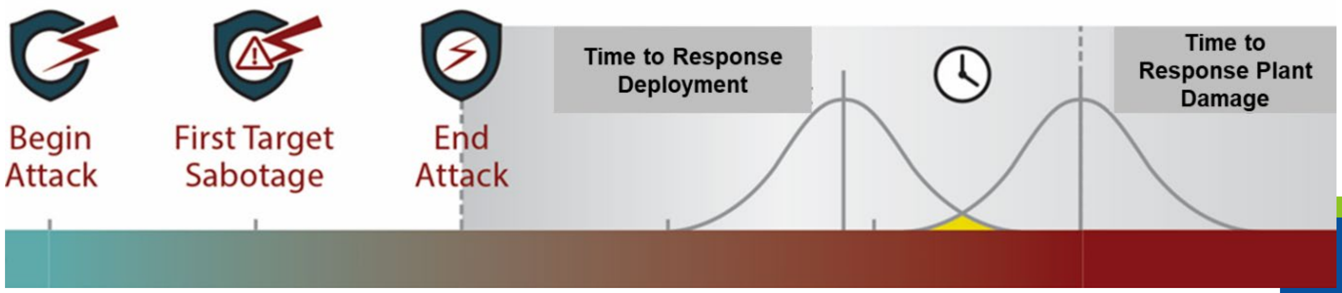
(derived from NEI 18-04)



