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Benchmark Analysis of MAAP and CONTAIN Against the ISP-35 Experimental Data

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1. Introduction

NUPEC, under the sponsorship of OECD/CSNI, conducted five experiments using a 1/4 scale model containment to investigate fluid mixing phenomena and thermal-hydraulic behavior under severe accident conditions. Among these, Test M-7-1 characterized by helium and steam injection from the lower region and spray operation from the upper region was designated as International Standard Problem (ISP-35) and has since served as a benchmark for code validation worldwide. Accurate simulation of fluid behavior within the containment is one of the key validation challenges for such codes. In this study, ISP-35 was simulated using both CONTAIN and MAAP, and the predictive capabilities of the two codes regarding fluid mixing and thermal-hydraulic behavior were compared and evaluated. Based on the results, the modeling characteristics and limitations of each code were analyzed.

2. Experimental Description and Code Models

This section outlines the ISP-35 test program, including experimental setup and procedures. It introduces the containment nodalization and analysis codes used for simulating severe accident phenomena.

2.1 ISP-35 test overview

The NUPEC hydrogen mixing test facility is a 1/4 linearly scaled model of a large containment vessel for a pressurized water reactor (PWR), featuring a cylindrical structure with a height of 17.4 m and a diameter of 10.8 m. It consists of 25 compartments arranged in three levels, with a total free volume of 1310 m³ [1]. The compartments are separated by steel walls and designed to simulate complex thermal-hydraulic behaviors through four circulation loops. The compartment and node layout of the test facility is illustrated in the Fig. 1. The NUPEC experiments included in the ISP-35 program were conducted according to the following procedure. Approximately 3.5 hours before the start of the experiment, steam was injected into compartment #22 node, which corresponds to the pressurizer compartment, to preheat the containment vessel, and this preheating continued until about 7 minutes prior to the test start. Then, approximately 1 minute before the experiment start, spray water was initiated through 21 nozzles located in compartment #25 node, the dome region, and continued for 30 minutes after the test start. Simultaneously, at the beginning of the experiment, a mixture of helium and steam was injected into compartment #8 node, representing the steam generator compartment, for a duration of 30 minutes. The mass flow rates of the injected steam, helium, and the spray flow rate are summarized in the Fig. 2, while the initial conditions and key test parameters of the experiment are tabulated by Table I, Table II [2].

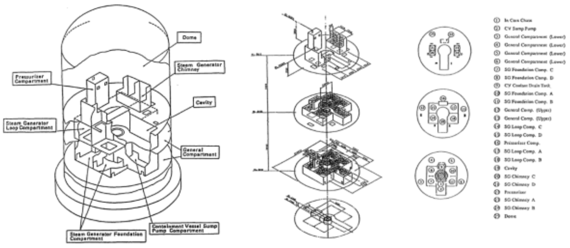

Fig. 1. Schematic of the NUPEC facility and model containment

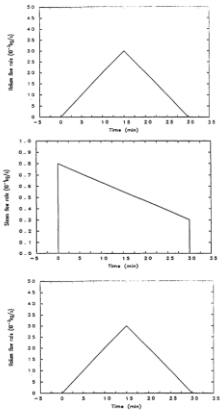

Fig. 2. Condition of helium, steam, and spray flow rate for test M-7-1

Table I: Initial conditions for the Test M-7-1

Item	Value
Containment Dome Pressure	139.7 kPa
Containment Dome Temperature	66.4 ℃
Containment Humidity	100 %
Composition of Gas	Steam
Drain Tank Water Temperature	40 ℃
Outer Atmospheric Temperature	11 ℃

Table II: Operating conditions for the Test M-7-1

Item	Value
He/Steam Injection	
Helium Flow Rate	0.0 - 0.03 - 0.0 kg/s
Steam Flow Rate	0.08 - 0.03 kg/s
Helium Supply Temperature	14 ℃
Steam Supply Temperature	165 ℃ (Saturated)
Duration of Injection	30 min
Location of Injection	S/G Foundation Comp. (No.8)
Spray Water Injection	
Total Spray Flow rate	19.4 kg/s (70 ㎥/h)
Spray Water Temperature	40 ℃
Duration of Spray Injection	30 min
Average Diameter of Droplet	0.75 mm
Number of Nozzles	21
Location of Injection	Dome Comp. (No.25)

