RIC 2010
Thermal Hydraulics & Severe Accident Code Development & Application

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

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)

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.

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)

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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

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

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

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)

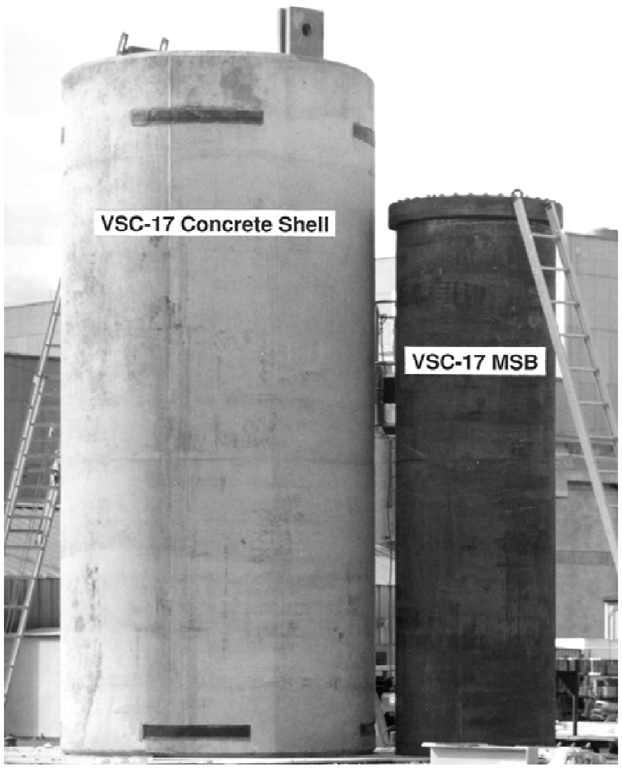
- ❑ USNRC is in process of putting a NUREG (CFD BPG for Dry Cask Application)

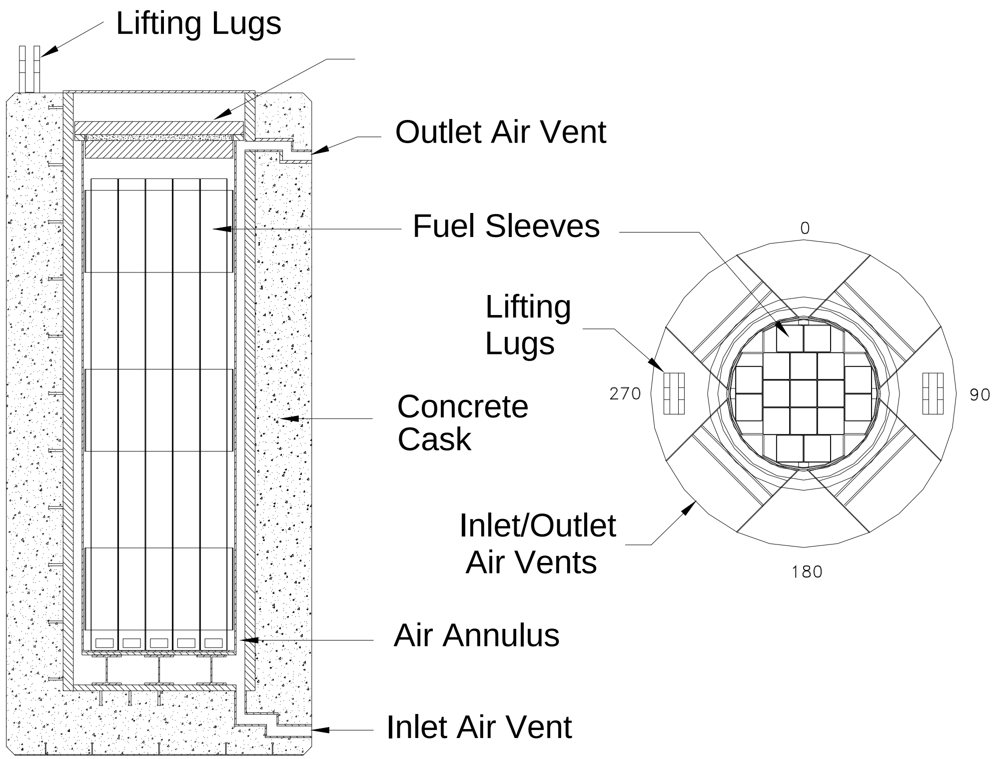
- ❑ USNRC is sponsoring CFD4NRS-3 Conference/Workshop (September 14-16, 2010)

