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The Impact Analysis of Various Spatial Grid Settings on Offsite Consequence Analysis

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1. Introduction

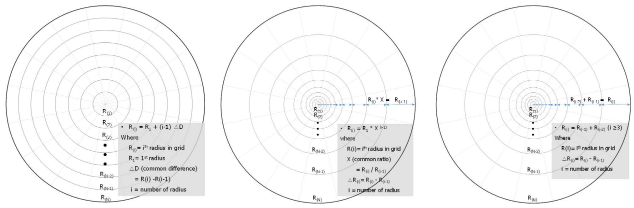
Analytical speed is crucial due to the significant computational demand to handle all possible situations for a single or multi-unit Level 3 PSA. Consequently, a high priority is placed on the speed of analysis [1][2]. Significant efforts were dedicated to finding an optimal approach that minimizes analysis time while maintaining the accuracy of offsite consequence analysis results [3][4]. Adjusting spatial grids by dividing them into finer segments is anticipated to improve the precision of the analysis. However, this process may lead to extended computation times for each analysis. Spatial grid setting can be defined as representing spatial grid data in polar coordinates by dividing it into various radii. The objective of this study is to define various divisions of spatial grids and to examine their impact on analysis accuracy and speed. Arithmetic growth, geometric growth and Fibonacci growth are applied to set the radius of the polar coordinate of spatial gird and their impact on the accuracy and speed of analysis compared to the best estimate case was investigated.

2. Various Spatial Grid Settings

In the event of an offsite nuclear power plant accident, the most rapid environmental transport route for radioactive material that could impact a large number of residents over a wide area is atmospheric dispersion and deposition. To analyze the consequences, the accident source serves as the reference point, requiring the establishment of a spatial grid to calculate dispersion and deposition patterns originating from this point.

In this study, the MACCS code [5] was utilized for offsite consequence analysis. MACCS is adopting a polar coordinate spatial grid system to depict the area surrounding a nuclear power plant. The plant is situated at the center point of the polar coordinate system (r=0). The polar coordinates of MACCS allow up to 35 radial rings and 64 compass sectors, but in this study, 24 radii with 16 directional sectors were assigned as the base case for near-field analyses, and 31 radii with 16 directional sectors were assigned as the base case for far-field analyses.

The rationale for setting 24 radial rings is to set the maximum distance of the PAZ (Precautionary Action Zone) with 5 km range, to be space evenly. Additionally, to assess the far-field sensitivity by grid settings, 31 radial rings were applied for UPZ (Urgent Protective Action Planning Zone), where residents take action (e.g., sheltering) depending on the level of emergency action, with a maximum range of 30 kilometers.



(a) Arithmetic Growth (b) Geometric Growth (c) Fibonacci Growth

Fig. 1. Various Spatial Grid Settings used in this study

2.1 Spatial grid settings for near-field (PAZ)

For spatial grid settings for PAZ, we set the analysis range (distance), analysis direction, and spatial grid as follows.

- Analysis range: 5 km
- Angular direction: 16
- Number of radial rings: 30
- Grid: Arithmetic, Geometric and Fibonacci Growth

Table 1: Spatial Grid Settings (PAZ)

Grid No	Arithmetic Growth Radius (km)				Geometric Growth Radius (km)				Fibonacci Growth (km)
	Common difference (d=0.2)*	0.25	0.5	1.0	Common ratio (r=1.25)	1.5	1.75	2.0	
1	0.5	0.50	0.5	0.5	0.50	0.50	0.50	0.50	0.50
2	0.6	0.75	1.0	1.0	0.67	0.66	0.93	1.25	0.60
3	0.8	1.00	1.5	2.0	0.84	0.99	1.63	2.50	0.75
4	1.0	1.25	2.0	3.0	1.05	1.48	2.86	5.00	0.90
5	1.2	1.50	2.5	4.0	1.31	2.22	5.00		1.15
6	1.4	1.75	3.0	5.0	1.64	3.33			1.55
7	1.6	2.00	3.5		2.05	5.00			2.20
8	1.8	2.25	4.0		2.56				3.25
9	2.0	2.50	4.5		3.20				5.00
10	2.2	2.75	5.0		4.00				
11	2.4	3.00			5.00				
12	2.6	3.25							
13	2.8	3.50							
14	3.0	3.75							
15	3.2	4.00							
16	3.4	4.25							
17	3.6	4.50							
18	3.8	4.75							
19	4.0	5.00							
20	4.2								
21	4.4								
22	4.6								
23	4.8								
24	5.0								

