Safety, constructability, and operational performance of the ABWR and ESBWR designs

Douglas McDonald
Vice President, Nuclear Power Plant Sales – Middle East and Africa

IAEA Technical Meeting on Technology Assessment for Embarking Countries
June 24-28, 2013
GE Hitachi Nuclear Alliance

- Wilmington, NC, USA
  - Nuclear Power Plants: ABWR, ESBWR and PRISM
  - Nuclear Services

- Tokyo, Japan
  - Uranium Enrichment ... Third Generation Technology

- Wilmington, NC, USA
  - Nuclear Fuel Fabrication ....BWR and CANDU
  - CANDU Services
  - Fuel Engineering and Support Services

- Yokosuka, Japan
- Peterborough, ON, Canada
BWRs around the world

84 operating BWRs
GE Hitachi’s new reactor portfolio

ABWR

Operational Gen III technology

- Lowest core damage frequency of any Generation III reactor
- Extensive operational experience since 1996
- Licensed in US, Taiwan, and Japan

ESBWR

Evolutionary Gen III+ technology

- Lowest core damage frequency of any Generation III+ reactor
- Passive cooling for >7 days without AC power or operator action
- Lowest projected operations, maintenance, and staffing costs
- 25% fewer pumps, valves, and motors than active safety nuclear plants

PRISM

Revolutionary technology with a rich, 40-year heritage

- Passive air-cooling with no operator or mechanical actions needed
- The answer to the used fuel dilemma - can reduce nuclear waste to ~300-year radiotoxicity while providing new electricity generation

1 Claims based on the U.S. DOE commissioned ‘Study of Construction Technologies and Schedules, O&M Staffing and Cost, and Decommissioning Costs and Funding Requirements for Advanced Reactor Designs’ and an ESBWR staffing study performed by a leading independent firm
2 To reach the same level of radiotoxicity as natural uranium
PWRs and BWRs – the basics

Typical Pressurized Water Reactor

Typical Boiling Water Reactor
Operation of a BWR

- Saturated water/steam mixture cooling fuel
- Direct cycle (No external steam generators)
- Water moderator modified by steam voids (bubbles)
The Boiling Water Reactor

550° F / 288° C
99.9% Steam

420° F / 216° F
100% Water

BWR Fuel Assembly
- 90 fuel rods encased in a ‘channel’
- 2 water rods
- part-length rods
- burnable absorbers

Reactor Pressure Vessel

Steam Dryer

Steam Separator

BWR Fuel Assembly

Reactor Internal Pumps (ABWR)

Control Rod Blades

Control Rod Rod Drives
A benchmark for operational performance

Capacity factors

- **1% BWR advantage provides 8 additional months** of revenue over 60-year lifetime

<table>
<thead>
<tr>
<th></th>
<th>BWR</th>
<th>PWR</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>90.96%</td>
<td>89.83%</td>
</tr>
<tr>
<td>90%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>80%</td>
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</tbody>
</table>

Data represents top quartile for 2002-2012

Average U.S. Cycle Length Trends

- BWRs – 20 months
- PWRs – 16.7 months

Average Outage length

- **10 fewer days in BWR outages in North America**

<table>
<thead>
<tr>
<th></th>
<th>BWR</th>
<th>PWR</th>
</tr>
</thead>
<tbody>
<tr>
<td>35.5 days</td>
<td></td>
<td>45 days</td>
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</tbody>
</table>

2002-2012 N. American outages including inspection, maintenance or repair with refueling

Fuel performance

- **Zero BWR fuel failures in North America**

Source: IAEA PRIS Database and 3/2013 EPRI Fuel Reliability Update

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**Safety and simplicity**

- **U.S. PWRs**: 2 E-5 (avg.)
- **U.S. BWRs**: 8 E-6 (avg.)
- **APR1400**: 2 E-6
- **APWR**: 1.2 E-6
- **EPR**: 2.8 E-7
- **AP1000**: 2.4 E-7
- **ABWR**: 1.6 E-7
- **ESBWR**: 1.7 E-8

**PRA of Core Damage Frequency**

*References: Plant licensing DCDs and publically available information*

*Note: PRA of CDF is represented in at-power internal events (per year)*

*Note: NSSS diagrams are for visualization purposes only*
Responses needed to maintain core cooling

Responses to extended loss of all AC power

- EPR and GEN II
  - 30 MIN
  - 2 HRS
  - 24 HRS

- ABWR
  - 30 MIN
  - ~36 HRS.*

- AP1000
  - DECAY HEAT

- ESBWR
  - >7 days

- Gen III+ passive plants allow for a much longer coping time
- Decay heat level impacts urgency

*ABWR DCD credits water addition at 8 HRS.
References: AP1000: US DCD rev. 18 Section 8.5.2.1, EPR: US DCD Rev. 1 Section 8.4
ABWR Reactor Specification

