nuclear energy

B&W mPower™ CHF Test and Correlation Development Plan Summary

February 22, 2011 – USNRC, Rockville, MD

AGENDA

- Introductions
- Meeting Objectives
- Design Overview (Optional)
- Overview of CHF Technical Report
- CHF Testing and Correlation
- Summary
- Discussions

Meeting Objectives

- To brief the USNRC staff on the B&W document submitted for information in the Spring of 2010 – B&W mPower CHF Test and Correlation Development Plan, 06-00000334-000
- To solicit USNRC comments on B&W's plans
- To update the USNRC staff on the current status of the CHF program

DESIGN OVERVIEW

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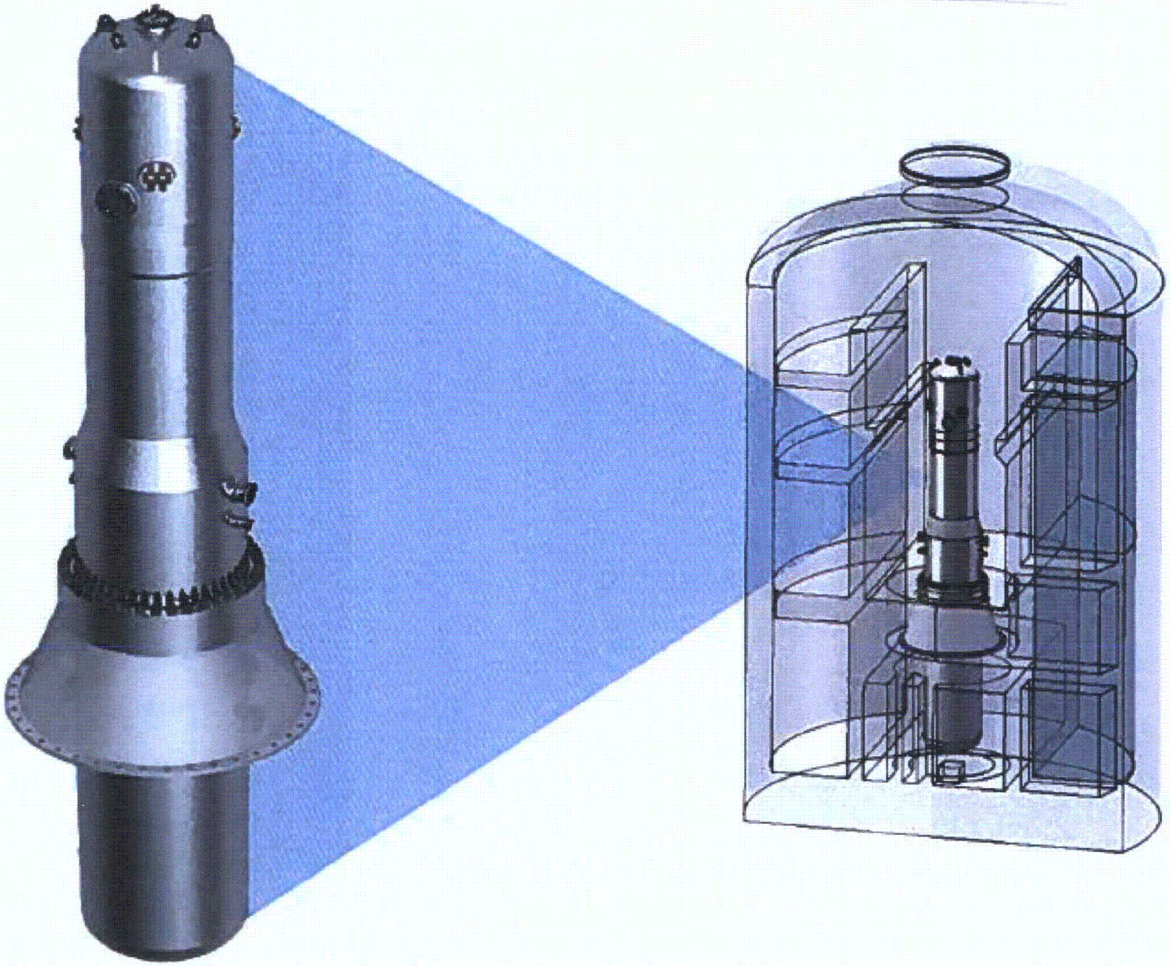


