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Microscopic Hydrodynamic Bubble Behaviour in Suppression Pool during Wetwell Venting

Doctoral dissertation by **Zablackaite Giedre**

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This dissertation demonstrates the necessity of introducing Sauter Mean Diameter as representative bubble diameter in the existing codes for analysing pool scrubbing effects. In addition, it experimentally clarified the hydrodynamic behaviour of bubbles prior to wetwell venting (constant pressure condition) and during wetwell venting (depressurization conditions) in suppression pool, and made proposals for improving the prediction accuracy of pool scrubbing effects and revising accident management.

Chapter 1, "Introduction", reviews the severe accident progression of the TEPCO's Fukushima Daiichi Nuclear Power Plant accident in March 2011. During wetwell venting the efficiency of pool scrubbing effect was lower than expected, resulting in the release of large amounts of fission products (FP) to the environment. In the existing codes for analysing the pool scrubbing effect, the FP aerosol transport model and the bubble hydrodynamic model are combined to evaluate the pool scrubbing effect. In the codes, pool scrubbing efficiency is obtained from FP aerosol removal mechanisms, inertial impaction, gravitational sedimentation, Brownian diffusion, and steam condensation, which depend on the bubble diameter and bubble rising velocity. In the codes the single bubble model has been adopted, but the physical basis for the representative bubble diameter selection has not been clarified. In this dissertation, Sauter Mean Diameter (SMD) is proposed as representative bubble diameter, which is defined as the ratio of the total volume of the bubbles that is proportional to the amount of FP inside the bubble and the total surface area of the bubbles that governs mass transfer of FP particles. This chapter describes the objective of this study, which will contribute to improve the predicted efficiency accuracy of pool scrubbing effects and to revise the accident management by experimentally clarifying the microscopic hydrodynamic bubble behaviour during wetwell venting in a suppression pool.

Chapter 2, "Bubble Behaviour under Prototypical Severe Accident Conditions", describes the hydrodynamics of bubbles under typical severe accident conditions such as pressure, pool water temperature, non-condensable gas content, downcomer pipe diameter, and downcomer pipe submergence. Experimental data were collected in the test facility, which consists of drywell and wetwell connected via downcomer pipe, a steam generator, an air compressor, and a heat exchanger. The scaling consideration for the design of the test facility was applied by identifying the essence of the phenomenon. The bubble behaviour was observed and evaluated near the pool surface and near the downcomer pipe outlet by the back-lit shadowgraphy technique. Under constant pressure, the effect of non-condensable gas content on SMD was small, and the bubble rise velocity decreased with increasing non-condensable gas content. Both SMD and bubble rising velocity decreased with increasing suppression pool water temperature. It was also shown that temperature stratification had little effect on SMD and bubble rising velocity. Physical reasons for the observed tendencies were also clarified. The measured SMD and corresponding bubble rise velocities v_b^{SMD} were generally in the same order of magnitude as those used in pool scrubbing codes. However, bubble parameter dependency on experimental conditions in the analysis codes was different from the obtained in the present study. As a result, deposition velocities of inertial impaction, gravitational sedimentation, Brownian diffusion, and steam condensation had different tendencies between analysis codes and experimental results.

In Chapter 3, "Validity of Sauter Mean Diameter Selection for Single Bubble Model in Pool Scrubbing Codes," the data of directly measured decontamination factor (DF) reported in the reference were utilized to validate the SMD selection. The DF was estimated based on not only the SMD and v_b^{SMD}, but also average values of bubble diameter and bubble rising velocity. DF based on SMD increased with the increased downcomer pipe submergence. The dependencies on downcomer pipe diameter, pool water temperature and non-condensable gas content were weak, and DF did not depend on Wetwell pressure. These tendencies showed a good agreement with total DF presented in the reference. On the contrary, order of DF based on average values was extremely larger than measured DF and were widely scattered. Thus, based on the present experimental results, SMD is more appropriate for single bubble model in pool scrubbing codes and is strongly suggested to adopt in the future updates of the pool scrubbing codes.

In Chapter 4, "Depressurization Effect on Decontamination Factor during Wetwell Venting," reflecting to the conditions in Fukushima Daiichi severe accident and the FPs release to the environment after W/W ventings, experimental data of bubble size and bubble rising velocity were collected under depressurization and were used for evaluation of depressurization effect on bubble parameters and evaluation of pool scrubbing deterioration under depressurization condition. SMD became slightly smaller under depressurization condition in comparison with constant pressure cases described in Chapter 2, due to high number of generated small bubbles. The steam condensation is the dominant FP removal mechanism, except for the low subcooling condition. Since there is no steam condensation under depressurization, the pool scrubbing effect is significantly degraded and Brownian diffusion becomes the dominant removal mechanism. Brownian diffusion deposition velocity showed only slight change under depressurization. Moreover, DF degrades to 1/100 under depressurization without steam condensation compared with the condition under constant pressure with steam condensation. DF did not change much under different levels of the initial pressure in wetwell. Thus, even though the pressure level in the present study is lower than in Fukushima Daiichi accident, similar result is expected under higher pressure level.

Chapter 5, "Conclusions," summarizes the results obtained in the chapters on the hydrodynamic behaviour of bubbles during wetwell venting in suppression pools and summarizes the conclusions of this thesis for improving the prediction accuracy of pool scrubbing effects and revising accident management.