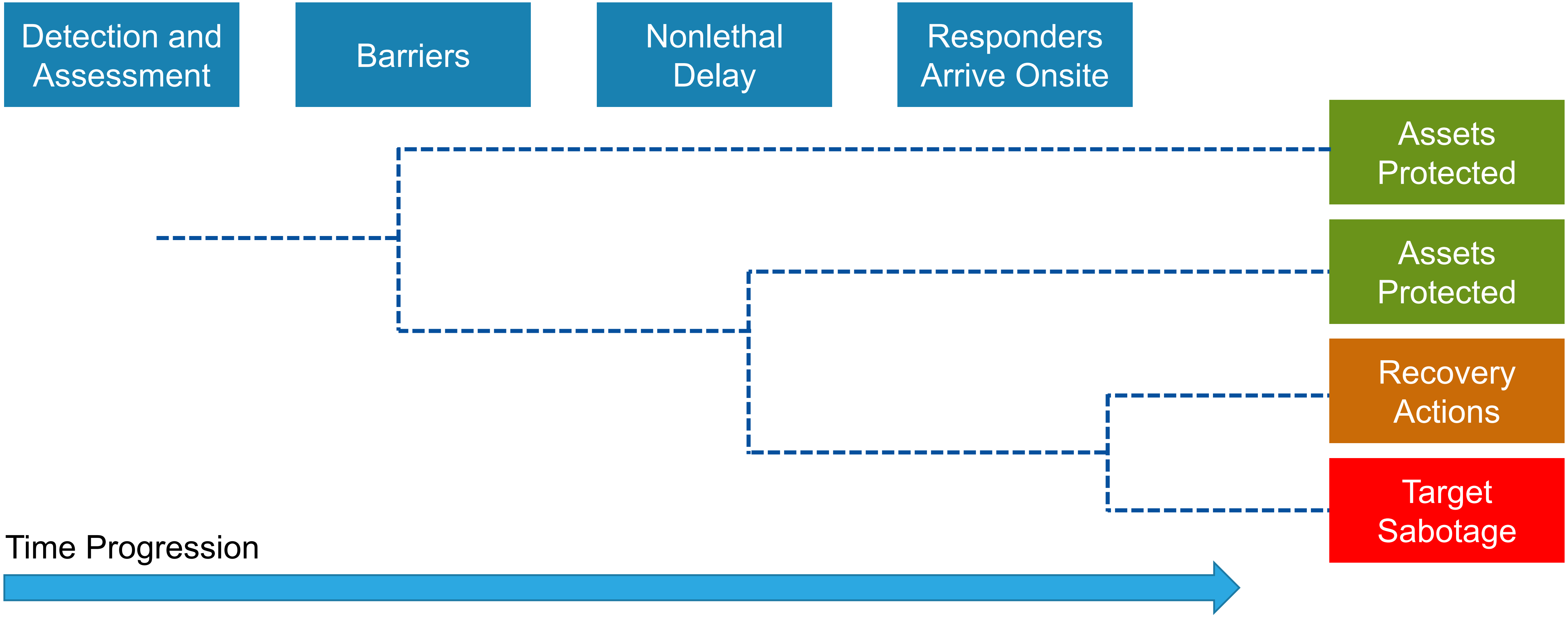
Curtis.Smith@inl.gov

Attributes of the Demonstration Infrastructure

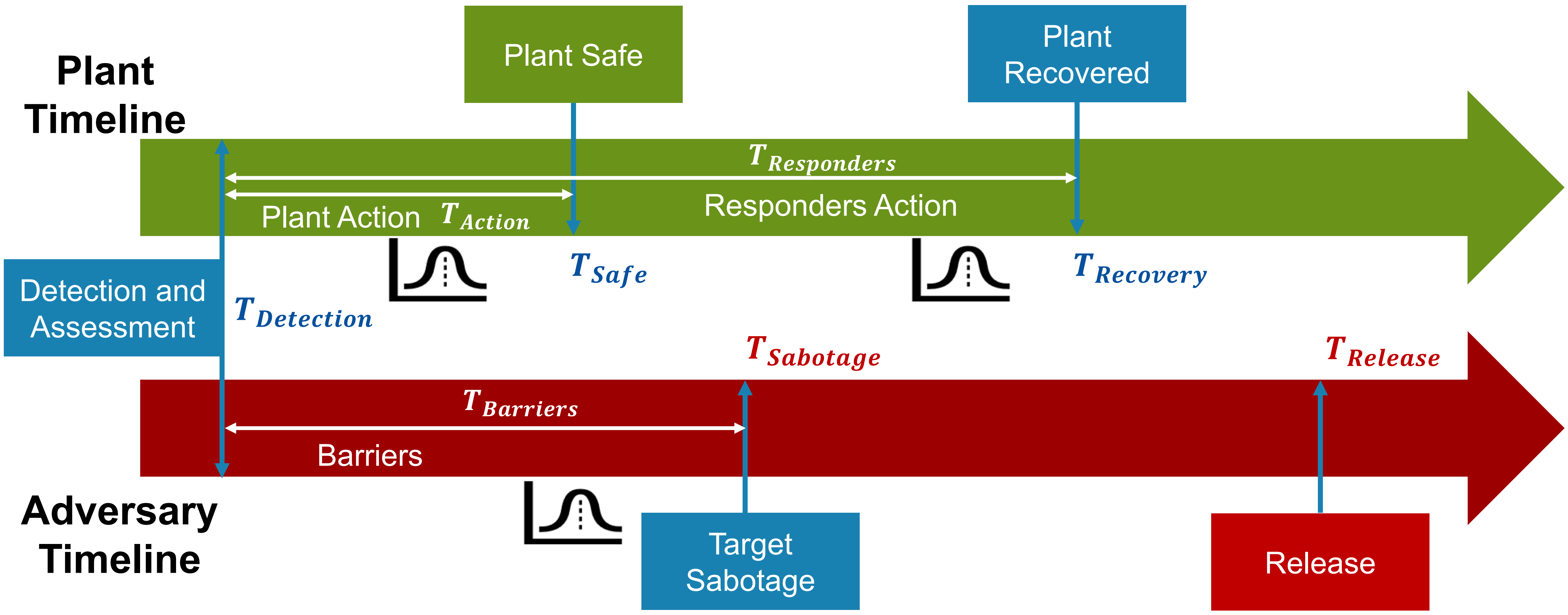
- Simulation to develop a risk-informed safety case
  - A highly transparent, traceable, scrutable framework
  - Used to inform all stakeholders (developers, regulators, operators)
- Leverage established technologies (e.g., EMRALD) for simulations
  - Risk scenario-based analyses & treatment of associated uncertainties
    - Uncertainties are captured by automating the "state space"
    - The state space represents variations in scenarios and outcomes
- Manage complex workflows to facilitate successful design evolution
  - Inform security design evolution from early design to operations
  - Also support creation of the technical basis



Modeling and Analysis in EMRALD (notional)