Overview of the B&W mPower™ Reactor Design

High-Level Requirements

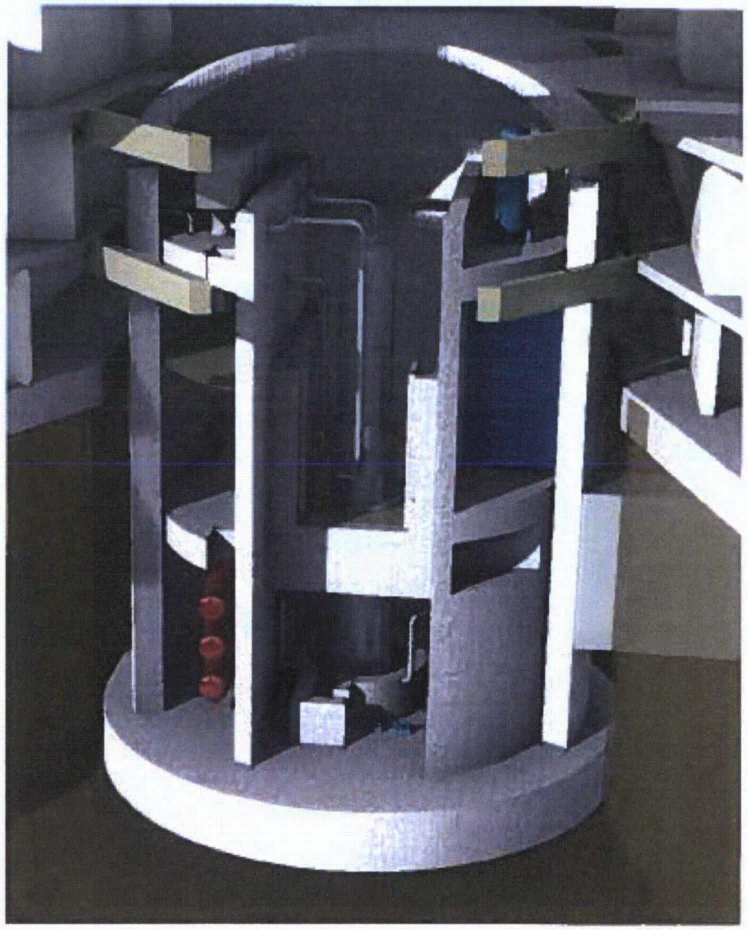
- 125 MWe plant net output per module & 60-year plant life
- NSSS forging diameter allows domestic forgings, unrestricted rail shipment
- Passive safety requirements – emergency (diesel) power is not required
  - Minimize primary coolant penetrations, maximize elevation of penetrations
  - Large reactor coolant inventory
  - Low core power density
- Standard fuel (less than 5% enriched U-235)
- Long fuel cycle, 4+ year core life

High-Level Requirements-Cont.

- Spent fuel storage on site for life of plant
- No soluble boron in primary system for normal reactivity control
- Conventional / off-the-shelf balance of plant systems and components
- Accommodate air-cooled condensers (Baseline) as well as water-cooled condensers
- Flexible grid interface (50 Hz or 60Hz)
- Digital instrumentation and controls compliant with NRC regulations

Containment Requirements

- Underground containment and fuel storage buildings
  - Favorable seismic response
  - Missile protection
- Environment suitable for human occupancy during normal operation
- Simultaneous refueling and NSSS equipment inspections
- Volume sufficient to limit internal pressure for all design basis accidents



