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Development of Physical Protection Criteria for Generation IV Nuclear Systems

Minimizing Guards, Guns and Gates

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Physical Protection of Nuclear Facilities

- A critical component of facility operations particularly since 9/11/01
- Without adequate facility design, the only remedy is strengthening defense through guards, guns, and gates – extrinsic features.
- Extrinsic features are not optimally applied and result in extreme operational costs, often making the facility economically infeasible.
- Can intrinsic features of a nuclear facility be maximized to minimize the operational costs of extrinsic physical protection?

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Proliferation Resistance and Physical Protection Goals of the GenIV Program

- *Generation IV nuclear energy systems will increase the assurance that they are a very unattractive and the least desirable route for diversion or theft of weapons-usable materials, and provide increased physical protection against acts of terrorism.*

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PR & PP Working Group
Program Objectives

- Determine measures for expressing:
  - Proliferation Resistance (PR)
  - Physical Protection (PP)
- Develop a comprehensive methodology for evaluation of the proliferation resistance and physical protection of Generation IV nuclear energy systems
- Decouple technical analysis from decision making
- Provide results useful to:
  - program policy makers
  - design teams

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Methodology Development Scope

- **Scope based on two related evaluation needs identified in the Generation IV Roadmap:**

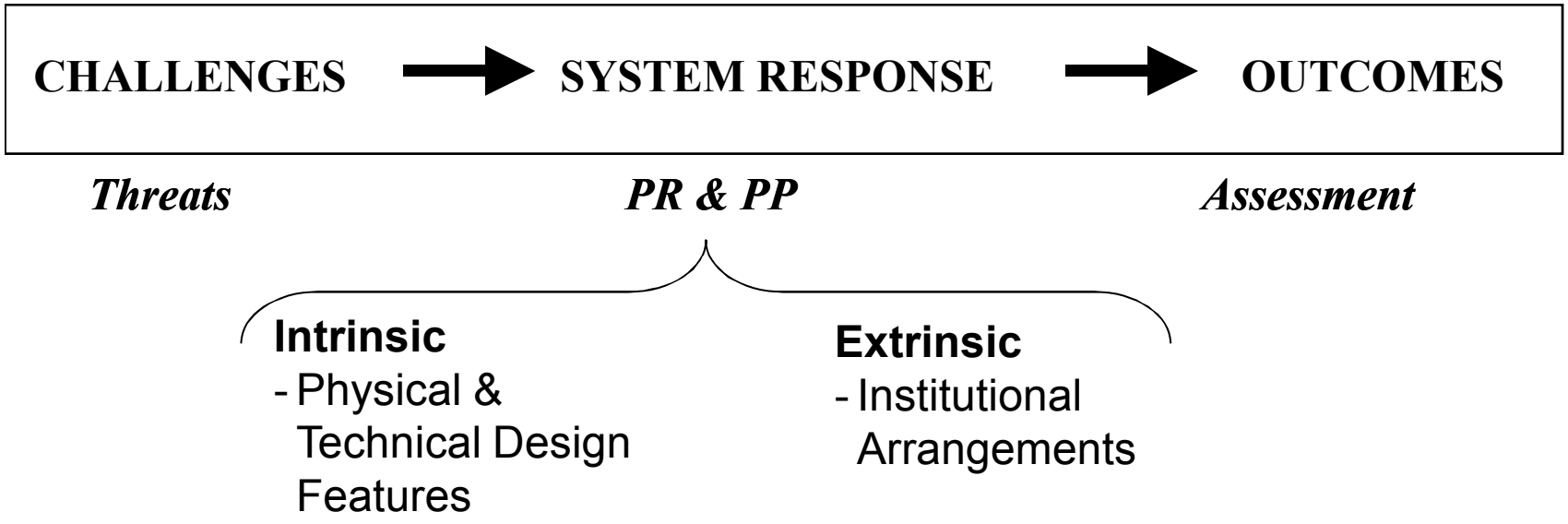
  1. **Proliferation resistance related to *diversion* of nuclear material from declared flows or inventories; *undeclared production*; *replication* of facilities/equipment = owner nation-state poses threat**

  2. **Physical protection related to *theft* of nuclear material for nuclear explosive devices or radiation dispersal devices; facility *sabotage; transport sabotage* = *Sub national* poses threat to owner**

Definitions

- **Proliferation Resistance (PR) definition**
  - Those characteristics of a nuclear energy system that impede the diversion or undeclared production of nuclear material, or misuse of technology, by States in order to acquire nuclear weapons or other nuclear explosive devices
- **Physical Protection (PP) robustness definition**
  - Those characteristics of a nuclear energy system that impede the theft of materials suitable for nuclear explosives or radiation dispersal devices, and the sabotage of facilities and transportation, by sub-national entities.

Assessment Paradigm



Proliferation, theft and sabotage involve **competing adversary and defender forces**. Important to recognize both perspectives and the human interplay.