Timeline Analysis in EMRALD

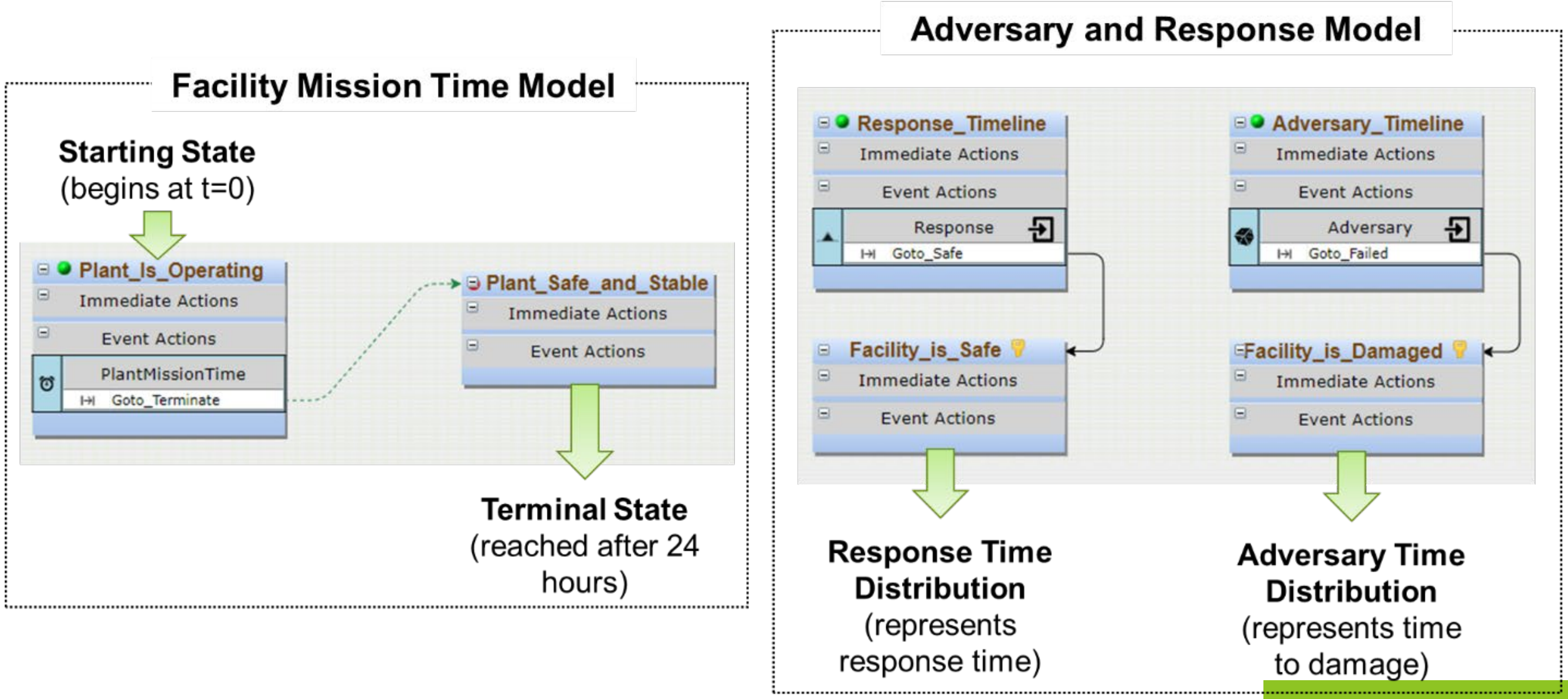


 Curtis.Smith@inl.gov

Example of Timeline Scenario Model

- A dynamic scenario timeline model contains three parts
  1. Facility mission time (duration required to control and cool the plant)
  2. A time-based model representing the time to sabotage of a facility
  3. A time-based model representing a response to counter the facility attack

EMRALD Model



 Curtis.Smith@inl.gov

EMRALD Capabilities for Advanced Reactors

Different Attack Scenarios

- Different paths
- Adversary capabilities
  - Strategies
  - Equipment
  - Variations

Sample Space

- Timings
- Probabilities
- Outcomes

Portfolio of Hazards/Targets

- List of targets: target super-set
- Combination of targets
- Initiating events as starting point
- Ability to integrate with other hazard types

Results & Insights

- Quantitative and qualitative results
- Sensitivities
- Visualization

Different Plant Layout

- Target set
- Topology
  - Geographical entities
  - Impact on timings
  - Plant structures
- Security posture
  - Protective strategies
  - Barriers
  - Responses
  - Law enforcement
  - Recalling off-duty personnel
- Important physics of the advanced reactor

Consequences from EMRALD

- Based on what has failed during a scenario
- To achieve insights that give frequency / consequence curve
- Level 2-3 analysis in EMRALD
  - Capture impact on timings
  - Integration with thermal hydraulics codes: MELCOR / MAAP / RELAP5