Site Development

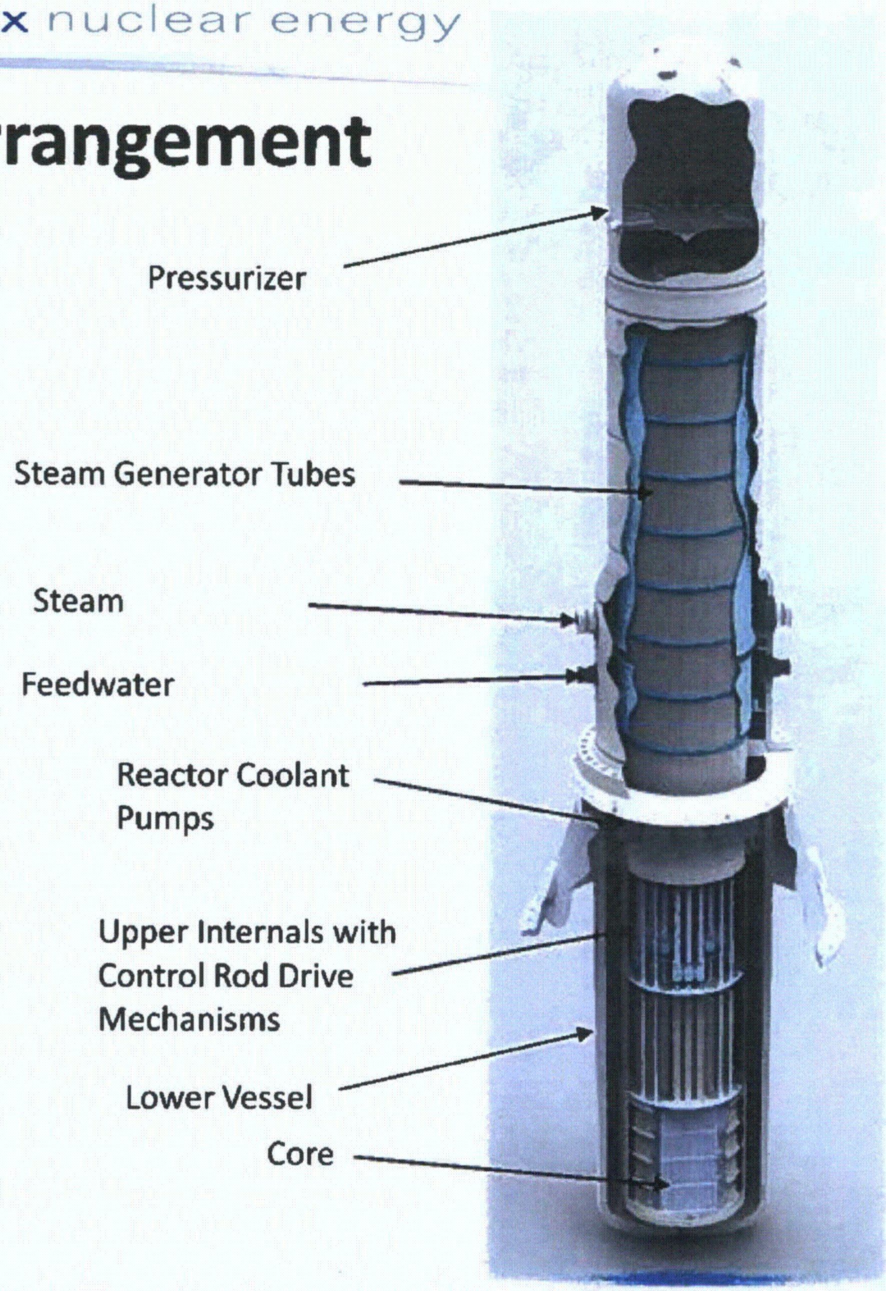
Technology Overview

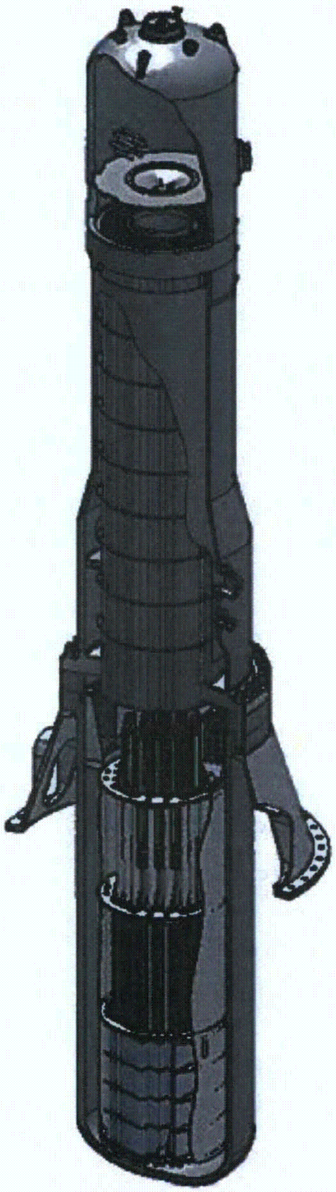
Integral Nuclear Steam Supply System

- Integrates core, steam generator, and pressurizer into a single vessel
- Control rod drive mechanisms (CRDMs) and primary coolant pumps inside vessel
- Reactor coolant pressure boundary penetration size and location minimize coolant loss during LOCA – core remains covered throughout the design basis LOCA
