Influence of Spatial Grids Setting on the Results and Speed of Offsite Consequence Analysis

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Abstract: A wide variety of input factors are considered when performing offsite consequence analysis. Some factors such as spatial grids, plume segments, and particle size distribution have flexible input formats and it may affect the accuracy of the results and speed of analysis depending on how they are set.
Fine setting by splitting spatial grids is expected to enhance the accuracy of analysis, whereas it can take a long running time for each analysis. Spatial grid setting is a way to represent spatial grid data of polar coordinates by dividing it into various radii. In this study, various divisions of spatial grids are defined and their influences on the accuracy and speed of analysis are investigated. Arithmetic growth and geometric 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. It is expected that the insight gained from this study can be used in the optimization study of spatial grid setting as a further work.

Keywords: Level 3 PSA, Offsite Consequence Analysis, Spatial Grid Settings, Modeling Optimization

1. INTRODUCTION

Analytical speed is crucial due to the extensive computations needed to handle all possible situations for a single or multi-unit Level 3 PSA. As a result, a high priority is placed on the speed of analysis. Certain elements like spatial grids, plume segments, and particle size distribution offer flexible input formats, allowing users to manage both the quantity and value of parameters. However, others, such as the washout coefficient or dispersion scaling factor, have a fixed format and a set number of parameters. Depending on their configuration, this flexibility could influence the precision of the outcomes and the speed of analysis.

Korea Atomic Energy Research Institute is undertaking a study to refine the analysis model for efficient execution of offsite consequence analysis. In this context, a methodology for optimizing plume segmentation has been developed, which can reduce the time required for analysis by up to 55%, while preserving the precision of the analysis results [1, 2]. Moreover, ongoing research is being conducted to assess the effects of other input parameters, such as the setting of particle size distribution [3, 4] and the spatial grid setting, on the results and speed of analysis.

A detailed setting by dividing spatial grids is expected to improve the precision of the analysis, but it may result in a longer time for each analysis. The setting of the spatial grid is a method to represent the spatial grid data of polar coordinates by dividing it into various radii. In this research, various divisions of spatial grids are identified, and a strategy for sensitivity analysis is established.

2. SPATIAL GRID SETTINGS

2.1. Spatial Grid

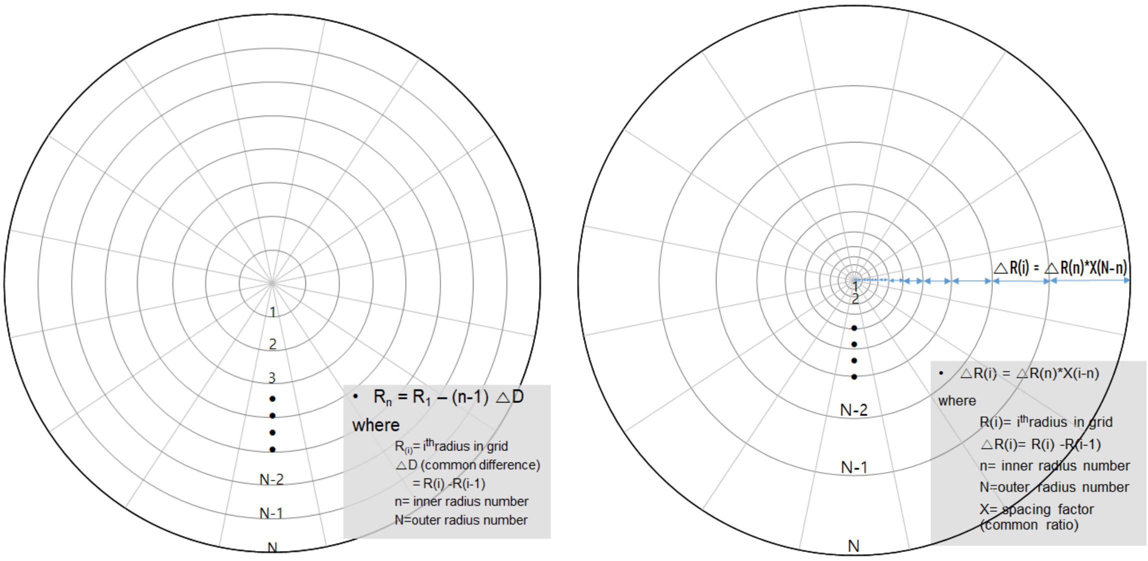
In the event of an offsite nuclear power plant accident, the most rapid environmental transport route for radioactive material that could impact a large number of residents over a broad area is atmospheric dispersion and deposition. The source of the accident in the offsite consequence analysis serves as the reference point for atmospheric dispersion and deposition, necessitating the creation of a spatial grid to compute dispersion and deposition based on this point.