3926 Rated MWt/1350 MWe
  • Can be uprated to 4,300 MWt

872 Fuel Bundles
  • N- Lattice (symmetric water gap)
  • Active Fuel Length (3.66 m; 12 ft)
  • Moderate Power Density (51 kw/liter)

205 Control Blades
  • Fine Motion Control Rod Drives (FMCRDs)
    • Reduced Fuel Duty
    • Fast Hydraulic Scram
ABWR Design Objectives

Improved operability

Improved capacity factor
  12-24 month fuel cycle
  ~95% on a 10 year rolling average

Improved safety and reliability
  No core uncovery during design basis accidents

Reduced occupational exposure

Reduced costs
  Predictable Construction Time and Costs
  Operations and Maintenance (O&M)
Emergency Core Cooling System

**FUNCTION**
- **HPCF** • HIGH PRESSURE CORE FLOODER
- **RCIC** • REACTOR CORE ISOLATION COOLING
- **ADS** • AUTOMATIC DEPRESSURIZATION SYS.
- **LPF** • LOW PRESSURE FLOODER
- **SUPRESSION POOL COOLING**
- **WETWELL SPRAY**
- **DRYWELL SPRAY**
- **SHUTDOWN COOLING**
- **FUEL POOL COOLING SUPPORT**

**TYPE**
- AUTO
- MAN

**NO. DIVS.**
- 2
- 1
- 2
- 3
- 2
- 2
- 3
- 2

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Key ABWR differentiators for extreme events

- Separate and passive containment venting to prevent hydrogen explosion
- Reactor depressurization capability for >7 days due to battery segregation and pneumatic controls
- Seismic AC independent water injection into core
ABWR Station Blackout prevention and mitigation

3 x 100% nominal safety divisions

Emergency Diesel Generators
- 3 located in Reactor Building
- Each has a 7-day fuel tank that is buried in a concrete vault outside the Reactor Building

Combustion Turbine Generator
- Air-cooled – Service Water not needed

Safety-related batteries are located in the Control Building - just below the Main Control Room

AC Independent Water Addition (ACIWA) System
- Hard-piped connections to reactor
Recent experience and project status

**In Operation**
- Kashiwazaki-Kariwa 6/7 ABWR
  - COD 1996/1997
- Shika-2 ABWR
  - COD 2006
- Hamaoka-5 ABWR
  - COD 2005

**Under Construction**
- Ohma ABWR
  - COD TBD
- Shimane-3 ABWR
  - Under Construction COD TBD
- Lungmen-1/2 ABWR
  - Under Construction COD 2014 (estimated)

**Key Sites**
- Kaminoseki-1
- Higashidori-1
- Taiwan

- BWR Power Plant Site

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Construction lessons learned: Efficient, repeatable execution model

- modularization with VHL crane
- open-top & parallel construction
- detailed engineering and schedule planning before on-site work
- Integrated Construction Management System

Results:
- on-site work reduction
- work leveling
- improved site work efficiency
- work efficiency and quality
ABWR modularization – proven in Japan

- Roof Truss Steels
- Upper Drywell Module
- MSIV/CV
- RWCU Reheat Exchanger
- Condensate Demineralizer
- RCCV Top Slab
- Central Mat
- Base Mat
- HCU Room
- RPV Pedestal
- Offgas Equipment
- Upper Condenser
- Lower Condenser Block
- T-G Pedestal Piping Unit
- Condensate Demin. Piping
Detailed engineering before on-site work
Modularization
Proven experience in operating Gen III plants

RCCV liner

Roof Truss Steel

Central Mat

Top Slab

RCCV Rebars
Predictability of Schedule

RI: Rock Inspection  BC: Start of Basemat Construction  FL: Fuel Loading  CO: Commercial Operation

<table>
<thead>
<tr>
<th>Plant</th>
<th>CO Date</th>
<th>BA</th>
<th>FL</th>
<th>COD</th>
<th>BC – CO</th>
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<tr>
<td>ABWR#1</td>
<td>1996/11</td>
<td>2M</td>
<td>38M</td>
<td>11.2M</td>
<td>49.2M</td>
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<td>Kashiwazaki-Kariwa-6</td>
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<tr>
<td>ABWR#2</td>
<td>1997/7</td>
<td>3.5M</td>
<td>39.5M</td>
<td>8.8M</td>
<td>48.3M</td>
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<tr>
<td>ABWR#3</td>
<td>2005/1</td>
<td>1M</td>
<td>43.5M</td>
<td>10.5M</td>
<td>54.0M</td>
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<td>Hamaoka-5</td>
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<tr>
<td>ABWR#4</td>
<td>2006/3</td>
<td>2.5M</td>
<td>44.5M</td>
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<td>55.0M</td>
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<tr>
<td>Shika-2</td>
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### Key plant / reactor characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Core Thermal Power Output</td>
<td>4500 MWt</td>
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<tr>
<td>Plant Net Electrical Output</td>
<td>1520 MWe</td>
</tr>
<tr>
<td>Reactor Operating Pressure</td>
<td>7.17 MPa (1040 psia)</td>
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<tr>
<td>Feedwater Temperature</td>
<td>216°C (420°F)</td>
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<tr>
<td>RPV</td>
<td></td>
</tr>
<tr>
<td>Diameter</td>
<td>7.1 meters (23.3 feet)</td>
</tr>
<tr>
<td>Height</td>
<td>27.6 meters (90.5 feet)</td>
</tr>
<tr>
<td>Reactor Recirculation</td>
<td>Natural Circulation</td>
</tr>
<tr>
<td>Fuel</td>
<td>1132 fuel bundles</td>
</tr>
<tr>
<td>Fuel</td>
<td>Shortened length of 3m</td>
</tr>
<tr>
<td>Fuel</td>
<td>269 Fine Motion Control Rod Drives (FMCRDs)</td>
</tr>
</tbody>
</table>