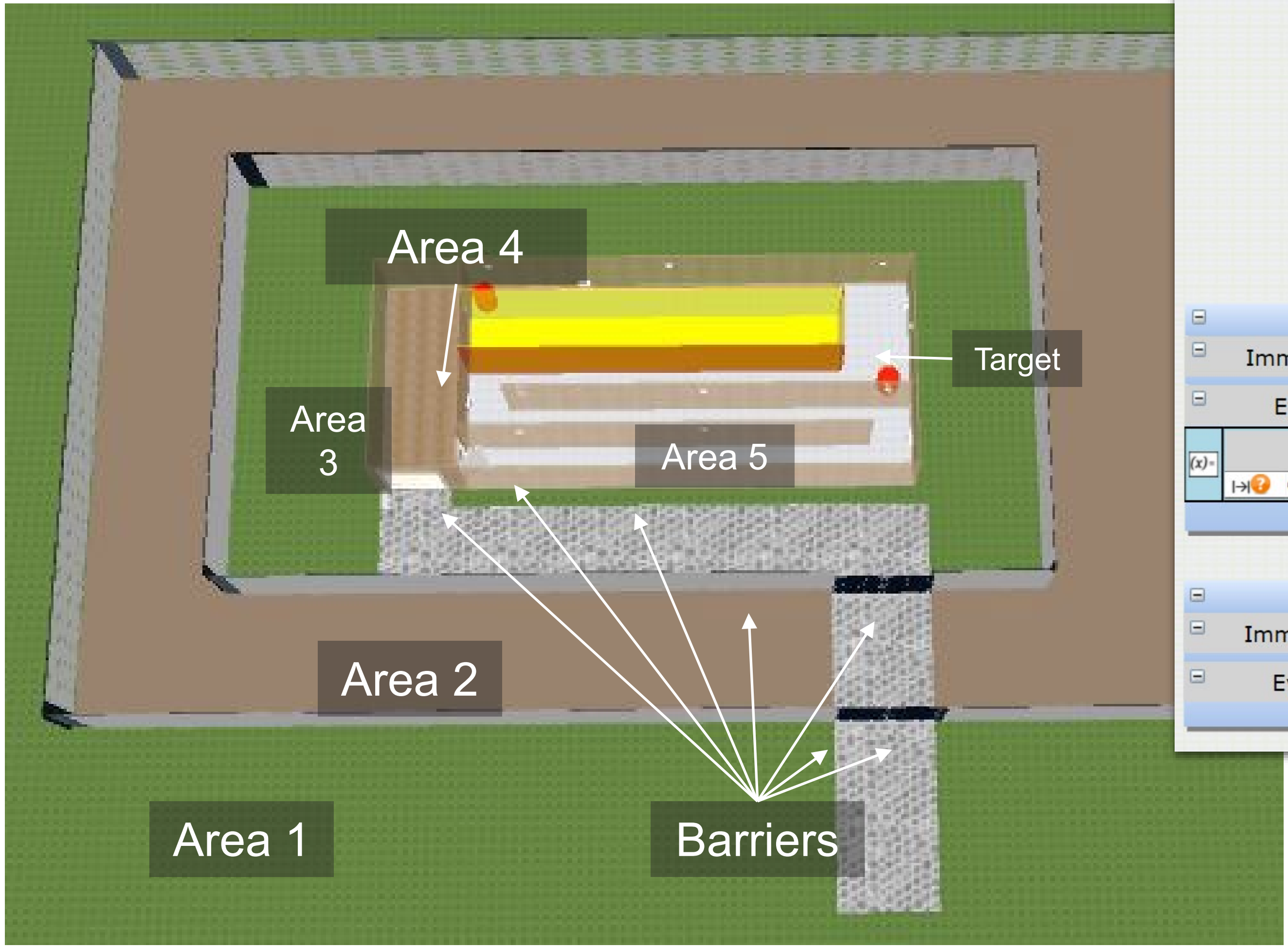
https://github.com/inl-labtrack/EMRALD

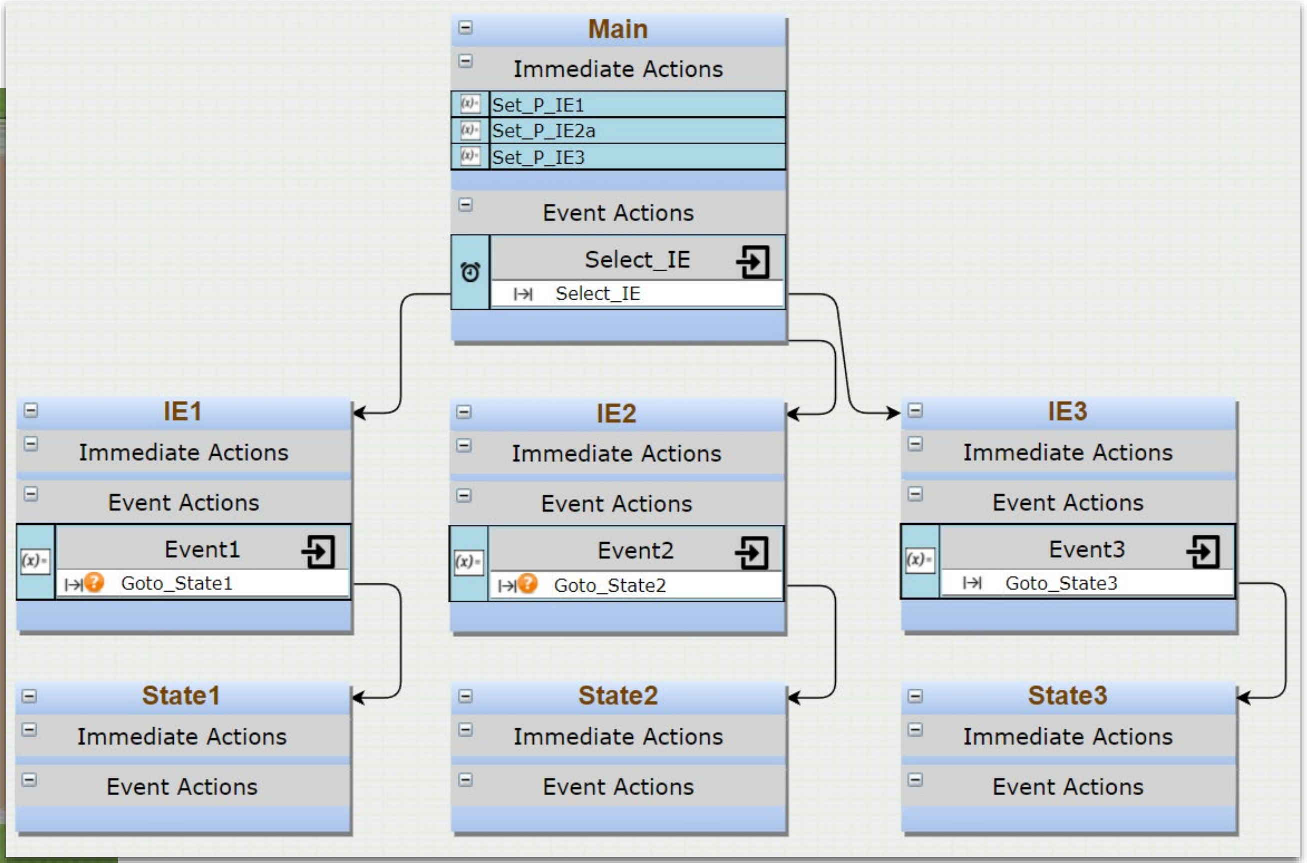
Overall Approach to Analysis

- We start by identifying a particular plant design's initial conditions (reactor type, source term, site, …)
- Identify physical protection system (PPS) characteristics
  - Design against theft, sabotage, or both
  - Credit local law enforcements and responders
  - Credit for co-located facility
- Formulate technical requirements for security designs
- These options are analyzed in EMRALD to evaluate their performance
- Verify results against design requirements, keep those that look promising
- Determine cost of these design options
- Select optimal design based on performance and costs
- Capture in the site Physical Security Plan

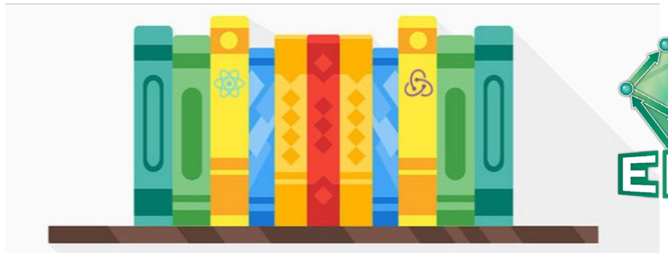
Example: Adversary Sequence Modeling in EMRALD

This is a hypothetical facility for demonstration purposes only.





