US-APWR

4th Pre-Application Review Meeting
Thermal & Hydraulic Design Methodology

January 31, 2007
Mitsubishi Heavy Industries, Ltd.

Meeting Attendee

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Meeting Objectives

1. Provide overview of Thermal & Hydraulic design methodology for US-APWR
2. Highlight focal points of Topical Report "Thermal Design Methodology" (May, 2007)
3. Obtain early NRC feedback on the proposed Topical Report contents

Contents

1. Design Basis
2. Design Methodology
3. Contents of Topical Report
4. Conclusions

1. Design Basis

➢ **General Design Criteria (10 CFR Part 50, Appendix A)**

GDC-10 Reactor Design

Specified acceptable fuel design limits are not exceeded during normal operation or anticipated operational occurrence

GDC-12 Suppression of Reactor Power Oscillations

Power oscillations, which could result in conditions exceeding specified acceptable fuel design limits, will not occur or can be reliably and readily detected and suppressed

➢ **Standard Review Plan (NUREG-0800)**

Section 4.2 Fuel system

Section 4.4 Thermal and Hydraulic Design

1. Design Basis

(1) Departure from Nucleate Boiling (DNB) Design Basis

DNB will not occur on the most limiting fuel rods with at least a 95% probability at a 95% confidence level during Condition I and II events

(2) Fuel Rod Temperature Design Basis

The peak fuel pellet centerline temperature will not exceed the fuel melting temperature with at least a 95% probability at a 95% confidence level during Condition I and II events

1. Design Basis

(3) Core Flow Design Basis

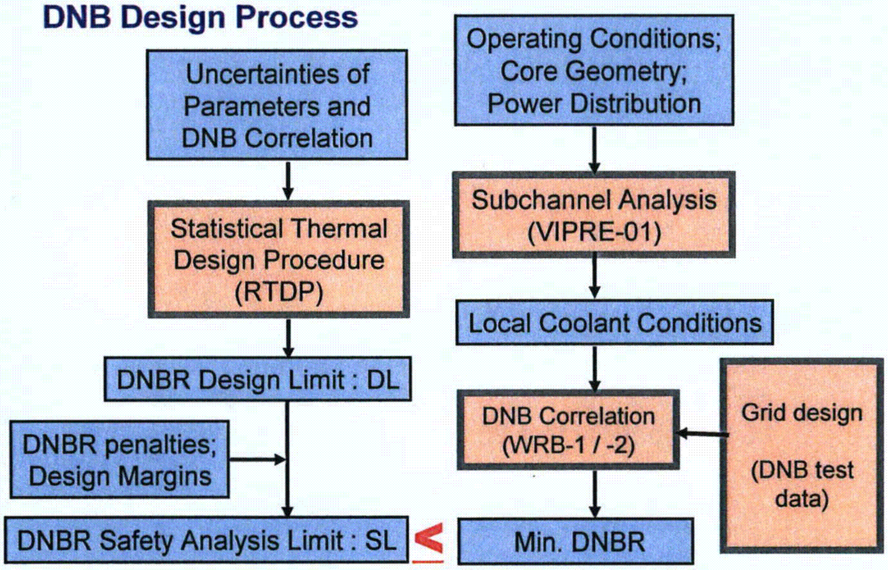
Sufficient effective core flow (excluding the core bypass flow) is provided for removing the heat generated in the core

(4) Hydrodynamic Stability Design Basis

Modes of operation under Condition I and Condition II events do not lead to thermo-hydrodynamic instabilities

2. Design Methodologies

DNB Design Process



2. Design Methodologies

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➢ **VIPRE-01/MOD2 Subchannel Analysis Code**

NRC generically approved:NP-2511-CCM-A Rev.3 (1993)

- ✓ Developed from COBRA codes by Battelle for EPRI
- ✓ Conservation equations for mass, momentum, and energy are solved
- ✓ Transient thermal behavior of the fuel rod is analyzed simultaneously with coolant T/H analysis
- ✓ Constitutive models for flow resistance, turbulent mixing and boiling are included and verified
- ✓ NRC requires the VIPRE-01 code users to demonstrate adequacy of the code application for licensing
  - Core modeling
  - Constitutive model options
  - DNB correlation

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2. Design Methodologies

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➢ **MHI Modifications to VIPRE-01**

- ✓ Modifications to add new design capabilities
  - Installation of DNB correlations (WRB-1 and WRB-2)
  - Fuel properties consistent with Mitsubishi's fuel rod design code (FINE)
  - Hot spot Peak Clad Temperature (PCT) analysis model for Condition III or IV events (forced film boiling mode, Zr / Water reaction)
  - Improvement of user interfaces (code I/O and dynamic memory allocation)
  - Solution methods and constitutive models are not changed
- ✓ Physical models added by MHI will be described in detail in the topical report "Thermal Design Methodology" in May 2007

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2. Design Methodologies

➢ DNB Correlations and Grid Spacers

✓Topical Report "Thermal Design Methodology"

- DNB Correlation : WRB-1, WRB-2
- Grid type : Z2 (conventional design)
  Z3 (latest design)

✓US-APWR Design Control Documents

- DNB Correlation : WRB-2
- Grid type : Z3

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2. Design Methodologies

➢ DNB Correlations

✓WRB-1

- Database: Westinghouse's R-grid and L-grid rod bundle DNB test data
- Developed and verified with THINC code
- WCAP-8762-P-A (1984)

