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Comparative study on aerosol removal by natural processes in containment in severe accident for AP1000 reactor

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ABSTRACT

Focusing on aerosol removal by naturally occurring processes in containment in severe accident for AP1000, integral severe accident code MELCOR and rapid assessment method mentioned in NUREG/CR-6189 are utilized to study aerosol removal by natural processes, respectively. Three typical severe accidents, induced by large break loss of coolant accident (LBLOCA), small break loss of coolant accident (SBLOCA) and steam generator tube rupture (SGTR), respectively, are selected for the study. The results obtained by two methods were further compared in the following several aspects: efficiency of aerosol removal by natural processes, peak time of aerosol suspended in containment atmosphere, peak amount of aerosol suspended in containment atmosphere, time when aerosol removal efficiency by natural processes is up to 99.9%. It was further concluded that results obtained by rapid assessment with shorter calculation process are more conservative. The analysis results provide reference to assessment method selection of severe accident source term for AP1000 nuclear emergency.

1. Introduction

In severe accidents of nuclear power plant (NPP), large amounts of radioactive fission products are released to the containment, which are mainly in form of aerosol, except noble gases and a small amount of iodine. Aerosols have specific characteristics of aerodynamics and they can be directly deposited onto heat structure and water pool surfaces through a number of naturally occurring processes, including gravitational settling, diffusion to surfaces, thermophoresis, and diffusiophoresis. Due to these natural processes, aerosol could be removed and mainly exists in water pool, on the surfaces of components and suspended in containment atmosphere. And this is significant for preventing radioactive fission products being released to environment even if containment is failed. Therefore, aerosol removal by natural processes is studied in this paper.

Currently, two popular methods are used to study radioactive aerosol removal by natural processes, the method utilizing integral severe accident analysis code and rapid assessment method. Advantages and disadvantages of the two methods are obvious that the results calculated by integral severe accident analysis code are more precise on account that the release processes of radioactive aerosol are coupled with thermal-hydraulic processes. Compared with the former method, rapid assessment method has advantages in fast calculation and no need of complex modeling. Nuclear emergency after severe accident is characterized with short response time to evaluate source term and take strategies to prevent or reduce radioactive fission products being released into environment. In addition to accuracy, time taken by calculation process also plays an important role in nuclear emergency response.

Integral severe accident analysis codes include ASTEC, MAAP, MELCOR and so on. ASTEC has been used as a reference tool for many years for most IRSN safety studies. And it is becoming the main reference severe accident integral code in Europe through projects of the European Commission Framework Programme (Van Dorsselaere et al., 2009). For instance, integral code ASTEC was used to analyze severe accident of VVER 1000 (Chatterjee et al., 2007). In AP1000 Final Safety Evaluation Report (AP1000 FSER, 2004) Design Control Document (DCD), integral code MAAP was used to analyze severe accident source term for AP1000 reactor. Integral code MELCOR was used to simulate the complete scenario of a hypothetical severe accident in a nuclear light water reactor (LWR). For instance, MELCOR was applied in severe accident analysis for Fukushima nuclear power plant (Sevon, 2015), TMI-2 nuclear power plant (Haste et al., 2006) and APR1400 nuclear power plant (Ahn et al., 2006). These integral codes couple

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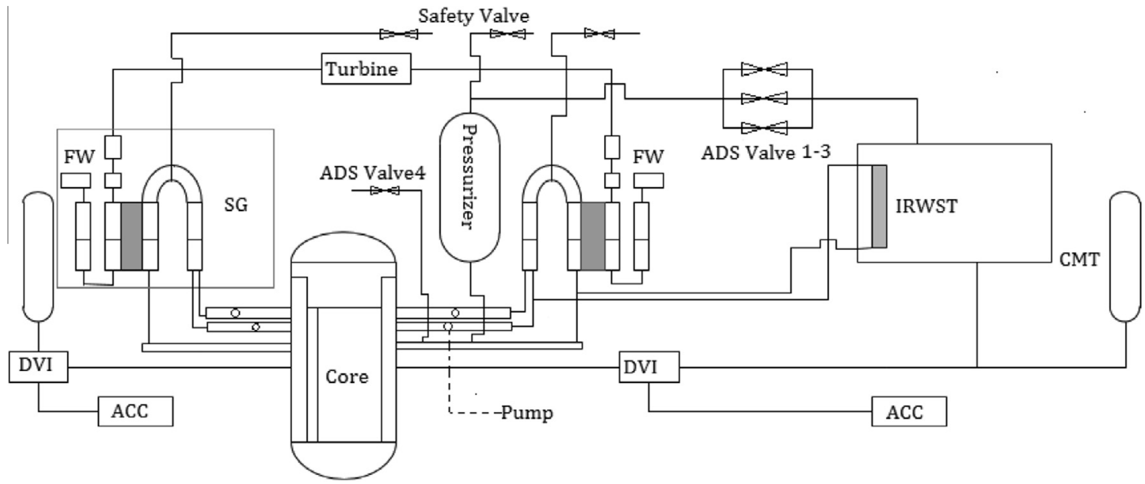

Fig. 1. Hydrodynamic nodalization of the AP1000 RCS.

the fission products releasing process and thermal hydraulic transient after accident occurs. Therefore, the source term analysis results calculated by these integral codes usually are reliable.

