Methods for Detector Placement and Analysis of Criticality Accident Alarm Systems

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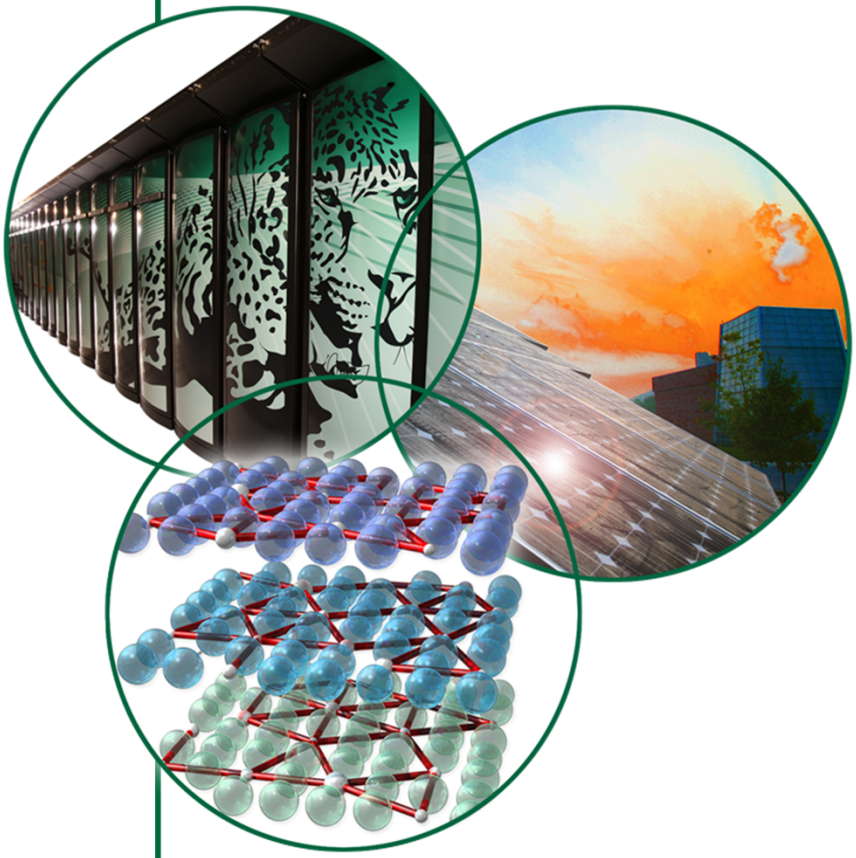
Tuesday, June 26, 2012



B&W nuclear operations group

U.S. DEPARTMENT OF ENERGY

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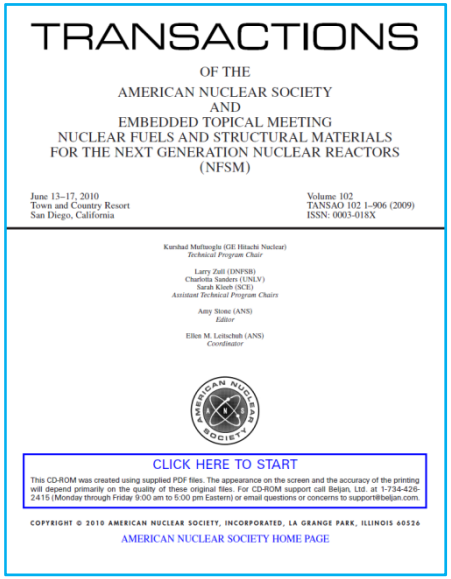
Introduction

- Analysis/Design of criticality accident alarm systems (CAAS) can be a large, complex problem
  - Large or infinite number of possible accident sites
  - Large or infinite number of possible detector locations
  - Iterative – find the minimum number of detectors
- MC simulation can be difficult
  - Criticality problem and possibly a deep penetration shielding problem at the same time
  - May require “answer” everywhere

SCALE CAAS Capability

- User can perform CAAS simulations using the following
  - Keno-VI/CSAS6
    - Model the source and nearby environment in geometry
    - Save the fission distribution as a mesh tally
  - Utility code
    - Convert mesh tally into Monaco mesh source
  - Monaco/MAVRIC
    - Use mesh source, optionally add fission photons
    - Include entire building/facility in geometry
    - Use CADIS or FW-CADIS to calculate detector responses



TRANSACTIONS

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"Modeling Criticality Accident Alarm Systems with SCALE 6.1," *Transactions of the American Nuclear Society* **102**, 297-299 (2010)

Design/Analysis of CAAS

- Specific Questions:
  - For a given source, which detector(s) will alarm?
  - For a given detector, which source(s) can be seen?
- Open-Ended Questions:
  - For a given source, where will the dose rate trigger an alarm?
  - For a given detector, where could a source be seen?

- Single Tally
  - Forward simulation
  - Adjoint simulation
- Mesh Tally
  - Forward simulation
  - Adjoint simulation

Design/Analysis of CAAS

- Accident sites
  - *P* specific sites or unknown sites
- Detector locations
  - *Q* specific locations or unknown locations
- Geometry
  - Mostly empty, line of sight between the source site and the detector location
  - Heavy equipment, thick walls, shielding
- For efficiency
  - $P<Q$ use forward calcs
  - $P>Q$ use adjoint calcs
- Variance Reduction
  - May not be needed
  - Required

Approaches

- List of Different Situations and What Computational Approach to Use

P Accident Sites and *Q* Detectors				Approach			
Comparison	*P*	*Q*	Geometry		Direction	Biasing	Tallies
P<Q	small	small	sparse	1.	forward	none	standard tallies
		large	sparse	2.	forward	none	mesh tally
		small	dense	3.	forward	CADIS	standard tallies
		large	dense	4.	forward	FW-CADIS	mesh tally
Q<*P*	small	small	sparse	5.	adjoint	none	standard tallies
	large		sparse	6.	adjoint	none	mesh tally
	small		dense	7.	adjoint	CADIS	standard tallies
	large		dense	8.	adjoint	FW-CADIS	mesh tally

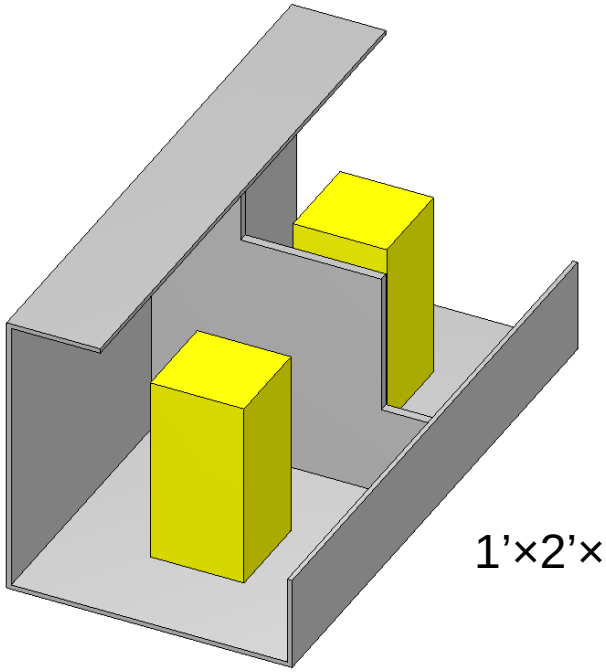
Approaches

- SCALE 6.2 is under development - adjoint MC not done yet
- Until then, the Denovo S_N code can be used