Model Error Example (turbulence)

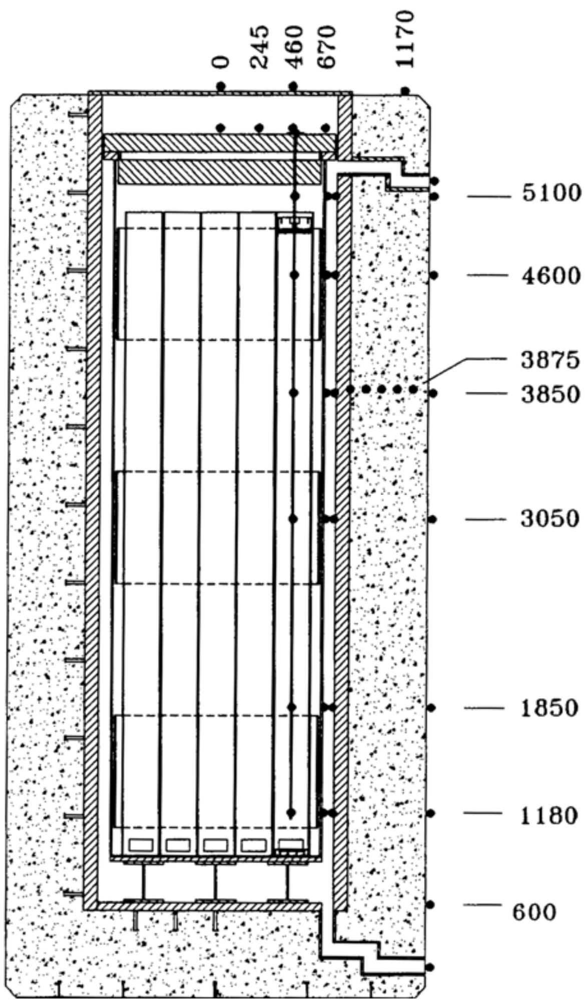
Dry Cask Validation

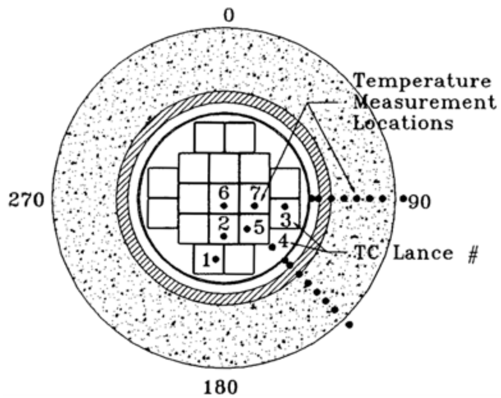
- ❑ VSC-17 data, collected by INEEL was used
- ❑ Similar flow structure as the casks presented to NRC for certification