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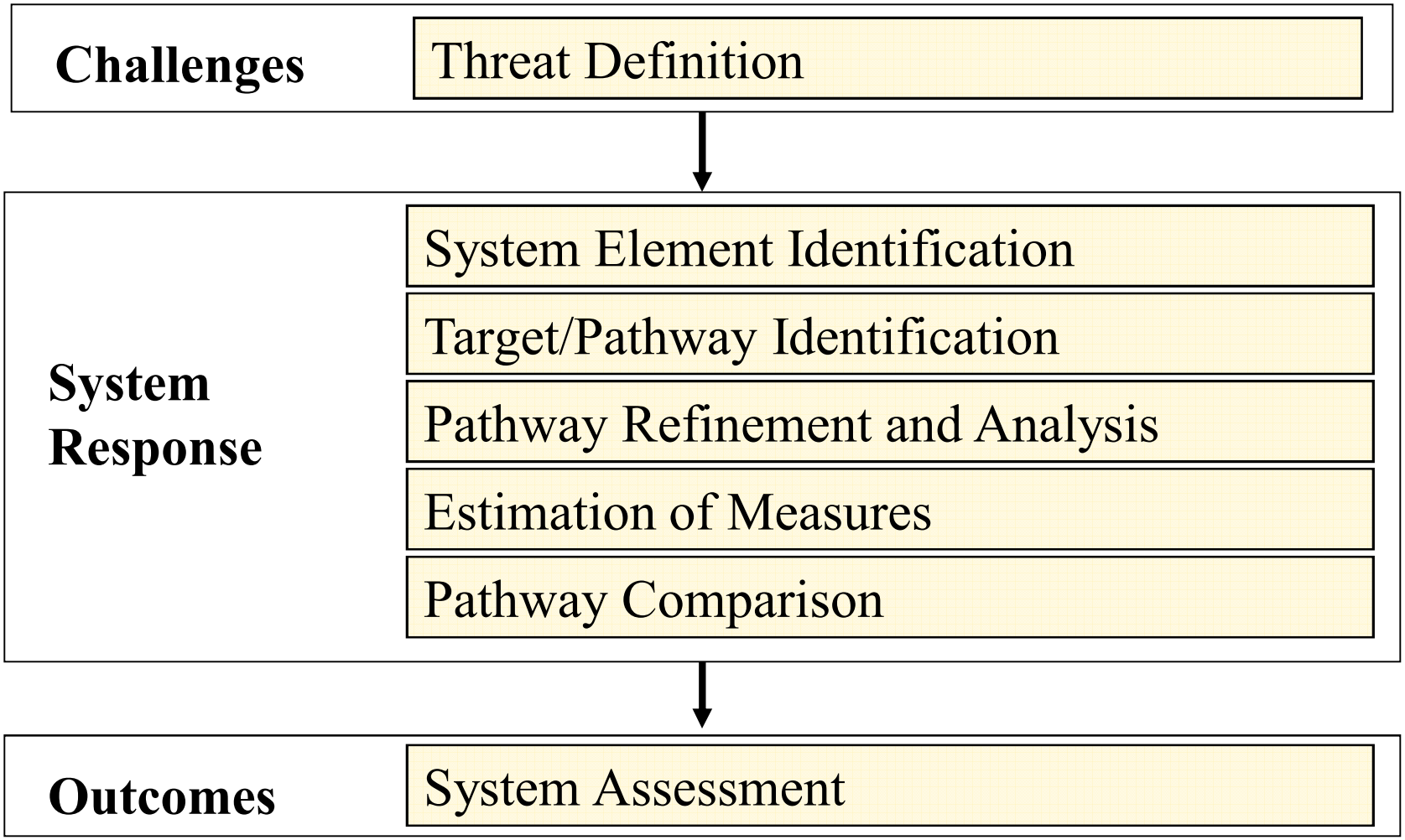
Evaluation framework



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PRPP Measures

- **Proliferation resistance**
  - *Proliferation Technical Difficulty*
  - *Proliferation Resources*
  - *Proliferation Time*
  - *Fissile Material Quality*
  - *Detection Time*
  - *Detection Resources*
- **Physical protection**
  - *Probability of Adversary Success*
  - *Consequences*
  - *Physical Protection Resources*

Each measure represents a major system characteristic that would be an important impediment to the strategy of a proliferant nation (PR), or of a non-state group attempting theft or sabotage (PP).

PP Measures for Conceptual Design Stage

- P_s(Prob. Of Adversary Success)=1-P_{ppe} (Prob. Of PP System Effectiveness)
  - Combine Detection Time, Adversary Delay Time, Operational Access, and Interruption Delay
  - Units: Probability
  - $P_{ppe} = P_{neutralize} * P_{interruption}$: for coarse pathway it is safe to assume that if interrupted, the adversary can be neutralized.
  - Therefore, P_s can be approximated by: $1-P_{interruption}$

PP Measures

- Consequences
  - Dependent on level of analysis
    - Conceptual – Limit to In facility, On Site, and Off Site – Units: Location
    - Engineering Design and Existing Design – Variety of tools available

PP Measures

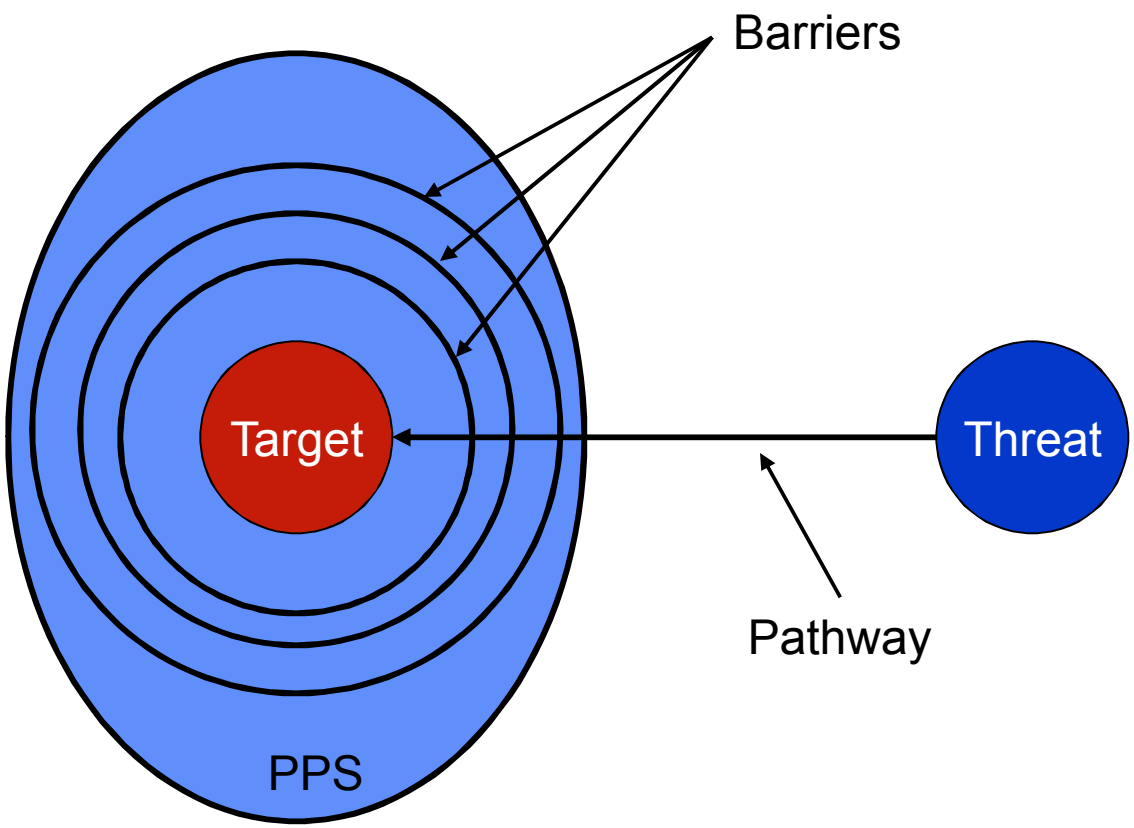
- PP Resources
  - Cost of PP system to:
    - Estimate to achieve performance objectives at coarse pathway
    - Cost of system at the detailed design level to implement performance objectives
  - Units: $

Threat Scenarios

Physical Protection

- Theft of nuclear weapons-usable material from facilities or transport
- Theft of hazardous radioactive material from facilities and transport for use in a radioactive dispersal device (dirty bomb)
- Sabotage at a nuclear facility or transport with the intention to release radioactive material to harm the public, damage facilities, or disrupt operations.