- Housed within a steel lined, reinforced concrete, dry containment

Integral design reduces overall plant complexity and enhances safety

Overall Reactor Arrangement



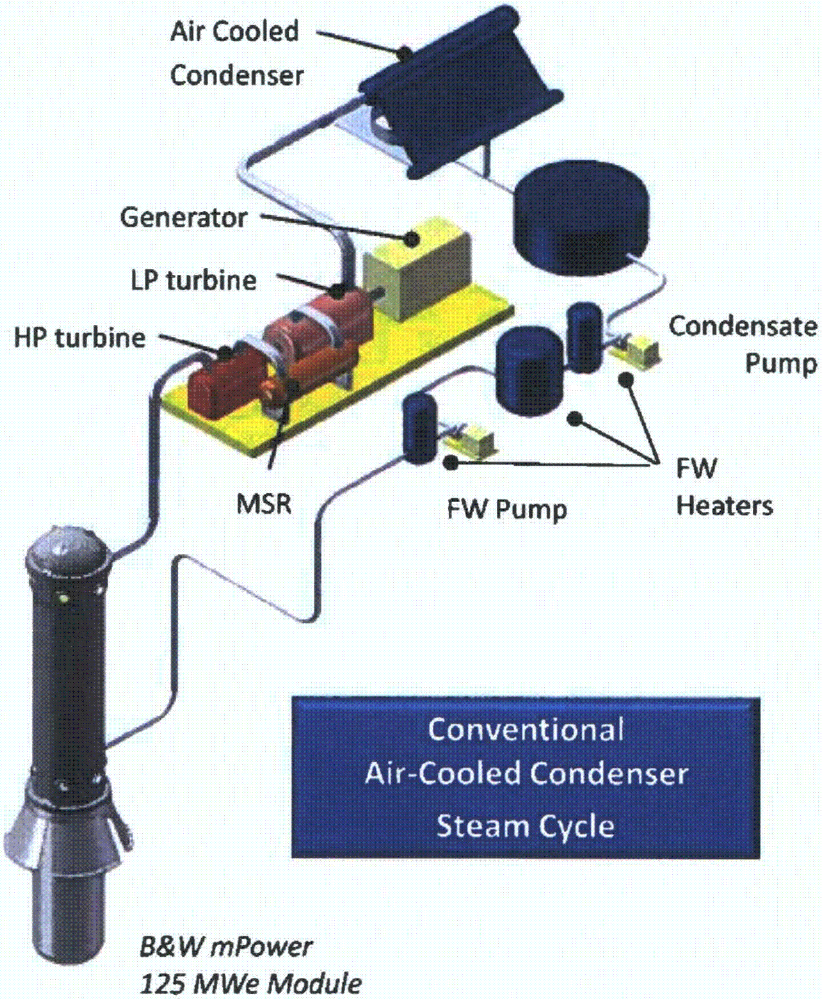


Inherent Safety Features

- Large reactor coolant volume
  - Large RCS volume
  - More coolant to protect the core
- Small penetrations at high elevation
  - High penetration locations
  - Small penetrations