Library of Barriers and Other Modular Pieces

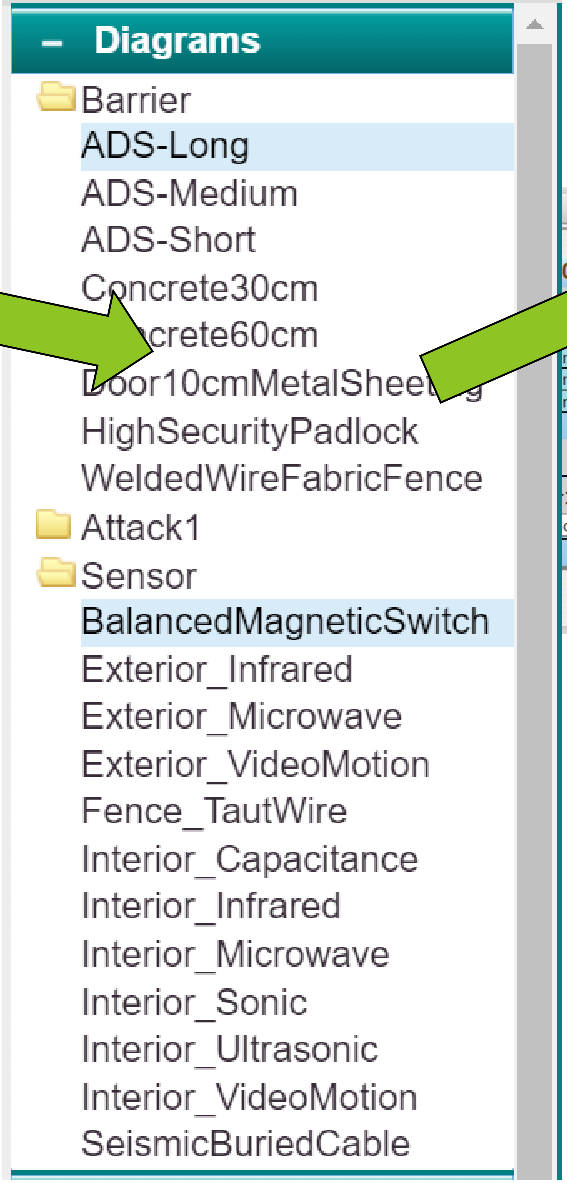


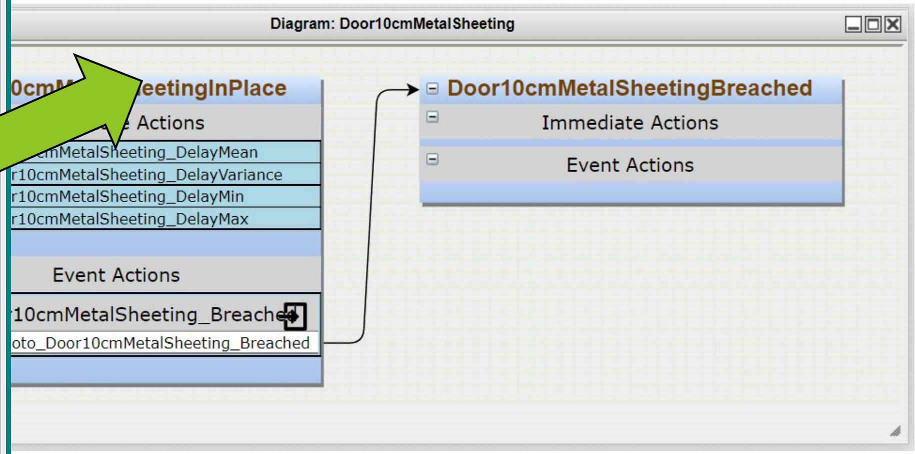
Barriers

- Fences
- Sticky Foam
- Concrete Walls
- Security Doors
- Active Delay Systems
- Etc.