PP Approach - Simple



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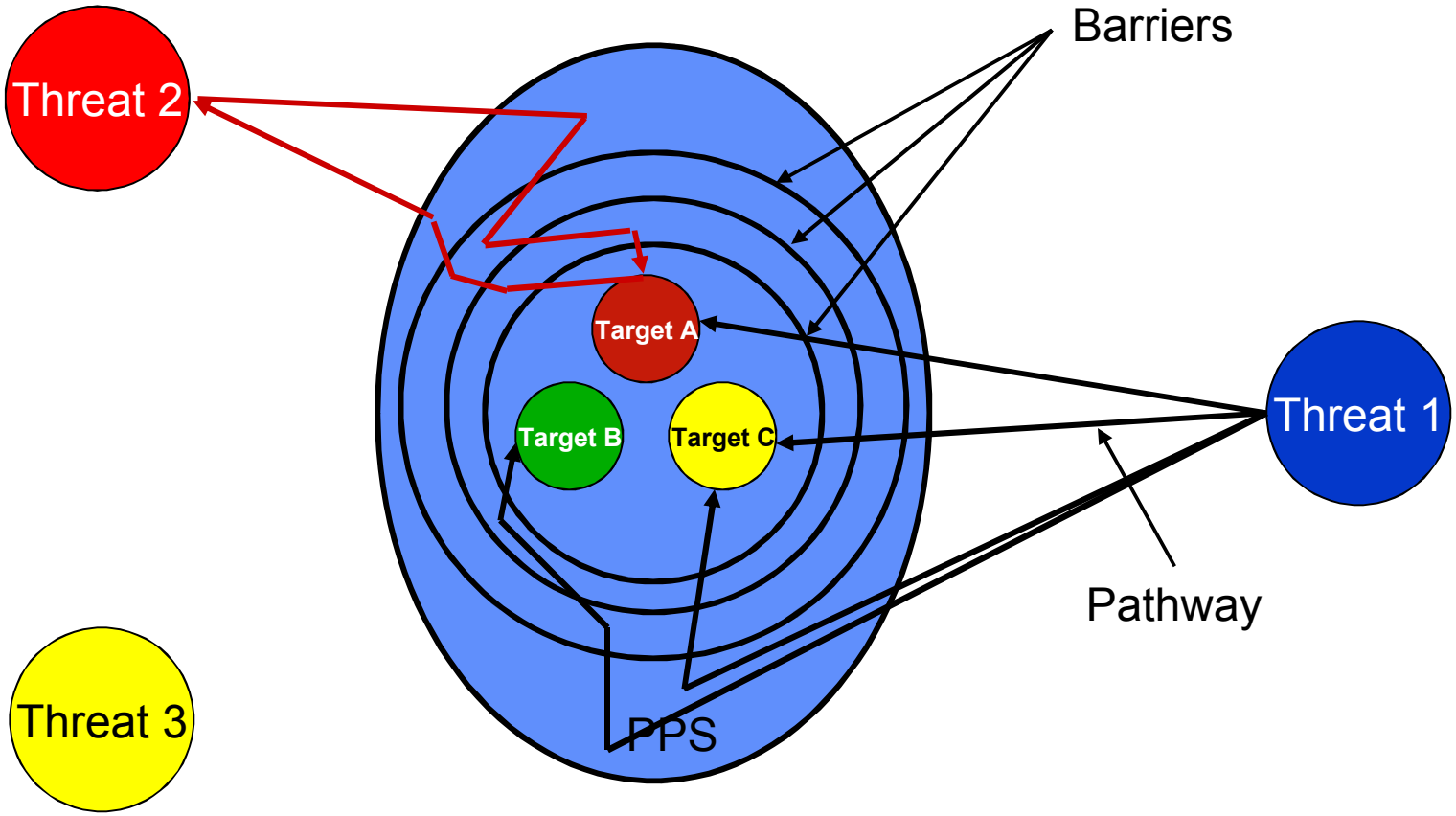
PP Approach - Comprehensive