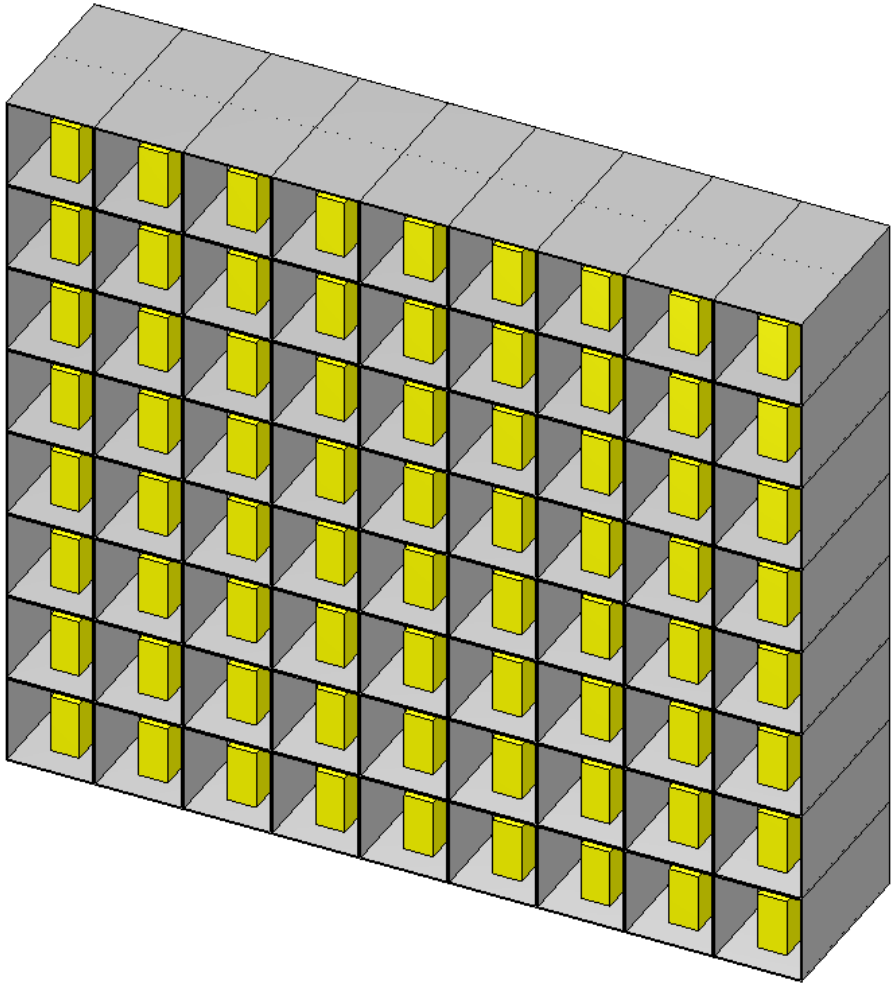
P Accident Sites and *Q* Detectors				Approach			
Comparison	*P*	*Q*	Geometry		Direction	Biasing	Tallies
P<Q	small	small	sparse	1.	forward	none	standard tallies
		large	sparse	2.	forward	none	mesh tally
		small	dense	3.	forward	CADIS	standard tallies
		large	dense	4.	forward	FW-CADIS	mesh tally
Q<*P*	small	small	sparse	5. – 8.	adjoint Denovo		
	large		sparse				
	small		dense				
	large		dense				

Example Problem

- Storage room
  - Blocks of natural UO_2 (21 kg)
  - 1 foot cubbies (double sided)
  - Racks of 80 cubies

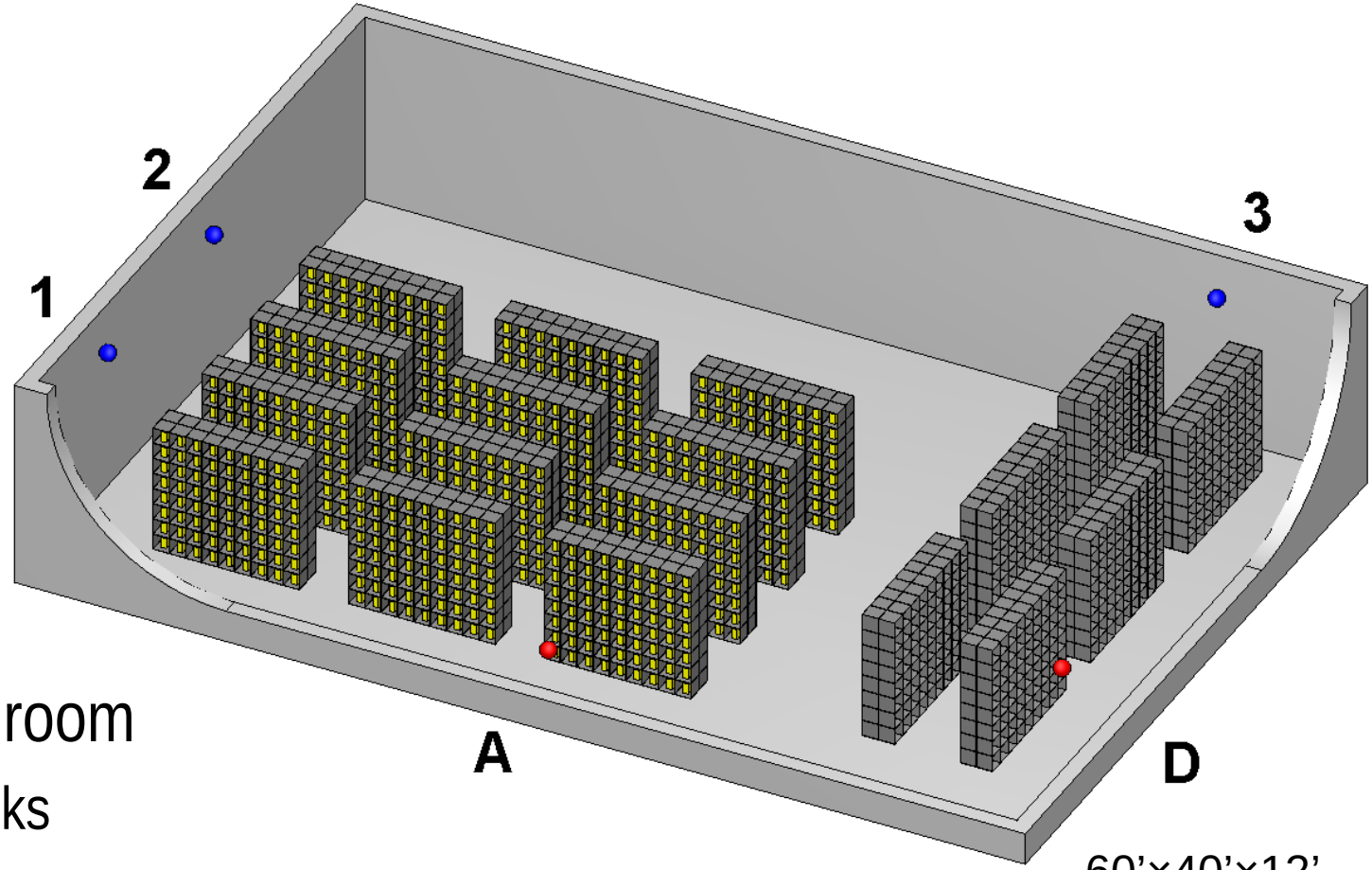


1’×2’×1’



10’×2’×8’

Example Problem

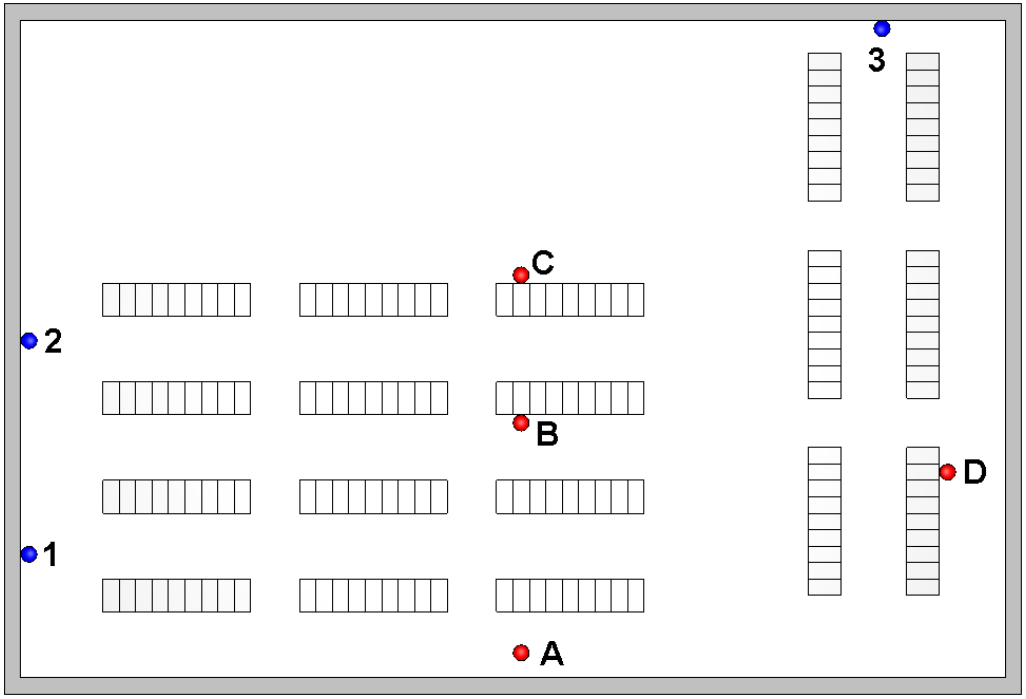


60’×40’×12’

