Agenda

• Introduction to the B&W mPower™ SMR

• B&W mPower I&C Design and Architecture

• The B&W mPower Engineering Simulator and Control Room Prototype

• Key Challenges in Regulatory Aspects of Digital I&C Systems
Introduction to the B&W mPower SMR
Goal and Value Proposition

Develop and deploy an SMR plant that is:

- **Proven**: GEN III+, established U.S. NRC regulation
- **Safe**: Robust margins, passive safety
- **Practical**: Standard fuel, construction and O&M
- **Unobtrusive**: underground, small footprint
High Level Requirements

- 180 MWe nominal output per module
- 60-year plant life
- NSSS forging diameter allows:
  - Greater sourcing options
  - Rail shipment
- Standard fuel (<5% $^{235}$U)
- Long fuel cycle, 4-year core life
- Long-term coping time without off-site support
- Minimize emergency planning zone
- Spent fuel storage on site
- Conventional/off-the-shelf balance of plant systems
- Accommodate air-cooled or water-cooled condensers
- Flexible grid interface (50 hz or 60 hz)
- Digital I&C compliant with NRC regulations

**Primary Conditions**

14.2 MPa (2060 psia)
318.89°C (606°F) Core outlet
14,062 MT/hr (31 Mlbm/hr)
Reactors Simplification

Loop plant incorporated into single vessel
B&W mPower Integral Reactor

Integral reactor has key features of conventional PWR
Development Testing Programs

Component Tests
- Reactor Coolant Pump
- CRDM
- Fuel Mechanical Testing
- CRDM/Fuel Integrated Test
- Fuel Critical Heat Flux

Integrated Systems Test (IST)
- Heat Transfer Phenomena
- Steam Generator Performance
- LOCA Response
- Pressurizer Performance
- Reactor Control

Greater than $100M Investment in Component Testing Program and IST Facility
• B&W Selected as Sole Winner Of U.S. DOE's Small Modular Reactor Program. Cooperative Agreement signed on April 15, 2013, with $79M made available in the first year

• Supports accelerated development of B&W mPower SMR technology

• Expected to be administered over the next five years, is the cornerstone of a public-private partnership created to share the challenges of developing and deploying SMRs across the U.S. before 2022

• B&W formed the mPower America project team with the Tennessee Valley Authority (TVA) and Bechtel to pursue an award under this program

• TVA is preparing an application to the Nuclear Regulatory Commission to license up to four B&W mPower SMRs at its Clinch River Site in Oak Ridge, Tennessee

• [http://www.babcock.com](http://www.babcock.com)
I&C Design and Architecture
B&W mPower I&C Philosophy

• Highly-Reliable, Integrated and Scalable Digital I&C System
• I&C System Must Have Highest Degree of Licensing Certainty
  ‣ Complies with Regulatory, URD Requirements
  ‣ Minimizes Regulatory Challenges with Digital I&C…Cyber-security, Diversity, Independence
• Integrated, Modernized Human-Factored Design
• High-level of Plant Automation
  ‣ Control of Startup, Shutdown, Load Following…support staffing plan
• Deliver Comprehensive O&M Strategy
  ‣ Use of commercially-available components
  ‣ Managed obsolescence
B&W mPower I&C Licensing Strategy

- Adherence to Current Regulations and Industry Standards
- Hardware Agnostic & Technology Neutral
- Lessons Learned from Previous Applicant Experience
- Regular and Frequent Interaction with US NRC
US NRC Design Specific Review Standard

- US NRC Licensing Reviews of New Reactor Instrumentation and Control Designs have been difficult to review under the existing Standard Review Plan.

- US NRC Office of New Reactors Division of Advanced Reactors has been developing design specific review standards (DSRS) to replace the Standard Review Plan.

http://www.nrc.gov/reactors/advanced/mpower/dsrs.html

B&W is Lead Applicant for New Design Specific Review Standard for I&C
Goal → Increase Efficiency of Reviews and Safety Focus
US NRC Design Specific Review Standard

• Working with US NRC for over a year on Chapter 7 (I&C)
• Complete Rewrite of Review Guidance

New Chapter 7 DSRS Framework

• Improves Safety Focus of Reviews
• Incorporates Lessons Learned from Previous Reviews
• Removes Duplication/Repeat Reviews
• Based on Fundamental Design Principles

Transition from a “systems-based” review to one that focuses on the overall I&C architecture and key fundamental design principles
New DSRS Structure and Framework

• Consolidation of Regulations and Standards
  ‣ Section 7.0: Introduction
  ‣ Section 7.1: Fundamental Design Principles
  ‣ Section 7.2: System Characteristics
  ‣ Appendix A: I&C Architecture
  ‣ Appendix B: Integrated Hazards Analysis
  ‣ Appendix C: Simplicity Attributes

The core of the DSRS Chapter 7 approach is based on the concept of applying proven system engineering principles (under the current regulatory framework):
  → Defense-in-depth
  → Design principles
  → Simplicity attribute
  → Integrated hazards
mPower Plant Control System (mPCS) Development Process

- Traditional systems engineering approach ensures that the mPCS will meet two fundamental directives:
  - U.S. NRC Requirements
  - B&W Internal Requirements
- Main focus on defining basic system architecture, interactions, and hazards analysis
• mPCS is being developed through a rigorous systems engineering process:
  ‣ Functional Analysis
  ‣ Requirements development
  ‣ Design Implementation
I&C Formative Requirements & Guidance

• The four key sources of authoritative requirements to use as regulatory basis:
  ‣ 10 CFR 50
  ‣ 10 CFR 73.54
  ‣ IEEE 603-1991
  ‣ IEEE 7-4.3.2

• Other relevant documents will be referenced when derived requirements are related to the source document
  ‣ Regulatory Guides
  ‣ Interim Staff Guidance
  ‣ Branch Technical Positions
  ‣ Industry Standards
The Requirements Development process works in concert with the system architectural design process to define and document the functional aspects of mPCS and operational procedures.