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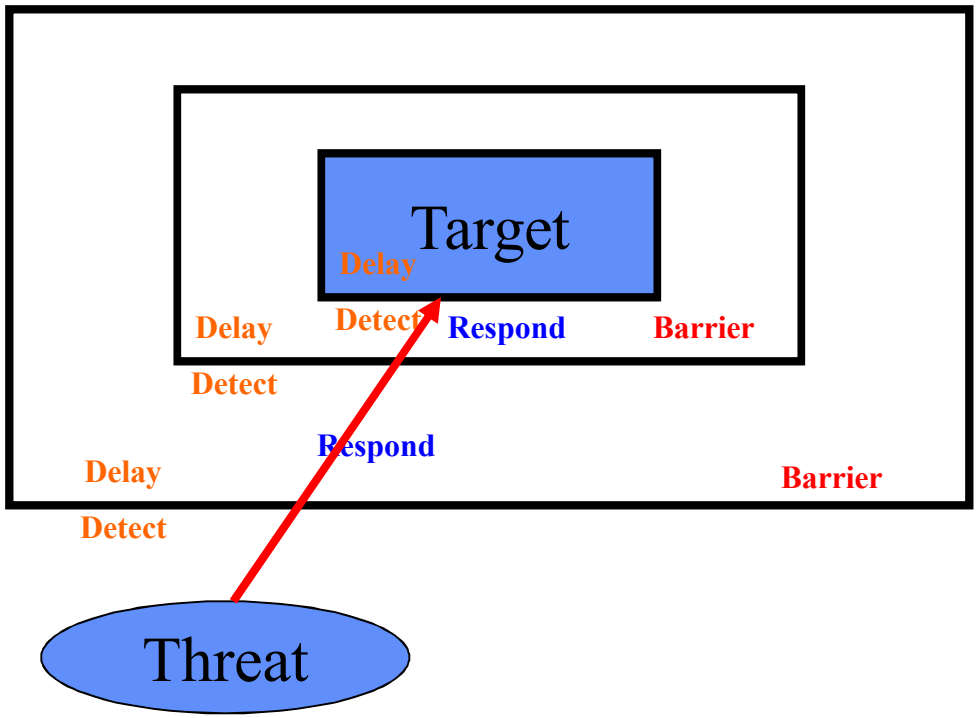
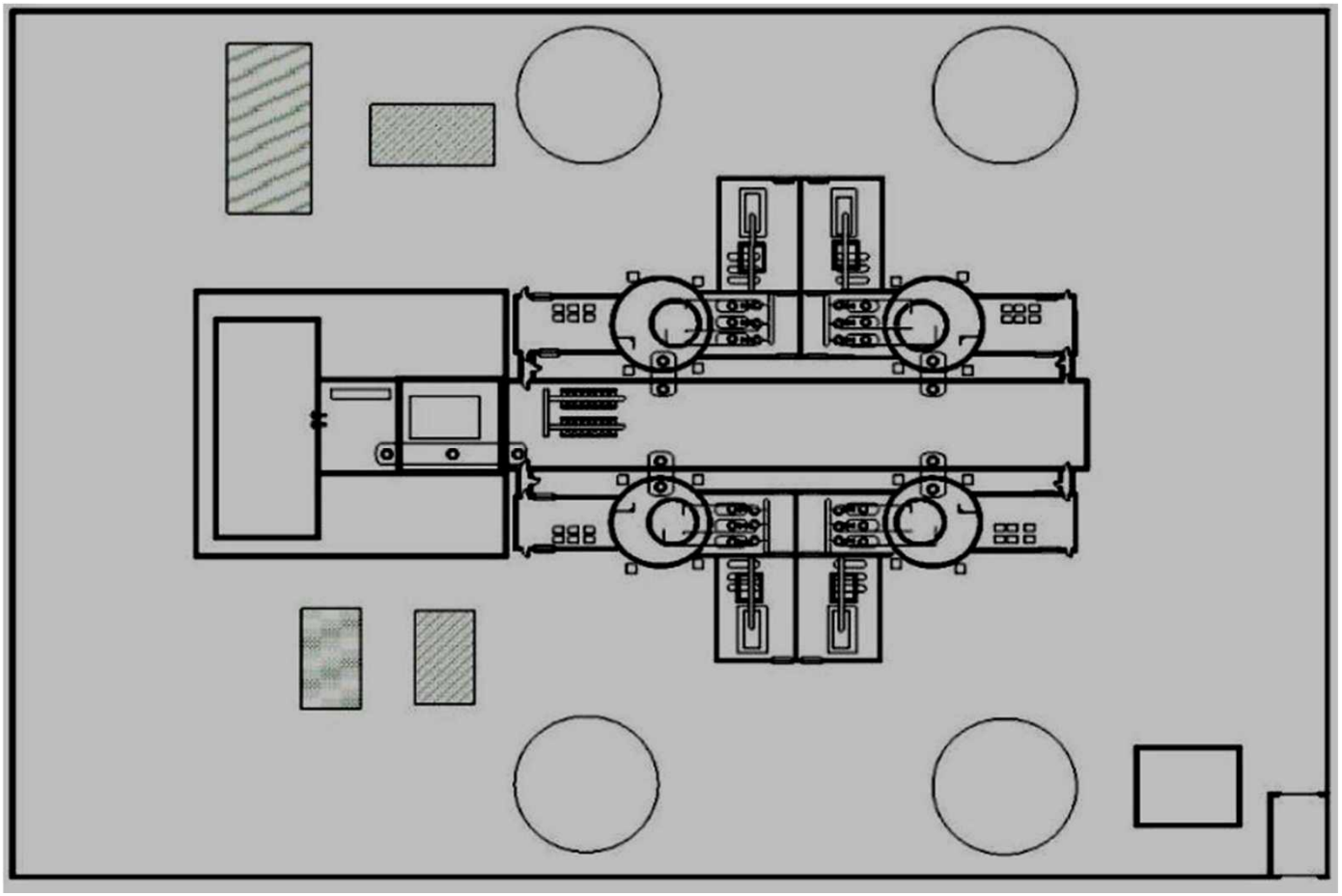
The PP Expert Vision of a Facility



