Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 7-8, 2015

Analytical Assessment of Environmental Impact for APR1400DC UHS Cooling Tower

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1. Introduction

In nuclear power plants (NPPs), the UHS (ultimate heat sink) has a major role in dissipating heat generated from equipment in component cooling water and essential service water systems. The UHS design is dependent on plant's site-specific conditions because it can be atmosphere or water body such as sea, lake, cooling pond, and river. However, regardless of the type of cooling source, it should be designed to maintain an adequate cooling water inventory at an acceptable temperature for 30 days without makeup [1]. In inland NPPs, unlike costal NPPs, the cooling towers are used as the UHS due to the capacity limitation of water source. Hot process water is pumped from the plant process to the cooling towers. Heat is rejected through evaporation of the process water, interacting with ambient air blown upward by fans. Plumes generated from exit ports of the cooling tower may have adverse effects on the environment, such as deposition of cooling tower drift release, fogging, icing, shadowing, and ground-level temperature and humidity increase. These kinds of environmental impact of the cooling tower are linked closely with the dispersion of the cooling tower plumes. In this respect, predicting the behavior of the plumes has become one of the most important issues in the environmental assessments of the cooling towers. The SACTI (seasonal/annual cooling tower impact) model is an analytical tool to predict the environmental effect of cooling tower, which was developed by Argonne National Laboratory and University of Illinois with support from EPRI (electric power research institute) [2]. The initial version of SACTI has been widely used to assess the environmental effect of cooling towers in many industrial fields such as steam power plants and NPPs. Guo et. al. [3-4] investigated impact of heat rejection and cooling tower height on plume dispersion using the SACTI model, for the purpose of the future construction of inland NPPs. They found that increasing cooling tower height decreases the plume length and height frequencies. Their simulation results showed that the increase in heat rejection increases the plum radius frequency.

The APR1400DC is an advanced light water reactor developed for the purpose of NRC-DC (design certification). In the United State, most NNPs have been constructed in inland. US-NRC insists on cooling towers as UHS for DC applicants. Thus, we determined cooling towers as APR1400DC UHS. The cooling towers for APR1400DC UHS consist of two linear mechanical draft cooling towers (LMDCTs). The LMDCT for APR1400DC UHS is conceptually designed because the plant site has not been decided yet. In the present study, the dependency of plume dispersion on the number of cooling towers is investigated using SACTI-2-beta, for predicting annual environmental effect of APR1400DC LMDCT.

2. Methods and Results

2.1 SACTI-2 Model

The initial version of SACTI model has been widely used to assess the environmental impact of cooling towers. However, it needs to be revised because it was designed for a mainframe minicomputer. In 2012, Argonne National Laboratory and University of Illinois started SACTI-2 development project with support from EPRI [5]. The previous SACTI has been upgraded into SACTI-2 by resolving several problems such as code bugs, conversion to Fortran 90, restructure code architecture, plume abatement simulation, update of meteorological data format, equivalent wind directions, daytime fogging impact, catalog runtime errors, and the number of exit ports [6]. The included at the SACTI-2 calculation are as follows:

- Frequencies of plume length, height and radius
- Hours of plume shadowing
- Plume fogging and icing
- Mineral deposition

Table I: Test Scenario

The number of towers	The number of cells	Exit port heights(m)
2	6	17
4	12	17
6	18	17
4	12	7

The SACTI-2 consists of three main modules: preprocessor module, plume module, and table module. To execute the preprocessor module, a meteorological data and input control parameters should be determined. For the assessment of the annual/seasonal impact, at least one year of hourly surface meteorological data and concurrent twice-daily mixing heights are required. Because the APR1400DC plant site is not decided, the hourly meteorological data for five years near Spokane international airport in United States is temporarily used as input surface data for SACTI-2 model. The APR1400DC is designed to have two divisions. Each division has two cooling towers respectively consisting of three cells. However, the number of cooling towers needed for operation is determined for different operating modes. In this study, we used four test scenarios for changing the number of cooling towers in operation. The test scenarios are shown in Table. 1.

2.2 Plume length and shadowing

When visible plumes are generated from cooling tower exit ports, they behave very much like clouds and decrease the solar energy passing through them. They may have adverse effects on the crop yield in a particular field by shadowing the sunshine during the growing season. Thus, predicting annual average and accumulated behavior of the visible plumes is important. Fig.1 shows the typical contour plots showing plume length frequency for changing the number of towers and port height. The contour lines represent percentage of occurrence frequency. At the higher number of towers, the plume length frequency occurs most significantly within 4km to the northeast. Increasing the number of cooling towers extends the higher frequency area further away from the plant. Meanwhile, increasing the exit port height has little effect on the plume length frequency. Fig. 2 shows the typical contour plots showing the annual plume shadowing frequency for changing the number of cooling towers and port heights. The plume shadowing frequency is represented in terms of hours. Regardless of the number of towers, the maximum impacts are shown within 0.5 km radius of the cooling tower. However, increasing the number of towers extends the effective shadowing radius of the cooling tower. Variation of port height has less impact on the plume shadowing frequency.

