ABWR Fuel LTR #6 – WCAP-17116-P

Westinghouse BWR ECCS Evaluation Model: Supplement 5 – Application to the ABWR

Presentation to ACRS Joint Subcommittee on Thermal Hydraulic/ABWR/Materials, Metallurgy and Reactor Fuels
03/05/2013

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Agenda

- Attendees
- Introduction
- Westinghouse Methodology
- Important Features of ABWR
- ABWR Evaluation Model
- Break Spectrum Results
- Draft SER Conditions and Limitations
- Summary and Conclusions

Attendees

• Scott Head	NINA Manager, Regulatory Affairs, STP 3&4
• James Tomkins	NINA Licensing, STP 3&4
• John Blaisdell	Westinghouse
• Robert Quinn	Westinghouse
• Bradley Maurer	Westinghouse

Introduction

- Fuel License Amendment to be submitted post-COL
- Ten topical reports submitted to NRC in support of this future amendment
- These topical reports generally extend existing Westinghouse BWR methods to ABWR

Introduction

Topical Reports Submitted

- SAFIR Control Rod Simulator
- BISON
- Fast Transient / ATWS
- POLCA-T for Anticipated Transients
- POLCA-T for ATWS
- Stability Methodology
- **ABWR ECCS**
- Sub-compartment Analysis
- Reference Safety Report for Core Analysis
- Control Rod Blades

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Introduction

- Purpose of the ABWR ECCS Topical
  - Demonstrate that the Westinghouse App. K methodology is acceptable for the ABWR
    - Provide additional qualification
      - Internal pump model
      - Prediction of dryout
  - It is not intended to be an STP design basis analysis

Introduction

- Timeline
  - WCAP-17116-P submitted to the NRC staff for review – Sep 2009
  - Initial RAIs received – May 2010
  - RAI responses provided July 2010 – August 2012
  - NRC Audit – Feb 2011
  - Draft SER Limitations and Conditions – Jan 2013
- Numerous RAIs to support NRC development of ABWR model for confirmatory analysis

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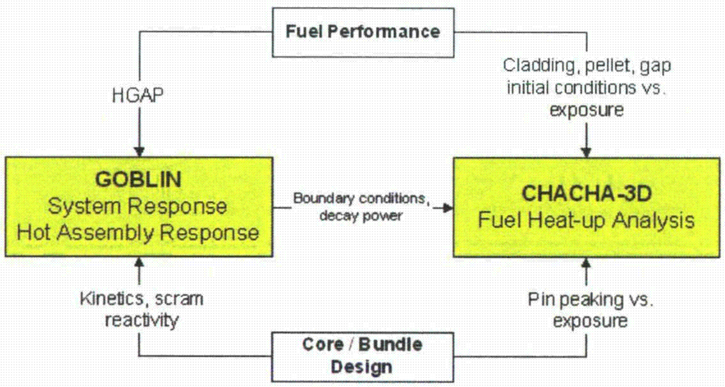
Westinghouse Methodology

- GOBLIN Code Series
- Appendix K-based Evaluation Model
- Approved in U.S. for BWR/2 through BWR/6
  - Applications include: Columbia, Hope Creek, Quad Cities 1 & 2, Dresden 2 & 3
- Applied in Europe for external loop plants (similar to BWR/2), BWR/6, internal pump designs (similar to ABWR)
  - Applications include Oskarshamn 1, 2 & 3, Barsebäck 1 & 2, Ringhals 1, Forsmark 1, 2 & 3, TVO 1 & 2, and Leibstadt



- **No GOBLIN or CHACHA code changes for ABWR application**

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Westinghouse Methodology

- GOBLIN Code Has 4 Main Sections

1. Hydraulic Model – Solves mass, energy and momentum equations together with the equation of state for each control volume. Uses empirical correlations for calculation of pressure drops, two-phase energy flow (drift flux), two-phase level tracking, spray-fluid interaction, and critical flow rate.
2. System Models – Includes models for steam separators, dryers, reactor level measurement, reactor trip, depressurization systems, recirculation pumps and emergency core cooling.
3. Thermal Model – Calculates heat conduction and heat transfer from the fuel rods, pressure vessel and internal structure to the coolant.
4. Power Generation Model – Calculates the heat generation due to fission (point kinetics), decay heat and metal water reaction.