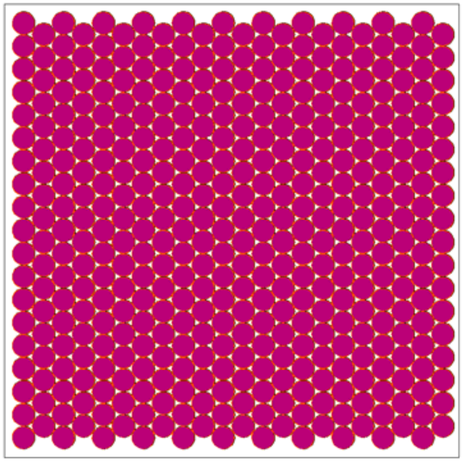


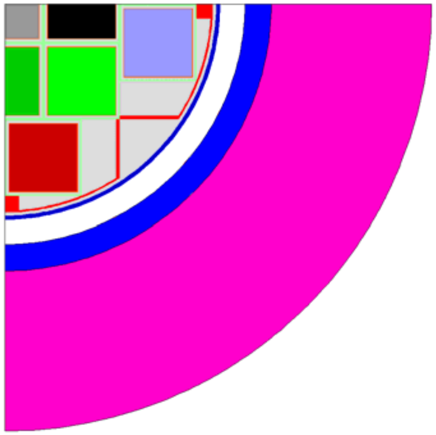


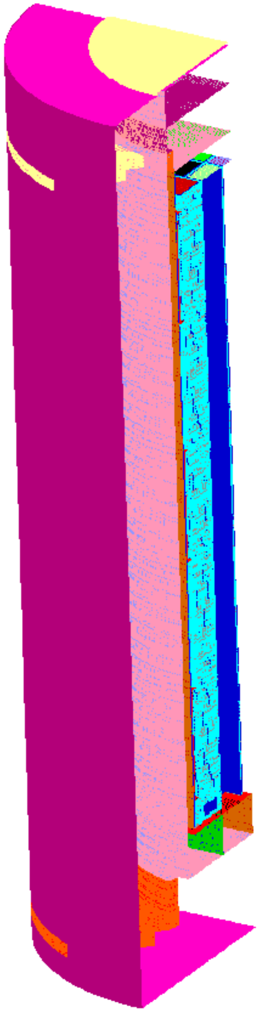
VSC-17 Experiment and Modeling











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-ε : requires fine mesh near the wall (y^+ ~1)
  - ➢ Transitional k-ω SST: requires fine mesh near the wall (y^+ ~1)
  - ➢ Standard k-ε : 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)

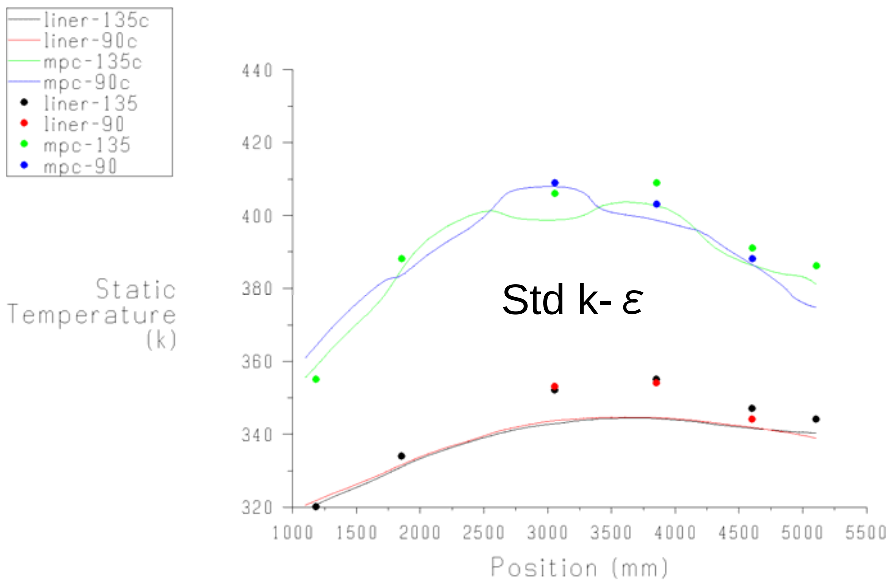
- Literature search showed that we may be dealing with laminar.
- Earlier applications used std k- ε to model turbulence in both the flow of Helium and air.
- 14.9 kW of heat decay
- Consolidated Fuel (410 rods)
- Grid independent solution was found first (BPG).