1. Typical (site dependent)
2. Nominal Rated Operation

**ESBWR: Economy of Scale and Simpler Design**
ABWR to ESBWR evolution: Nuclear Island

Standby Liquid Control System – simplified design
2 Fuel and Aux Pool Cooling – equivalent designs
3 Suppression Pool Cooling & Cleanup System – equivalent capability
4 Residual Heat Removal System – equivalent for shutdown cooling
5 Reactor Water Cleanup System – equivalent designs
6 Hydraulic Control Unit – equivalent design

7 High Pressure Core Flooder – replaced by HP CRD makeup
8 Reactor Core Isolation Cooling – replaced by Isolation Condenser
9 Residual Heat Removal Containment Spray – replaced by PCCS
10 Safety Relief Valves – Diversified by Depressurization Valves

Systems are Equivalent or Simplified
ESBWR modularization – based on ABWR

- Roof Truss Steels
- Upper Drywell Module
- MSIV
- RWCU Reheat Exchanger
- Condensate Demineralizer
- RCCV Top Slab
- RCCV liner
- Central Mat
- Base Mat
- HCU Room
- RPV Pedestal
- Offgas Equipment
- Upper Condenser
- Lower Condenser Block
- T-G Pedestal Piping Unit
- Condensate Demin. Piping
• Passive safety/natural circulation
  - Increased volume of water in the vessel
  - Increased driving head
    - Chimney, taller vessel
  - Reduced flow restrictions
    - Open downcomer
    - Shorter core

• Significant reduction in components
  - Pumps, motors, controls, Heat Exchangers

• Power Changes with Feedwater Temperature and Control Rod Drives
  - Minimal impact on maintenance
ESBWR Passive Safety Systems
ESBWR LOCA response
Isolation Condenser System

- Fully passive – only requires gravity to function and starts automatically (fails in-service if DC power is lost)
- 4 separate systems in reinforced concrete vaults
- Limits reactor pressure (no SRV lifts) and temperature and conserves water inventory following containment isolation
- Steam (heat) rises from reactor to the condenser pool, condenses, then gravity pulls the cool water down into the reactor (closed-loop)
Simple refill actions – even in the worst conditions
Simple refill actions – even in the worst conditions
Simple refill actions – even in the worst conditions
ESBWR ... Proven innovation

- PCCS heat exchanger test
- Depressurization Valve test
- drywell to wetwell vacuum breaker test
- Panda Full Height Containment Test facility
- Isolation Condenser Testing
- natural circulation proven at Dodewaard
- BiMAC testing
- GIST facility

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Operations
ABWR and ESBWR state-of-the-art operations

Fully Digital Control System

• Fewer components, No drift, less power and heat
• Fault tolerance control
• Four division safety redundancy
• Automated operation
• Surveillance testing greatly reduced

Improved Man-Machine Interface

• Large mimic displays
• Prioritized alarms
• Flat panel controls minimize hard switches
• Human factored displays
ABWR and ESBWR offer substantial improvements in O&M

Simplifications in design –
- Safety, operations, and reliability
- O&M costs

Improvements in plant maintenance –
- Easier operations, greater reliability
- Maintenance cost and dose

Simpler to operate –
- Safety and reliability
- Operator actions and transients

Key component redundancy –
- Maintenance flexibility
- Operational transients

Lower radiation exposure –
- Outage efficiency and FME reduction
- Occupational dose and rad waste costs

Passive safety (ESBWR) –
- Safety and plant simplification
- Maintenance costs and dose
ESBWR requires significantly fewer plant personnel than any other Generation III/III+ design.

- A direct reflection of the ESBWR’s simpler design
- Allows for a higher percentage of local workforce
- Fewer ex-pats results in direct cost savings
1 Based on the industry standard measure of reactor safety - core damage frequency
2 Claims based on the U.S. DOE commissioned 'Study of Construction Technologies and Schedules, O&M Staffing and Cost, and Decommissioning Costs and Funding Requirements for Advanced Reactor Designs' and an ESBWR staffing study performed by a leading independent firm