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Evaluation of impacts of cooling tower design properties on the near-field environment

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ABSTRACT

In a nuclear power plant, ultimate heat sink (UHS) and circulating water system (CWS) cooling towers both ultimately remove heat from the essential service water system, main condenser, and non-essential service water system during all operation modes including accident conditions. Since the visible plume from the cooling tower has an adverse effect on the environment, however, an environmental impact assessment of the cooling tower is required for the construction of a new nuclear power plant. In this study, the environmental impact of UHS and CWS cooling towers of an APR1400 standard design plant was assessed for the purpose of testing and demonstrating the recently-updated SACTI2 model. Because the site for the APR1400 standard design plant had not been decided, one-year meteorological data from the Spokane International Airport weather station, WA, USA, were used as hypothetical input data for the environmental impact assessment. The quantitative effect of cooling tower design changes on the environment was analyzed in terms of index-value dispersion area (A_D) and dispersion ratio (δ) for nine environmental assessment indexes. Scenario test conditions were varied by changing cooling tower arrangement, distance between cooling towers, length of cooling tower, exit port height, exit port diameter, the number of exit ports, heat load per tower, and air flow rate per tower.

1. Introduction

Since 1980, in the United States, closed-cycle cooling design such as in cooling towers has been applied to most new nuclear power plants on account of environmental regulations and policies relating to the effect of the increased temperature of discharged water on the environment, the impact of the cooling intake structures on underwater organisms, and fresh water availability (EPRI, 2012). However, plumes from cooling towers can generate adverse impacts on the environment such as through plume shadowing, water and salt deposition, ground level fogging and icing, and solar energy loss, among others (Davis, 1998; U.S. NRC, 2007). The environmental impact of cooling towers operating on the plant site can be investigated by measurement devices placed near the cooling tower region. On the other hand, the evaluation of the environmental impact of a cooling tower under construction or to be constructed in the future should be conducted through experiment or numerical analysis based on past meteorological information. Full-scale experiments for predicting the dynamic behavior of cooling tower plumes are expensive; scale model experiments (Michioka et al., 2007; Ruiz et al., 2016) have their limitations; therefore, many studies (Carhart and Policastro, 1991; Carhart et al., 1992; Orville et al., 1980; Moore, 1977) on the environmental impact of cooling towers have focused on developing an analytical plume prediction model. Policastro et al. (1981a) developed an improved mathematical model, more well-known as the seasonal/annual cooling tower impact (SACTI) model, for predicting plume and drift behavior occurring from cooling towers. They also developed a user manual of the improved mathematical model (Policastro et al., 1984) and updated it in terms of user friendliness (Dunn et al., 1987). The single plume behavior using the SACTI model was tested and validated with data from the Chalk Point Dye Tracer Study (Policastro et al., 1981a). The behavior of multiple plumes using the SACTI model was also validated against the multiple unit cooling towers at Pittsburgh, CA (Policastro et al., 1981b). The original SACTI code has been available in public domain and accepted by both the United States Environmental Protection Agency (U.S. EPA) and the United States Nuclear Regulatory Commission (U.S. NRC) (EPRI, 2015).

Due to recent advances in computational fluid dynamics (CFD) techniques, studies (Lucas et al., 2010; Meroney, 2008; Chahine et al., 2015; Milosavljevic and Heikkilä, 2001) have been carried out to apply CFD techniques to the environmental assessment of a cooling tower, yielding predictions of more detailed accurate plume behaviors. Nevertheless, the SACTI model has been popular due to its low cost for

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Nomenclature

A_D	index-value dispersion area
n	number of radial locations from the starting point of the coordinate system
m	number of the wind rose direction used in the model
N_i	number of i_{th} subsector in the j_{th} location
S_j	the area of subsector
A_0	the region-of-interest area

Greek symbols

δ	dispersion ratio ($\delta = A_D/A_0$)
$\delta_{Test}/\delta_{Test\text{-}1}$	normalized dispersion ratio