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Westinghouse Methodology

- CHACHA-3D Code Has 9 Main Sections
  1. Fuel Rod Conduction Model
  2. Channel Temperature Model
  3. Heat Generation Model
  4. Metal-Water Reaction Model
  5. Thermal Radiation Model
  6. Gas Plenum Model
  7. Surface Wetting Model
  8. Pellet / Cladding Gap Heat Transfer Model
  9. Cladding Strain and Rupture Model
  - Many of these features are not important for the ABWR since there is no significant heatup

Important Features of the ABWR

- Recirculation System
  - 10 Reactor internal pumps (RIPs) vs. 2 external loops / internal jet pumps
  - Lower inertia leads to faster coastdown time constant (< 1 s vs. ~ 5 s)
- No Large Breaks Below Top of Active Fuel (TAF)

Break	Area	Elev. Above TAF
BWR Recirculation Line Break (double-ended)	7.23 ft^2	-16.7 ft
ABWR Steam Line Break (after MSIV isolation)	1.06 ft^2	20.4 ft
ABWR FW Line Break (vessel side)	0.90 ft^2	7.6 ft
ABWR RHR Suction Line Break	0.85 ft^2	5.8 ft
ABWR HPCF Line Break	0.10 ft^2	3.2 ft
ABWR Bottom Drain Line Break	0.02 ft^2	-30.0 ft

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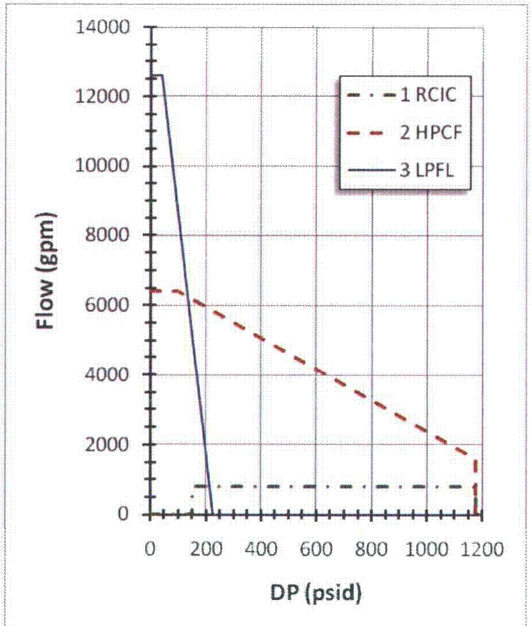
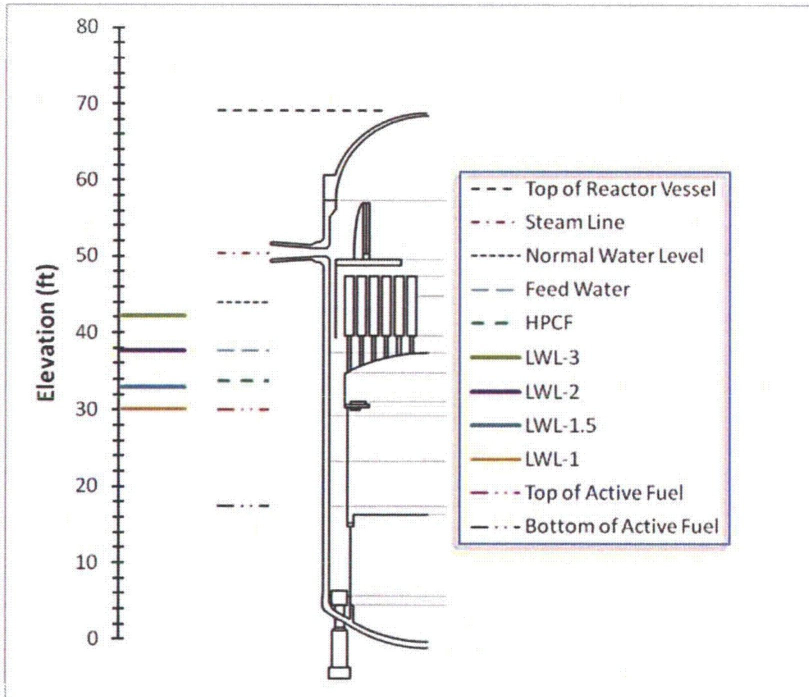
Important Features of the ABWR

- ABWR ECCS
  - Reactor Core Isolation Cooling (RCIC) – 1 steam-driven turbine drives pump; discharges to 1 feed water (FW) line; actuates on high drywell pressure or LWL-2.
  - High Pressure Core Flooder (HPCF) – 2 loops powered by different emergency power sources; discharges into upper plenum; actuates on high drywell pressure or LWL-1.5.
  - Low Pressure Flooder (LPFL) – 3 loops powered by different emergency power sources; 1 loop discharges to 1 FW line; 2 loops discharge directly to downcomer; actuates on high drywell pressure or LWL-1.
  - Automatic Depressurization System (ADS) – 8 Safety Relief Valves (SRVs); open 30 s after high drywell pressure and LWL-1.

