RIC 2010
Thermal Hydraulics & Severe Accident Code Development & Application

Ghani Zigh
USNRC/RES
3/11/2010

# Computational Fluid Dynamics (CFD) Best Practice Guidelines in Nuclear Reactor Safety (NRS) Applications

2

## Outline

- ❑ Introduction
- ❑ Source of Errors and Uncertainty
- ❑ Validation and Sensitivity Tests of CFD Models
- ❑ NRC Activities With OECD/CSNI CFD Writing Groups
- ❑ Model Error Examples (turbulence)
  - ➢ Pacific Sierra Nuclear VSC17 (Validation + Sensitivity)
  - ➢ Generic Vertical Fuel Storage Cask (Sensitivity Analysis)

3

## Introduction

- Use of CFD for the solution of thermal/hydraulic problems in Nuclear Reactor Safety (NRS) applications is growing:
  - The availability of robust CFD software
  - High speed computing
- Growing awareness that CFD can be difficult to apply reliably
- CFD is a knowledge-based activity despite the availability of CFD software
- Initiatives to structure existing knowledge in the form of Best Practice Guidelines (ERCOFTAC, QNET-CFD, OECD/CSNI/CFD/WG
- USNRC is looking for the best way to implement and include BPG for application reviews.

4

## Sources of Errors and Uncertainties

- There is no universal classification of errors, but ERCOFTAC BPG adopts the following seven different source of errors and uncertainties:

**Error**: a recognizable deficiency that is not due to the lack of knowledge

**Uncertainty**: a potential deficiency that is due to lack of knowledge.

- Model errors and uncertainties:
  - Difference between the real flow and the exact solution of the modeled equation
  - Exact governing equation replaced with a physical model that may not be good model of reality.
    - e.g. Viscous Flow Models (most published),
    - Potential Flow (inviscid)

5

## Sources of Errors and Uncertainties (Cont)

- Discretization (numerical) errors (spatial and temporal):
  - Difference between exact solution and discretized equations
  - Discretized equations has a limited resolution in time and space.
  - The greater the number of cells, the closer the results to the exact solution
- Iteration (convergence) errors:
  - Difference between fully converged solution and not converged
  - Incomplete iterative process lead to errors.
- Round-off errors:
  - A computer solves the equation with a finite number of digit.
  - Arithmetic operations are below the available accuracy

6

## Sources of Errors and Uncertainties (Cont)

- Application uncertainties:
  - Uncertainty in the precise geometry, uncertainty in BC, steady vs. transient.
- User errors:
  - Inadequate use of the CFD code by the user e.g.
    - oversimplification of the problem
    - mistakes and carelessness of the user
  - Management errors when inexperienced users are given complex application
- Code errors
  Bugs in the software

7

## Validation and Sensitivity Tests of CFD Models

- Validation: To test if the model accurately represents reality
- Verification: To test if the code solves the equations accurately

### Guidelines on Validation

- It is not possible to validate the entire code
- Validate a CFD code before using it for a particular application
- Use test data for a similar application with similar flow structures
- Check carefully the quality and accuracy of data used for validation
- Experiment should reflect the relevant boundary and initial conditions
- Data should include quantities that are needed for CFD validation
- Close collaboration between experimentalists and CFD analysts

8

## NRC Activities with OECD/CSNI CFD Writing Groups

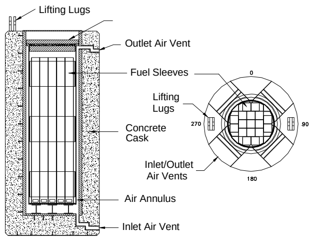
- Exploratory meeting of CFD experts led to an action plan (May 2002)
  **Action Plan: Set Up 3 Writing Groups under the sponsorship of OECD/NEA**
- WG1: Provide a set of guidelines for the application of CFD to NRS problems
  "Best Practice Guidelines for the use of CFD in Nuclear Reactor Safety Applications,"
  CSNI Report NEA/CSNI/R(2007)5 (Concluded: December 2006) ML071581053
- WG2: Evaluate the existing CFD assessment basis, and identify gaps to be filled.
  "Assessment of CFD Codes for Nuclear Reactor Safety Problems"
  CSNI Report NEA/CSNI/R(2007)13 (Concluded: December 2007) ML081070381
- WG3: Summarize the extensions needed to CFD codes for two-phase NRS problems
  (To be concluded: December 2010)
- USNRC is in process of putting a NUREG (CFD BPG for Dry Cask Application)
- USNRC is sponsoring CFD4NRS-3 Conference/Workshop (September 14-16, 2010)

9

## Model Error Example (turbulence)

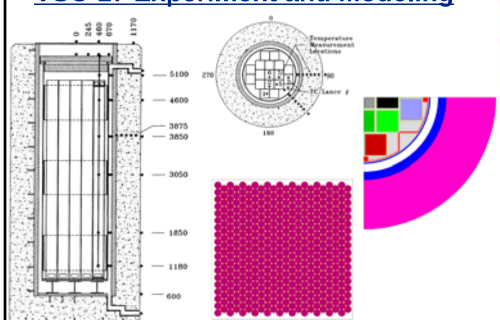
### Dry Cask Validation

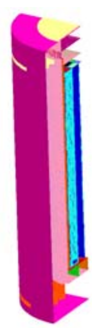
- ❑ VSC-17 data, collected by INEEL was used
- ❑ Similar flow structure as the casks presented to NRC for certification






