Vaibhav Yadav, PhD
Distinguished Staff Scientist

Methodology for Risk Informed Assessment of Physical Security Compensatory Measures at Nuclear Power Plants

18th International Probabilistic Safety Assessment & Management (PSAM) Conference

Pittsburgh, PA

July 19-24, 2026

INL/CON-26-90505

Battelle Energy Alliance manages INL for the
U.S. Department of Energy's Office of Nuclear Energy

Idaho National Laboratory

Motivation

- Physical security at commercial NPPs is highly labor intensive
  - nearly 20% of the entire workforce at several NPPs
- Current methods for physical security assessment are static and binary (success/fail)
- Current regulations for physical security are prescriptive

§ 73.55 Requirements for physical protection of licensed activities in nuclear power reactors against radiological sabotage.

(iii) The number of armed responders shall not be less than ten (10).

...are that the capabilities to detect, assess, interdict, and ... threats up to and including the design basis threat of radiological ...tage as stated in § 73.1, are maintained at all times.

...censee shall test each intrusion alarm for operability ... beginning and end of any period that it is used for security, or if the period of continuous use exceeds seven (7) days. The intrusion alarm ...be tested at least once every seven (7) days.

US NRC, 10 CFR 73.55: Requirements for physical protection of licensed activities in nuclear power reactors against radiological sabotage

Compensatory Measures

- Degraded or inoperable security equipment:
  - Fence, cameras, sensors etc.
  - ~2000+ hours per year at a single facility
- Traditional CM: immediately place guards
  - Inefficient, labor-intensive
- Some plants are exploring approaches to assess the impact of security degradation
  - subjective
  - non-quantitative
  - not risk-informed
  - no clear connection of failure impact to CM recommendation

10 CFR 73.55(b)(3)(i)

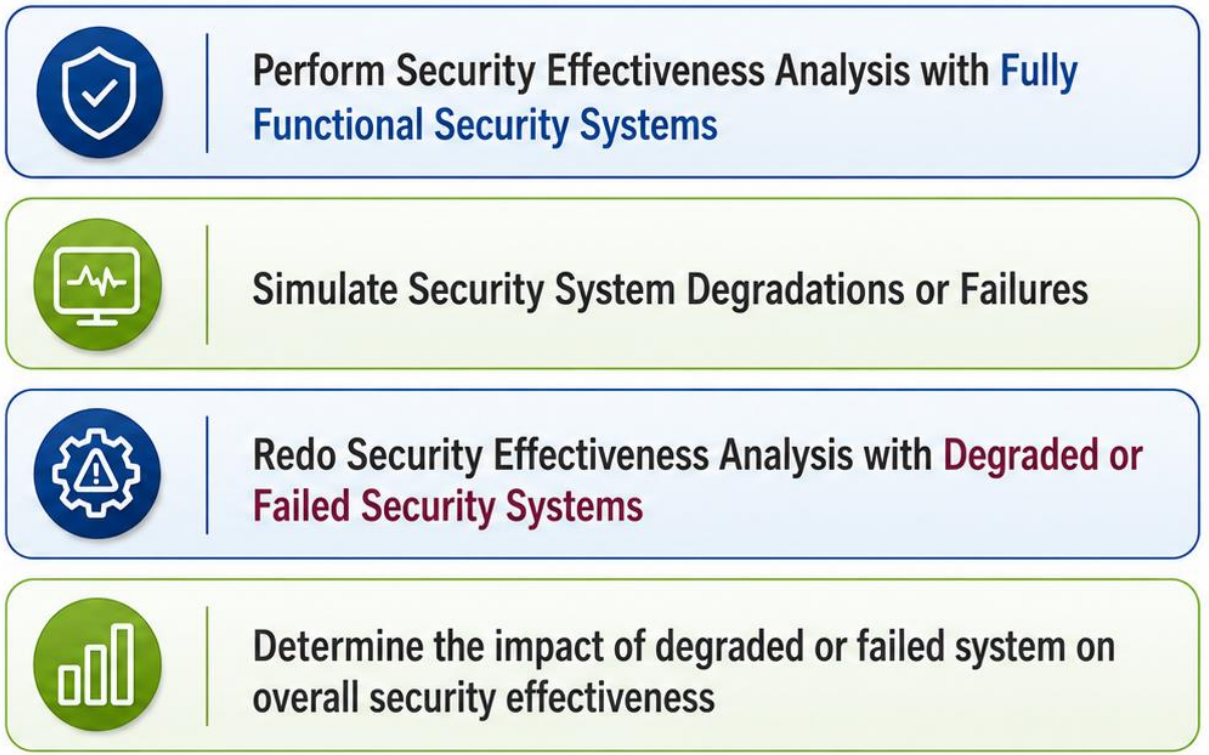
(3) The physical protection program must be designed to prevent significant core damage and spent fuel sabotage. Specifically, the program must:

(i) Ensure that the capabilities to detect, assess, interdict, and neutralize threats up to and including the design basis threat of radiological sabotage as stated in § 73.1, are maintained at all times.