- Storage room
  - 18 racks
  - Accident sites: A, B, C, D (3.3’ above floor)
  - Detector locations: 1, 2, 3 (9.5’ above floor)

Example Problem

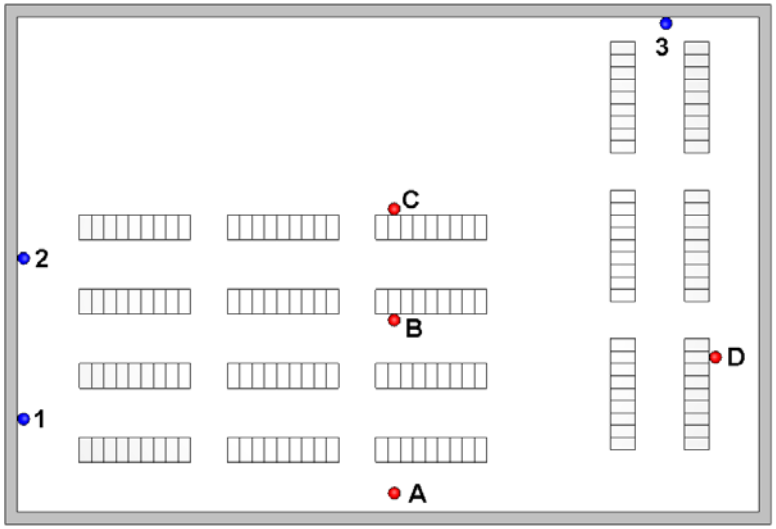
- Source (A, B, C, or D)
  - point, isotropic, at z=100cm
  - 2×10^{15} n burst (no fission gammas)
  - Generic Watt spectrum
- Detector (1, 2, or 3)
  - Gamma dose
  - 0.150 rem to trigger
  - at z=290 cm
- Demonstrate each approach



Approach 1

- Forward simulation, analog MC, standard tallies

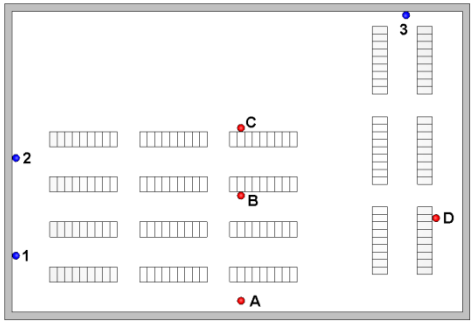
source	detector	Gamma Dose rem	Gamma Dose rel unc
A	1	**0.1757**	**3.0%**
	2	0.1092	3.8%
	3	0.0968	4.1%
B	1	**0.1858**	**3.1%**
	2	**0.1777**	**3.2%**
	3	0.1441	3.5%
C	1	0.1061	3.8%
	2	**0.1961**	**2.9%**
	3	**0.2976**	**2.3%**
D	1	0.0535	5.7%
	2	0.0571	5.3%
	3	**0.2440**	**2.6%**

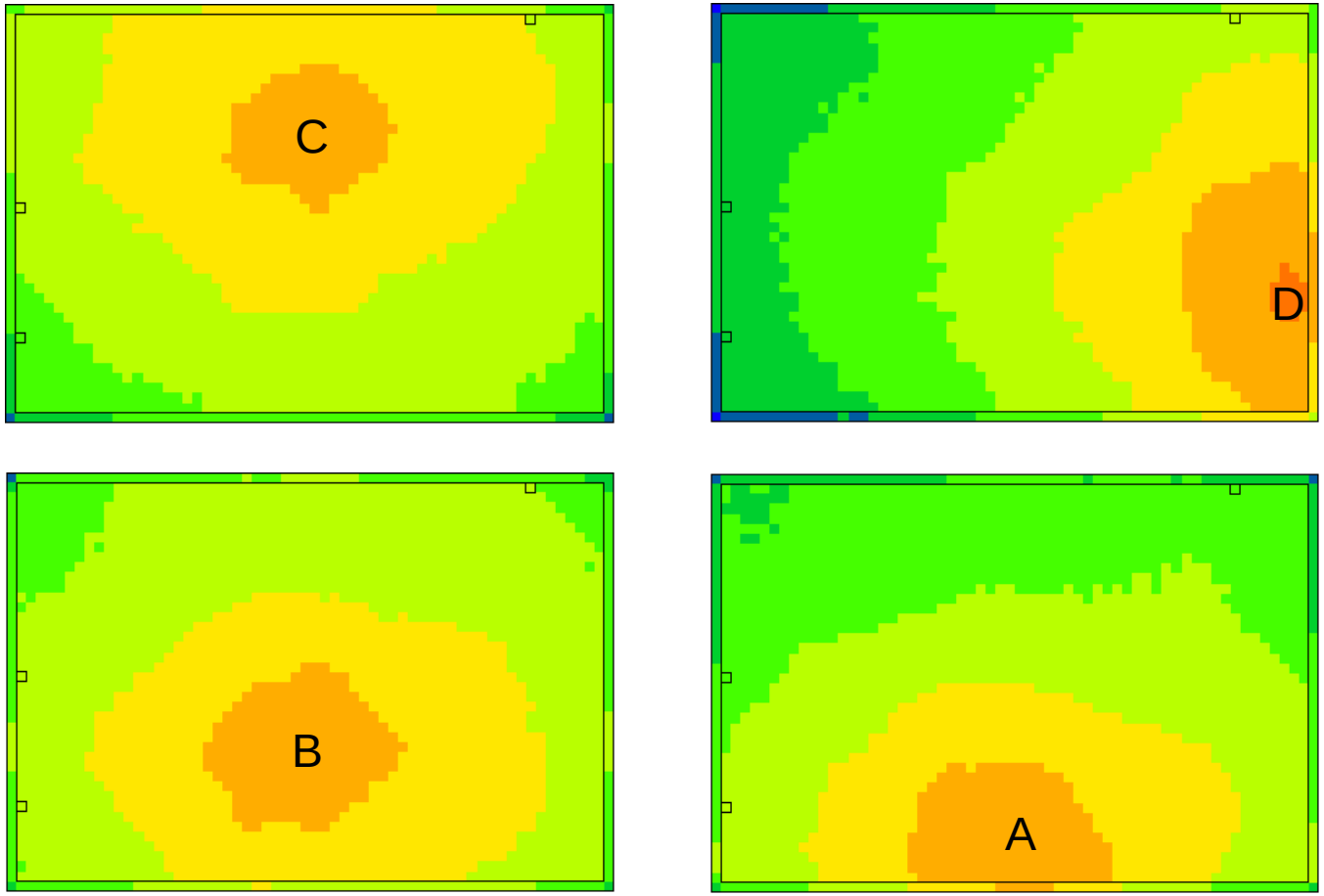


Four simulations, 10 hours each
Total time: 40 hours

Approach 2

- Forward simulation, analog MC, mesh tally





Responses
Rem
Values

- 6.96E00 - 1.50E01
- 3.23E00 - 6.96E00
- 1.50E00 - 3.23E00
- 6.96E-01 - 1.50E00
- 3.23E-01 - 6.96E-01
- 1.50E-01 - 3.23E-01
- 6.96E-02 - 1.50E-01
- 3.23E-02 - 6.96E-02
- 1.50E-02 - 3.23E-02
- 6.96E-03 - 1.50E-02
- 3.23E-03 - 6.96E-03
- 1.50E-03 - 3.23E-03