In this research, the MACCS code [5] was employed 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 permit up to 35 radial rings and 64 compass sectors, but in this study, 31 radii with 16 directional sectors were established as the base case for far-field analyses, and 24 radii with 16 directional sectors were established as the base case for near-field analyses.

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

2.2. Various Grid settings

For various spatial grid settings, arithmetic growth and geometric growth used in this study. Figure 1 illustrates the concepts of spatial grid setting using arithmetic growth and geometric growth.



(a) Arithmetic Growth (b) Geometric Growth

Figure 1. Spatial Grid Settings

An arithmetic growth means the analysis area is split into equal sections, as shown in Figure 1(a), with even distances between the rings. A geometric growth means the spaces between the rings grow by a fixed ratio, as shown in Figure 1(b), creating larger gaps as the distance from the source increases. This analysis method shows the dilution of dispersed and deposited concentrations as the radioactive material moves away from the source of the accident.

3. VARIATION ON SPATIAL GRID SETTINGS

3.1. Spatial Grid Settings for Near-Field (PAZ Boundary)

For the spatial grid settings for PAZ, the analysis parameters were configured as follows:
- Analysis range: 5 km
- Angular direction: 16 sectors
- Maximum number of radial rings: 24
- Grid setting: Arithmetic Growth and Geometric Growth

Table 1 presents examples of spatial grid settings for near-field analysis, employing both arithmetic and geometric growths. In the arithmetic growth scenario, the base case involves setting 24 radial spatial elements with each ring spaced 0.2 kilometer apart, in a maximum analysis distance of 5 kilometers, , followed by the case of setting the spacing to 0.25 kilometers, 0.5 kilometers and 1.0 kilometers.

For the geometric sequence, the table illustrates the distances at which each ring is positioned, with the ratio set to 1.25, 1.5, 1.75, and 2, respectively.

Table 1. Spatial Grid Settings (Near-Field)

Arithmetic Growth Radius (km)					**Geometric Growth** Radius (km)				
Common Difference (d=)	0.20	0.25	0.50	1.00	Common Ratio (r=)	1.25	1.50	1.75	2.00
1	0.50	0.50	0.50	0.50	1	0.50	0.50	0.50	0.50
2	0.60	0.75	1.00	1.00	2	0.67	0.66	0.93	1.25
3	0.80	1.00	1.50	2.00	3	0.84	0.99	1.63	2.50
4	1.00	1.25	2.00	3.00	4	1.05	1.48	2.86	5.00
5	1.20	1.50	2.50	4.00	5	1.31	2.22	5.00	
6	1.40	1.75	3.00	5.00	6	1.64	3.33		
7	1.60	2.00	3.50		7	2.05	5.00		
8	1.80	2.25	4.00		8	2.56			
9	2.00	2.50	4.50		9	3.20			
10	2.20	2.75	5.00		10	4.00			
11	2.40	3.00			11	5.00			
12	2.60	3.25							
13	2.80	3.50							
14	3.00	3.75							
15	3.20	4.00							
16	3.40	4.25							
17	3.60	4.50							
18	3.80	4.75							
19	4.00	5.00							
20	4.20								
21	4.40								
22	4.60								
23	4.80								
24	5.00								

3.2. Spatial Grid Settings for Far-Field (UPZ Boundary)

For the spatial grid settings for UPZ, the analysis parameters were configured as follows:

- Analysis range: 30 km
- Angular direction: 16 sectors
- Maximum number of radial rings: 31
- Grid setting: Arithmetic Growth and Geometric Growth

Table 2 presents examples of spatial grid settings for far-field analysis, employing both arithmetic and geometric growths. In the arithmetic sequence scenario, the base case involves setting 31 radial spatial elements with each ring spaced 1 kilometer apart, in a maximum analysis distance of 30 kilometers. Further cases consider spacings of 2 kilometers, 3 kilometers and 5 kilometers per ring.

For the geometric sequence, the table illustrates the distances at which each ring is positioned, with the ratio set to 1.25, 1.5, 1.75, and 2, respectively.