Engineers Vision of a Facility



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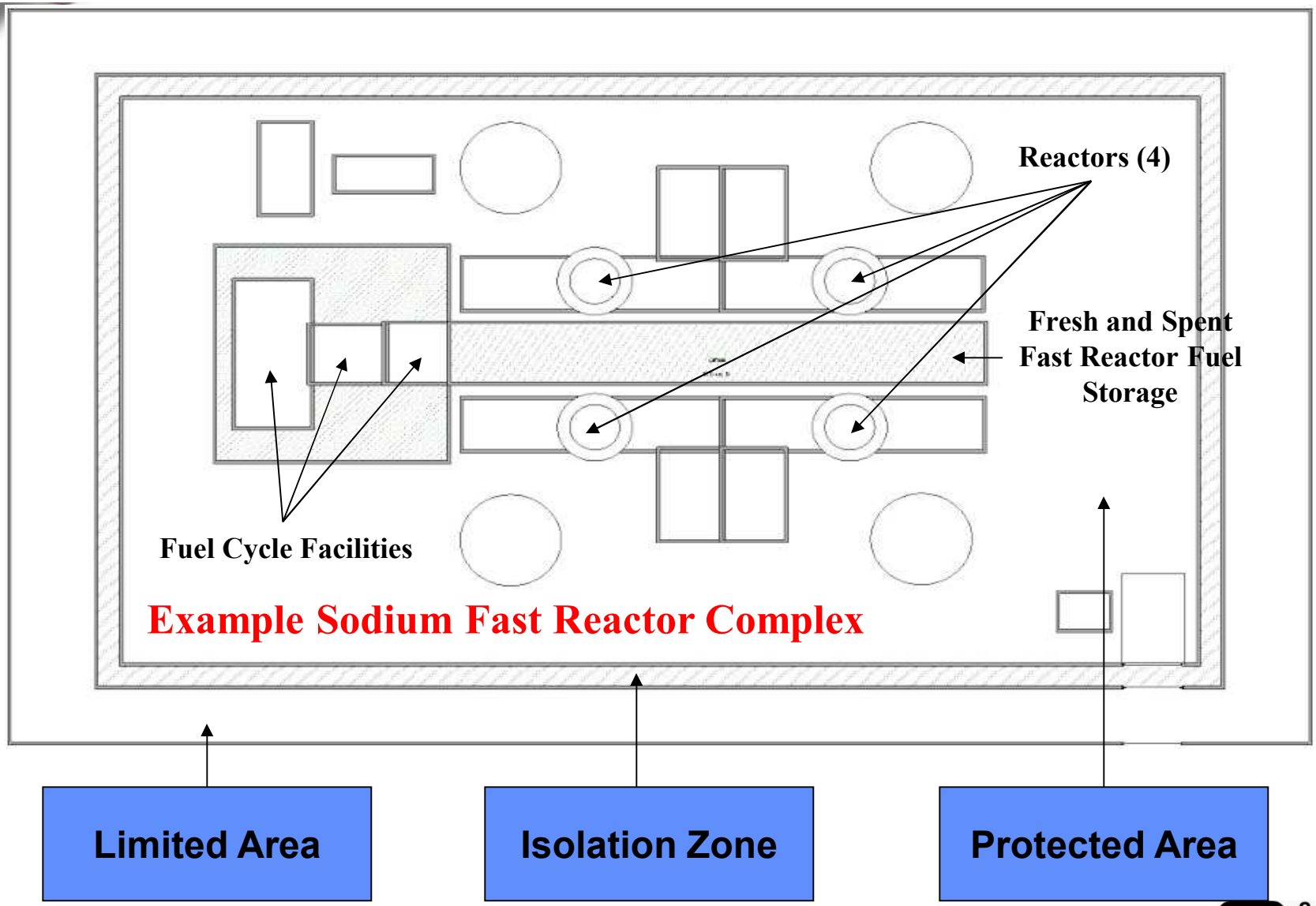
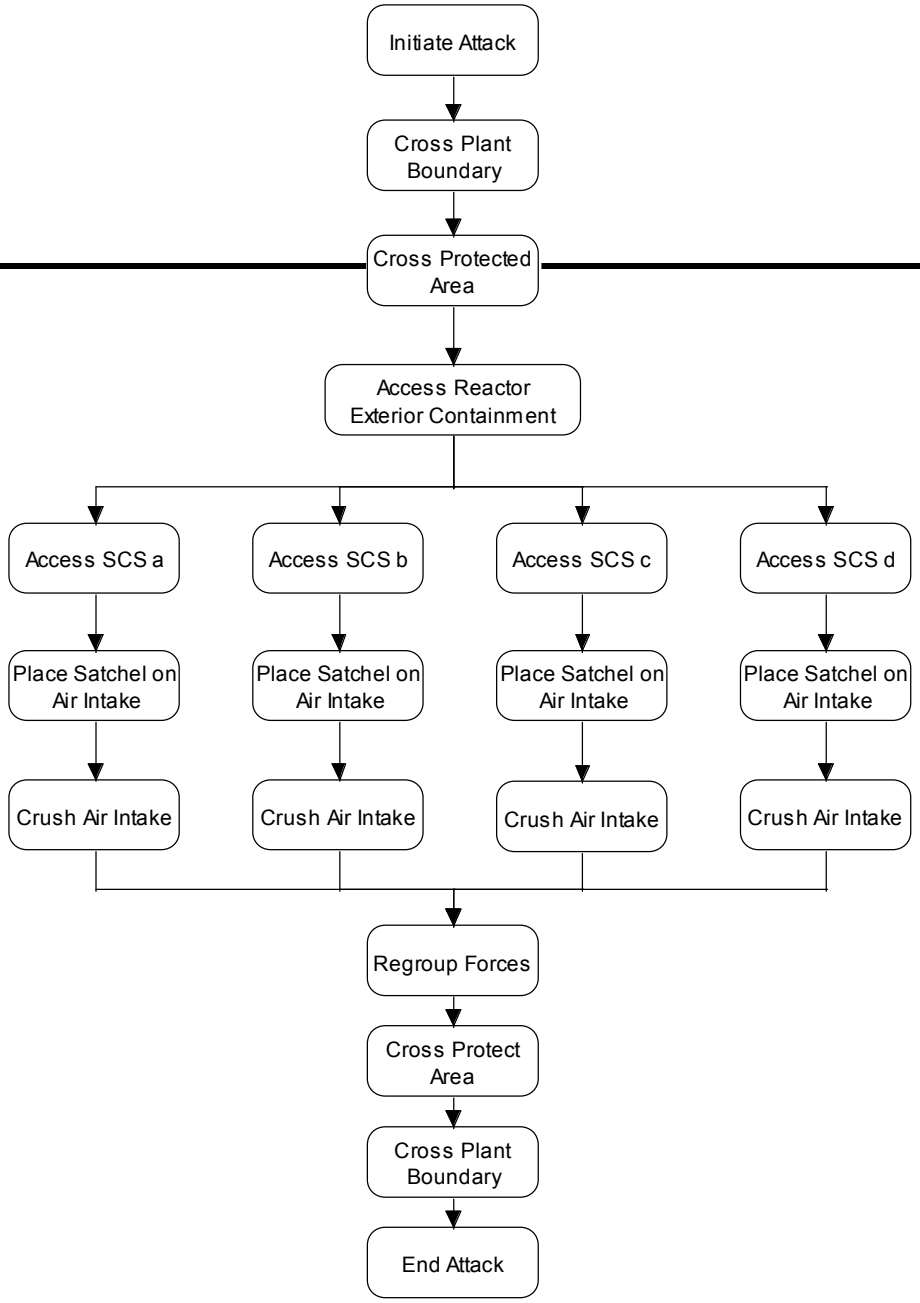
Facility Boundaries



Sabotage Target Sets

- Threat Analysis on Target Objectives:
  - Release of radiological material (off-site, on-site)
  - Disruption of operational capacity (reduce power output)
  - Generic attack to promote fear
- Consequence Analysis:
  - Plant Operational State
  - Damage Analysis (i.e. surrounding area)
  - Politically Motivated Outcomes (i.e. plant shutdown)
- Target/System Analysis (based on consequence and material availability):
  - Reactor Facility
  - Fuel Cycle Facility
  - Fuel Storage Facility
- Target Set Identification
  - System vs. Consequence
- Adversary Sequence Diagram

