INVESTIGATING THE VALIDITY OF WEATHER BIN SAMPLING IN LEVEL 3 PSA

Sung-yeop Kim*

Korea Atomic Energy Research Institute: 111, Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon, 34057, Republic of Korea

*sungyeop@kaeri.re.kr

EXTENDED ABSTRACT

Level 3 probabilistic safety assessment (Level 3 PSA) requires statistical consideration of weather because of the presence of uncertainty in the risk assessment, as it involves postulating an accident that has not happened. One year of meteorological data consisting of 8,760 hours of data is typically utilized. A set of weather data considered in one offsite consequence analysis is defined as a weather sequence or weather trial. Traditionally, a weather sequence includes a series of meteorological data of one hour or a few hours, but more recently, it includes data for several days, such as 72 hours. The best-estimate statistical analysis is to perform 8,760 offsite consequence analyses using all 8,760 starting points of weather sequences and find statistical values such as mean, peak, and percentile values. However, the computing time or burden increases proportionally to the number of calculations. To overcome this limitation, sampling methods such as bin sampling and stratified random sampling have been employed in MACCS code [1, 2].

Stratified random sampling randomly samples a user-specified number of calculation starting points during each 24-hour day. This method is independent of the length of the weather sequence because it randomizes the calculation starting points. This approach does not employ weather binning. Instead, a user-defined number of weather trials is randomly selected from each individual weather day [3].

Bin sampling groups similar weather sequences into a bin and only performs computations representing each bin. However, it is questionable whether it is possible to find commonalities in weather sequences containing tens of hours of changing meteorological data and assign them to a bin. This study investigated whether bin sampling is still a valid method in the recent research trend of considering long weather sequences. The bin structure is designed to characterize precipitation conditions across varying downwind distance intervals from the accident site, in conjunction with 16 predefined bins representing initial meteorological conditions categorized by atmospheric stability class and wind speed. The rain bins are defined by user-specified values for rain intensity and distance intervals, which are entered via the Rain Distances and Rain Intensities configuration forms. The total number of weather bins is determined by the number of rain intensities (NRINTN) and the number of rain distance intervals (NRNINT), which are specified in the respective configuration forms. The aggregate number of weather bins is calculated as NRNINT × (NRINTN + 1) + 16. Consequently, depending on user input, the total number of bins may range from 28 to 40.

In the uniform bin sampling approach, the parameter NSMPLS specifies the number of weather sequences to be selected from each individual weather bin. Increasing the number of samples enhances the statistical robustness of the simulation outcomes. The actual number of sequences extracted from a given weather bin corresponds to the lesser of either the total number of time periods available within that bin or the value specified by NSMPLS. Nonuniform bin sampling operates similarly to uniform bin sampling, with the key distinction that the user separately specifies the number of weather trials (INWGHT) to be sampled from each bin. As with the uniform method, 1200 hours of weather data are retrieved per trial to characterize temporal variation.

For the analysis, two site data sets, the Korean reference site and the NRC Sample provided by MACCS, were used. Since the NRC sample problem uses nonuniform bin sampling, the nonuniform bin sampling method is adopted as a representative method of bin sampling. Stratified random sampling was analyzed by increasing the number of samples (NSMPLS) from 1 to 24. This study focused on a one-week emergency phase and cases with or without emergency responses such as evacuation and relocation were analyzed. As results, population-weighted risks for early fatality and cancer fatality were considered.

TABLE I. Relative error of the mean value for each sampling method compared to the mean value considering all weather data (NSMPLS = 24)

		Pop-weighted Risk	Nonuniform Bin Sampling	Stratified Random Sampling (Number of Samples per Day)						
				1	2	4	8	12	18	24 (Best-estimate)
With Emergency Response	NRC Point Estimate LNT	Early Fatality	18.75%	2.08%	1.46%	-4.48%	2.92%	0.42%	-3.12%	0.00%
		Cancer Fatality	-2.69%	8.52%	-4.93%	-0.45%	0.90%	-0.45%	-17.49%	0.00%
	Reference Site	Early Fatality	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Cancer Fatality	2.02%	-1.01%	1.35%	1.68%	0.67%	-0.67%	-10.44%	0.00%
Without Emergency Response	NRC Point Estimate LNT	Early Fatality	4.39%	-1.88%	-13.79%	-2.35%	0.63%	0.16%	-7.84%	0.00%
		Cancer Fatality	-4.12%	8.82%	-4.41%	-0.88%	1.18%	-0.44%	-17.35%	0.00%
	Reference Site	Early Fatality	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Cancer Fatality	2.02%	-1.18%	1.18%	1.68%	0.34%	-0.84%	-10.59%	0.00%

Table I shows the results of the analysis, the average value derived from considering all weather data and the average value derived from each sampling. In Stratified random sampling, when the number of samples to be extracted per day is set to 24, the results can be calculated considering all weather data and this becomes the best-estimate case. For stratified random sampling, the results tend to be closer to the best-estimate case as the number of samples increases. However, it can be observed that there is an unusually high difference when the number of samples is 18. This is because the number of samples can introduce bias into the sampling algorithm if the number of samples is not a factor of 24, which is the number of days in a year. Users should be careful not to enter a number of samples that is not a factor of 24. It can also be seen that nonuniform bin sampling has a relatively large difference in results. This is due to the MACCS sample problem entering a nonuniform number of samples for the 36 weather bins and over-sampling from some bins. Therefore, when utilizing nonuniform bin sampling, it is necessary to carefully consider the number of weather trials to be sampled from each bin.

In conclusion, the results of this study show that the error of stratified random sampling is less than 5%, 3%, and 1% when the number of weather trials to be sampled per day is set to 4, 8, and 12, respectively. While, when nonuniform bin sampling is utilized, the results can be skewed toward some weather bins and show a large error from the best-estimate. The results of this study may not be representative of all cases, so it is necessary to consider more years of weather data, different numbers of plumes, and other factors. It is also worth extending the study to the long-term phase, not just the emergency phase, to evaluate the impact of the sampling method.

ACKNOWLEDGMENTS

This work was supported by the Nuclear Safety Research Program through the Korea Foundation of Nuclear Safety (KoFONS) using financial resources granted by the Nuclear Safety and Security Commission (NSSC) of the Republic of Korea (No. RS-2023-00240452).

REFERENCES

[1] Sandia National Laboratories, *MACCS User Guide – Version 4.2*, SAND2023-01315, Sandia National Laboratories (2023).

[2] Sandia National Laboratories, *MACCS Model Description*, NUREG/CR-4691, SAND86-1562 Vol. 2, Sandia National Laboratories (1990).

[3] J.C. Helton, J.D. Johnson, C.J. Sallaberry, C.B. Storlie, Survey of sampling-based methods for uncertainty and sensitivity analysis, *Reliability Engineering and System Safety*, **91**, 1175–1209 (2006).