The ROSA-SA Project on Containment Thermal Hydraulics

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- Current research activities
  - The CIGMA facility for integral testing
  - CFD analyses on
    - Erosion of density stratified layer by impinging jet
    - Condensation with non-condensables
- Summary
Background and Objectives

- The Fukushima Dai-Ichi NPS accident re-emphasized the importance of severe accident research in Japan.
- JAEA started the project on the containment thermal hydraulics related to:
  - Over-temperature Containment Damage
  - Hydrogen Risk
  - Aerosol Migration

The ROSA-SA(Severe Accident) project

- ROSA: Rig of Safety Assessment
- A series of ROSA projects have focused on T/H issues, e.g.,
  - ROSA-III for BWR LOCA, ROSA-IV for PWR Small Break LOCA, etc.
- Consists of integral tests, separate effects tests and analytical study for the LP and CFD codes

Objectives

- Obtain better physical understanding on the T/H phenomena
- Validate and improve analysis methods for the LP and CFD codes
Technical Issues 1/2

- Over-temperature Containment Failure
  - Interaction of high-temp. gas flow and structure

- Hydrogen Risk
  - Thermal hydraulics of hydrogen-mixed gases
    SETH, SETH2, HYMERES, ISP-47 (stratification not predicted), PANDA, MISTRA, THAI, ....

- Aerosol Transport
  - Pool scrubbing
    relation with two-phase flow behavior, etc.
  - Behavior in large space
    water condensation on aerosol particles, etc.

- Effects on above phenomena of T/H behavior:
  - natural circulation, density stratification, jet, plume, cooling (spray, fan cooler, outer surface), mixing, phase change, heat transfer, mass transfer, etc.
  - scaling laws between test and reactor conditions
Technical Issues 2/2

- Effectiveness of Accident Management (AM) Measures
  - Spray cooling, Fan cooler, Containment outer surface cooling
  - Containment vent, Nitrogen substitution
  - Performance outside the design conditions (e.g., low flow spray)

- Validation and improvement of prediction models
  - Lumped parameter (LP) codes such as MELCOR, RELAP5
  - CFD codes
    - To be used for technical support to the system analysis code being developed by Nuclear Regulation Authority (NRA), Japan

- Measurement technique
  - Detailed data for CFD model validation including distribution of gas molar fraction, velocity, turbulence, void fraction, etc.
Current Research Activities

1. Design of large-scale containment test facility CIGMA
2. CFD analysis on erosion of density stratified layer by impinging vertical jet
   - Turbulence model improvement for the RANS analysis based on the LES analysis
   - OECD/NEA PANDA benchmark test analysis
3. CFD analysis on steam condensation with noncondensables
1. Large-Scale Containment Test Facility

Integral Test Facility: CIGMA
- Containment InteGral Measurement Apparatus

Characteristics
- High design temperature & pressure
  - 573~773 K depending on pressure for boundary wall
  - Up to 973K for gas injection nozzle
  - Up to 1.5 MPa for pressure
- Instrumentation with high space resolution & CFD-grade
  - Temperature (fluid 380, wall 240)
  - Gas sampling for QMS (118)
  - Velocity measurement using LDV, PIV through large windows of 650mm dia.
- Testing on AM measures
  - Outer surface cooling
  - Vent, nitrogen substitution etc.

First test scheduled in 2015

QMS: Quadrupole Mass Spectrometer
LDV: Laser-Doppler Velocimetry
PIV: Particle Image Velocimetry

The CIGMA facility is developed under the auspices of the Nuclear Regulation Authority (NRA), Japan.
Planned Experiments at CIGMA

- Erosion of density stratification due to Helium/Steam jet
- Effects of outer surface cooling on stratification, natural circulation
- Wall temperature behavior responding to impingement of high temperature jet
- Effects of internal structure, etc.
## Comparison with Existing Facilities

- High design temperature and pressure
- Instrumentation with high space resolution