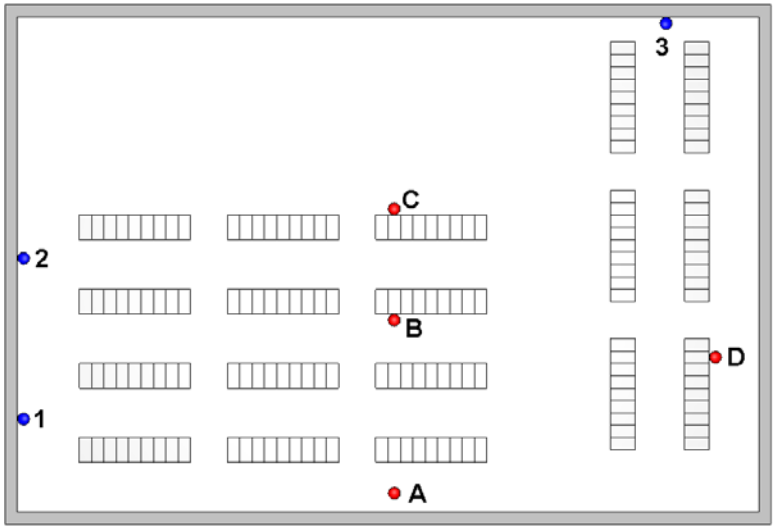
trigger

Total time:
40 hours

Approach 3

- Forward simulation, CADIS var. reduction, standard tallies

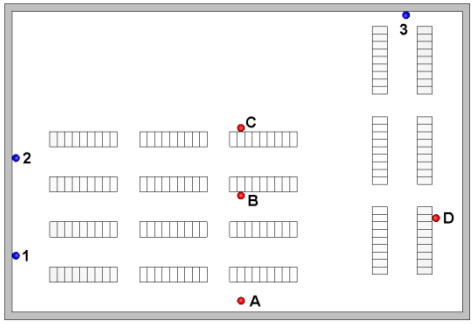
source	detector	Gamma Dose rem	Gamma Dose rel unc	Speed Up
A	1	**0.1802**	**2.8%**	3.7
	2	0.1083	2.5%	7.4
	3	0.0928	3.5%	4.3
B	1	**0.1799**	**2.4%**	5.2
	2	**0.1790**	**2.4%**	5.3
	3	**0.1543**	**3.3%**	3.6
C	1	0.1168	3.3%	4.3
	2	**0.1904**	**2.4%**	4.6
	3	**0.2901**	**2.6%**	2.5
D	1	0.0467	4.1%	6.1
	2	0.0566	4.0%	5.4
	3	**0.2430**	**2.0%**	5.2

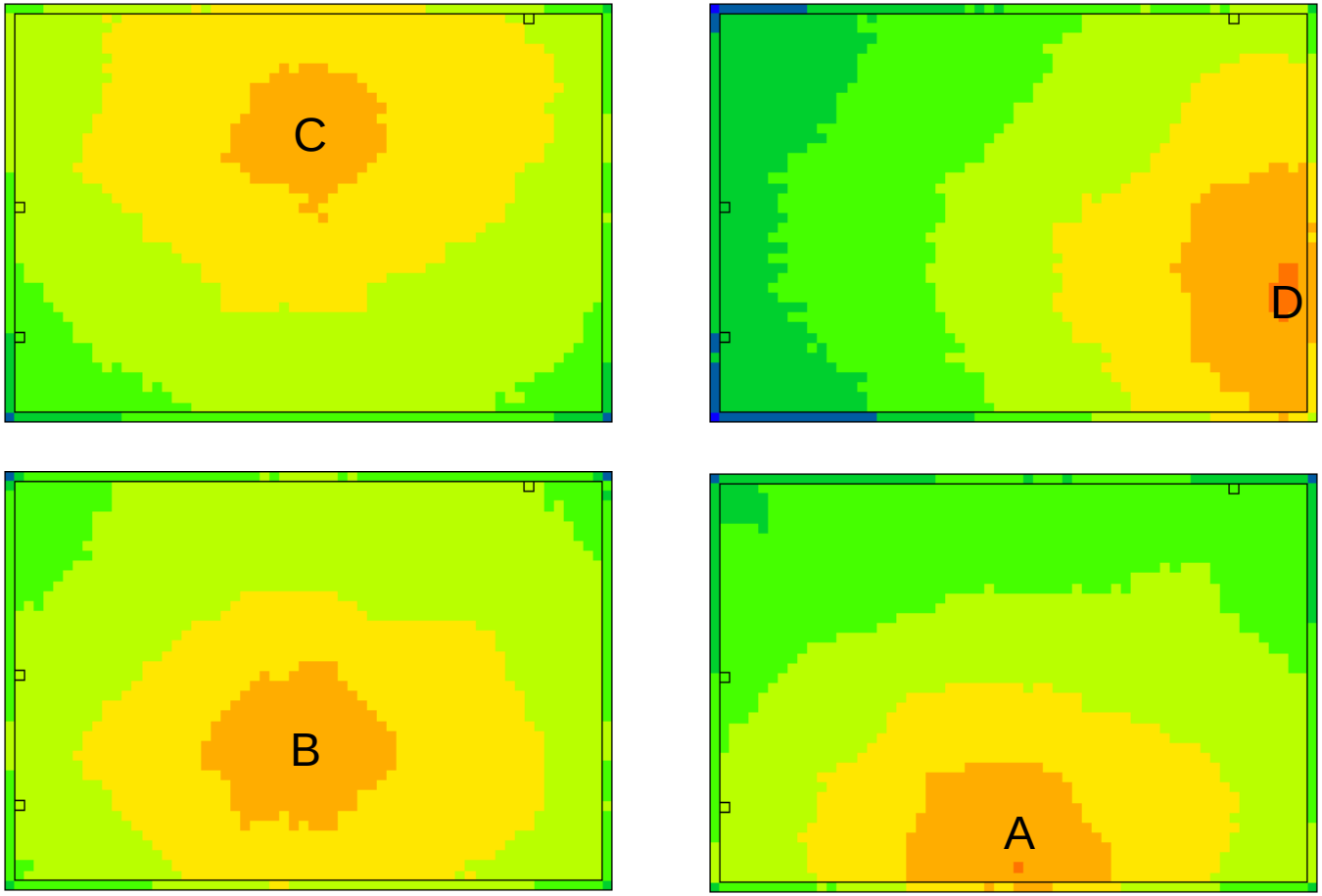


Twelve simulations
Total time: 40 hours

Approach 4

- Forward simulation, FW-CADIS, mesh tally





Responses
Rem
Values

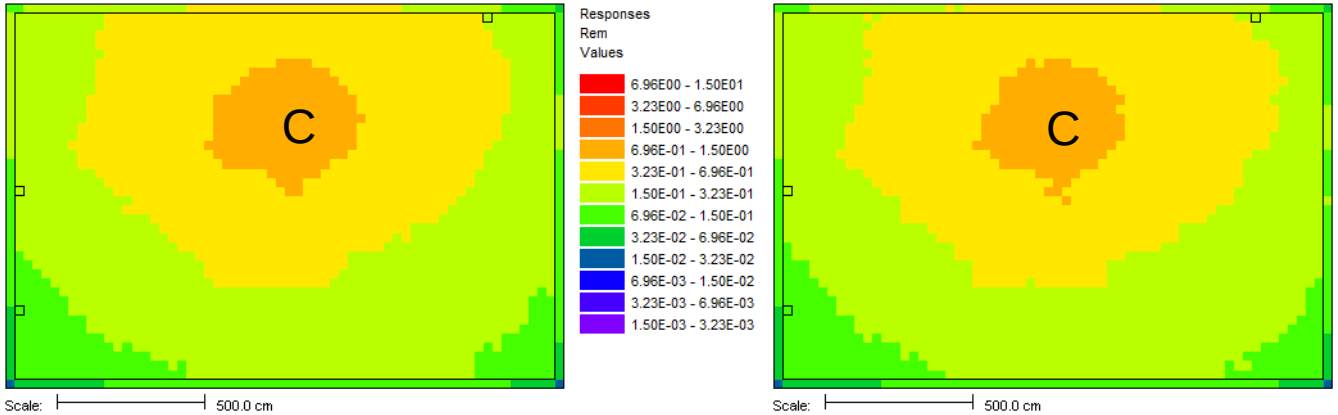
- 6.96E00 - 1.50E01
- 3.23E00 - 6.96E00
- 1.50E00 - 3.23E00
- 6.96E-01 - 1.50E00
- 3.23E-01 - 6.96E-01
- 1.50E-01 - 3.23E-01
- 6.96E-02 - 1.50E-01
- 3.23E-02 - 6.96E-02
- 1.50E-02 - 3.23E-02
- 6.96E-03 - 1.50E-02
- 3.23E-03 - 6.96E-03
- 1.50E-03 - 3.23E-03