Important Features of the ABWR





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ABWR Evaluation Model

- **Evaluation Model Assumptions**
  - Hot assembly power in GOBLIN established by placing hottest node at the [ ]^{a,c}
  - Initial core flows considered minimum and maximum permissible at rated power
  - Loss of offsite power assumed concurrent with LOCA
  - Feed water flow rate ramped to zero in 1 s
  - Steam line isolated by turbine control valve (TCV) closure (fast / slow)
  - RIPs connected to M/G sets not credited (all 10 lose power at t=0)
  - Reactor scram on narrow range water level < LWL-3
  - MSIVs close on LWL-1.5 or high steam flow (4.5 s + response time)

ABWR Evaluation Model

- **Major Conservatisms in App K Evaluation Model**
  - Decay heat
  - Initial hot assembly power
  - Pump coastdown
    - Time constant
    - No credit for MG sets
  - Bounding ECCS performance and delay times
  - Critical flow model
  - No rewet after dryout

ABWR Evaluation Model

[ ] a,c

ABWR Evaluation Model

- Core Noding
  - Fast Coastdown of RIPs Expected to Result in Early Dryout
    - Core noding expected to be important in prediction of dryout
  - Benchmark FRIGG Transient Dryout Experiments
    - Increasing power tests
    - Decreasing flow / power tests (similar to LOCA event)
    - Three axial power distributions (top, symmetric, bottom)
    - 85 tests were benchmarked
  - Used GOBLIN to Simulate Tests ([ ]^{a,c} Axial Nodes)
    - Results for [ ]^{a,c} nodes nearly identical
    - GOBLIN core model is comprised of [ ]^{a,c} axial nodes.

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ABWR Evaluation Model

[ ] a,b,c

ABWR Evaluation Model

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ABWR Evaluation Model

- Pump Modeling
  - Fast Coastdown of RIPs Expected to Result in Early Dryout
    - Pump modeling expected to be important
  - GOBLIN Pump Model
    - Based on conservation of angular momentum
      - Pump moment of inertia
      - Hydraulic and frictional torque
      - Homologous curves, two-phase degradation etc.
  - RIP Specification
    - Minimum inertia time constant - [ ][a,c]

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ABWR Evaluation Model

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Break Spectrum

	Available ECCS				
Break Location	RCIC	HPCF	LPFL	ADS	**Failure**
HPCF Line	1	0	2	8	Failure of 1 EDG
MS Line (RCIC side)	--	1	2	8	Failure of 1 EDG
FW Line (RCIC side)	--	1	2	8	Failure of 1 EDG
FW Line (LPFL side)	1	1	1	8	Failure of 1 EDG
RHR Suction Line	1	1	2	8	Failure of 1 EDG
RHR Injection Line	1	1	1	8	LPFL break + 1 EDG
Drain Line	1	1	2	8	Failure of 1 EDG

Break Spectrum Results

- HPCF Line Break
  - Guillotine break of 1 of 2 HPCF injection lines
  - Break area is limited by the flow area of the nozzles on the sparger [ ]a,c
  - Limiting single failure is the emergency diesel generator (EDG) powering the unaffected HPCF loop and 1 LPFL
    - Remaining equipment: 1 RCIC + 2 LPFL + 8 ADS
  - Sensitivity studies performed on:
    - Initial core flow (90% and 111%)
    - Steam line isolation method (TCV fast closure vs. pressure regulator)
    - Break size (25% - 100%)

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Break Spectrum Results

- HPCF Line Break (cont'd)
  - Results
    - Peak cladding temperature (PCT) occurs during RIP coastdown and before ECCS actuation.
    - 90% initial core flow results in highest PCT, 111% initial core flow results in minimum inventory.
    - TCV closure: fast closure results in highest PCT; little effect on minimum inventory.
    - Largest break size results in minimum inventory; little effect on PCT.
    - No uncovery of hot assembly, but partial uncovery occurred in some low power assemblies.