RIS 2017-04 ML16110A366

… the NRC staff conducted a lessons-learned review of the NRC's force-on-force inspection program. As a result of this review, the NRC identified that in certain cases, licensees are applying immediate compensatory measures where such measures are not required by NRC regulations and guidance.

Risk Informed Compensatory Measures: Modeling and Simulation



P_E

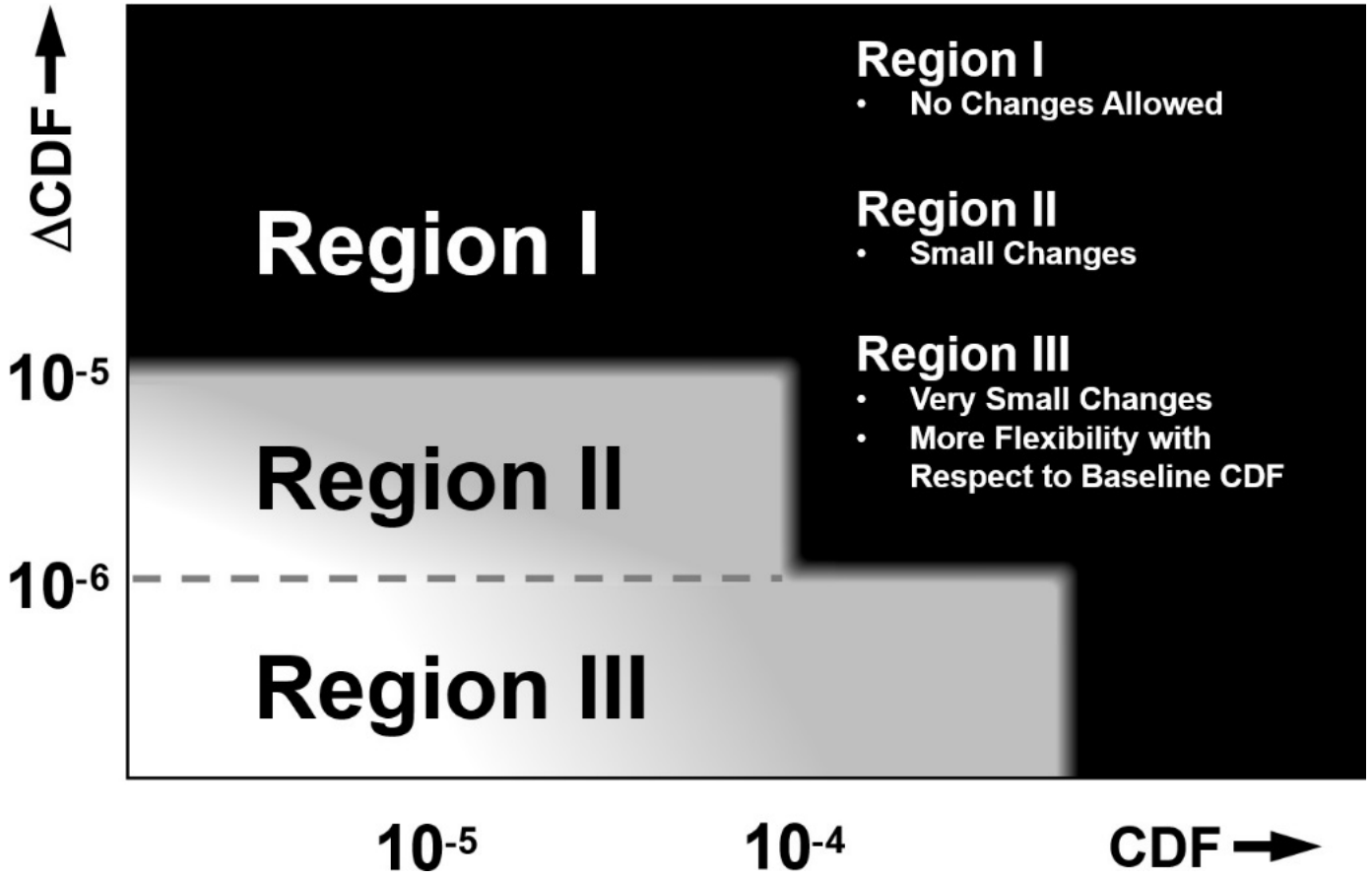
P_{E_F}

ΔP_E

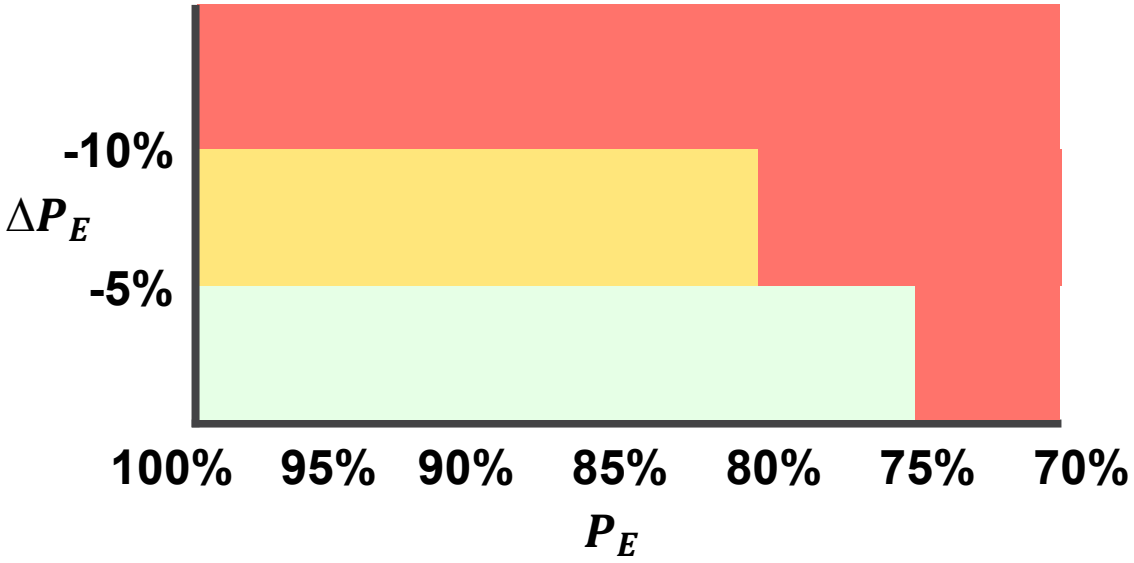
What about compensatory measures?

NRC RG 1.174 Rev 3

An Approach For Using Probabilistic Risk Assessment In Risk-informed Decisions On Plant-specific Changes To The Licensing Basis



Risk Informed Compensatory Measures: CM Recommendation



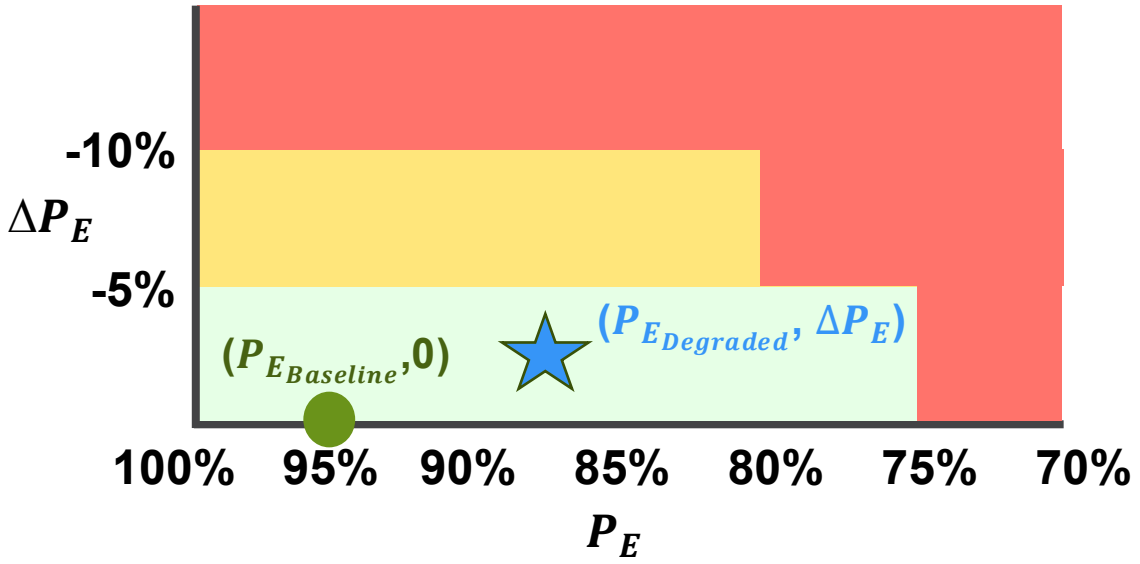
Region I
Take immediate compensatory measure