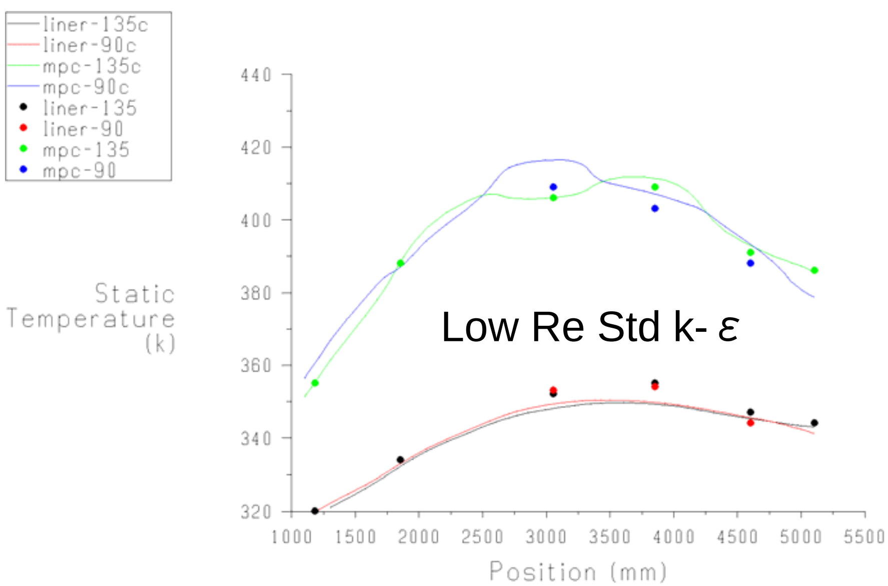
Liner and MPC Walls Temperature

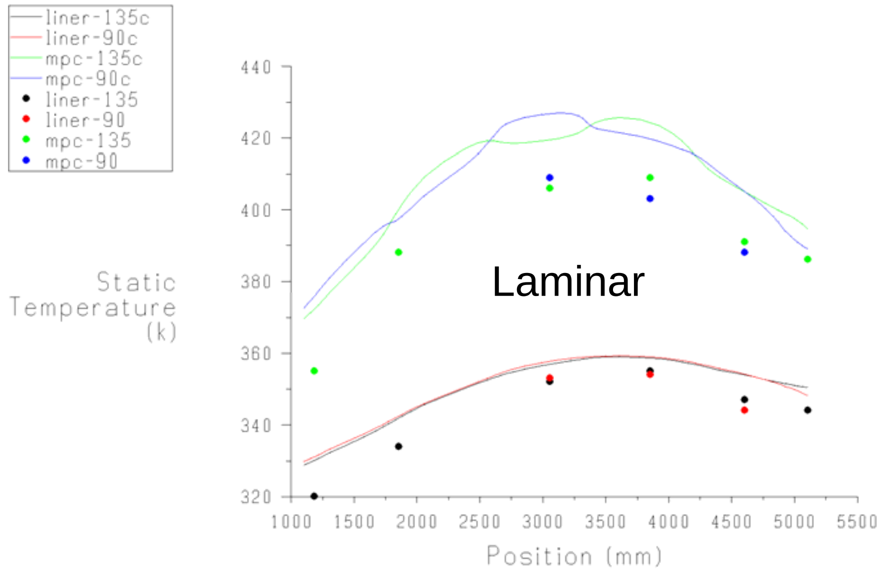
VSC-17 Results

- Different turbulence Models in the air channel

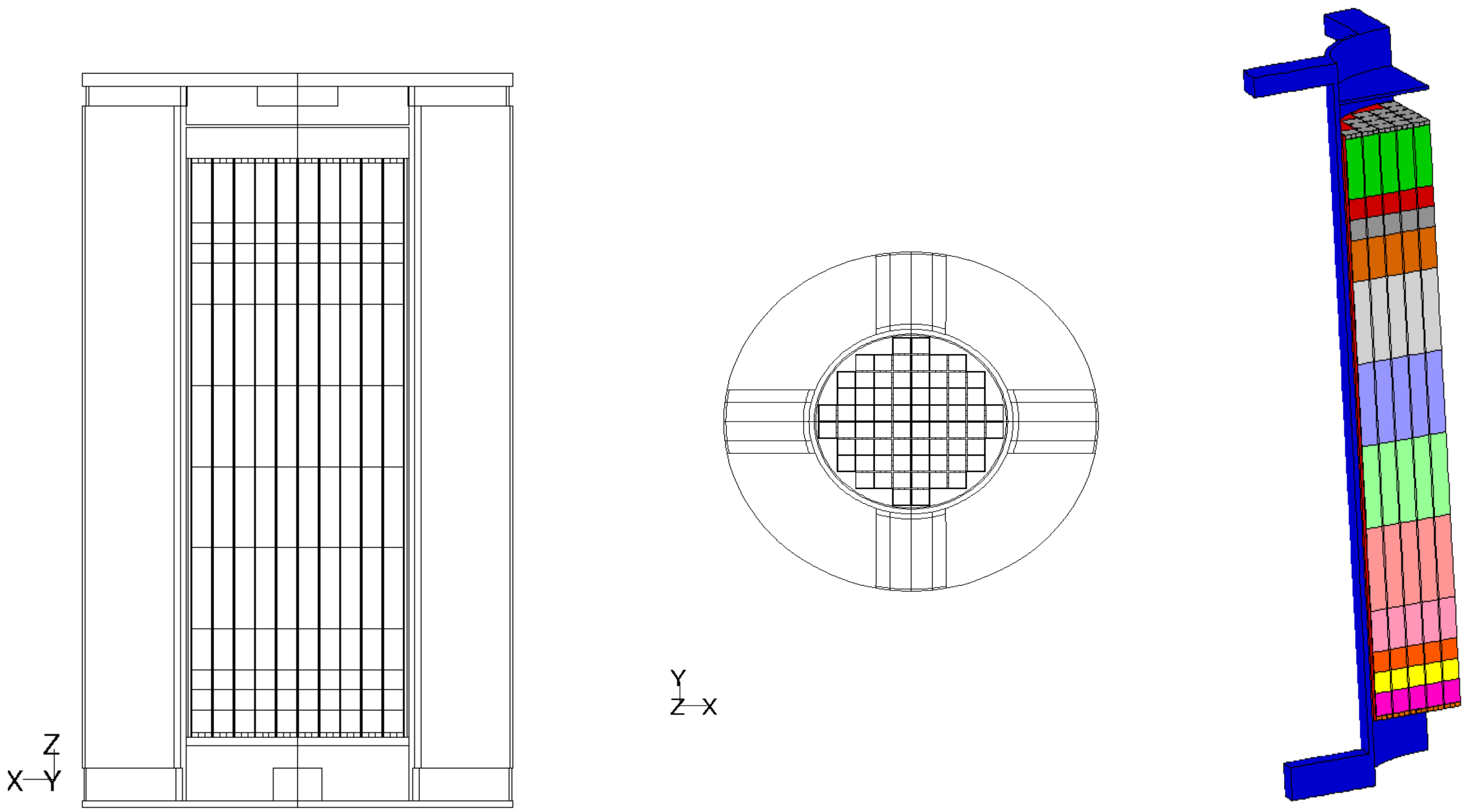
- Laminar regime inside the canister (he flow)







Generic Vertical Fuel Storage Cask



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- ω	Laminar	704	0.33	22,532	367
Low Re k- ε	Laminar	702	0.34	22,915	367
Std k- ε	Laminar	666	0.344	25,705	370
Std k- ε	Std k- ε	658	0.346	25,760	369

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

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.

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