Table 2. Spatial Grid Settings (Far-Field)

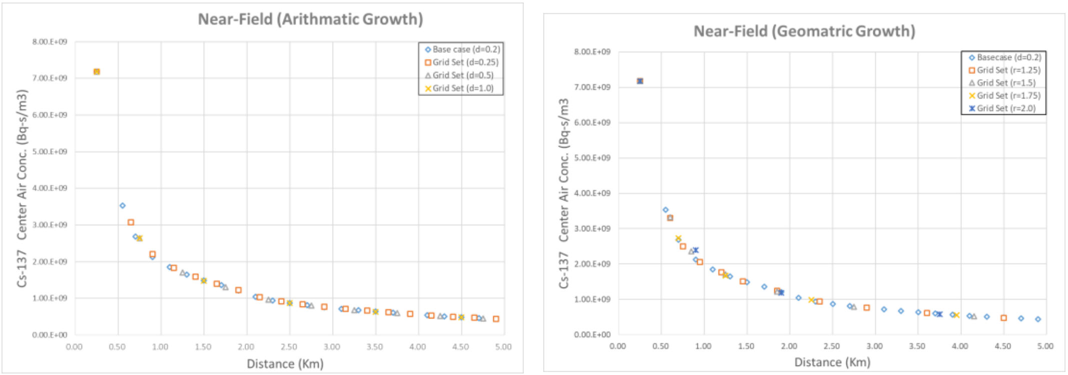
Arithmetic Growth Radius (km)					**Geometric Growth** Radius (km)				
Common Difference (d=)	1.00	2.00	3.00	5.00	Common Ratio (r=)	1.25	1.50	1.75	2.00
1	0.50	0.50	0.50	0.50	1	0.50	0.50	0.50	0.50
2	1.00	2.00	3.00	5.00	2	0.68	0.78	1.04	0.94
3	2.00	4.00	6.00	10.00	3	0.84	1.17	1.83	1.88
4	3.00	6.00	9.00	15.00	4	1.06	1.76	3.20	3.75
5	4.00	8.00	12.00	20.00	5	1.32	2.63	5.60	7.50
6	5.00	10.00	15.00	25.00	6	1.65	3.95	9.80	15.00
7	6.00	12.00	18.00	30.00	7	2.06	5.93	17.14	30.00
8	7.00	14.00	21.00		8	2.58	8.89	30.00	
9	8.00	16.00	24.00		9	3.22	13.33		
10	9.00	18.00	27.00		10	4.03	20.00		
11	10.00	20.00	30.00		11	5.03	30.00		
12	11.00	22.00				6.29			
13	12.00	24.00				7.86			
14	13.00	26.00				9.83			
15	14.00	28.00				12.29			
16	15.00	30.00				15.36			
17	16.00					19.20			
18	17.00					24.00			
19	18.00					30.00			
20	19.00								
21	20.00								
22	21.00								
23	22.00								
24	23.00								
25	24.00								
26	25.00								
27	26.00								
28	27.00								
29	28.00								
30	29.00								
31	30.00								

4. IMPACT OF SPATIAL GRID SETTINGS

An impact analysis of offsite consequences was conducted using the spatial grid settings based on arithmetic and geometric growths as proposed in this study. Sensitivity analyses for both near-field (PAZ boundary) and far-field (UPZ boundary) were performed, with the results presented in section 4.1 and section 4.2

4.1. Impact on the ground-level air concentration

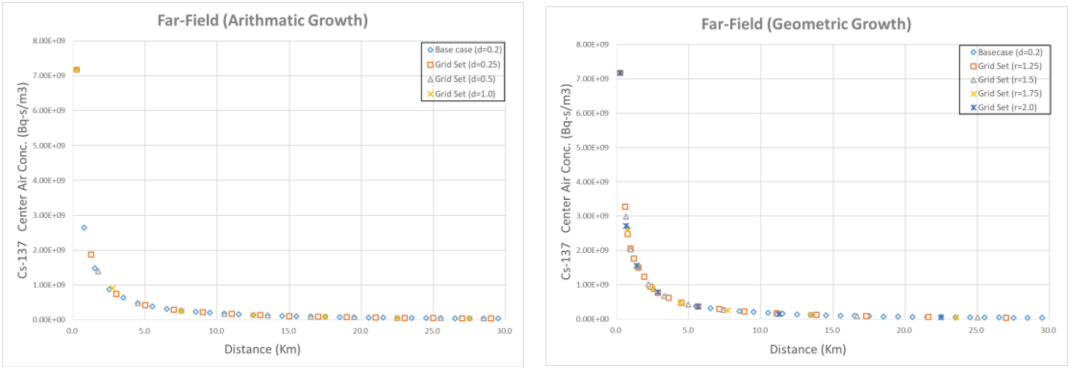
Figure 2 illustrates the impact on the ground-level air concentration for near-field applying arithmetic and geometric growths. Specifically, Figure 2(a) demonstrates that the Cs-137 concentration results for grid sets 2 and 3 align closely with the result line of grid set 1 (the base case) when using arithmetic growth. Similarly, in the case of geometric growth shown in Figure 2(b), grid sets 2, 3, and 4 also yield accurate results compared to the base case.



