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Aerosol Characterization in Containment Air during Severe Accident

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1. Introduction

Containment filtered venting system (CFVS) has been considered as an effective approach to prevent the containment failure due to over-pressurization and large release of radioactive materials to environment [1]. The basic idea is to vent the containment atmosphere in high pressure and high temperature containing radioactive aerosols through a filtration system. To ensure the reduction of the radioactive aerosol concentration and to guarantee the filter efficiency in accident scenarios with various conditions, it is essential to characterize the aerosols in the containment air.

This study is to investigate the aerosol size distribution and the concentration in containment air during the severe accident scenario by using numerical simulations. NAUA code was used to model the behavior of radioactive aerosol particles [2]. As input parameters for NAUA simulation, the data of the currently operating nuclear power plant (OPR-1000) was used [3] and conservative thermal hydraulic conditions were provided from the conservative simulation results [4]. For verification, the simulation results were compared with the data found in the literature.

2. Severe Accident Analysis

The accident scenario is chosen conservatively with respect to the containment pressurization [4]. Note that the term “conservative” is generally used in nuclear engineering community to imply the condition that is disadvantageous with respect to safety. Specifically in this study, conservative condition means the rapid containment pressurization. According to Ref. [4], the Station Black-Out (SBO) sequence with safety injection available 1 hour after reactor vessel failure is selected as the representative scenario. Main event timing is shown in Table I. Since the SBO accident initiated, the pressure and the temperature of the primary system (the water in reactor vessel and reactor coolant system) increases. As the pressure increases, the safety relief valve of the pressurizer is opened to discharge the steam into the containment atmosphere to reduce the pressure of the primary system. Due to continued cycling operation of the relief valves (discharging steam), the coolant is lost and, because there is no additional injection, the core is uncovered and damaged. Eventually, (volatile) radioactive materials in gap between cladding and fuel are released into the primary system and the containment atmosphere through pressurized relief valves or break point in the primary system (hotlet creep rupture). Due to insufficient heat removal, the uncovered core melts down to the lower head of reactor vessel and ultimately the reactor vessel fails. Then, the molten core (corium) is relocated to containment floor and interacts with the concrete interaction (MCCI). Meanwhile, the containment pressure continues to increase due to steam generation and MCCI. When the containment pressure reaches 5 bar, the CFVS is opened to vent the pressure.

Table I: Main event occurrence timing

EVENT	TIMING (HOUR)
SBO Accident Initiating	0
CORE UNCOVERED	1.94
START OF GAP RELEASE	2.58
HOTLEG CREEP RUPTURE	3.95
REACTOR VESSEL FAIL	7.09
FIRST CFVS OPENING	13.92

In Figure 1, the release rates of steam and aerosol into containment are compared. There can be seen the oscillation of steam release rate before hotleg creep rupture (3.95 hours) because of safety valve cycling. The most of aerosols are released at the time of cladding failure. Large spike also can be seen at the time of hotleg creep rupture which means the most of reactor coolant inventory poured into containment prior to the reactor vessel failure.

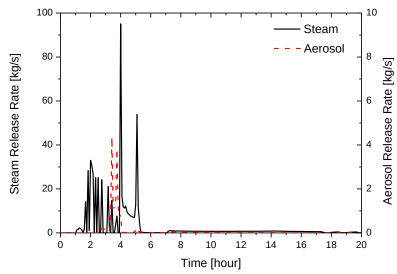

Figure 1. Steam/aerosol release rate to containment

3. Aerosol Dynamics Modeling

The severe accident analysis results are used as input data for NAUA simulation (e.g. steam and gas release rates via pressurizer safety relief valve, break points at hotleg and reactor vessel to containment atmosphere).

The size distribution of initially emitted particles was assumed to be log-normal; geometric mean diameter and geometric standard deviation (GSD) were assumed to be 0.15 μm and 1.56 during the early emission phase and, afterward, 0.8 μm and 1.46, respectively. Emission into the containment, growth due to Brownian and gravitational coagulation and water condensation, and removal by gravitational settling, diffusiophoresis, and turbulent diffusion were taken into account. To examine the effects of the uncertainties of the input parameters, a large set of sensitivity analysis was carried out with different mean size of emitted particles, wall temperature, and particle shape factor. The effects of CFVS operation were also investigated.