Characterize Regulatory Imperatives
- Identify applicable regulatory documents
- Identify requirement or guidance statements in those documents

Rigorously analyze each imperative statement for its effect on B&W mPower I&C Architecture
mPower Rqmts. Development Methodology

• Interpret the effect on mPCS design and/or cyber security program as derived requirement statements
  ․ Statement expression documented in terms of state-of-the-art security practices
  ․ Results organized into modules for architectural element or operational program specifications

• Validate requirements model
  ․ Ensure complete fulfillment of required objectives
  ․ Verify that requirements are expressed in all affected modules

• Analysis/interpretation/validation cycle repeated at increasing levels of detail as requirements are allocated to architectural elements
Layered Architecture Characteristics

- Safety, control, and management functions segregated in their own defensive security levels

Incorporates Key Defense-in-Depth Protective Strategies
Bringing it All Together…

Common Control Layer

Control of Common Plant Systems
The B&W mPower Engineering Simulator and Control Room Prototype
B&W mPower Control Room Prototype Begins Operations

• The B&W mPower engineering simulator is a key milestone in the overall development program

• The control room is connected to a plant engineering simulator to allow validation of the man-machine interfaces and operating controls architecture

• The facility will be used by about two dozen engineers starting in 2014. Using their experience operating existing reactors, these engineers will refine B&W mPower plant system design and the reactor’s response to a variety of anticipated and postulated events
B&W mPower Control Room Prototype Development
B&W mPower Control Room Prototype

Key objectives:
- Concept of Plant Operations
- Develop Operator Interface Prototypes
- Validate Control Logic
• Digital, layered, and separated, I&C architecture
• 3 Layers: Protection, Control and Monitoring
• Operator role shifts from “actor” to “monitor”
Key Challenges in Regulatory Aspects of Digital I&C Systems
Digital I&C Challenges

Simplicity and Integrated Hazards Analysis

• Challenge: How to Define Objective Simplicity Attributes?
  ‣ Flat Hardware Logic
  ‣ Separate Primary Safety Functions and Auxiliary Functions
  ‣ Design for Verifiability: All functions traceable to single requirement

*Electric Power Research Institute (EPRI), TR-102293, Recommended Approaches and Design Criteria for Application of Field Programmable Gate Arrays in Nuclear Power Plant Instrumentation and Control System, June, 2011

• Challenge: What Method or Tactical Approach for Performing Integrated Hazards Analysis?
  ‣ External Hazards (Flood, Fire, Seismic)
  ‣ Hardware (FMEAs, Fault Trees)
  ‣ Hazards Contributed by Engineering Activities: Requirements, Software, Architecture
Digital I&C Challenges

Operator Staffing

• Challenge: Optimize Operator Staffing for SMRs
  ‣ Reduce Operator Burden During Abnormal/Emergency Operations
  ‣ Streamline Operator Roles and Responsibilities
  ‣ Efficient In-Plant Operator Functions
Summary

• Robust I&C Architecture that Meets Current U.S. NRC Regulations
• New U.S. NRC Design Review Standard Aims to Improve Review Process
• Actively Working to Address Key Challenges in I&C Aspects of Small Modular Reactors
• Main Control Room Prototype In Operation and Supporting Key SMR Concept of Operations

B&W mPower proceeding aggressively toward 2022 Commercial Operation
BACKUP INFORMATION
1. 2 x 180 MWe* units
2. Compact <0.16 km² (40-acre) site footprint*
3. Separated Nuclear and Turbine Islands
4. All safety-related systems underground
5. One-to-one reactor to T/G alignment
6. Optimized for minimum staff and O&M
7. Water- or air-cooled condenser option
8. Conventional steam cycle components
9. “Island Mode” and load following operation
10. Small Emergency Planning Zone (EPZ) radius

*with water-cooled condenser
B&W mPower Nuclear Island Features

• Fully underground
  ‣ Protected from external threats
  ‣ Enables security-informed architecture
  ‣ More efficient seismic design
  ‣ Robust containment, with space for O&M
• “Passive safety” design
  ‣ No safety-related emergency AC power required
  ‣ 72-hour safety-related control/monitoring battery
  ‣ No shared active safety systems between units
  ‣ 14-day “coping time” under station blackout
  ‣ Simple, with no sprays, sumps, or recirculation
• Enhanced spent fuel pool configuration
  ‣ Underground, inside reactor building
  ‣ Large heat sink with 30-day “coping time”

“Simple and robust” architecture lowers cost and risk, enhances licensing