## VSC-17 Experiment and Modeling





## VSC-17 Modeling

- ❑ Inert gas (He) inside the canister (closed system). It is laminar based on Ra.
- ❑ Air flows outside to cool the canister (**Pressure Boundaries were used**)
- ❑ Both are Buoyancy driven flow
- ❑ **Regime of the flow** inside and outside is very important. (PCT)
- ❑ Different turbulence models (sensitivity analysis) were tried including:
  - ➢ Low Reynolds std k- $\varepsilon$ : requires fine mesh near the wall ($y^+$ ~1)
  - ➢ Transitional k- $\omega$ SST: requires fine mesh near the wall ($y^+$ ~1)
  - ➢ Standard k- $\varepsilon$ : requires a mesh near the wall ($y^+$ ~ 30), std wall functions used to bridge the wall to the fully turbulent core
  - ➢ Laminar flow regime: requires fine mesh.

## VSC-17 Modeling (Cont)

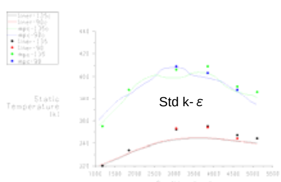
- Literature search showed that we may be dealing with laminar.
- Earlier applications used std k- ε to model turbulence in both the flow of Helium and air.
- 14.9 kW of heat decay
- Consolidated Fuel (410 rods)
- Grid independent solution was found first (BPG).

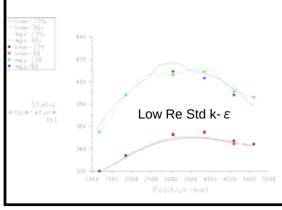
13

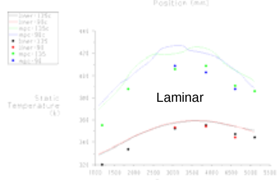
## VSC-17 Results

**Liner and MPC Walls Temperature**

- Different turbulence Models in the air channel
- Laminar regime inside the canister (he flow)

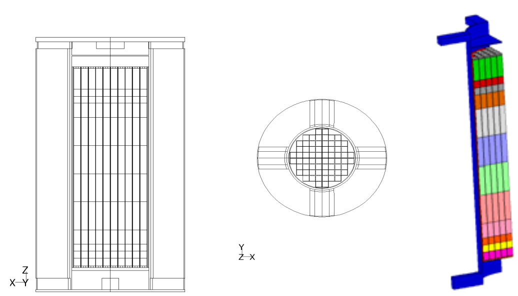



14

## Generic Vertical Fuel Storage Cask




15

## Generic Vertical Fuel Storage Cask Results

| Turbulence Model in Air Passage | Turbulence Model Inside MPC | Peak Clad Temperature (Kelvin) | Air Mass Flow Rate (kg/s) | Heat Absorbed by air (Watts) | Air Exit Temperature (Kelvin) |
|---|---|---|---|---|---|
| Laminar | Laminar | 718 | 0.292 | 21,032 | 371 |
| Transitional k-$\omega$ | Laminar | 704 | 0.33 | 22,532 | 367 |
| Low Re k-$\varepsilon$ | Laminar | 702 | 0.34 | 22,915 | 367 |
| Std k-$\varepsilon$ | Laminar | 666 | 0.344 | 25,705 | 370 |
| Std k-$\varepsilon$ | Std k-$\varepsilon$ | 658 | 0.346 | 25,760 | 369 |

$(PCT)_{Limit}$ = 673 K

16

## Summary

- Validate your CFD model to ensure that the new model is applicable with confidence.
- The influence of the assumptions and simplifications should be tested with a sensitivity analysis. (Be Skeptical)
- Modeling errors are the most difficult to avoid; depends on the available CFD package and the experience of the user. (QA-QC Procedures)
- There is strong interaction between the different types of errors (i.e. modeling errors and discretization errors).
- USNRC is part of few Organization's CFD BPG Writing Groups and in process of finding a best way to include BPG in application reviews.

17

## Validation and sensitivity tests of CFD models

- Validation: To test if the model accurately represents reality
- Verification: To test if the code solves the equations accurately
- Calibration: To test the ability of the code to predict global quantities of interest for specific geometry.

### Guidelines on Validation

- It is not possible to validate the entire code
- Validate a CFD code before using it for a particular application
- Use test data for a similar application with similar flow structures
- Check carefully the quality and accuracy of data used for validation
- The experiment should reflect the relevant boundary and initial conditions
- Data that are sensitive to boundary conditions should be reported
- The data should include quantities that are needed for CFD validation
- Close collaboration between experimentalists and CFD analysts

18