Adversary Sequence Diagram



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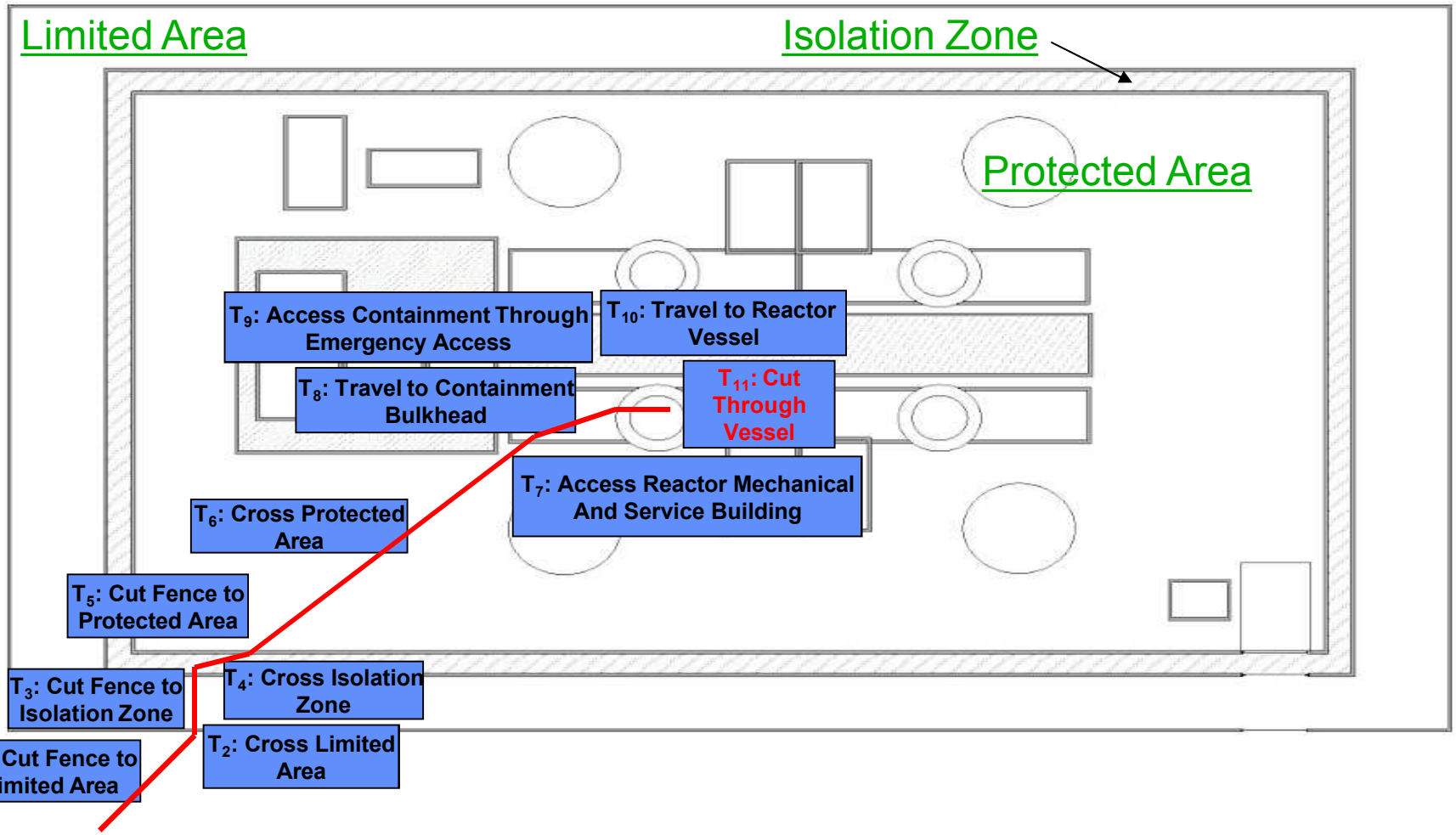
Time Based Interruption Analysis



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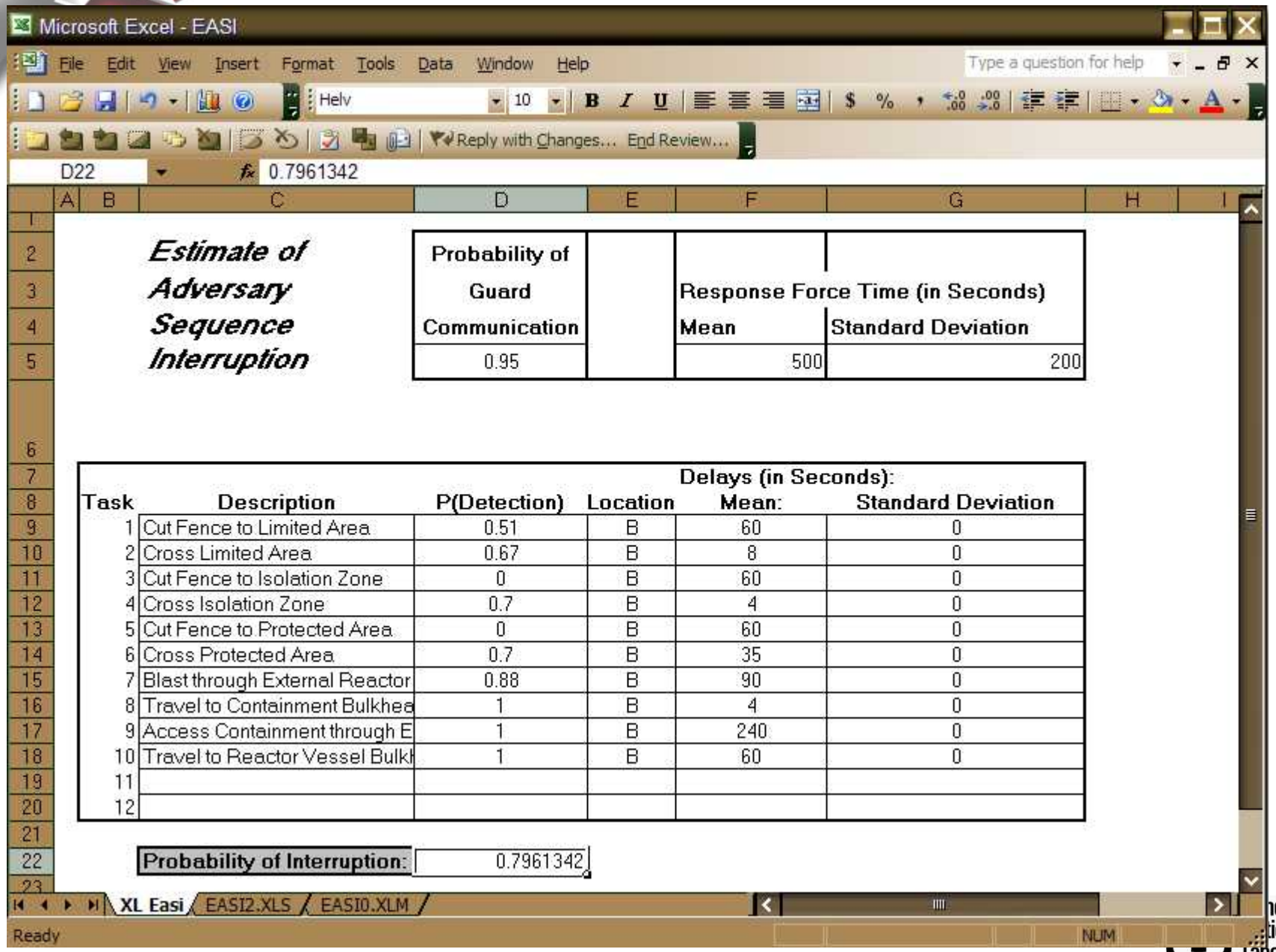
Estimate of Adversary Sequence Interruption (EASI) Model