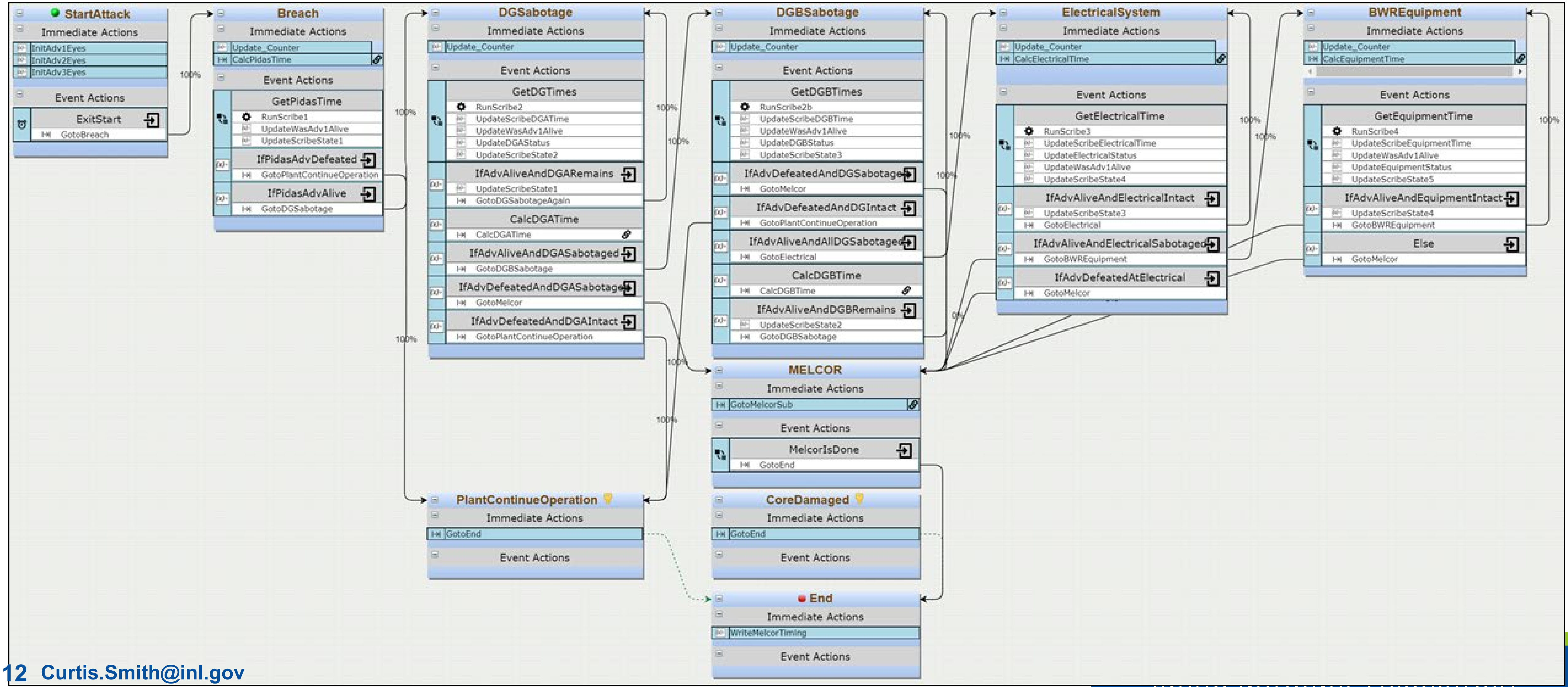
Properties

- Delay Time
- Equipment Requirements
- Detection Probability
- Etc.