* Basecase

2.2 Spatial grid settings for far-field (UPZ)

For spatial grid settings for UPZ, we set the analysis range (distance), analysis direction, and spatial grid as follows.

- Analysis range: 30 km
- Angular direction: 16
- Number of radial rings: 30
- Grid: Arithmetic, Geometric and Fibonacci Growth

Table 2: Spatial Grid Settings (UPZ)

Grid No	Arithmetic Growth Radius (km)				Geometric Growth Radius (km)				Fibonacci Growth (km)
	Common difference (d=1.0)*	2.0	3.0	5.0	Common ratio (r=1.25)	1.5	1.75	2.0	
1	0.5	0.50	0.5	0.5	1	0.50	0.50	0.5	0.50
2	1.0	2.0	3.0	5.0	2	0.68	0.78	1.04	0.94
3	2.0	4.0	6.0	10.0	3	0.84	1.17	1.83	1.88
4	3.0	6.0	9.0	15.0	4	1.06	1.76	3.20	3.75
5	4.0	8.0	12.0	20.0	5	1.32	2.63	5.60	7.50
6	5.0	10.0	15.0	25.0	6	1.65	3.95	9.80	15.0
7	6.0	12.0	18.0	30.0	7	2.06	5.93	17.14	30.0
8	7.0	14.0	21.0		8	2.58	8.89	30.0	
9	8.0	16.0	24.0		9	3.22	13.33		
10	9.0	18.0	27.0		10	4.03	20.00		
11	10.0	20.0	30.0		11	5.03	30.00		
12	11.0	22.0			12	6.29			
13	12.0	24.0			13	7.86			
14	13.0	26.0			14	9.83			
15	14.0	28.0			15	12.29			
16	15.0	30.0			16	15.36			
17	16.0				17	19.20			
18	17.0				18	24.00			
19	18.0				19	30.00			
20	19.0								
21	20.0								
22	21.0								
23	22.0								
24	23.0								
25	24.0								
26	25.0								
27	26.0								
28	27.0								
29	28.0								
30	29.0								
31	30.0								

* Basecase

3. Impact Analysis

An impact analysis of offsite consequences was performed on the spatial grid settings by the arithmetic, geometric and Fibonacci sequence suggested in this study. Both near-field (PAZ) and far-field (UPZ) sensitivity analyses were conducted for all STCs of the OPR1000 depicted in Fig. 2 and the average results of all STCs were represented in Table 3 and Table 4.

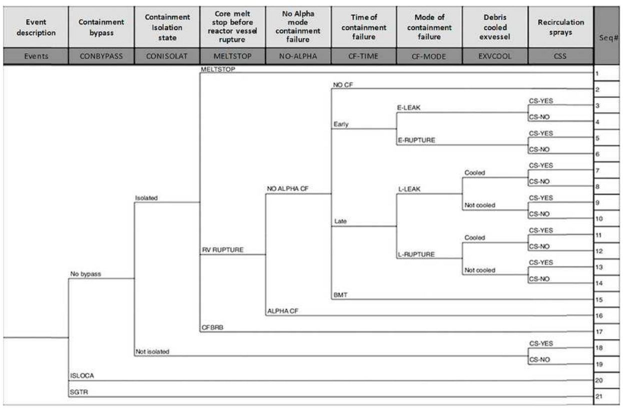


Fig. 2. Source term category (STC) logic diagram for the OPR1000.