- Evaluates basic functions of physical protection systems:
  - Detection
  - Assessment
  - Communications
  - Delay
  - Response
- Provides an estimate of adversary sequence interruption
- Output is the Probability of Interruption

EASI Calculation



Estimate of Adversary Sequence Interruption

Probability of Guard Communication		Response Force Time (in Seconds)	
		Mean	Standard Deviation
0.95		500	200

Task	Description	P(Detection)	Location	Delays (in Seconds): Mean:	Standard Deviation
1	Cut Fence to Limited Area	0.51	B	60	0
2	Cross Limited Area	0.67	B	8	0
3	Cut Fence to Isolation Zone	0	B	60	0
4	Cross Isolation Zone	0.7	B	4	0
5	Cut Fence to Protected Area	0	B	60	0
6	Cross Protected Area	0.7	B	35	0
7	Blast through External Reactor	0.88	B	90	0
8	Travel to Containment Bulkhea	1	B	4	0
9	Access Containment through E	1	B	240	0
10	Travel to Reactor Vessel Bulkh	1	B	60	0
11					
12					

Probability of Interruption: 0.7961342

Path Event Timeline Scenario Description

Stage	Task	P_D	Delay (s)	Area
T_1	Cut fence to Limited Area	.51	60	Limited Area
T_2	Cross Limited Area	.67	8	Limited Area
T_3	Cut fence to Isolation Zone	0	60	Isolation Zone
T_4	Cross Isolation Zone	.70	4	Isolation Zone
T_5	Cut fence to Protected Area	0	60	Protected Area
T_6	Cross Protected Area	.70	35	Protected Area
T_7	Blast through External Reactor Mechanical and Service Building Door	.88	90	Protected Area
T_8	Travel to Containment Bulkhead	.70	4	Protected Area
T_9	Access Containment through emergency hatch	1	240	Protected Area
T_{10}	Travel to Reactor Vessel Bulkhead	1	60	Protected Area
T_{11}	Cut through Reactor Vessel Bulkhead (Target)	1	200	Protected Area

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PPS_{1A}: Path Event Timeline

Response Force Deployment Time (RFT): 500 seconds

	T_1:	T_2:	T_3:	T_4:	T_5:	T_6:	T_7:	T_8:	T_9:	T_{10}:	T_{11}:
Task Delays (s):	60	8	60	4	60	35	90	4	240	60	200

	P_1:	P_2:	P_3:	P_4:	P_5:	P_6:	P_7:	P_8:	P_9:	P_{10}:	P_{11}:
P_D:	.51	.67	0	.70	.0	.70	.88	.70	1	1	1

Critical Interruption Point

	TR_1:	TR_2:	TR_3:	TR_4:	TR_5:	TR_6:	TR_7:	TR_8:	TR_9:	TR_{10}:	TR_{11}:
Timely Response:	821	761	753	693	689	629	594	504	500	260	200

Timely Detection:	No	No	No	No	No	No	No	No	No	No	No

629 + 500 = 1129

Critical Detection Point

No Timely Detection

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PPS_{1B}: Path Event Timeline

Response Force Deployment Time (RFT): 500 seconds

	T_1:	T_2:	T_3:	T_4:	T_5:	T_6:	T_7:	T_8:	T_9:	T_{10}:	T_{11}:
Task Delays (s):	60	8	60	4	60	35	90	4	240	60	200

	P_1:	P_2:	P_3:	P_4:	P_5:	P_6:	P_7:	P_8:	P_{10}:	P_{11}:
P_D:	.51	.67	0	.70	.0	.70	.88	Critical Interruption Point		1

	TR_1:	TR_2:	TR_3:	TR_4:	TR_5:	TR_6:	TR_7:	TR_8:	TR_9:	TR_{10}:	TR_{11}:
Timely Response:	821	761	753	693	689	629	594	504	500	260	200

Timely Detection:	Yes	Yes	No	No							No

260 + 500 = 760

Critical Detection Point

Timely Detection

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PPS_2: Path Event Timeline

Response Force Deployment Time (RFT): 100 seconds

	T_1:	T_2:	T_3:	T_4:	T_5:	T_6:	T_7:	T_8:	T_9:	T_{10}:	T_{11}:
Task Delays (s):	**90**	**13**	**60**	**7**	**60**	**35**	**120**	**4**	**240**	**4**	**240**
	P_1:	P_2:	P_3:	P_4:	P_5:	P_6:	P_7:	P_8:	P_9:	P_{10}:	P_{11}:
P_D:	**.66**	**.70**	**.61**	**.74**	**.81**	**.72**	**.89**	**.87**	**1**	**1**	**1**
	TR_1:	TR_2:	TR_3:	TR_4:	TR_5:	TR_6:	TR_7:	TR_8:	TR_9:	TR_9:	TR_9:
Timely Response:	**873**	**783**	**770**	**710**	**703**	**643**	**608**	**488**	**484**	**244**	**240**
Timely Detection:	**Yes**	**Yes**	**Yes**	**No**	**No**	**No**	**No**	**No**	**No**	**No**	**No**