trigger

Total time:
40 hours

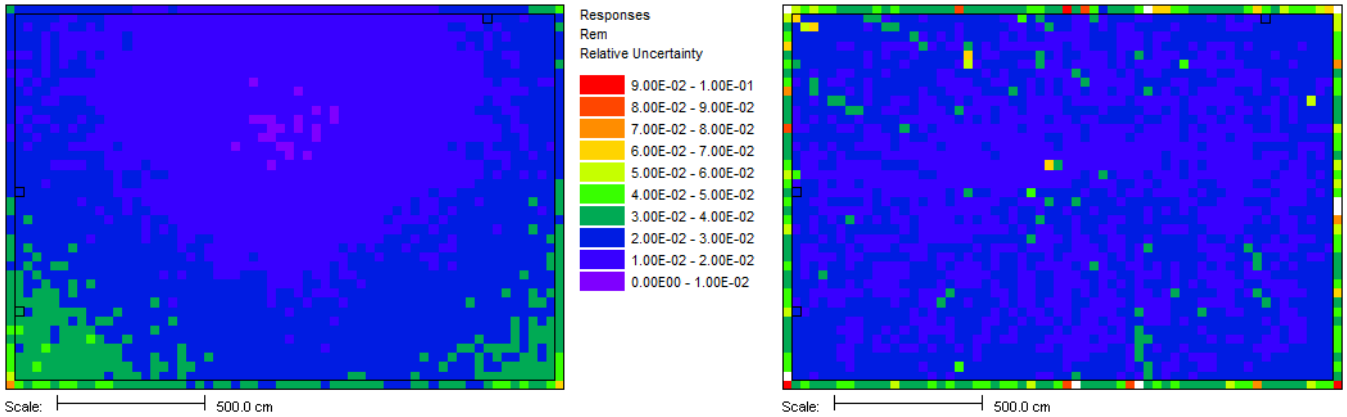
Approach 2 & 4 Comparison

- FW-CADIS – more uniform rel. uncertainties across mesh

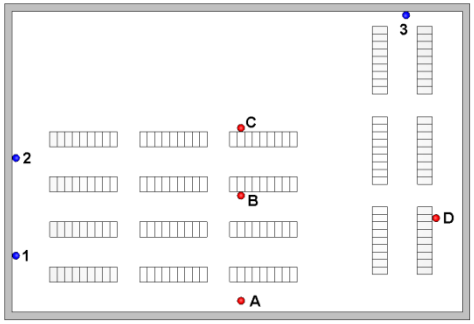


Approach 2: analog

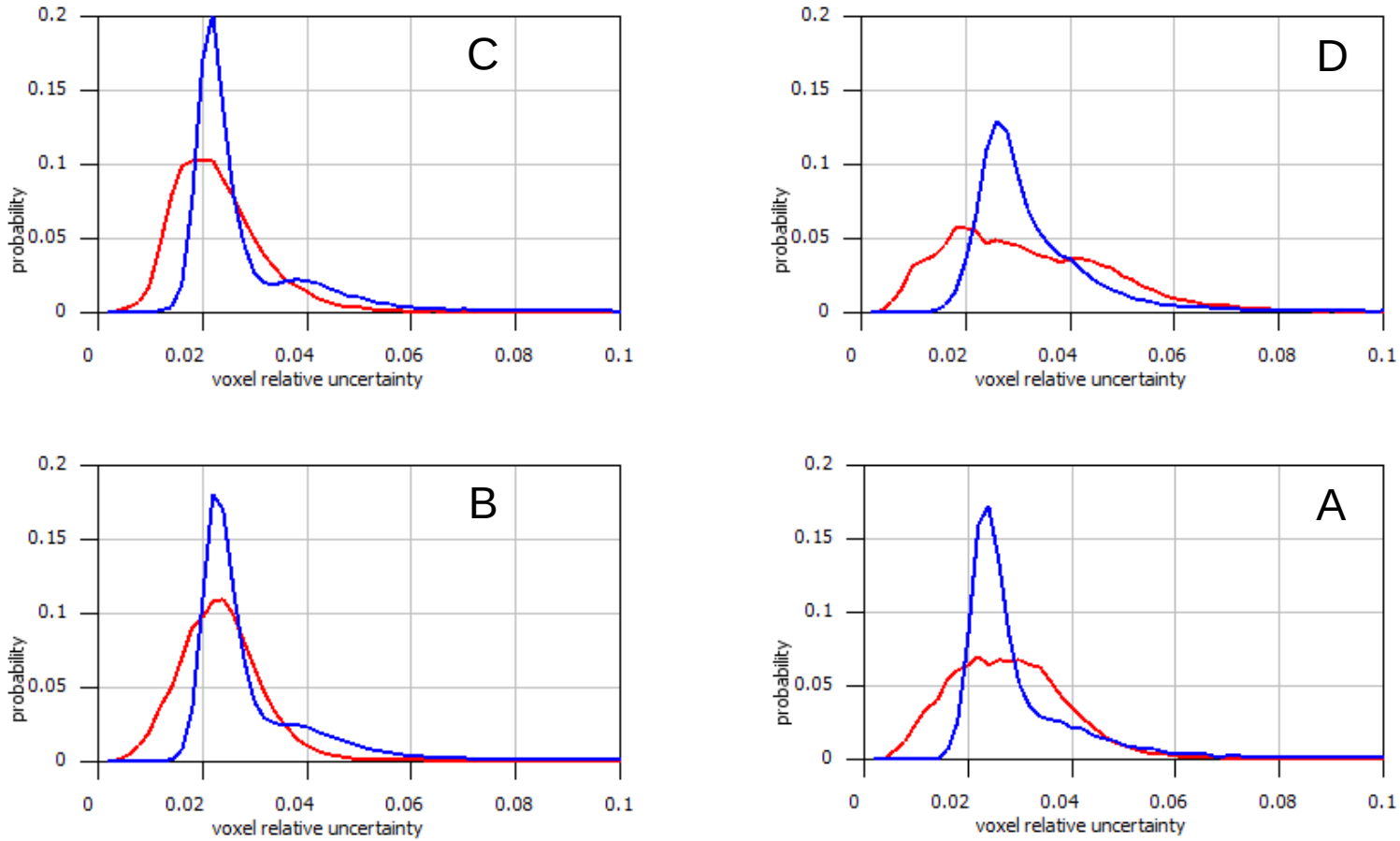
Approach 4: FW-CADIS



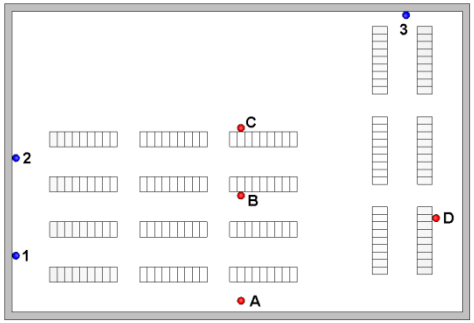
Approach 2 & 4 Comparison



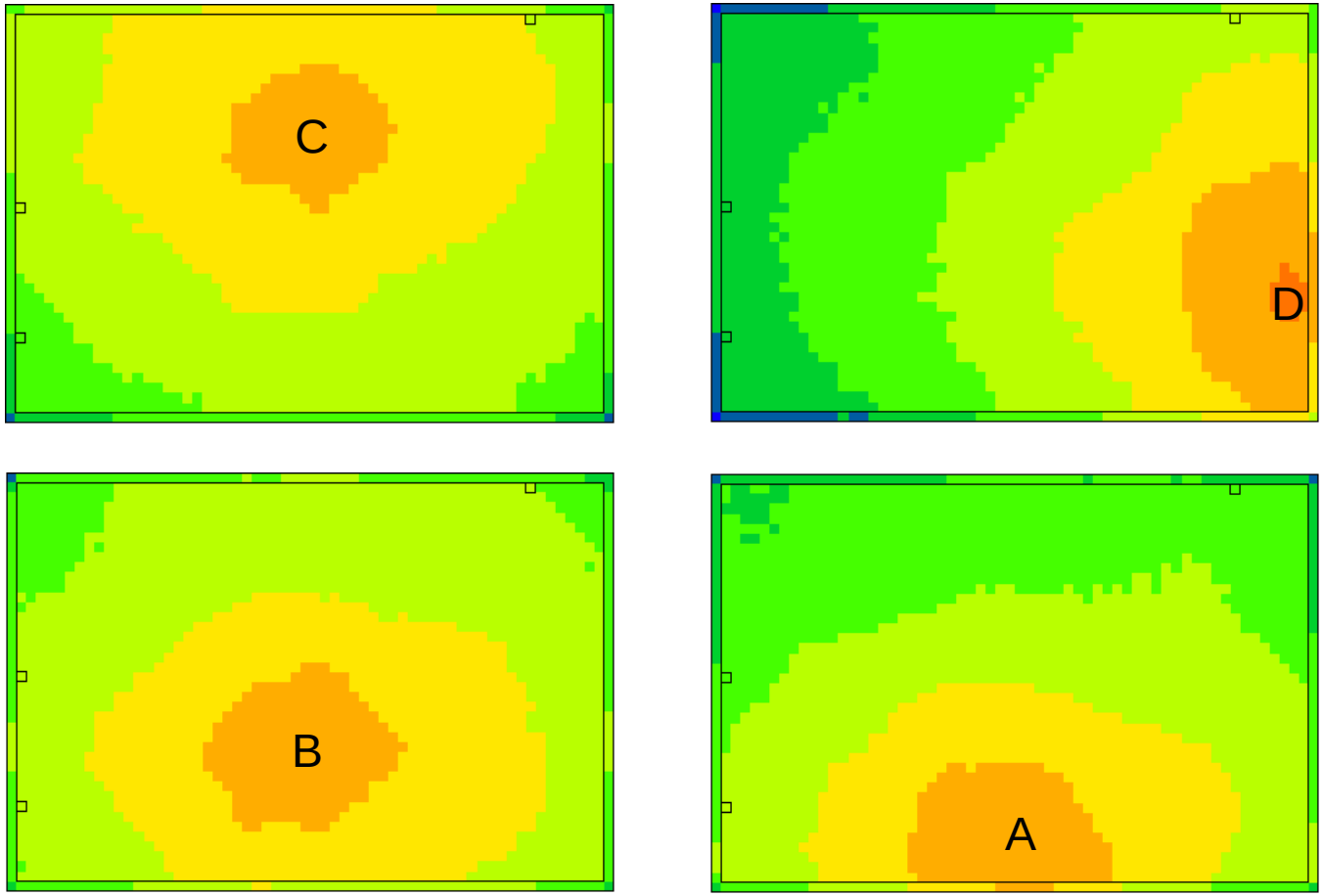
- Analog mesh tally vs. FW-CADIS



Detector Placement



- Forward simulation, where will alarm trigger?

