Best Practice Guidelines for the Use of CFD in Dry Cask Applications

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Introduction

- NRC's technical review of dry cask designs is performed in accordance with 10 CFR Part 72 and the Standard Review Plans (SRPs)
- A thermal review is performed to ensure that the cask and fuel material temperatures of the dry cask storage system will remain within the allowable limits for normal, off-normal, and accident conditions
- Applications have increasingly used computational fluid dynamics (CFD) codes (e.g., ANSYS FLUENT) to demonstrate the adequacy of the thermal design

CFD BPG (NUREG-2152)

- NRC developed NUREG-2152 report to provide practical advice for reviewing CFD methods used in vendor's applications and for achieving high quality dry cask CFD simulations
- Includes definition of the concepts of general errors and uncertainties in CFD and a comprehensive section providing guidelines on how to deal with these general errors and uncertainties
- Gives guidelines to draw the user's attention to the likely sources of uncertainty when formulating a problem, and to know the sources of error inherent in CFD methods

CFD BPG (NUREG-2152)

- Presents a check list for CFD BPG
- Provides example using CFD to analyze and evaluate dry cask thermal response, discusses many issues that are dealt with in dry cask applications, and provides guidelines based on validation and sensitivity analysis
- To address the modeling uncertainties, the report focused on turbulence modeling of buoyancy-driven air flow
- Similarly, in the application uncertainties, the pressure boundary conditions used to model the air inlet and outlet vents were investigated and validated

Checklist for BPG

- Initial Preparation
- Geometry Generation
- Grid Generation
- Selection of physical models
- Numerical Methods
- Verification
- Validation
- Uncertainty Quantification

Checklist for CFD PBG

- Any assumptions to simplify the geometry of the problem
- Mesh quality (type of elements, skewness, aspect ratio, expansion ratio, orthogonality, y+)
- Grid Convergence Index (GCI)
- Porous media input
- Underelaxation factors
- Interpolation schemes order of accuracy
- Interpolation schemes for all equations
- Placement of boundaries for external flows (will the physical boundaries affect the free inlet Dirichlet conditions)

Checklist for CFD PBG

- Coupling scheme
- Thermophysical properties (density, heat capacity, conductivity, viscosity) as function of temperature
- Radiation properties (model used, emissivity)
- Turbulence model
- Outside surface heat transfer coefficient correlations
- Mass and heat balance
- Target variable monitoring

Checklist for CFD PBG

- Residuals
- Engineering judgement for target variable like peak cladding temperature and velocity vector
- Perform additional iterations to see where the solution will go
- Equation of state(ideal gas, real gas, incompressible ideal gas…)
- Roughness of walls if important (turbulence will be affected, law of the wall will be affected if used)
- Pressure boundary conditions need to be carefully inspected as you need input for the operating density (very important to not use the default set up)

Uncertainty

- To obtain accurate thermal results, CFD simulations should include determination of modeling and application uncertainty

- Thermal analyses that have been submitted have not provided modeling and application uncertainty

- The modeling (turbulence, radiation heat transfer, porous media, etc.) and application uncertainty (boundary conditions) can only be determined through adequate validation and sensitivity analysis

Uncertainty

- Recent thermal analyses submitted to the staff have not provided proper validation, especially considering higher heat loads being proposed

- Without adequate validation the staff has to rely on the adequacy of the analysis provided in the applications

- In order to compensate for the unavailability of data to support adequate validation of thermal models for new designs (configurations), the staff may request that cask heat loads be reduced to provide acceptable margin for ensuring safety

Turbulence Modeling

- In addition, recent thermal analyses provided to the staff have not properly characterized and validated the flow regime for both internal and externals flows

- External air flow in ventilated casks could operate in the laminar/transitional/turbulence regime

- Proper selection of turbulence model is important because it would impact the predicted results

Turbulence Modeling

- Selection of turbulence model to characterize external flows in ventilated casks is a concern because of the lack of adequate data to validate the selected model, especially for pressurized canisters containing high burnup fuel at high heat loads

Additional Guidelines

- Additional guidelines will be added based on the following reports:
  - Impact of variation in environmental conditions (NUREG-2174)
  - Performing validation using data from the BWR and PWR assembly zirc fire programs performed in Sandia National Laboratories (temperature and induced mass flow rate) (NUREG-2208)
  - Dry Cask Simulator Experiment NUREG/CR**** report (Available 02/2018)
- NRC uses the ASME V&V 20 (“Standard for Verification and Validation in Computational Fluid Dynamics and Heat Transfer”) guidelines for dry cask applications

Environmental Conditions (NUREG-2174)

- The thermal evaluation of a dry storage cask generally assumes a set of fixed environmental factors (e.g., average annual ambient temperature, quiescent conditions, sea level, etc.)
- This set of fixed environmental factors are assumed to bound all sites in the continental United States
- Using average values may not be adequate because more adverse ambient conditions could exist for prolonged periods of time
- This would allow a storage system to reach new steady-state conditions that could result in higher spent fuel cladding temperatures as compared to the cask's Safety Analysis Report

Environmental Conditions (NUREG-2174)

- For cases with predicted small thermal margin, these adverse ambient conditions could result in peak cladding temperatures exceeding recommended limits for normal conditions of storage

- For some designs, low speed wind direction and magnitude would also affect the cask thermal performance

Validation of CFD Using Single Assembly T-H Data

- Objective was to perform validation studies for CFD codes using PWR and BWR fuel assemblies thermal-hydraulic data
- Assist NRC staff in making the regulatory determination of adequate protection for storage and transportation casks using analytical methods
- Validation studies demonstrated that the vendor's calculated porous media friction factors were underestimated by as much as 35%
- In addition, as requests for higher heat loads and high burnup fuel continue to be the norm, available margins are reduced to the point that predicted peak cladding temperatures are very close to the allowable limits

Validation of CFD Using Single Assembly T-H Data

- NUREG-2208 documents the analysis and results to support NRC staff in making the regulatory determination of adequate protection for storage and transportation casks
- The results indicated that effective thermal conductivity and porous media models are capable to predict the thermal response of an assembly when using the proper input
- Modeling lessons learned and guidelines discovered from this work will be added to the CFD Best Practice Guidelines for Dry Cask Applications (NUREG-2152) and applicable SRPs

Summary

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Protecting People and the Environment

- The NRC continues to encourage the use of NUREG-2152 to address common identified thermal analysis problems
- The NRC issued NUREG-2174 report that highlights potential identified concerns regarding environmental variables on storage designs
- The NRC performed validation studies using single assembly T-H data to verify effective thermal conductivity and porous media models (NUREG-2208)
- The NRC in collaboration with DOE performed a dry cask simulator experiment to help address thermal validation issues
- As a result of additional experiments and validation studies, CFD BPG and SRPs are being revised accordingly

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