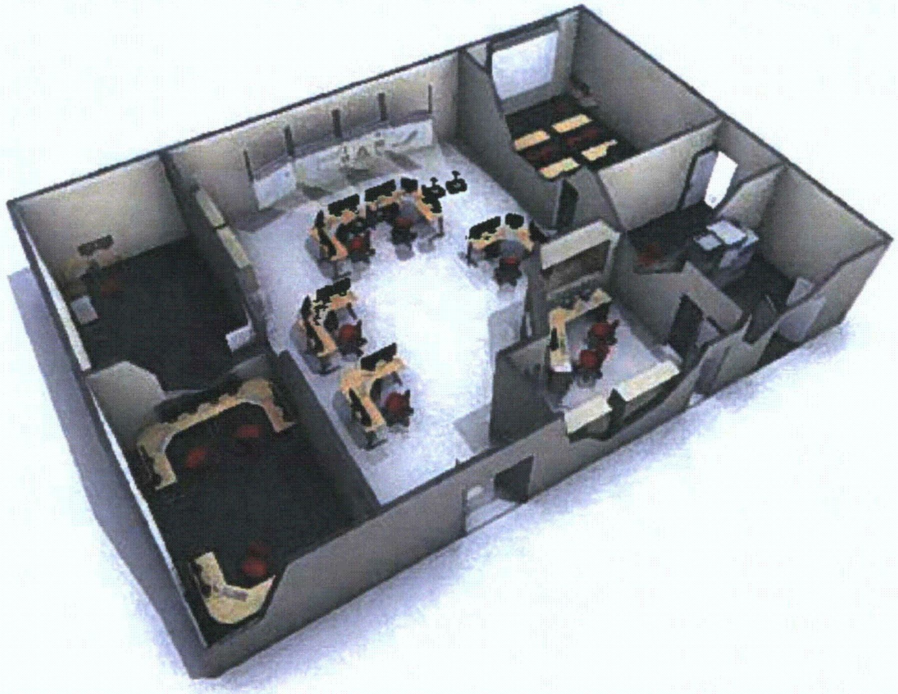
Balance of Plant Design

- Plant designed to produce a nominal 125 MWe
  - Air-cooled condenser (Baseline)
  - Water-cooled condenser
- Conventional steam cycle equipment (small, easy to maintain and replace)
- BOP operation not credited for design basis accidents
  - All fuel can be cooled for a minimum of 72 hours without any BOP system



Instrumentation and Controls

- State of the art digital system
- Provides monitoring, control, and protection functions
- Separate safety and non-safety systems
- Implement lessons learned from current licensing activities
- Northrop Grumman under contract to develop I&C architecture



Summary

- NSSS utilizes an integral PWR design
  - Uses a single integral economizer once through steam generator to produce superheated steam
  - Internal reactor coolant pumps and control rod drive mechanisms
  - Internal pressurizer
- Passive safety systems, inherent NSSS safety features
- Long operating cycle
- Underground containment
- Spent fuel storage on site for life of plant
- Reactor plants for multiple module designs

Development Testing Programs

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B&W CHF TESTING

BACKGROUND, PERSPECTIVES, AND TEST INFORMATION

B&W mPower Core Design Overview

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Top Level B&W mPower Reactor Core Design Requirement for DNBR

No rod will experience critical heat flux (CHF) under any normal operating condition or anticipated operational occurrence (AOO)

- The EPRI correlation is being used for the design phase
- Assumption: At an EPRI-correlation-calculated departure from nucleate boiling ratio (DNBR) of 1.3, there is a 95% confidence that 95% of fuel rods with this value of DNBR will not experience CHF
- A new B&W correlation is being developed and will be applied when available