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Break Spectrum Results

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Break Spectrum Results

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Break Spectrum Results

[ ]a,c

Break Spectrum Results

- HPCF Line Break (cont'd)

[ ]a,c

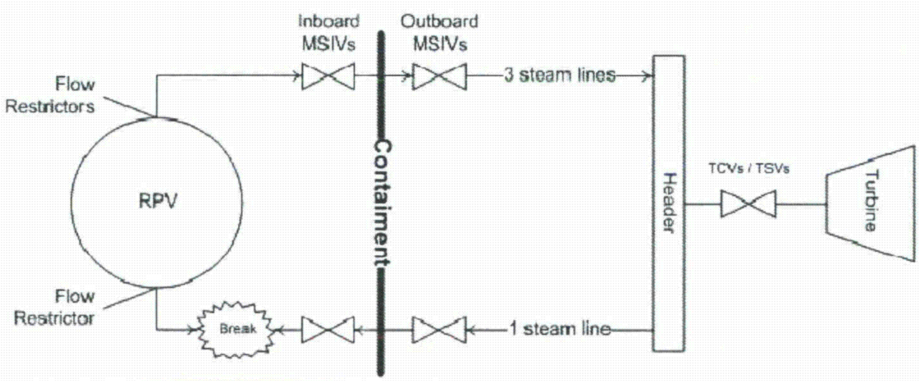
Break Spectrum Results

- HPCF Line Break (cont'd)

[ ]a,c

Break Spectrum Results

- Main Steam Line Break (MSLB)
  - 4 steam lines attach to the reactor vessel – each with an integral flow restrictor.
  - Break outside containment – isolated by MSIV closure.
  - Break inside containment – discharge from all 4 steam lines until MSIVs close.



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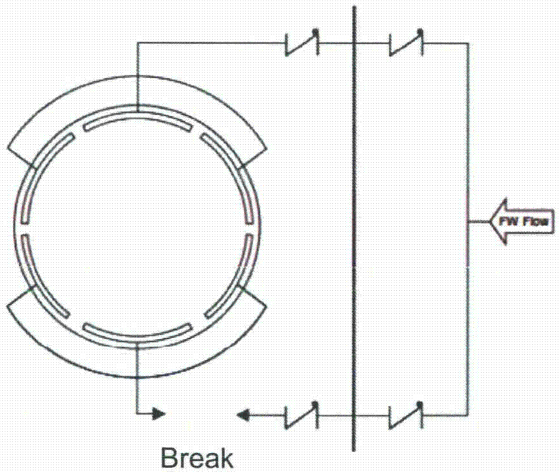
Break Spectrum Results

- MSLB (cont'd)
  - Limiting failure is the one that results in the least injection – failure of the EDG that powers 1 HPCF pump and 1 LPFL pump, with break in the steam line that feeds the RCIC turbine.
  - Remaining equipment – 1 HPCF + 2 LPFL + 8 ADS
  - Results
    - PCT occurs during pump coast down; no core uncovery
    - Break size sensitivity showed negligible difference in minimum inventory because steam line side isolates and the vessel side discharge is limited by the integral flow restrictor.
    - 90% core flow resulted in highest PCT, 111% core flow resulted in minimum inventory

Break Spectrum Results

- Main FW Line Break
  - 2 FW lines penetrate containment. Each line branches into 3 lines that penetrate the reactor vessel and connect to a sparger inside the downcomer.
  - The 3 FW spargers associated with a single FW line have 54 nozzles to distribute the feed water in the downcomer.
  - 1 train of LPFL injects into 1 FW line; RCIC injects into the other FW line.



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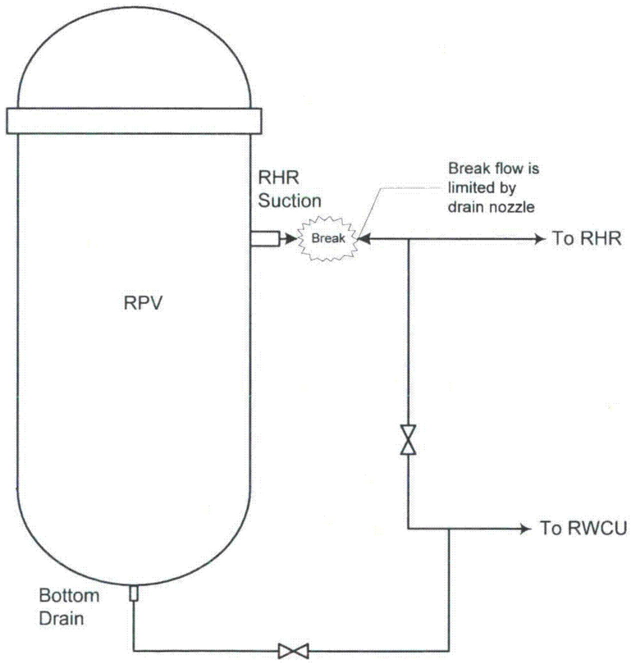
Break Spectrum Results

- Main FW Line Break (cont'd)
  - Failure of 1 EDG powering 1 HPCF pump and 1 LPFL pump results in the following equipment available
    - RCIC side break: 1 HPCF + 2 LPFL + 8 ADS
    - LPFL side break: 1 HPCF + 1 LPFL + 1 RCIC + 8 ADS
  - Results
    - PCT occurs during pump coast down; no core uncovery.
    - 90% core flow resulted in highest PCT; 111% core flow resulted in least inventory.
    - TCV closure: fast closure results in highest PCT with little effect on minimum inventory.
    - Largest break size results in minimum inventory with little effect on PCT.