Subscript

Test	test scenario
i	wind rose direction index
j	radial location index
0	region-of-interest
D	dispersion

the analysis and conservative results for licensing; therefore, it has been widely used in developing environmental reports required for combined construction and operation licensing application (COLA) of nuclear power plants (Wan, 2007; U.S. NRC, 2011; U.S. NRC, 2013; U.S. NRC, 2008). Due to that reason, EPRI (Electric Power Research Institute) developed an upgraded SACTI2 model for new nuclear power plant construction (EPRI, 2015). For the real testing of the updated SACTI2 model, in the present study, environmental assessment of ultimate heat sink (UHS) and circulating water system (CWS) cooling towers of an APR1400 (for Advanced Power Reactor 1400 MW electricity) for the application of U.S. NRC standard design certification were numerically carried out for a hypothetical plant site: Spokane International Airport station (WBAN No.: 24157 and USAF No.: 727850) from the national weather service (NWS). Most nuclear power plants in the U.S. are located in the central and eastern U.S. which are in humid climates. However, SACTI2 user's manual used one year meteorological data for Spokane International Airport providing sufficiently cold condition to investigate the effect of plume-induced fogging and icing due to cooling towers.

For the air quality modeling analysis, the U.S. EPA recommends to use five-year data of a site of interest so that the data covers the wide spectrum of the meteorological conditions for the site (U.S. EPA, 2005). One year meteorological data might be not enough to fully address meteorological conditions for the environmental assessment of the site of interest because of a wide variability of meteorological conditions from year to year. In this study, however, the same one year meteorological data for Spokane International airport used in SACTI2 user's manual (EPRI, 2015) was applied for the environmental assessment of cooling towers of the APR1400 standard plant because the site for APR1400 has not been determined yet.

The main objective of this study is to quantify the effect of cooling tower design changes of APR1400 standard design plant on the environment using SACTI2 model. Several test conditions were applied to investigate the effect of cooling tower design changes on the near-field environment of the plant. The results were analyzed using environmental assessment indexes: plume length frequency (PLF), plume shadowing hour (PSH), plume fogging hour (PFH), plume icing hour (PIH), plume salt deposition flux (PSDF), plume water deposition flux (PWDF), fractional solar energy deposition loss (FSDL), fractional beam deposition loss (FBDL), and total solar energy loss (TSL).

2. Methodology

2.1. Cooling tower design

The main cooling system of pressurized water reactor (PWR) nuclear power plants consists of safety-related UHS and non-safety-related CWS. The UHS is responsible for finally removing reactor residual heat and essential station heat loads during all modes of operation including accident conditions. The key safety functions of the UHS are to dissipate residual heat after normal shutdown and an accident such as a LOCA (loss-of-coolant-accident), and the expected maximum decay heat from the spent fuel pool (NRC RG 1.27, 2015). On the other hand, the CWS provides cooling water to dissipate heat from the main condenser and

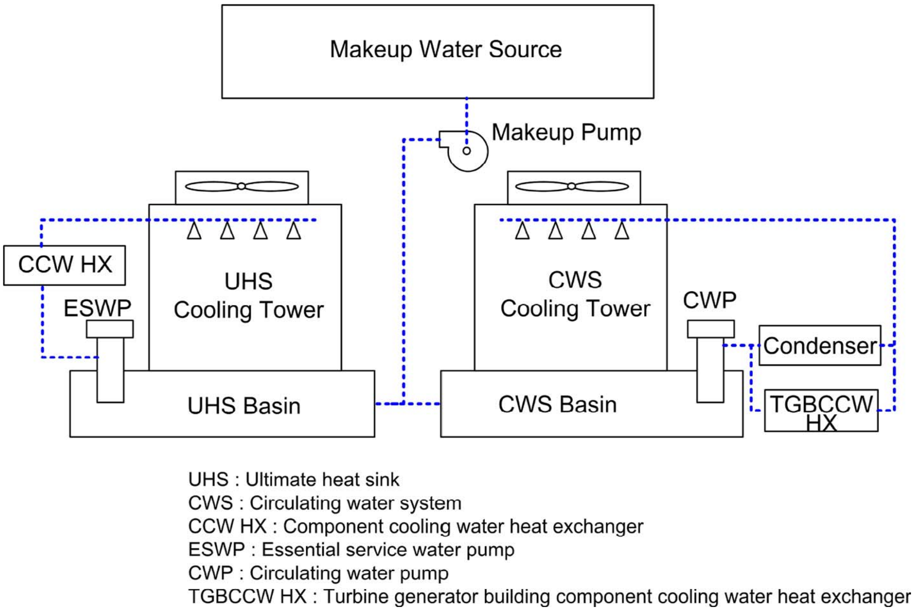

Fig. 1. Simplified diagram of water flows in circulating water system (CWS) and ultimate heat sink (UHS).