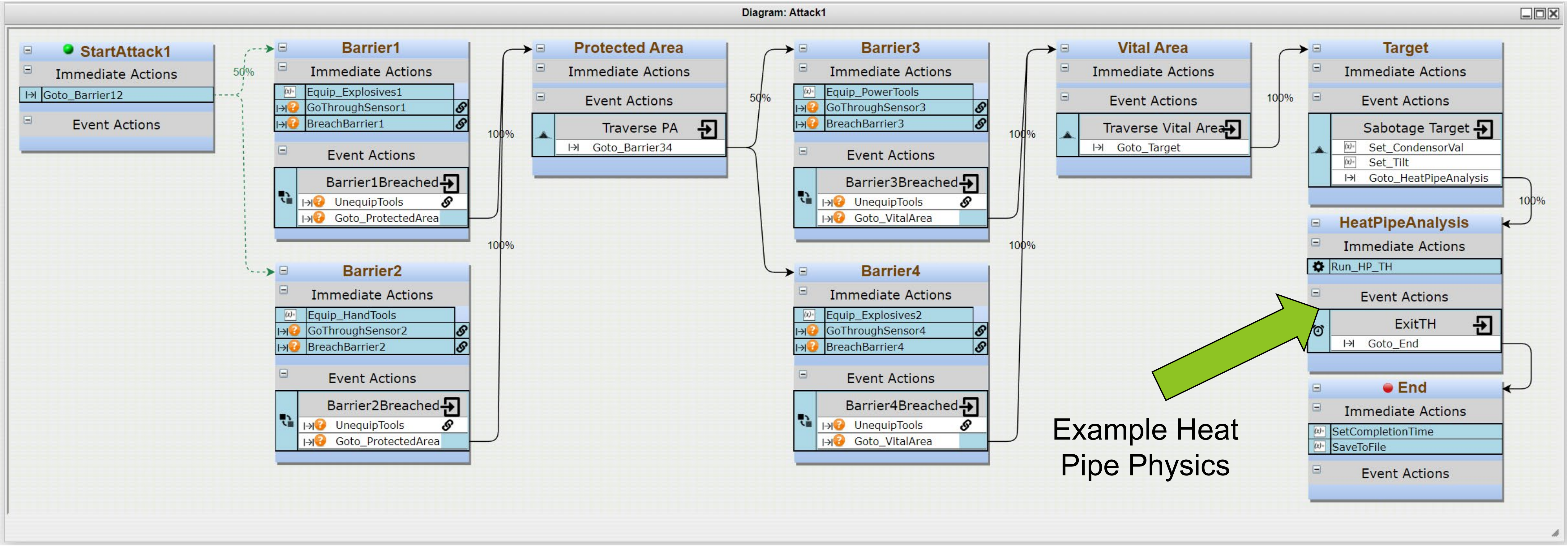




Modular Pieces are Integrated into a Facility Model

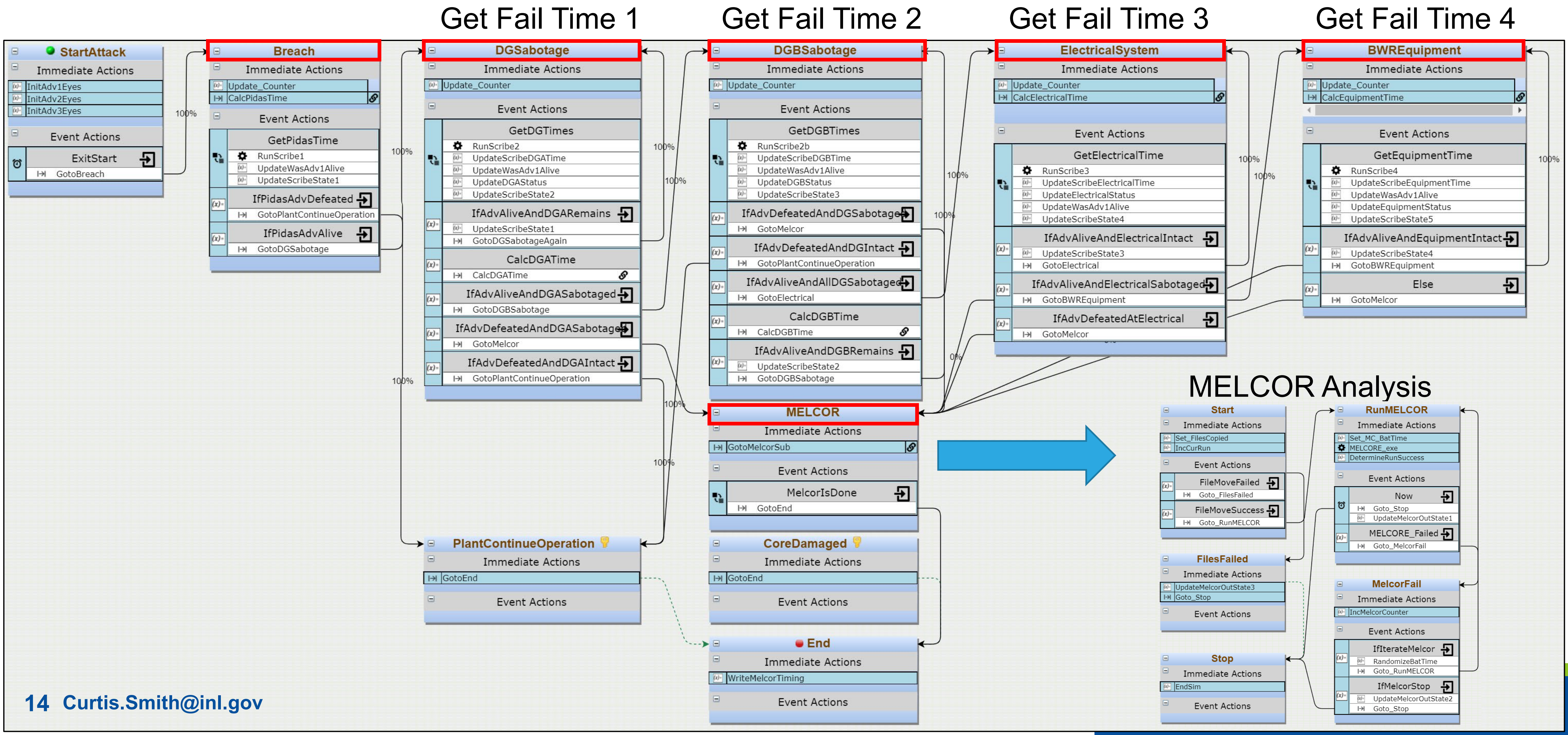


A Generic Facility Model can be Customized

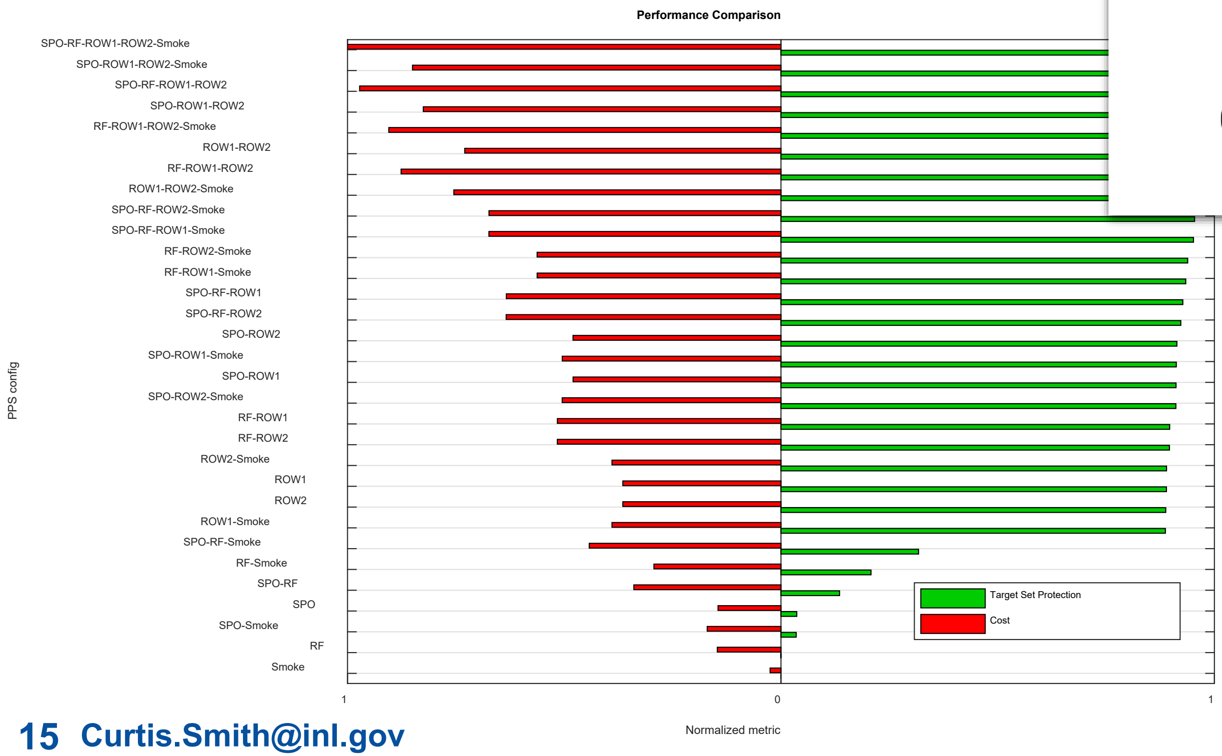


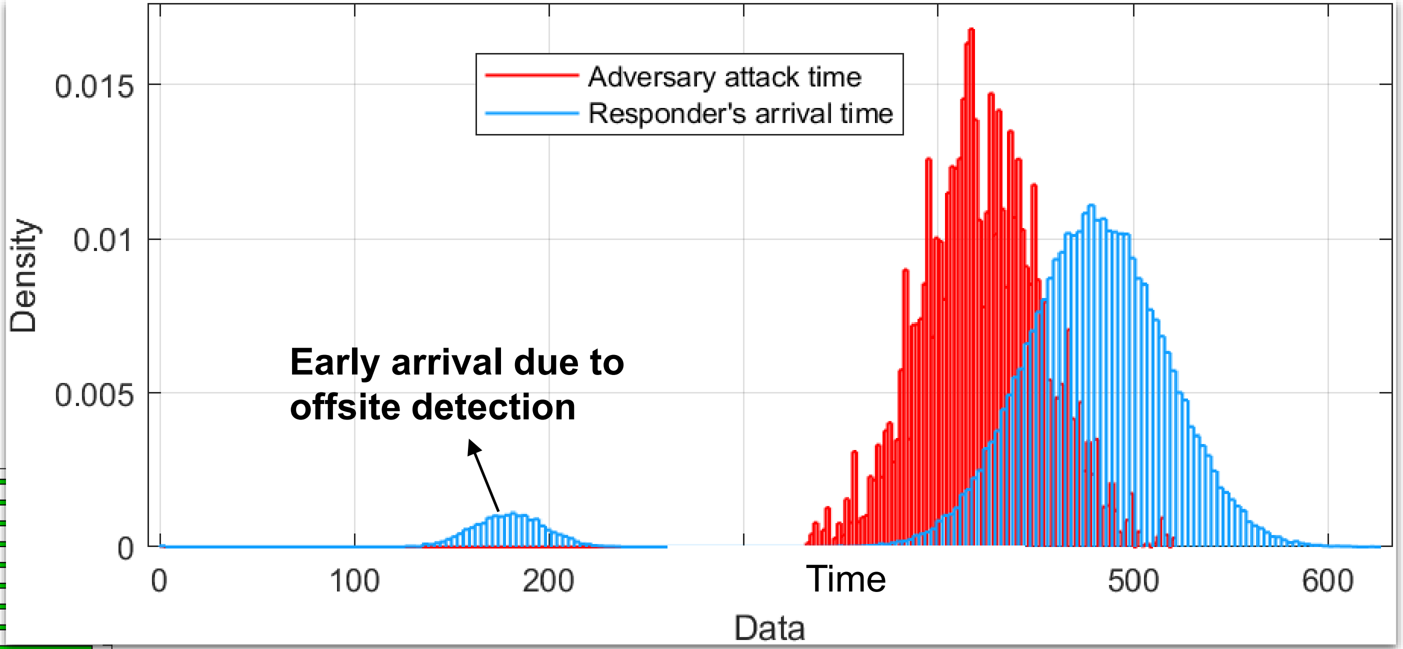
Example Heat Pipe Physics

Timing Informs the Consequence Analysis



Details are Found by Running the Simulation





Conclusions

- Next-generation reactors will be able to use risk to inform licensing
- Methods (models & tools) are needed to evaluate potential timelines for security
- We have developed an approach to generate qualitative and quantitative insights using risk-informed simulation
- The modeling process looks at three aspects
  - Facility mission time
  - Attacker timeline
  - Response timeline
- Modeling capabilities can include physical phenomena
- Additional details of the approach can be found in the report
  - INL/ RPT-22-68664 Approach and Model Used to Represent a Timeline Analysis for Security Design Enhancements

And Thanks to the INL Team

Robby Christian
Chris Chwasz
Shawn St. Germain
Steven Prescott
Vaibhav Yadav

Idaho National Laboratory