2.2 Containment nodalization

The containment nodalization was developed based on the NUPEC experimental facility configuration, dividing the containment into 25 compartments represented by 25 thermal hydraulic nodes, with 66 flow paths (junctions) connecting them to model gas and aerosol transport. Additionally, 199 slab type heat structures were modeled to account for heat conduction through walls, floors, and internal structures, thereby accurately representing the thermal sink effects during the test. The nodalization scheme, including node connectivity and flow path locations, is illustrated in Fig. 3. Detailed node specifications such as height, free volume, cross sectional area, and elevation are based on the OECD/CSNI FINAL COMPARISON REPORT ON ISP-35 [2] and summarized in Table III. This modeling approach ensures consistency with the physical layout of the 1/4 scale containment and supports accurate simulation of stratification, mixing, and spray induced convection.

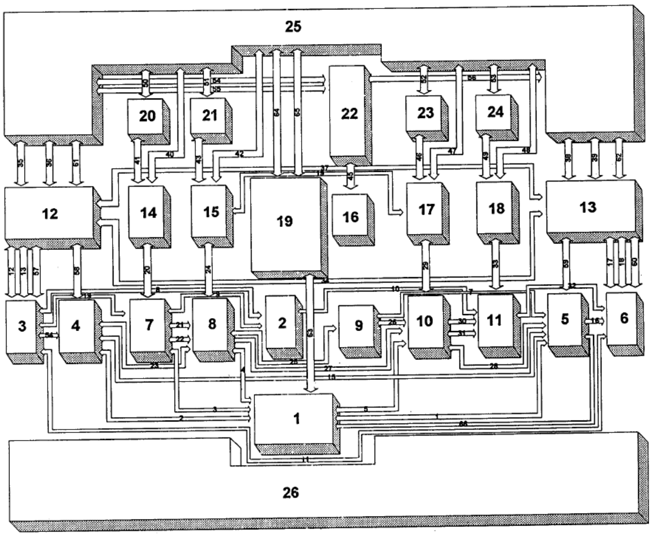

Fig. 3. Nodalization for the model containment

Table III: Compartment node description for the model containment

Node	Compartment Name	Free Volume (m^3)	Elevation (m)	Height (m)
1	ICI Chase	5.95	2.097	3.316
2	CV Sump Pump	14.95	3.200	2.213
3	Lower General Compartment	28.91	3.200	2.213
4	Lower General Compartment	32.84	3.200	2.213
5	Lower General Compartment	32.84	3.200	2.213
6	Lower General Compartment	28.91	3.200	2.213
7	SG Foundation Compartment C	10.80	3.200	2.213
8	SG Foundation Compartment D	12.66	3.200	2.213
9	CV Coolant Drain Tank	3.74	3.200	2.563
10	SG Foundation Compartment A	12.66	3.200	2.213
11	SG Foundation Compartment B	10.80	3.200	2.213
12	Upper General Compartment	53.05	5.425	1.888
13	Upper General Compartment	53.05	5.425	1.888
14	SG Loop Comp. C	9.22	5.425	1.888
15	SG Loop Comp. D	10.80	5.425	1.888
16	Pressurizer Comp.	2.14	5.775	1.463
17	SG Loop Comp. A	10.80	5.425	1.888
18	SG Loop Comp. B	9.22	5.425	1.888
19	Cavity	24.14	5.425	1.900
20	SG Chimney C	2.01	7.325	1.371
21	SG Chimney D	2.016	7.325	1.371
22	Pressurizer	5.44	7.250	3.725
23	SG Chimney A	2.016	7.325	1.371
24	SG Chimney B	2.01	7.325	1.371
25	Dome	931.3	7.325	12.1175

2.3 Code description

The CONTAIN code is a containment-specific analysis tool developed by Sandia National Laboratories under the sponsorship of the U.S. Nuclear Regulatory Commission (USNRC) to predict the physical, chemical, and radiological conditions inside nuclear reactor containments during accidents. It is capable of simulating thermal-hydraulic behavior, gas mixing, and spray effects, and has been used as a key tool in the USNRC's Severe Accident Research Program [3].