✓WRB-2

- Database: Westinghouse's 17x17 rod bundle DNB test data and VANTAGE-5 DNB test data
- Developed and verified with THINC code
- WCAP-10444-P-A (1985)

✓Compatibility with the VIPRE-01 code and applicability for Mitsubishi fuel designs will be demonstrated in the Topical Report

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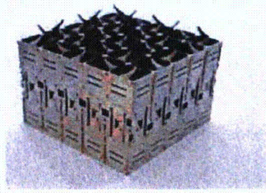
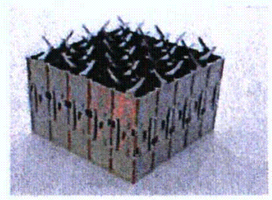
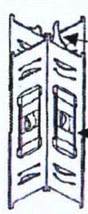
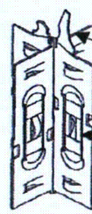
Mitsubishi Grid Spacers

Grid type	Z2 (Current type of Zircaloy grids)	Z3 (Advanced type of Zircaloy grids)
Material	Zircaloy-4	Zircaloy-4
Bird's eye view of 5 x 5 partial model		
Structure of grid strap	 Normal vane; I type spring	 Cross over vane; Streamlined shape of I type spring

2. Design Methodologies

- **Revised Thermal Design Procedure (RTDP)**
  - ✓ NRC approved: WCAP-11397-P-A (1989)
  - ✓ Parameter uncertainties are statistically combined with DNB correlation uncertainty
    - Plant operating parameters
      - Reactor coolant flow rate, core power, coolant temperature, system pressure, effective core flow fraction
    - Nuclear and thermal parameters ($F^N_{\Delta H}$, $F^E_{\Delta H}$)
    - Fuel fabrication parameters ( )
    - Subchannel and transient codes

2. Design Methodologies

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➢ Revised Thermal Design Procedure (RTDP)

- ✓ DNBR limits cover all the uncertainties and plant specific margin
  - Statistical uncertainties of RTDP are re-evaluated for US-APWR design with VIPRE-01 code and WRB-2 DNB correlation (for DL)
  - Plant specific margin allocated to offset penalties (for SL)
    - Rod bow by method of WCAP-8691-R1 (1979)
    - Transition core
  - Core design flexibility (for SL)
- ✓ DNBR design limit (DL) will be described in DCD
  - MHI will refer to WCAP-11397-P-A

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2. Design Methodologies

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➢ Design for Fuel Temperature : FINE code

- ✓ Fuel rod design code validated with extensive data including high burnup data
- ✓ UO_2 thermal conductivity degradation effect with burnup is included
- ✓ The melting temperature of UO_2
  - 5,070 deg F for non-irradiated fuel
  - Decreases by 58 deg F per 10 GWd/t burnup accumulation
- ✓ A separate topical report "Fuel Design Criteria and Methodology" describing FINE will be submitted in May, 2007

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2. Design Methodologies

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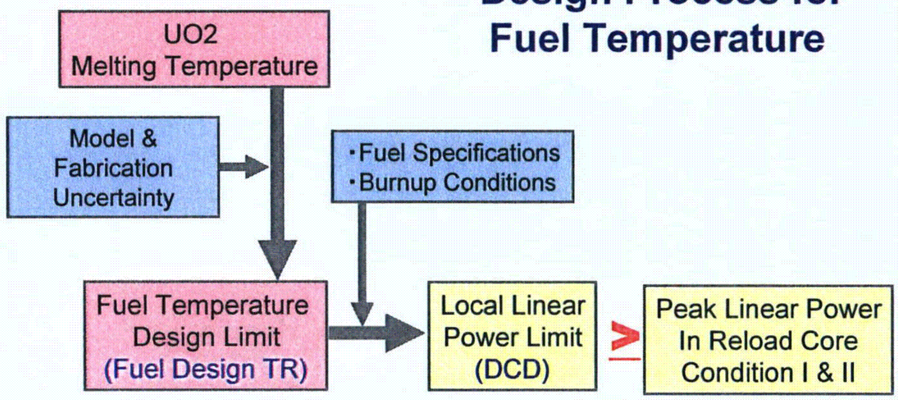
Design Process for Fuel Temperature



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3. Contents of Topical Report

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"Thermal Design Methodology"

✓ Overview of DNB design methodology

✓ VIPRE-01 Application and its adequacy

- Core modeling
  - Noding, time step size
- Constitutive model options
  - Flow resistance, turbulent mixing, boiling, fuel thermal properties
- Example of design applications and comparison with other codes
  - Typical core design analysis (THINC)
  - Fuel rod steady state analysis (FINE)
  - Fuel rod transient analysis (FACTRAN)

✓ Verification of WRB-1 & -2 / VIPRE-01 combination

- WRB-1 & -2 original data base
- DNB test data for Mitsubishi fuel with Z2 & Z3 grid

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4. Conclusions

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1. **T&H design bases and methodologies**
   - ✓ Identical to those adopted for most existing PWR designs in the US
2. **Topical Report "Thermal Design Methodology" Submittal in May 2007**
   - ✓ Application method of VIPRE-01 to design analysis
   - ✓ Verification of the models added by Mitsubishi
   - ✓ Applicability of DNB correlations to Mitsubishi fuel designs
3. **Topical Report "Fuel Design Criteria and Methodology" Submittal in May 2007**
   - ✓ Design methodology for fuel temperature is described