Table 3 shows impact of health effect for near field when applying various spatial grid settings.

For the PAZ near-field analysis, compared to the results of the base case, early fatality shows small relative errors within 10% in r(1.25) and r(1.5) in the geometric growth and Fibonacci growth spacing. However, cancer fatality shows valid results with small relative errors in d(0.25) and d(0.5) in the arithmetic growth and r(1.25) in the geometric growth. In the case of analysis time, the analysis time is reduced in proportion to the number of radial rings.

Table 3: Impact of Spatial Grid Settings (Health Effects – PAZ)

				Number of Radial Rings	Relative Error(%)	Time
Near Field (PAZ)	Early Fatality	Basecase	d=0.2	24	0.0%	100.0%
		Arithmetic Growth	d=0.25	19	10.4%	78.8%
			d=0.5	10	17.9%	42.0%
			d=1.0	6	20.1%	25.6%
		Geometric Growth	r=1.25	11	6.8%	47.3%
			r=1.5	7	7.4%	29.9%
			r=1.75	5	19.3%	21.3%
			r=2.0	4	27.1%	17.3%
		Fibonacci Growth		9	1.3%	38.2%
	Cancer Fatality	Basecase	d=0.2	24	0.0%	100.0%
		Arithmetic Growth	d=0.25	19	0.9%	79.0%
			d=0.5	10	4.9%	41.2%
			d=1.0	6	10.5%	25.1%
		Geometric Growth	r=1.25	11	7.2%	47.1%
			r=1.5	7	12.8%	29.8%
			r=1.75	5	16.5%	21.3%
			r=2.0	4	18.6%	17.3%
		Fibonacci Growth		9	12.3%	38.2%

Table 4 shows impact of health effect for far field when applying various spatial grid settings.

In the case of UPZ far-field analysis, the early fatality shows similar results to the base case when the spatial grid is set with an r(1.25), r(1.5) and r(1.75) in the arithmetic growth, and cancer fatality shows valid results at d(2.0) and d(3.0) in the arithmetic growth and r(1.25) in the geometric growth spacing. As in the case of near-field analysis, the analysis time is reduced in proportion to the number of radial rings

Table 4: Impact of Spatial Grid Settings (Health Effects – UPZ)

				Number of Radial Rings	Relative Error(%)	Time
Far Field (UPZ)	Early Fatality	Basecase	d=1.0	31	0.0%	100.0%
		Arithmetic Growth	d=2.0	16	38.8%	51.2%
			d=3.0	11	54.6%	35.2%
			d=5.0	7	70.3%	22.5%
		Geometric Growth	r=1.25	19	21.5%	61.9%
			r=1.5	11	7.0%	36.0%
			r=1.75	8	6.4%	26.0%
			r=2.0	7	6.4%	22.9%
		Fibonacci Growth		13	26.2%	41.8%
	Cancer Fatality	Basecase	d=1.0	31	0.0%	100.0%
		Arithmetic Growth	d=2.0	16	4.3%	51.7%
			d=3.0	11	7.9%	35.2%
			d=5.0	7	14.0%	22.5%
		Geometric Growth	r=1.25	19	6.6%	62.1%
			r=1.5	11	13.8%	35.8%
			r=1.75	8	18.2%	26.1%
			r=2.0	7	20.5%	22.9%
		Fibonacci Growth		13	14.5%	41.8%

4. Conclusions

This study examined the impacts of various spatial grid divisions on the accuracy of offsite consequence analysis results. To evaluate their influence, numerical sequences such as arithmetic, geometric, and Fibonacci were used to determine the radii in polar coordinate spatial grids, comparing the results to the best estimate scenario. Additional grid configurations, like logarithmic spacing and natural logarithms, could be explored in future research. The findings from this study are anticipated to contribute to the optimization of spatial grid settings in subsequent studies.

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