(a) Arithmetic Growth (b) Geometric Growth

Figure 2. Impact of Spatial Grid Settings (Concentration, Near-Field)

The results of the far-field analysis, as depicted in Figure 3 also have a similar pattern to the results of near-field analysis.



(a) Arithmetic Growth (b) Geometric Growth

Figure 3. Impact of Spatial Grid Settings (Concentration, Far-Field)

The impact analysis indicates that using arithmetic and geometric growth for spatial grid settings does not compromise the accuracy of ground-level air concentration results itself.

4.2. Impact on the Health Effect

Table 3 shows the results of spatial grid setting on health effects. Each row includes the spatial grid type, number of radial rings, relative error by averaging fatality of each ring, and relative elapsed time.

Table 3. Impact of Spatial Grid Settings (Health Effects)

				Number of Radial Rings	Relative Error	Time
Near Field (0.5~5km)	Early Fatality	Base case	d=0.2	24	100.0%	100.0%
		Arithmetic Growth	d=0.25	19	99.4%	79.1%
			d=0.5	10	98.8%	41.4%
			d=1.0	6	95.1%	24.9%
		Geometric Growth	r=1.25	11	98.4%	45.6%
			r=1.5	7	96.3%	29.2%
			r=1.75	5	93.9%	20.8%

			r=2.0	4	91.0%	16.7%
	Cancer Fatality	Base case	d=0.2	24	100.0%	100.0%
		Arithmetic Growth	d=0.25	19	98.9%	79.1%
			d=0.5	10	94.2%	41.3%
			d=1.0	6	87.8%	24.9%
		Geometric Growth	r=1.25	11	91.8%	45.9%
			r=1.5	7	84.9%	29.2%
			r=1.75	5	81.0%	20.9%
			r=2.0	4	78.3%	16.9%
Far Field (0.5~30km)	Early Fatality	Base case	d=1.0	31	100.0%	100.0%
		Arithmetic Growth	d=2.0	16	81.1%	51.9%
			d=3.0	11	59.2%	35.6%
			d=5.0	7	33.7%	22.8%
		Geometric Growth	r=1.25	19	103.0%	62.1%
			r=1.5	11	96.8%	36.1%
			r=1.75	8	95.2%	26.3%
			r=2.0	7	91.2%	23.1%
	Cancer Fatality	Base case	d=1.0	31	100.0%	100.0%
		Arithmetic Sequence	d=2.0	16	94.5%	51.8%
			d=3.0	11	90.6%	35.5%
			d=5.0	7	83.6%	22.7%
		Geometric Sequence	r=1.25	19	93.0%	62.1%
			r=1.5	11	84.4%	36.0%
			r=1.75	8	78.9%	26.2%
			r=2.0	7	75.7%	23.0%

In the case of far-field analysis, the early fatality shows similar results to the base case when the spatial grid is set with an arithmetic growth, and cancer fatality shows valid results at d(2.0) in the arithmetic growth and r(1.25) in the geometric growth. It is also shown that the analysis time is proportional to the number of radii in the case of far-field analysis.

5. CONCLUSIONS

In this study, various divisions of spatial grids are defined and their influences on the result accuracy of offsite consequence analysis were investigated. Two numerical sequences such as arithmetic growth and geometric growth are applied to set the radius of the polar coordinate of spatial gird to evaluate influences on the accuracy of analysis compared to the best estimate case. Other grid settings such as logarithmic spacing, grid settings using Fibonacci and natural logarithms can be employed in further studies. It is expected that the insight gained from this study can be used in the optimization study of spatial grid setting as a further work.

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