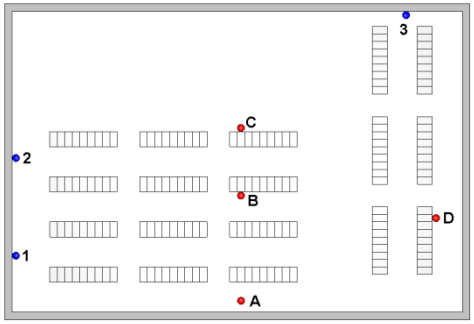


Responses
Rem
Values

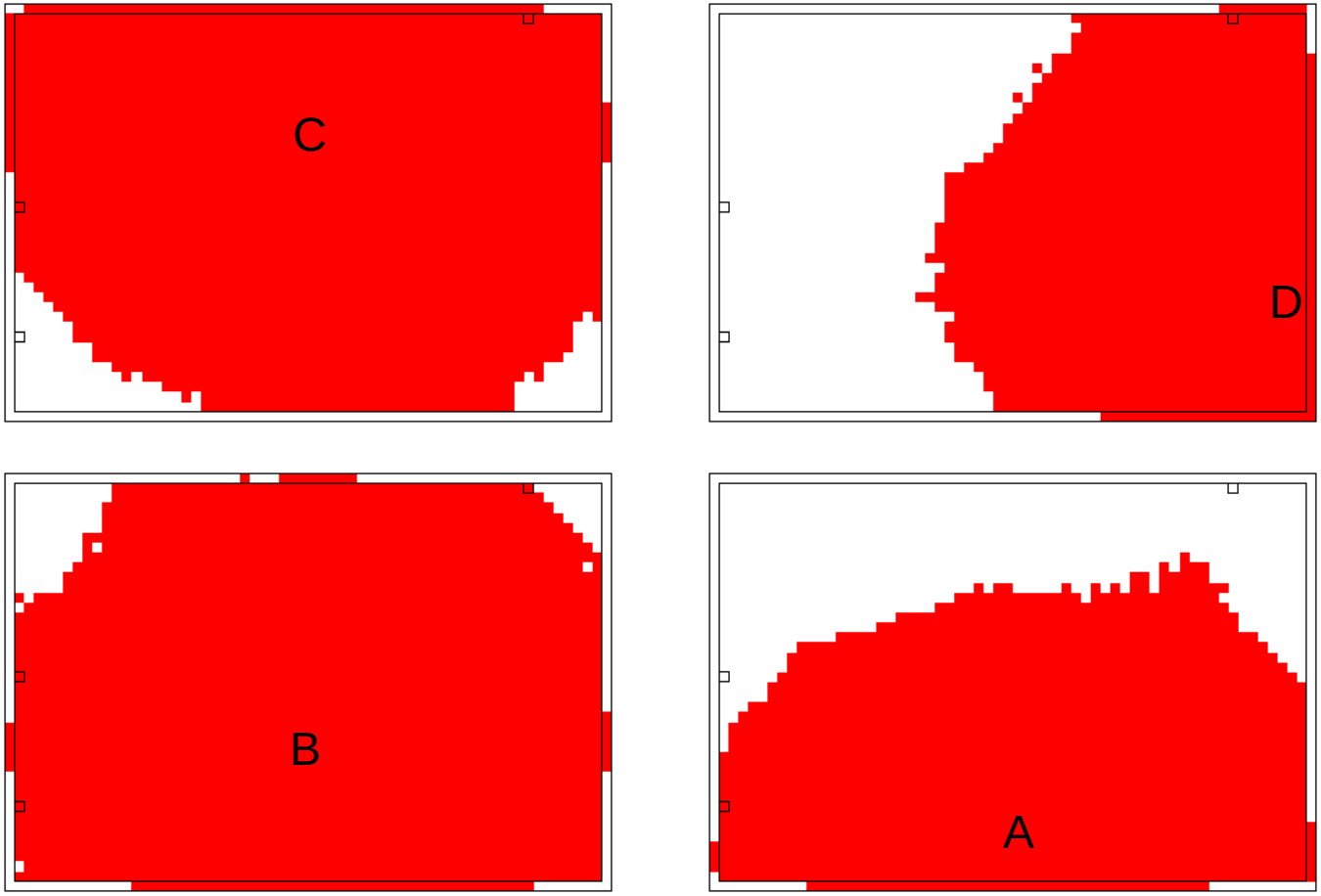
- 6.96E00 - 1.50E01
- 3.23E00 - 6.96E00
- 1.50E00 - 3.23E00
- 6.96E-01 - 1.50E00
- 3.23E-01 - 6.96E-01
- 1.50E-01 - 3.23E-01
- 6.96E-02 - 1.50E-01
- 3.23E-02 - 6.96E-02
- 1.50E-02 - 3.23E-02
- 6.96E-03 - 1.50E-02
- 3.23E-03 - 6.96E-03
- 1.50E-03 - 3.23E-03

trigger

Detector Placement

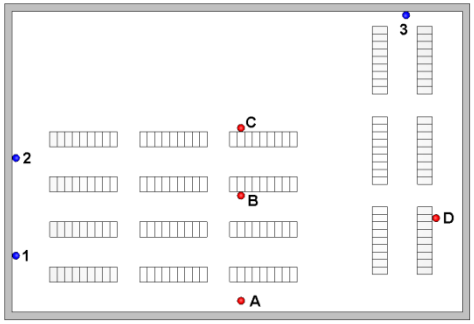


- Forward simulations, where will alarm trigger?