Region II
Take compensatory measure within 36 hours

Region III
Take compensatory measure within 72 hours

Risk Informed Compensatory Measures: CM Recommendation

- Perform Security Effectiveness Analysis with Fully Functional Security Systems $P_{E_{Baseline}}$
- Simulate Security System Degradations or Failures
- Redo Security Effectiveness Analysis with Degraded or Failed Security Systems $P_{E_{Degraded}}$
- Determine the impact of degraded or failed system on overall security effectiveness ΔP_E



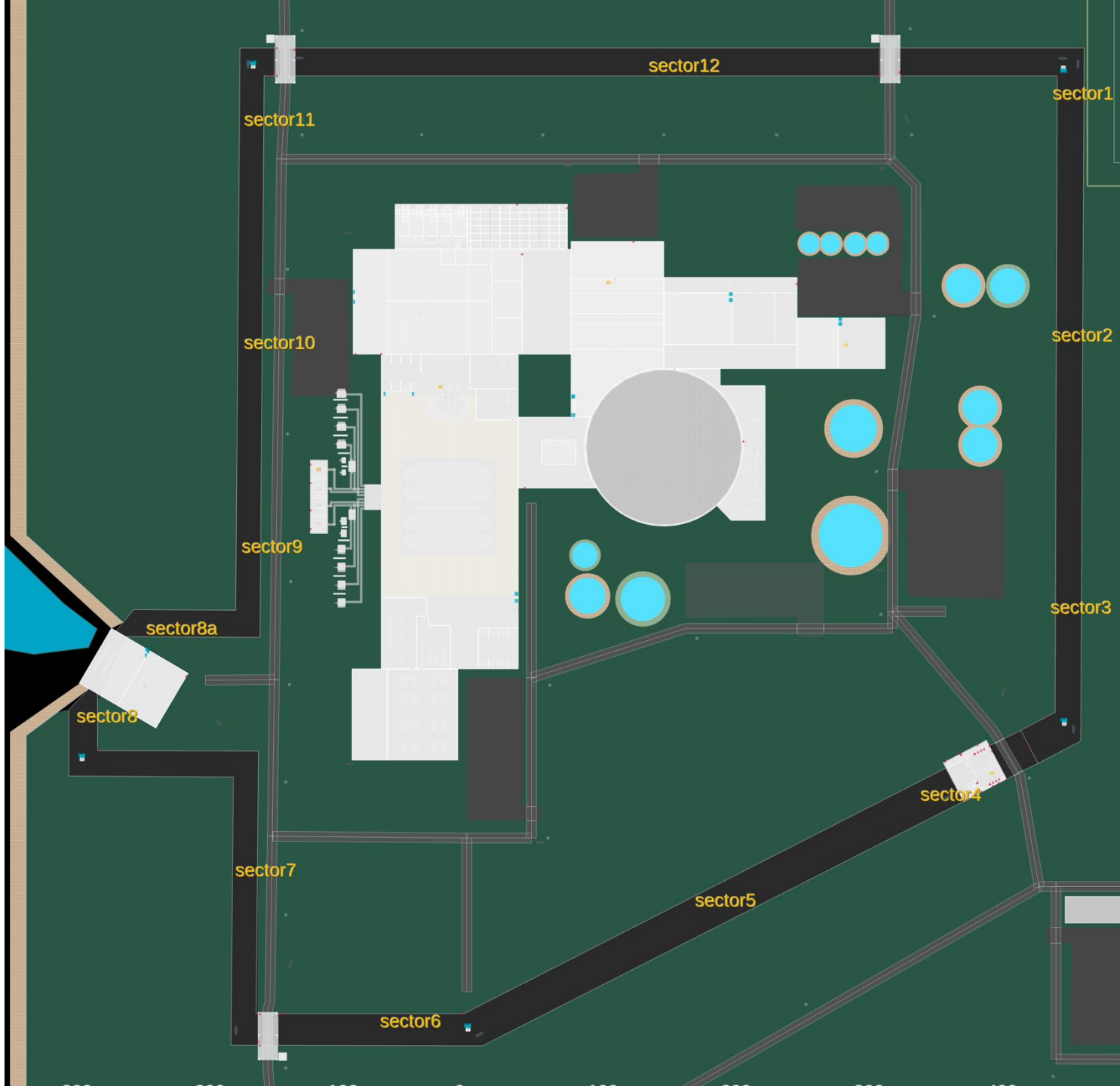
Region I
Take immediate compensatory measure