Core Thermal-Hydraulic Model General Description

- VIPRE-01 mod 2.3 is used to model the core thermal-hydraulics
- Each bundle can be individually modeled at the subchannel level
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VIPRE Subchannel Model Configuration

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CHF Correlation Options in VIPRE

	Westinghouse W-3s	Combustion Engineering CE-1	Bowring (WSC-2)	EPRI	B&W mPower™ Nominal
Pressure	1000 to 2400 psia 6.89 to 16.5 MPa	1785 to 2415 psia 12.30 to 16.6 MPa	440 to 2400 psia 3.03 to 16.5 MPa	200 to 2450 psia 1.38 to 16.9 MPa	
Mass Flux	1.0 to 3.0 Mlb/(hr-ft²) 1356 to 4069 kg/(s-m²)	0.9 to 3.2 Mlb/(hr-ft²) 1180 to 4354 kg/(s-m²)	0.4 to 3.7 Mlb/(hr-ft²) 542 to 5018 kg/(s-m²)	0.2 to 4.5 Mlb/(hr-ft²) 271 to 6049 kg/(s-m²)	
Equilibrium Quality	-15 to 15 %	-16 to 20 %	-20 to 86 %	-25 to 75 %	
Heated Length	0.8 to 12.0 ft 0.24 to 3.66 m	7.0 to 12.5 ft 2.13 to 3.81 m	4.0 to 15.0 ft 1.22 to 4.57 m	2.5 to 15.0 ft 0.76 to 4.57 m	
Hydrualic Diameter	0.2 to 0.7 in 0.005 to 0.018 m	0.36 to 0.54 in 0.009 to 0.014 m	0.3 to 1.1 in 0.008 to 0.028 m	not applicable	

- The Babcock & Wilcox BW-2 correlation is available in VIPRE, [ ]
- Other correlations are for BWRs or non-applicable geometries

Results with Available CHF Correlations

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EPRI-Published Data

- The Columbia University Heat Transfer Research Facility performed numerous CHF test programs sponsored by many different reactor vendors
- EPRI published the results of 235 of these tests (11077data points) in 1982, and the report became free to the public in 2008
- Overview of the EPRI data:
  - 9 sponsors (both PWR and BWR)
  - Multiple pin configurations and bundle lengths
  - Pressure range – 1.3 to 17.0 MPa (185 to 2465 psia)
  - Flow range – 54 to 6049 kg/(s-m^2) (0.04 to 4.46 Mlbm/(hr-ft^2))
  - Includes uniform and non-uniform profiles and rod bow to contact data
- Could be used to support and/or validate new B&W test data

Reduced EPRI Data Set

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Stern Laboratories

- Located in Hamilton, Ontario, Canada (http://sternlab.com)
- Forty nine years of reliability and safety testing
  - Originally owned by Westinghouse
  - Privately owned and operated since 1988
- Recent critical heat flux testing experience:
  - CANDU assemblies (full size, full length)
  - BWR assemblies
- Direct or indirect heater rods
  - Indirect heaters can reverse current in half the rods to minimize magnetic forces
  - No need for simple support grids when using indirect heaters
- QA program meets requirements of:
  - ISO 9001 (standards for quality management systems)
  - 10CFR50 appendix B (QA criteria for nuclear power plants)

Stern Laboratories CHF Test Loop

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Test Configuration

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Axial Power Profiles

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Core Average Axial Power Profiles for the B&W mPower Core

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Range of Test Conditions

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Stern Test Conditions

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Test Matrix

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Data to Be Acquired

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Schedule and Status

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Summary

- A critical heat flux correlation derived specifically for the B&W mPower reactor core design is necessary to complete the licensing of the reactor
- A qualified vendor is under contract to provide the test data required
- B&W has hired experienced personnel to assist with development of the required correlation