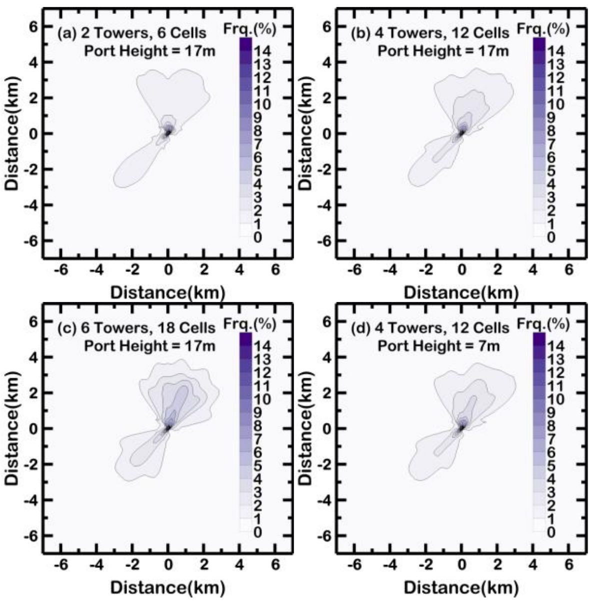

Fig. 1. Annual plume length frequency for different cell numbers and port heights

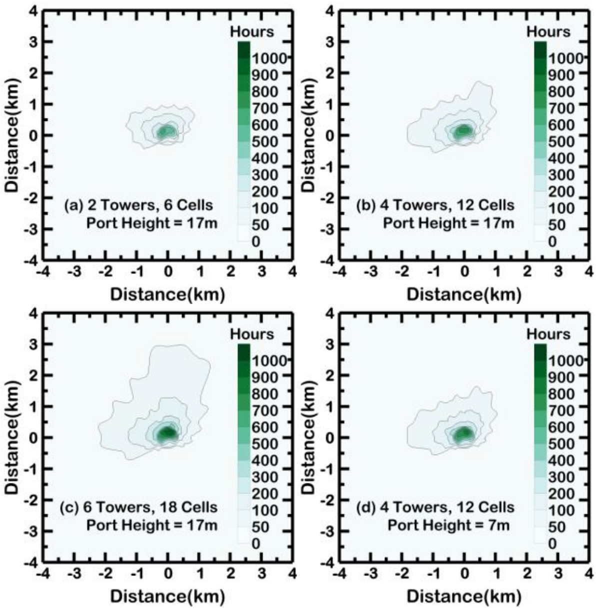

Fig. 2. Annual plume shadowing frequency for different cell numbers and port heights

2.2 Plume induced fogging and icing

Plume-induced fogging occurs when visible plumes approach to the ground. Fig. 3 shows the effect of the number of cooling towers on the plume-induced fogging. The total hours of fog is represented as a function of downwind distance and direction for annual meteorological data. As shown in Fig. 3(a) and (b), increasing the number of cooling towers influences on the size of plume-induced fogging area. Fig. 3(b) shows the plume-induced fogging area extends one kilometer radius toward the northeast. Plume-induced icing may occur when visible plumes approach to the ground at below-freezing temperature. The plume induced icing is represented as a function of downwind distance and direction in Fig. 4. Increasing the number of towers increases the level of plume-induced icing. In Fig. 4(b), the predominant location of the plume-induced icing is toward the southwest of the cooling towers, extending to a maximum distance of approximately 0.5km.

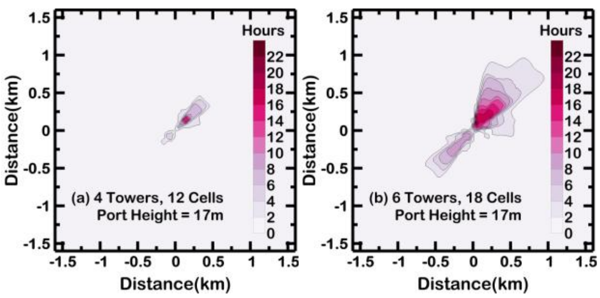

Fig. 3. Annual plume-induced fogging of APR1400DC LMDCT.

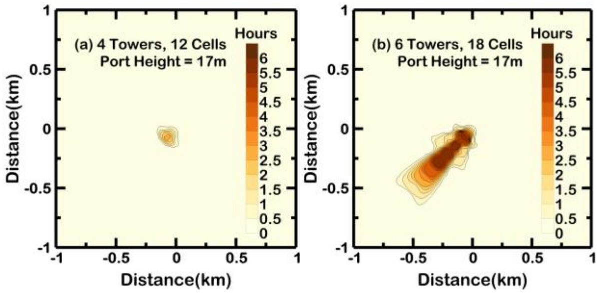

Fig. 4. Annual plume-induced icing of APR1400DC LMDCT

3. Conclusions

In the present study, annual/seasonal impacts of cooling towers for APR1400DC are analyzed using SACTI model. The main conclusions are as follows:

1. Increasing the number of cooling towers increases the level of plume length frequency and plume shadowing frequency. However, variation of exit port height has less effect on them.
2. The areas of plume-induced fogging and icing are enlarged with increase in the number of cooling towers.

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