The main particle removal mechanism in the base case was gravitation settling. The operation of CFVS resulted in reduced particle concentration, mass median diameter (MMD), and GSD because aged larger particles were removed by CFVS causing the particle size distribution to be dominated by fresh smaller particles. The effect of diffusiophoresis was negligible compared to gravitational settling throughout the simulation period. The mass concentration, MMD, and GSD of airborne particles prior to the first operation of CFVS was 6.6 g/m^3, 2.4 μm, and 1.65, respectively.

Concentration and GSD of airborne particles decreased with increasing mean size of emitted particles because of selective removal of large particles by gravitational settling. When wall temperature was substantially (by 10℃) lower than air temperature, diffusiophoresis was the dominant particle removal mechanism, over gravitational settling, leading to lower particle concentration and mean size than those of the base case. For non-spherical particles with a high particle shape factor value, the rate of particle removal due to gravitational settling was lower than that of spherical particles, resulting in higher airborne particle concentration, MMD, and GSD. When the mean size of emitted particles was increased leaving the particle number unchanged (thus mimicking hygroscopic growth), particle number concentration and GSD in the containment decreased due to enhanced gravitational settling, while MMD increased. When the mean size of emitted particles was increased by a factor of 1.5 and 2, respectively, particle number concentration decreased by 8% and 20%, respectively, and MMD increased by 19% and 37%, respectively, prior to the first operation of CFVS.

4. Aerosol Size Distribution

Filtration efficiency and decontamination processes are mainly dependent on particle size. Therefore, many experimental studies have been conducted to understand the aerosol behavior and the characteristics by assuming a distribution of aerosol size [5]. Those are reviewed for the purpose of comparisons in Table II. The distribution is mostly assumed to be log-normal and AMMD (aerodynamic mass median diameter) and GSD are used as parameters. When particle density is about 4, which is the case for many metal-containing radioactive aerosol particles, MMD is about half AMMD. Note that the most of the size distributions in previous studies and the simulation results in this study are within the uncertainty of the analysis.

Table II: Particle size distribution parameters reported in previous experiments

Experiment	Size Distribution
Phebus FPT0	AMMD 2.4~3.5 μm / GSD 2.0
Phebus FPT1	AMMD 3.5~4 μm / GSD 2.0
Phebus FPT3	AMMD 3.35 μm / GSD 1.5
ACE-C	A few μm
DEMONA	~ 1 μm
MARVIKEN-V	Ag-based: ~ 1 μm / Mn-based: ~0.1 μm
VANAM	MMD 0.86 μm / GSD 1.8
AHMED	AMMD 2.1~2.7 μm / GSD 1.6~1.7
VICTORIA	AMMD 2.3 μm / GSD 1.9

4. Conclusions

Aerosol in containment air during severe accident is modeled by using NAUA code. The aerosol characteristics are calculated and variations due to some parameters are investigated. For verification, the main results are compared with the information of the previous works. The simulation results in this study for particle size distribution in containment air during severe accident were in general agreement with previously reported measurements. The simulation results and findings would be useful data for prototypic CFVS design and for planning further experimental studies.

Acknowledgements

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REFERENCES

[1] Safety Inspection Group, "Domestic NPP Safety Inspection Result Report", KINS/AR-916, Korea Institute of Nuclear Safety, 2011.

[2] Bunz, H., Koyro, M. and Schoeck, W., NAUA-MOD5 and NAUA-MOD5-M - Two Computer Codes for the Description of the Aerosol Behaviour in the Containment System of a LWR after a Core Melt Accident, KfK-4278, Kernforschungszentrum, Karlsruhe, 1987.

[3] www.kepco-enc.com/English/sub.asp?Mcode=B010020

[4] Youngsuk Bang, et al., “Severe Accident Analysis for Containment Filtered Venting System Design”, Transactions of the Korean Nuclear Society Spring Meeting, Jeju, Korea, May 29-30, 2014

[5] Hans-Josef Allelein et al., State-of-the-Art Report on Nuclear Aerosols, Nuclear Energy Agency, Committee on the Safety of Nuclear Installations, NEA/CSNI/R(2009)5, 2009