B&W CHF TESTING AND CORRELATION

B&W CHF Testing and Correlation

CHF TEST FACILITY

Capabilities and Experience

CHF TEST PROGRAM

Diversity of Geometries

CHF CORRELATION DEVELOPMENT

Practical and NRC Requirements

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CHF TEST PROGRAM

Test Program

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CHF TEST PROGRAM

Testing Ranges

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CHF TEST PROGRAM

Columbia Data and Proposed Stern Data

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CHF TEST PROGRAM

Test Section Geometry

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CHF TEST PROGRAM

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CHF TEST PROGRAM

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CHF CORRELATION DEVELOPMENT
Local Conditions

- **Use VIPRE Subchannel Code for Local Conditions**
  - **Main Dependent Variables**
    - **Pressure**
    - **Mass Velocity**
    - **Thermodynamic Quality**
  - **Secondary Dependent Variables**
    - **Geometry** (Heated Diameter, Pitch/Diameter Ratio, etc)
    - **Other Thermodynamic** (Void Fraction, Liquid Flow Energy, etc)

CHF CORRELATION DEVELOPMENT

Correlation Form

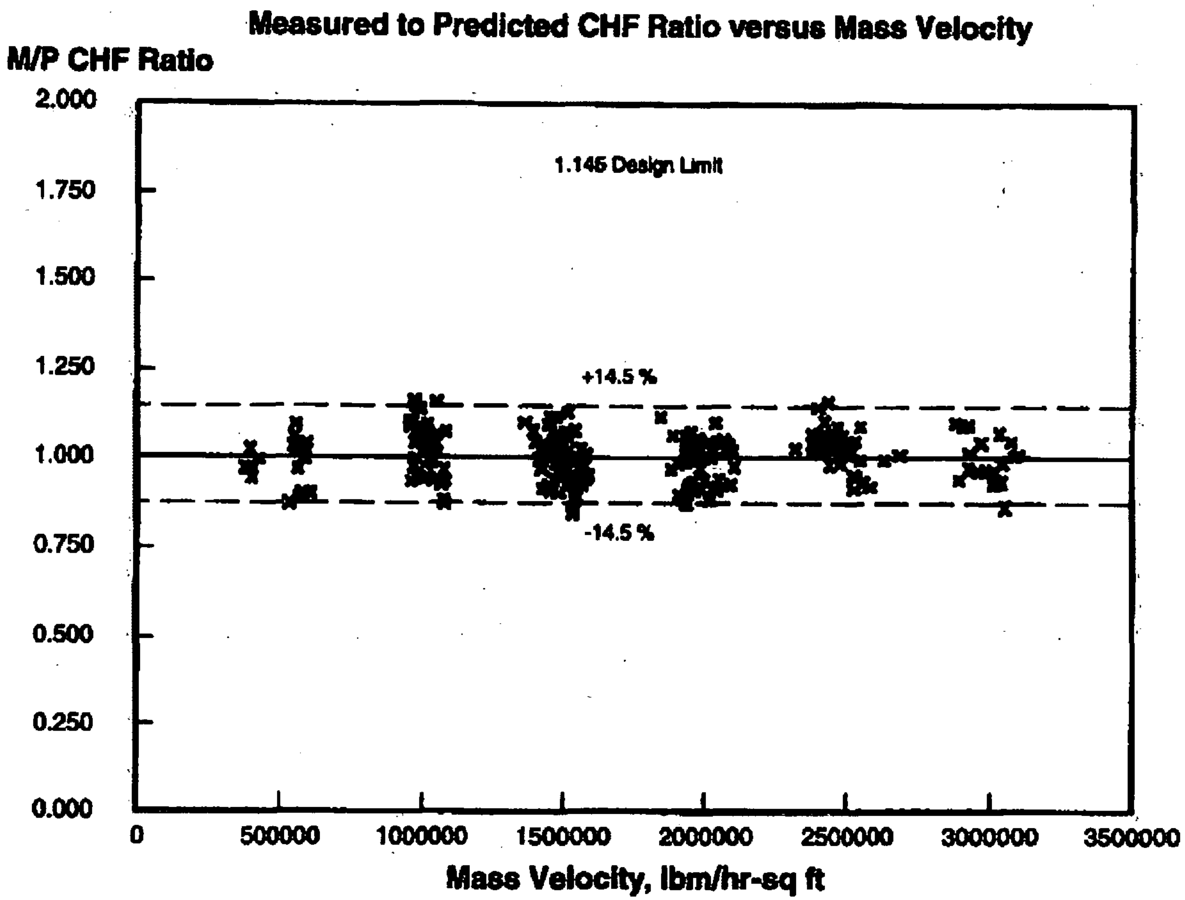
- **First Generation: A – B*Quality** (B&W-2, W-3, EPRI)
    - **Negative CHF (calculated) May Result** when out of Bubbly Regime
    - **Limited Range in P, G and X** (> 1.0 G, > 1400 psia, < 25% X)
- **Second Generation: Surface fit in P, G and X with Geometry Factors**
    - **Extended Ranges** (up to 70% X, down to 300 psia, 0.25 G)
    - **Much Easier Optimization** (Linearized System with Transformations)
    - **Non-Proprietary Form**
- **Modification for Rod Bow**
    - **Multiplicative** Factor on CHF
    - Function of **% Gap Closure and Pressure**
    - Based on **EPRI Bowed Rod Tests** (NP-2609)