Region II
Take compensatory measure within 36 hours

Region III
Take compensatory measure within 72 hours

RICM: Use Case

- Lone Pine: A hypothetical single unit 2-loop PWR plant
- 12 PIDAS Sectors
- 7 FOF Scenarios modeled to capture involvement of each PIDAS
- One PIDAS sector can be involved in more than one FOF scenario
- FOF Scenario runs in Simajin tool to determine statistical value of P_E for each scenario

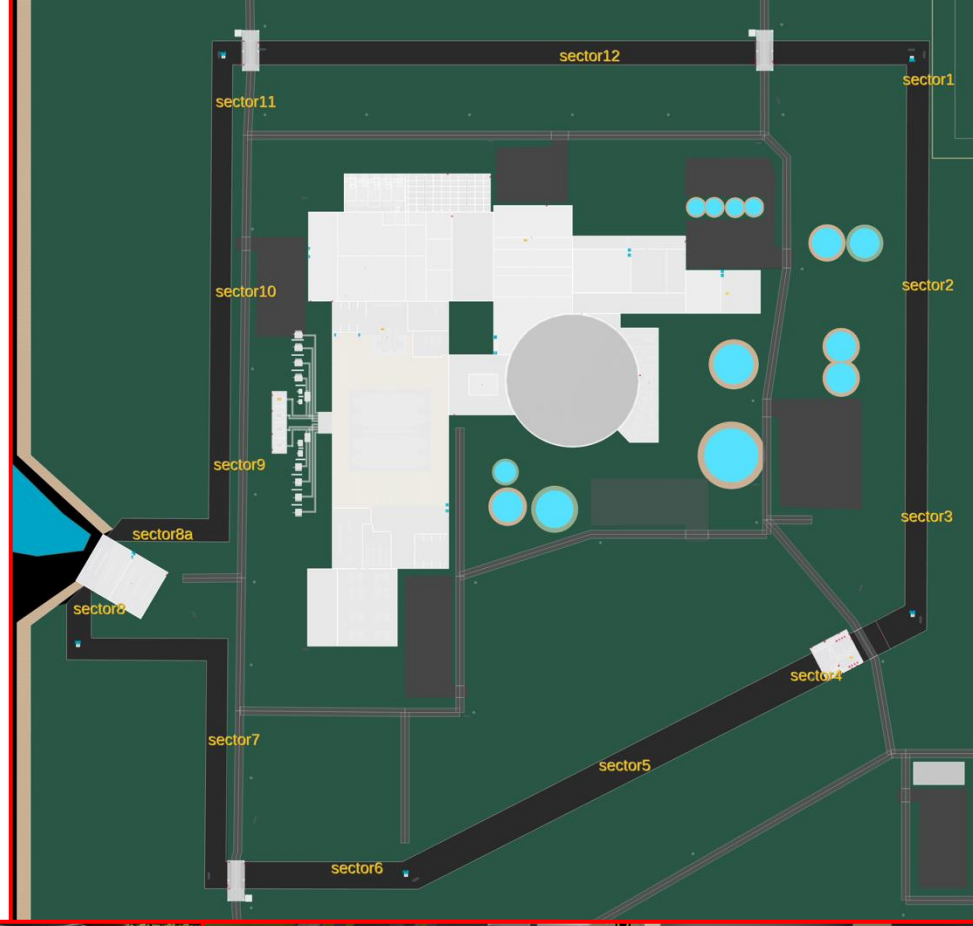


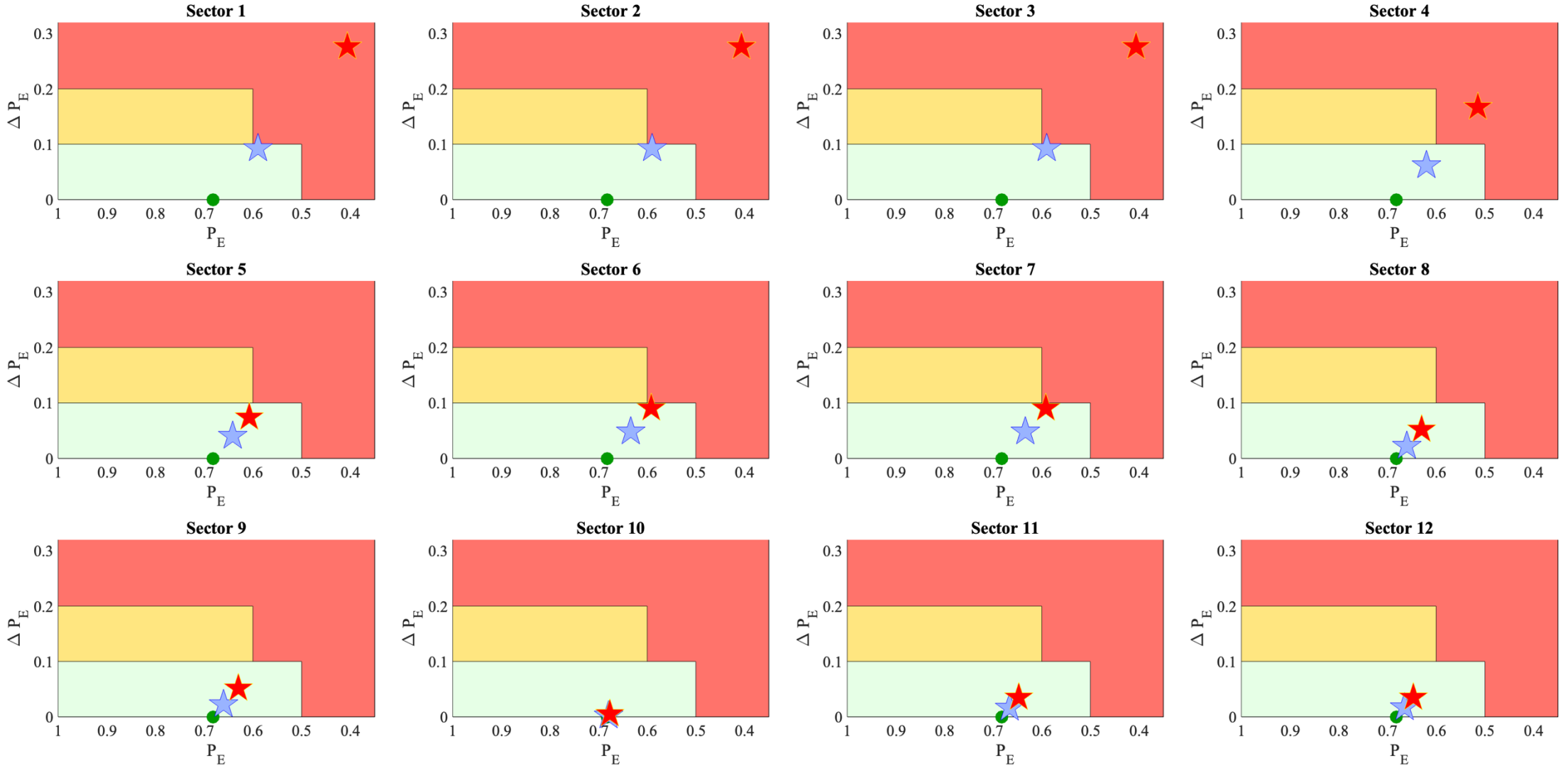
RICM Use Case: Analysis

Scenarios	Results from FOF Simulation			w_i	$w_{i,N}$			
	Raw PE			$\frac{1}{P_{E,baseline}} - 1$	$\frac{w_i}{\sum w_i}$	Weighted PE		
	Baseline PE	Minor Impairement PE	Major Impairement PE	Raw Weights	Normalized Weights	Baseline PE	Minor Impairement PE	Major Impairement PE
Scenario 1	0.884	0.504	0.057	0.131	0.077	0.068	0.039	0.004
Scenario 2	0.827	0.504	0.038	0.209	0.123	0.102	0.062	0.005
Scenario 3	0.941	0.827	0.770	0.063	0.037	0.035	0.031	0.029
Scenario 4	0.836	0.418	0.057	0.196	0.116	0.097	0.048	0.007
Scenario 5	0.523	0.352	0.010	0.912	0.538	0.282	0.190	0.005
Scenario 6	0.893	0.446	0.067	0.120	0.071	0.063	0.032	0.005
Scenario 7	0.941	0.884	0.798	0.063	0.037	0.035	0.033	0.030