The MAAP code, developed in the early 1980s by Fauske & Associates, Inc. (FAI), is a severe accident analysis code currently owned and distributed by the Electric Power Research Institute (EPRI). It treats the full spectrum of important phenomena that could occur during an accident, simultaneously modeling those that relate to the thermal-hydraulics and to the fission products. It simultaneously models the primary system and the containment and reactor/auxiliary building. MAAP is designed to account for plant signals, signal delays and component strokes, and for equipment opening or actuation times [4].

3. Analysis Results

Helium concentration analysis shows that most compartments, including the dome, reach an equilibrium concentration of approximately 12%, consistent with experimental data. However, in compartment #8 the helium injection location the peak concentration is underpredicted compared to the experiment, a trend also observed in international benchmark studies. This discrepancy arises because helium forms a buoyant plume under low flow resistance, whereas lumped-parameter codes such as MAAP and CONTAIN assume uniform gas distribution within each compartment. To accurately predict helium behavior near the injection point and along the primary rising path, application of 3D codes or multi-node and junction model capable of accounting for counter current is recommended.

The baseline analysis using a 25 node containment model revealed discrepancies between experimental data and predictions from severe accident codes. These differences are primarily attributed to variations in flow loss coefficients, spray modeling approaches, and inadequate flow development in dead-end compartments. In particular, compartment #16 node, representing the lower region of the pressurizer compartment, is connected to the upper compartment #22 node via a single flow path, resulting in a dead-end configuration that hinders natural convection and gas transport. To address this limitation, a 2 stack modeling approach was implemented by splitting compartment #16 node into upper and lower nodes, with independent assignments of volume, flow area, and heat structure. Furthermore, a comparative assessment of flow loss coefficients and spray modeling strategies across different codes was conducted to enhance the reliability of the analysis.

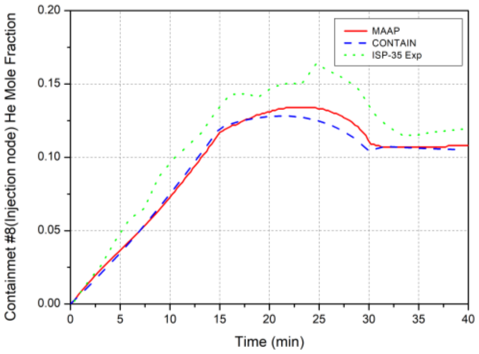

Fig. 4. Helium mole fraction in compartment #8 – the helium injection location

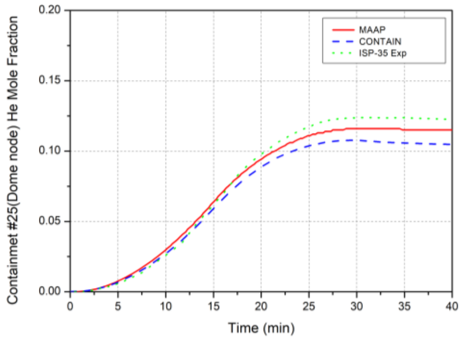

Fig. 5 . Helium mole fraction at the dome node

3. Conclusions

The present study demonstrates that MAAP and CONTAIN generally predict the overall helium concentration behavior of the ISP-35 experiment reasonably well; however, discrepancies are observed in local phenomena, particularly at the helium injection point and in compartments with dead-end configurations. These differences are attributed to variations in flow loss coefficients, spray modeling approaches, and the assumption of uniform mixing inherent in lumped-parameter codes. In dead-end compartments, inadequate flow development leads to challenges in accurately predicting gas transport. To address this limitation, a 2 stack modeling approach was applied, and the need for multi-node and junction model capable of accounting for counter current was highlighted.

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