CHF CORRELATION DEVELOPMENT
Correlation and Defense

- **Future CHF Topical**: Pre-Submittal Meeting with NRC
- **Required Justification** of Correlation and Design Limit
    - **ANOVA Testing** with P, G, X, etc. Groupings
    - **Bias (Slope) Testing** of P, G, X, etc. over entire ranges
    - **Scatter Plots** – M/P (Measured to Predicted), M versus P
    - **Normality Testing** – D Prime, Satterwaite
- **Defense of Correlation**
    - **Presentation to NRC** (both Facility and Correlation Development)
    - **Respond to RAIs** (Request for Additional Information)
    - **Receive SER** (Safety Evaluation Report)

CHF CORRELATION DEVELOPMENT

Hypothetical Graphical Results (non-B&W *mPower*)



CHF CORRELATION DEVELOPMENT

Hypothetical Tabular Results (non-B&W *mPower*)

Measured to Predicted Results by Pressures

Pressure psia	Data	Avg M/P	Standard Deviation	Max M/P	Min M/P	Coefficient of Variation
Below 375	3	0.9828	0.0561	1 037	0.925	0.057
375 to 900	14	0.9962	0.0609	1.071	0.872	0.061
900 to 1250	15	1.0287	0.0734	1.161	0.920	0.071
1250 to 1650	40	0.9942	0.0708	1.165	0.870	0 071
1650 to 1950	44	0.9991	0.0673	1 161	0.883	0.067
1950 to 2250	55	1.0078	0.0682	1.148	0.842	0.068
Above 2250	50	1.0005	0.0680	1.118	0 851	0.068
	221	1.0023	0 0679	1.165	0.842	0.068

0 1 % Slope (bias), ANOVA:F = 0 609 (6/214 df) - Fcrit = 2 139

CHF CORRELATION DEVELOPMENT

Hypothetical Statistical Results (non-B&W *mPower*)

/---------- ANOVA ----------\

Variable	Degrees of Freedom	F	Fcrit	Slope [Bias]
Pressure	6/214	0.609	2.139	0.1%
Mass Velocity	5/215	3.138	2.255	-0.1%
Quality	6/214	1.203	2.139	0.0%

221 Data, 1.0023 Mean, 0.0702 Standard Deviation → 1.145 Design Limit

B&W CHF Testing and Correlation
Summary

CHF TEST FACILITY

Capabilities and Experience

CHF TEST PROGRAM

Diversity of Geometries

CHF CORRELATION DEVELOPMENT

Practical and NRC Requirements

DISCUSSIONS