Rapid assessment methods are mainly applied in second-generation reactors in America, including the method proposed in NUREG/CR-6189 (Powers et al., 1995), the method recommended in RTM-96 (Mckenna et al., 1996) and the calculation method recommended in RASCAL (Ramsdell et al., 2012). For study on aerosol removal by natural processes in containment, the most accurate results among the ones obtained by these three methods are those obtained by the method mentioned in NUREG/CR-6189 (Zhao et al., 2015a). Therefore, the method mentioned in NUREG/CR-6189 is chosen to be applied in rapid assessment of aerosol removal by natural processes in this paper.

The rapid assessment method is proposed for the second-generation reactors. It needs further study whether it is applicable for the third-generation reactors, such as AP1000. As is known, structures in the containment of AP1000 are different from those of the second-generation reactors. And passive containment cooling system is applied in AP1000 nuclear power plant (Westinghouse Electric Company, 2003). Passive containment cooling system can change the temperature gradient in areas near the inner surface of containment which enhances steam condensation on the inner surface of containment wall, and therefore enhances thermophoresis and diffusiophoresis of aerosols. Besides, cooling of containment enhances air and steam convection in containment atmosphere, and therefore enhances aerosol deposition by gravitational settling (Zhao et al., 2015b). In addition, passive core makeup tank (CMT), accumulators (ACC), automatic depressurization system (ADS), in-containment refueling water storage tank (IRWST) and external reactor vessel cooling (ERVC) system are designed for AP1000 nuclear power plant (Westinghouse Electric Company, 2003). These designs will lead to the thermal hydraulic progress in reactor cooling system (RCS) during severe accident being different from that of second-generation reactors. Therefore, whether the rapid assessment method mentioned in NUREG/CR-6189 (Powers et al., 1995) is applicable for AP1000 nuclear plant reactor needs further verification. Firstly, three representative severe accidents, induced by LBLOCA, SBLOCA and SGTR, respectively, are chosen to study aerosol deposition and suspension in containment after severe accident in AP1000 nuclear power plant by integral severe accident analysis code MELCOR. Subsequently, the amount of aerosol removed by natural processes is obtained. The results are compared with those calculated by the rapid assessment method mentioned in NUREG/CR-6189 (Powers et al., 1995). Comparison of the results will verify the applicability of rapid assessment method for AP1000 reactor. The final analysis results will provide reference to method selection of source term assessment in nuclear emergency response after severe accident.

2. Calculation based on integral code MELCOR

2.1. Model of AP1000

Integral code MELCOR is used to establish the model of AP1000 nuclear power plant. This model couples the calculation between the thermal hydraulic and the transport and release process of the radioactive fission products, which simulates the whole process of severe accident in AP1000 reactor. In the model of AP1000 nuclear power plant, CMT, ACC, ADS, IRWST and ERVC system are modeled. As illustrated in Fig. 1, the AP1000 RCS is modeled by reactor pressure vessel with six nodes, two reactor coolant loops with four cold legs and two hot legs, four reactor coolant pumps, two steam generators with twelve nodes. And the turbine, ACC, CMT, pressurizer, direct vessel injection (DVI) lines, IRWST and feedwater system (FW) are respectively modeled by one node. As illustrated in Fig. 2, the core active region and

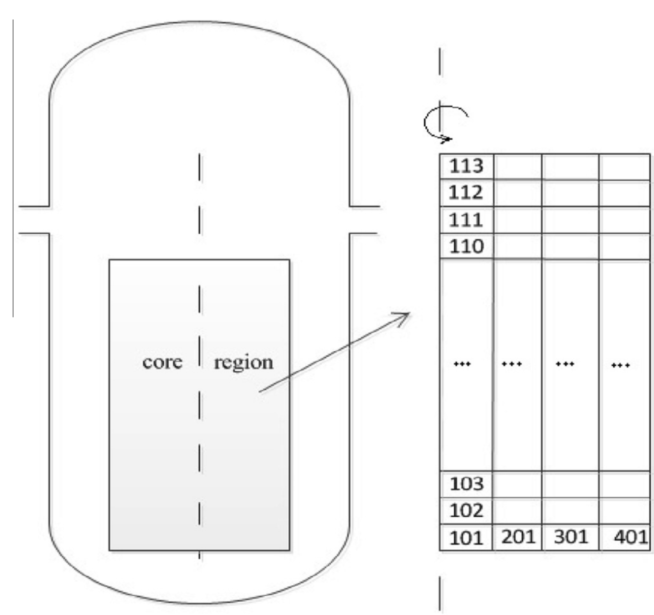

Fig. 2. Model of core active region and lower head.

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