Critical Interruption Point

Critical Detection Point

Timely and Appropriate Response

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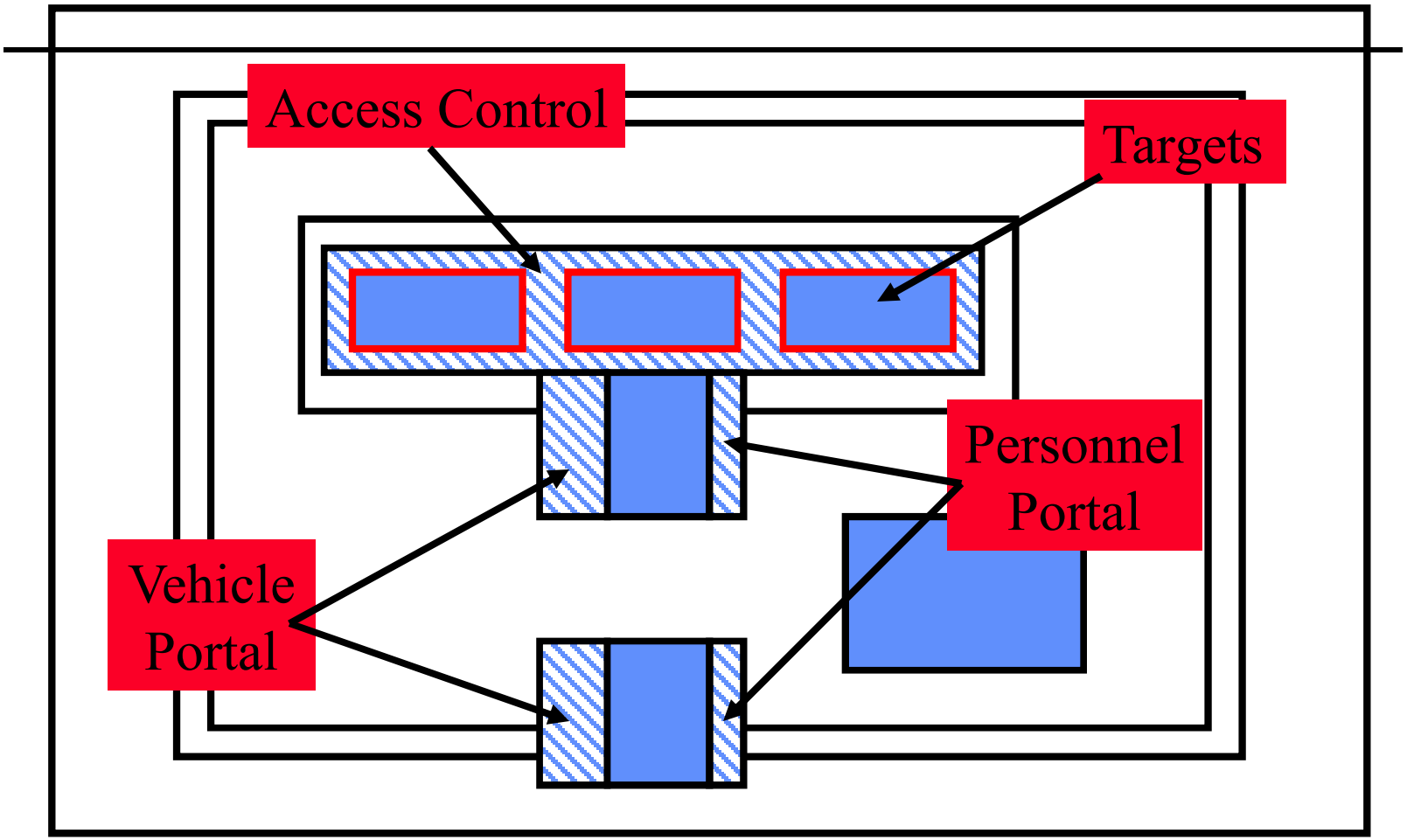
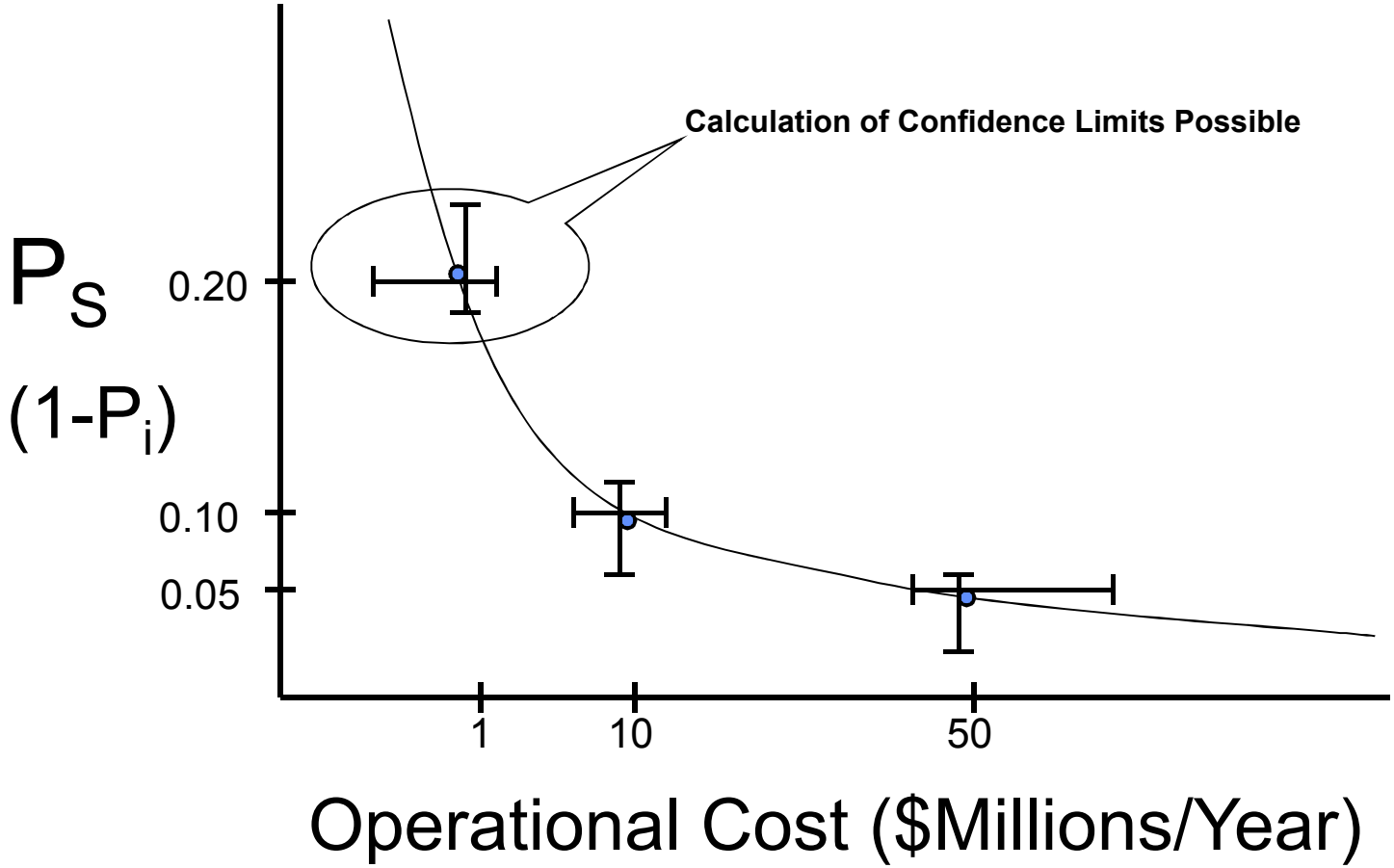
ESFR View for Performance Specifications



Probability of Successful Attack (P_S) versus Cost of Physical Protection System (PPS)



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Conclusion

- Tools are needed to assist nuclear facility designers to examine alternative facility designs and layouts to minimize the reliance on extrinsic physical protection features.
- These tools exist, but reformatting for the facility designer is required in improve the intrinsic features of the facility.
- A tool for conceptual design analysis is being developed to allow the designer to get “a feel” for the impact of facility design on physical protection.
- Establishing a layered set of performance requirements then allows the designer to begin working with the architect-engineer to finalize the design.