RICM Use Case: Analysis

	Scenarios						
Sectors	1	2	3	4	5	6	7
Sector 1					✓		
Sector 2					✓		
Sector 3					✓		
Sector 4					✓	✓	
Sector 5				✓		✓	
Sector 6				✓			
Sector 7				✓			
Sector 8		✓	✓				
Sector 9		✓	✓				
Sector 10							✓
Sector 11	✓						✓
Sector 12	✓		✓				





Baseline

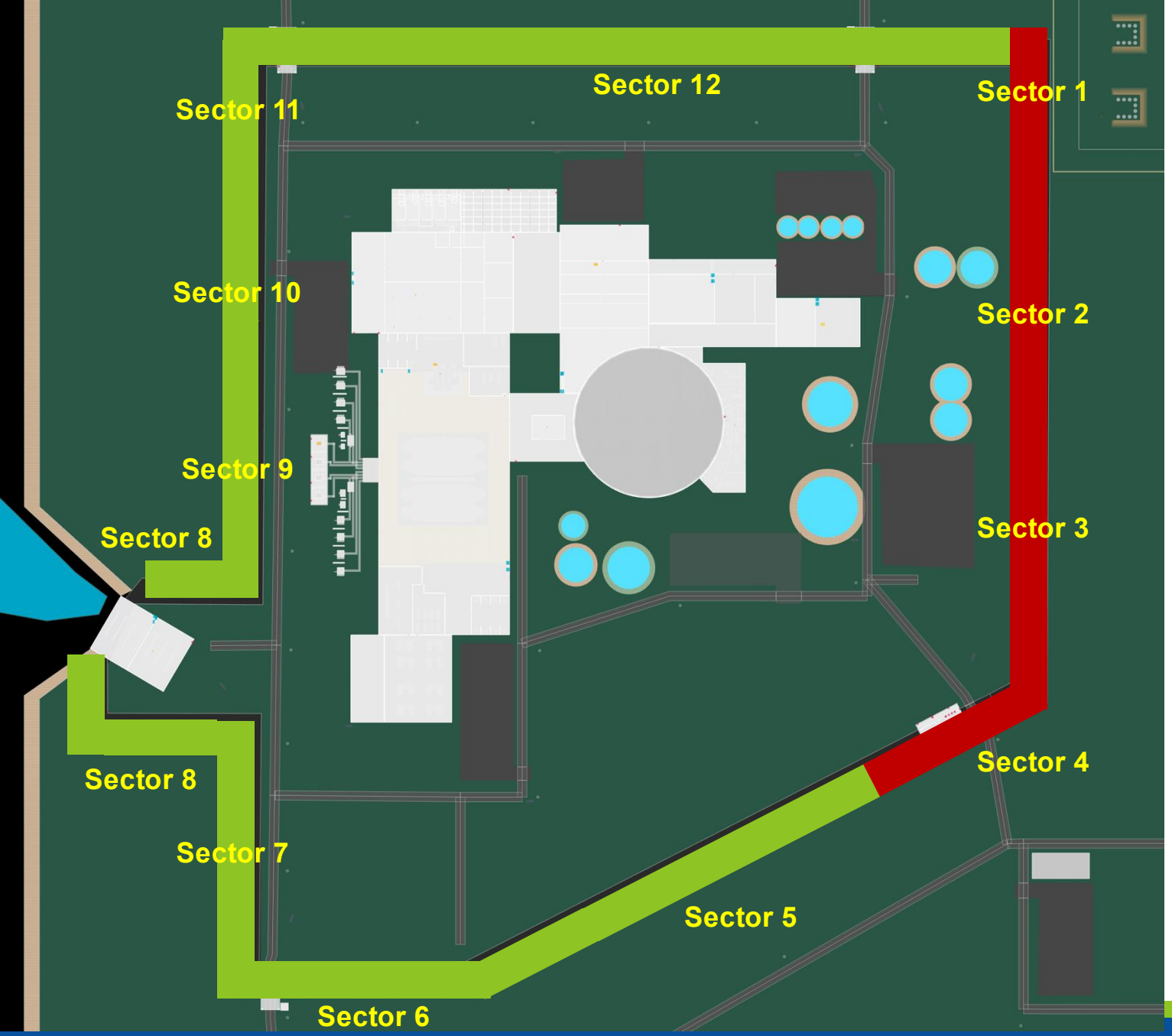
Minor Impairment

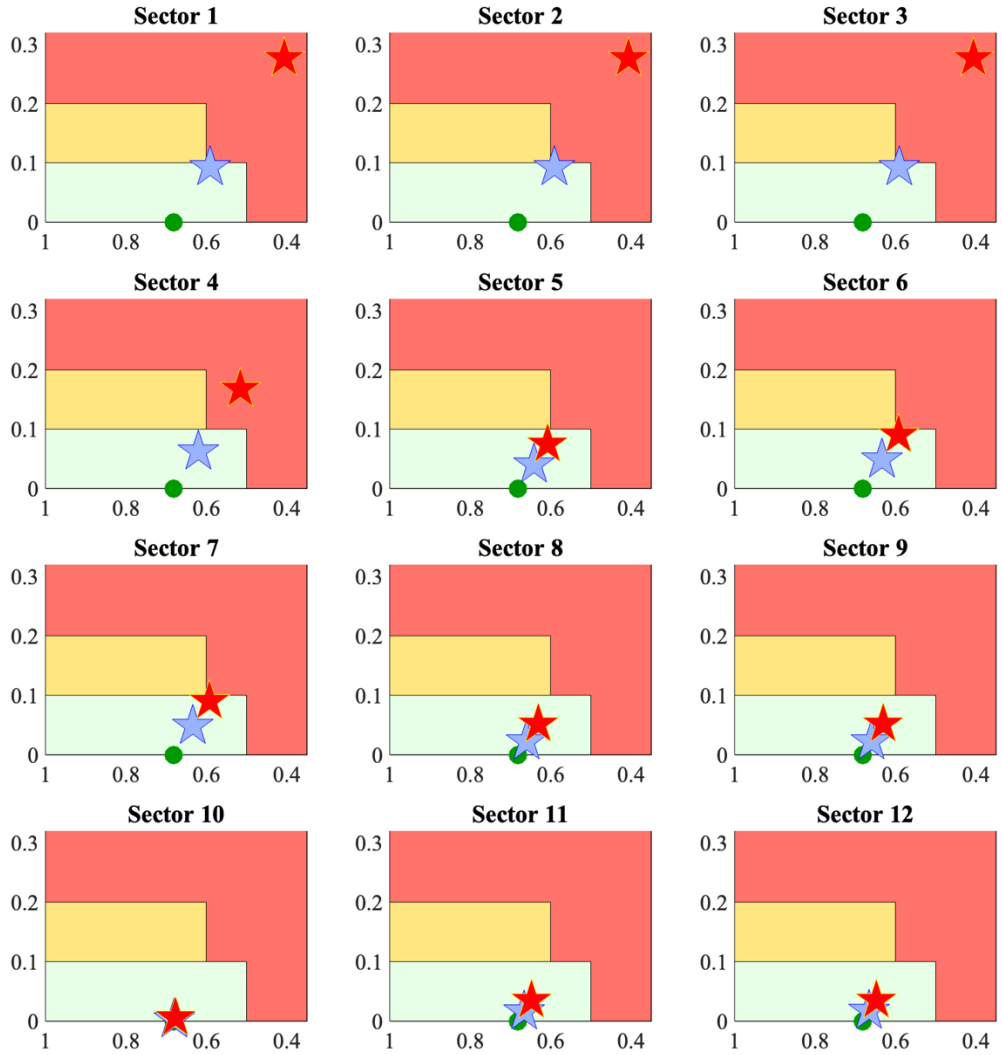
Major Impairment

Region I
Take immediate compensatory measure

Region II
Take compensatory measure within 36 hours

Region III
Take compensatory measure within 72 hours


Sector 11
Sector 12
Sector 1
Sector 10
Sector 2
Sector 9
Sector 8
Sector 3
Sector 8
Sector 4
Sector 7
Sector 5
Sector 6


Sector 1
Sector 2
Sector 3
Sector 4
Sector 5
Sector 6
Sector 7
Sector 8
Sector 9
Sector 10
Sector 11
Sector 12
0.3
0.2
0.1
0
1
0.8
0.6
0.4

Future Work

- Pilot implementation of RICM approach on plant specific data
- Developing robust approach for assigning scenario weights
- Implementing a more rigorous P_E calculation
- Developing clearly defined CM recommendations
- Integrating with INL MASS-DEF for crediting operator actions in FOF simulations

Team

- INL
  - Vaibhav Yadav
  - Steven Prescott
  - Shawn St. Germain
- RhinoCorps
  - Dan McCorquodale

https://lwrs.inl.gov/about/physical-security/

Idaho National Laboratory

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy. INL is the nation's center for nuclear energy research and development, and also performs research in each of DOE's strategic goal areas: energy, national security, science and the environment.