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<th>MISTRA(^3)</th>
<th>PANDA(^1,2)</th>
<th>CIGMA</th>
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**Notes**

1. two vessel + interconnection pipe
2. 573~773 K for boundary wall depending on pressure, and up to 973K at gas injection nozzle

References

Comparison with previous experiment conditions

- Pressure & Temperature
  - OECD/SETH-2, for example,
    Investigate hydrogen stratification break-up induced by heat and mass sources or by the actuation of a system (e.g. spray, ...)
    - PANDA: $P < 2.6$ bar, $T < 130^\circ C$, $T_{inj} < 150^\circ C$
    - MISTRA: $P < 1.1$ bar, $T < 99^\circ C$, $T_{inj} < 148^\circ C$

- CIGMA tests will enlarge validation-range for models
  - Empirical correlations used in codes
    - Turbulent models, Similarity laws, etc.
      will be validated under enlarged T/H conditions
2. Erosion of density stratified layer by jet flow

- RANS turbulence model improvement
  - Analysis using OpenFOAM for a containment
  - Model improved to include effects of jet-stagnation and buoyant
  - Compared with LES analyses
    - Using fine meshing, LES is believed to be more accurate.

- Result
  - Erosion rates much larger for RANS than LES
  - Modified model agrees well with LES.

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References in this page

PANDA Benchmark Test Analysis

- OECD/NEA & PSI sponsored benchmark test
- Vertical jet effects on density stratified layer using PANDA
- 19 organizations
  - Test in 2013
  - Presentation CFD4NRS-5, 2014
- Post-test analysis using the improved RANS model agree well with the data

References in this page
1. S. Abe et. al., JAEA approach OECD/NEA PANDA Benchmark, Erosion of a stratified layer by a buoyant jet in a large volume, presented in the poster session at the CFD4NRS-5, 2014
2. S. Abe et. al., RANS analyses on erosion behavior of density stratification consisted of helium-air mixture gas by a low momentum vertical buoyant jet in the PANDA test facility, the third International Benchmark exercise (IBE-3), submitted to Nucl. Eng. Des.

Note: reprinted from Ref.1.
Future Plans for Stratified Layer Analysis

- Effects of mesh geometry*
  - Already identified
  - Hexahedral mesh recommended in some CFD Best Practice Guidelines
  - Several merits of tetrahedral mesh
  - Investigate a numerical scheme

- Models validation and improvement using exp. data from CIGMA and small-scale test facilities

* The use of the hexahedral mesh was recommended by Dr. Studer of CEA to Dr. Abe, one of Authors, when he visited the CEA Saclay.
3. Wall condensation with noncondensables

- CFD Analysis of test data in literature
  - Condensation of steam-air mixture on horizontal wall
  - OpenFOAM: open source CFD code
  - Analysis models
    - Condensation rate determined by diffusion of steam
    - Thermodynamic equilibrium, No phase change
    - Liquid film not modeled
    - Liquid surface temp. given as a boundary condition
  - Results
    - Distribution predicted well for fluid velocity, but not for temperature, which suggests
      - Requirement in model improvement?
      - Problem in measurement?
- Planned experiments at JAEA
  - Atmospheric pressure
  - Slope changed: horizontal to vertical


Note: The figures showing comparisons are reprinted from Ref. 1.
Summary

- The ROSA-SA project started in 2013 for research on containment thermal hydraulics related to:
  - Containment over-temperature damage
  - Hydrogen risk
  - Aerosol and gaseous FP transport

- The project has focused on:
  - Development of a large-scale containment experiment facility CIGMA & separate effects test facilities for condensation, density stratified layer, pool scrubbing, instrumentation testing, etc
  - CFD analyses of literature data to identify technical issues and improve analysis models

- The CIGMA tests will start in 2015

Acknowledgments: The CIGMA facility is developed under the auspices of the Nuclear Regulation Authority (NRA), Japan. We appreciate the technical discussions with the NRA staffs.