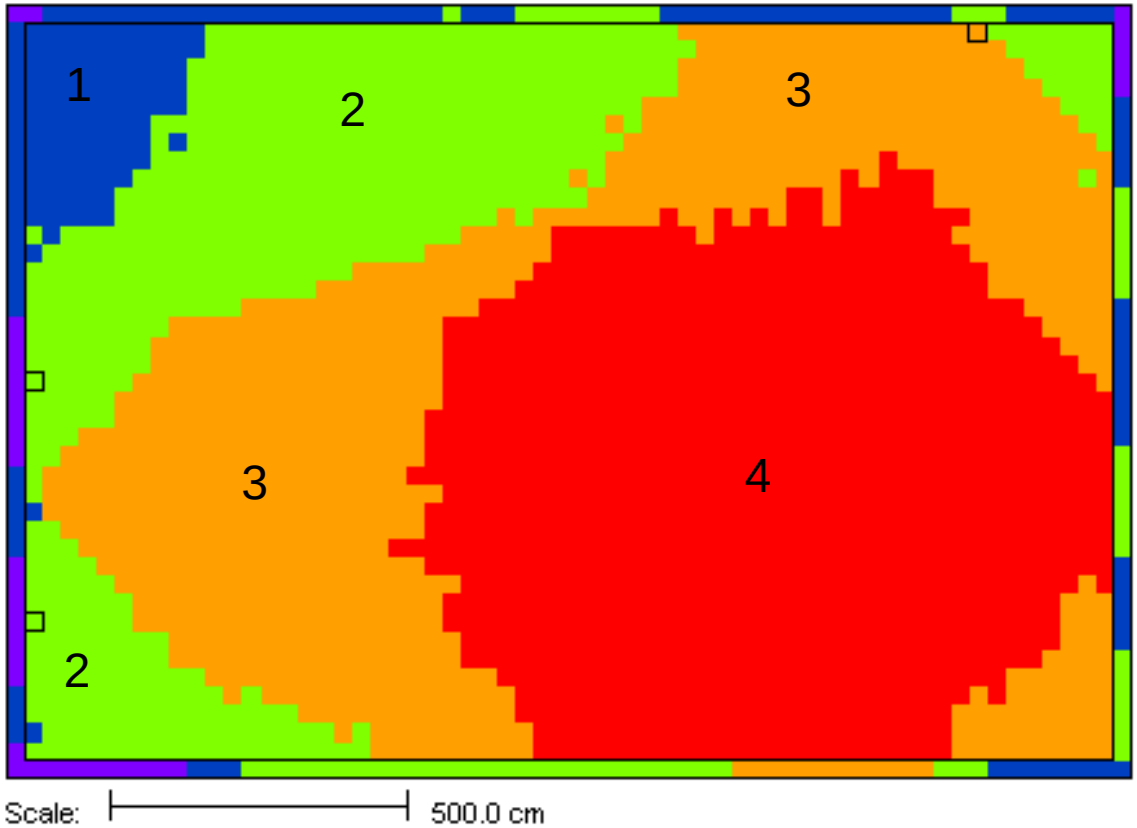


High-pass filter:
keep >0.150 rem

Detector Placement

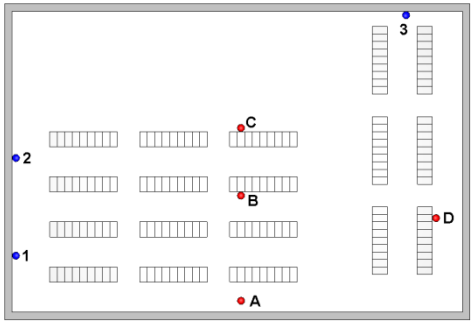


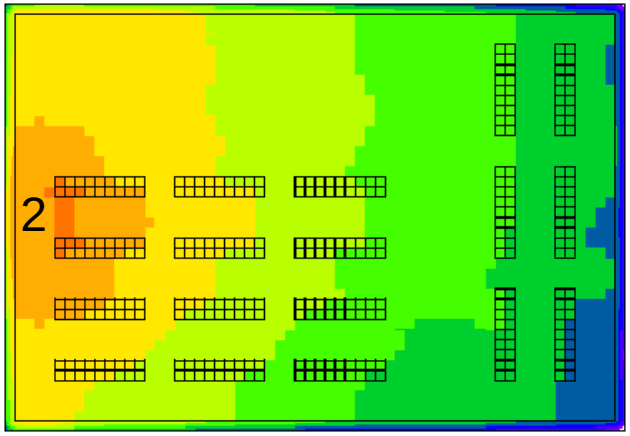
- How many of the accident sites (A, B, C, D) would a detector located at z=290 cm see?

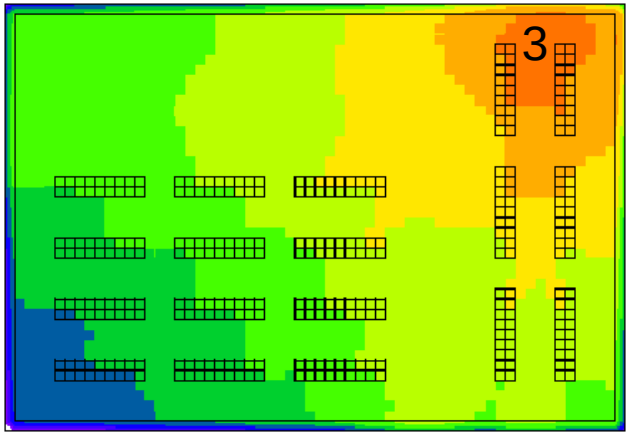


Approaches 5-8

- Adjoint simulation



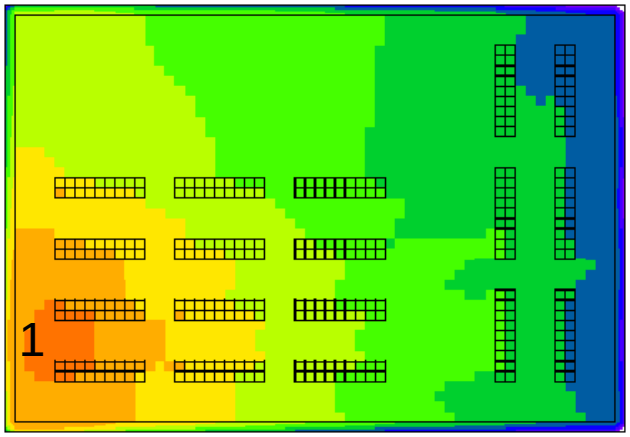




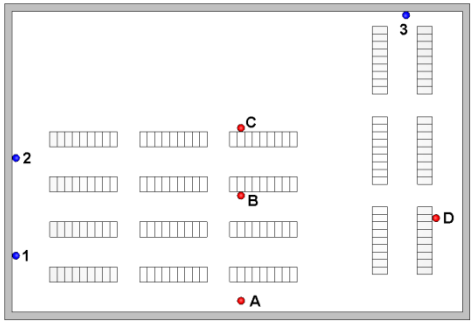
Responses
Rem
Values

- 6.96E00 - 1.50E01
- 3.23E00 - 6.96E00
- 1.50E00 - 3.23E00
- 6.96E-01 - 1.50E00
- 3.23E-01 - 6.96E-01
- 1.50E-01 - 3.23E-01
- 6.96E-02 - 1.50E-01
- 3.23E-02 - 6.96E-02
- 1.50E-02 - 3.23E-02
- 6.96E-03 - 1.50E-02
- 3.23E-03 - 6.96E-03
- 1.50E-03 - 3.23E-03