Break Spectrum Results

- RHR Suction Line Break
  - The RHR suction line nozzle is located between the feed water nozzle and HPCF line nozzle.
  - The suction line also connects to the bottom head drain line.
  - Failure of 1 EDG results in:
    - 1RCIC + 1 HPCF +2 LPFL + 8 ADS



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Break Spectrum Results

- RHR Suction Line Break (cont'd)
  - Results
    - PCT occurs during pump coast down; no core uncovery.
    - 90% core flow resulted in highest PCT; 111% core flow resulted in least inventory.
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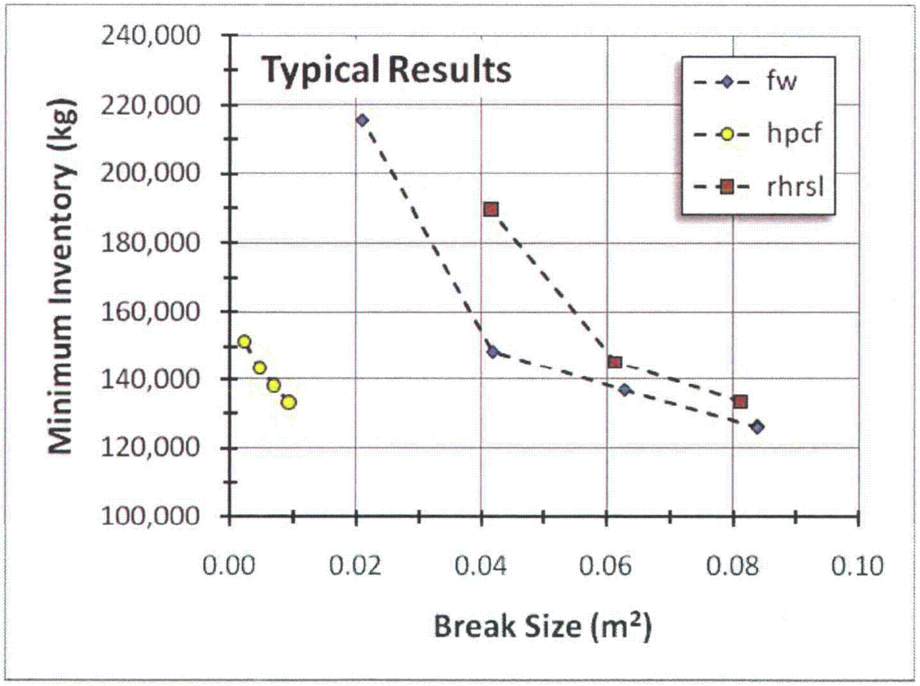
    - Largest break size results in minimum inventory; little effect on PCT.

Break Spectrum Results



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Break Spectrum Results

- Summary
  - PCT occurs during RIP coast down before actuation of ECCS.
  - ECCS performance can be judged by minimum reactor pressure vessel inventory.
    - Feed water line break had the smallest minimum inventory.
  - High initial core flow rate resulted in smallest minimum inventory.
  - No core uncovery, except for minimal uncovery of low power assemblies for breaks in HPCF injection line.

Draft SER Conditions and Limitations

- Modeling of longitudinal feed water line breaks shall be restricted to sizes greater than 50% of the size of a double-ended guillotine break in the feed water line.
- The DRAGON option shall not be used for hot channel analysis without prior review and approval.
- The compensation factor, which accounts for the effect of pressure on the measurement of WR level should be used in all future analyses.
- If downward flow from the upper plenum into the core region is predicted during the HPCF injection period, the two-phase level tracking and injection flow – fluid interaction code option should be used.
- Changes in numerical methods to improve code convergence or code enhancements or error corrections must be tested, and auditable records must be kept.

Summary and Conclusions

- Evaluation model is very conservative:
  - Hot assembly power
  - RIP coastdown
  - Other App. K requirements
- PCT occurs before actuation of ECCS
- Core uncovery limited to some low power assemblies for certain scenarios
- The model is applicable to the ABWR

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