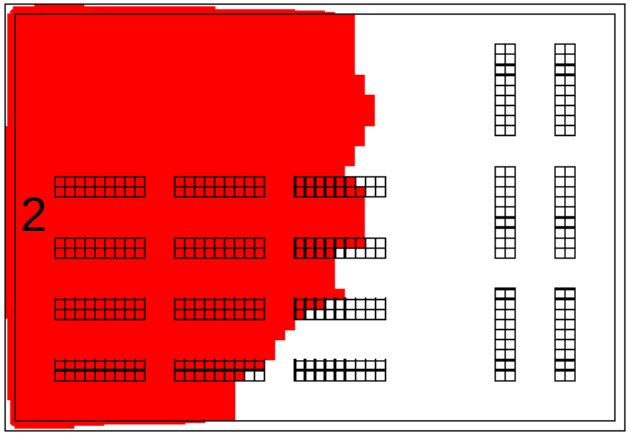
trigger

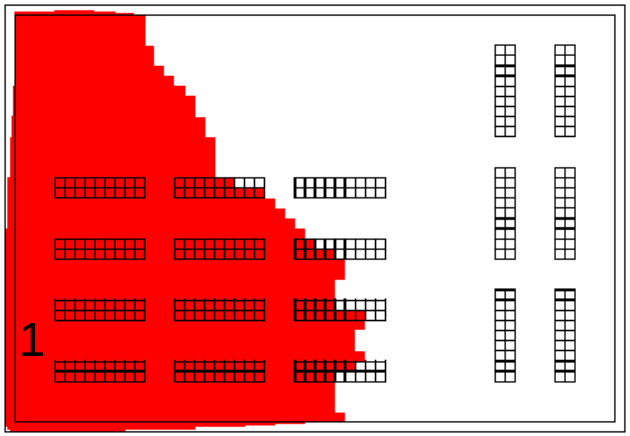


Detector Coverage



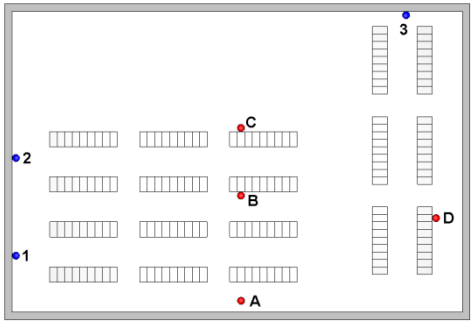
- Accident sites where the detector will alarm



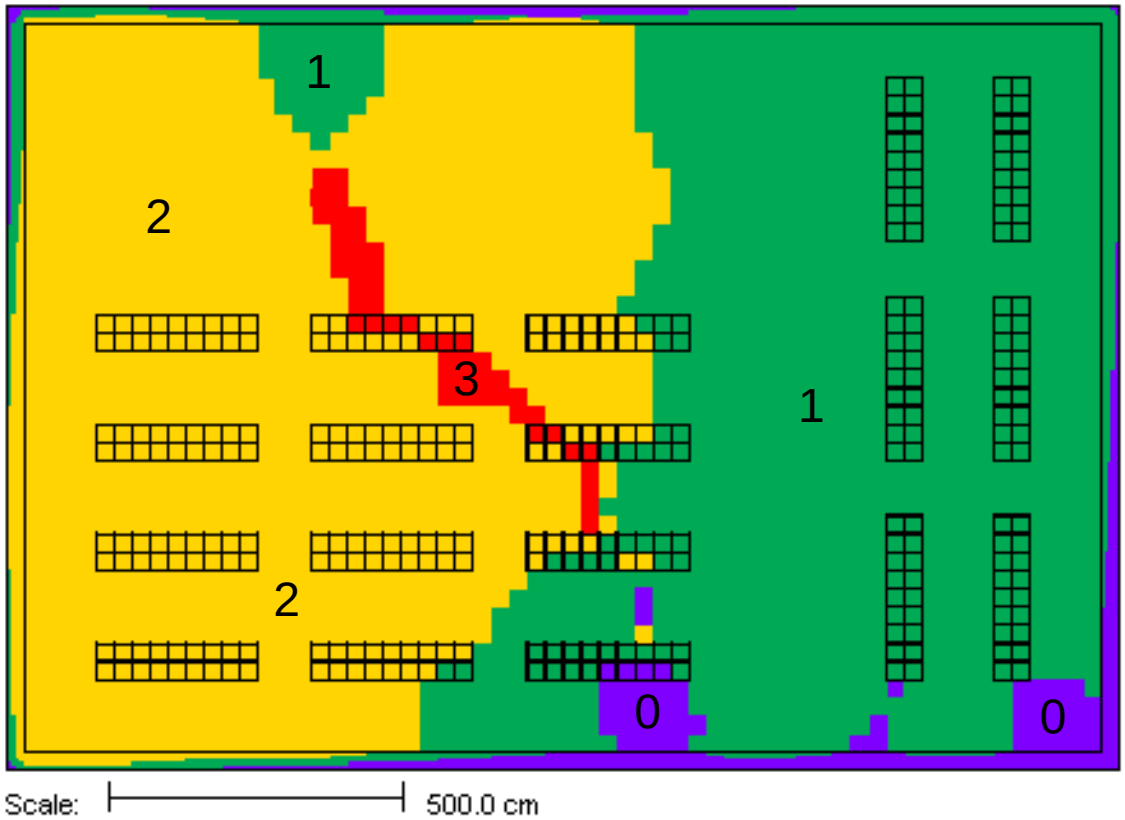


High-pass filter:
keep >0.150 rem

Detector Coverage



- How many of the detectors (1, 2, 3) would trigger for an accident located at z=100 cm?

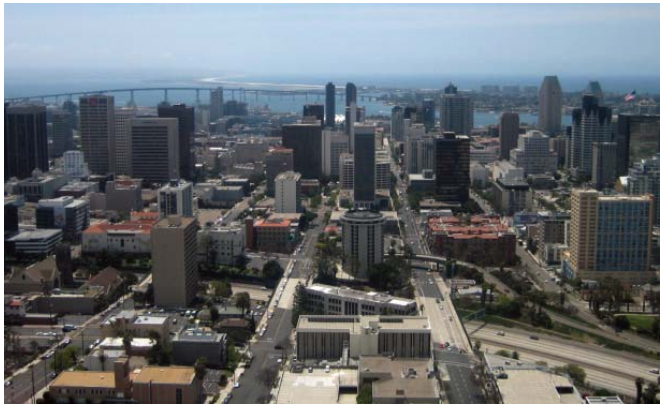


Summary

- Different approaches to CAAS design/analysis for
  - What is known – source and detectors
  - What is needed – source alarm area or detector coverage
  - Geometry (open or well-shielded)
- Tools available in SCALE
  - 6.1: All forward approaches with MC, adjoint approach with S_N
  - 6.2: Extra utilities for working with mesh tallies or flux files
    - Will work with SCALE 6.1 (request via scalehelp@ornl.gov)
  - 6.2+: Adjoint MC for approaches 5-8

Coming Attraction

- New CAAS for B&W NOG Lynchburg
  - Major CAAS study by Larry Wetzel using SCALE
  - Facility: Multiple buildings, over 900,000 sq. ft., spread over ~85 acres, and divided into 4 zones
  - Number of evaluated accident sites: 572
  - Number of detectors: 172
  - 572 calculations requiring 3875 hours of run time. Total project was 24 person-months.



- Presentation in San Diego (Nov. 2012)