Westinghouse Non-Proprietary Class 3

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ABWR Fuel LTR – WCAP-17116-P

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

Presentation to ACRS

04/11/2013

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Agenda

- Attendees
- Introduction
- Westinghouse Methodology
- Important Features of ABWR
- ABWR Evaluation Model
- Break Spectrum and Results
- LOCA Methodology Summary
- Response to Question from ACRS Subcommittee Meeting
- 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

- Purpose of the ABWR ECCS Topical
  - Demonstrate that the Westinghouse App. K methodology is acceptable for the ABWR
    - Provide additional qualification
      - Reactor Internal Pump (RIP) model
      - Prediction of dryout

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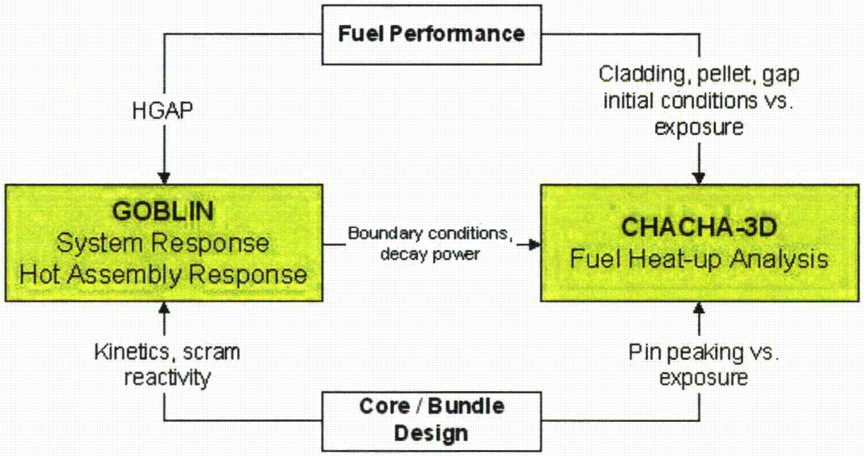
Westinghouse Methodology

- 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 required for ABWR application**

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

Important Features of the ABWR

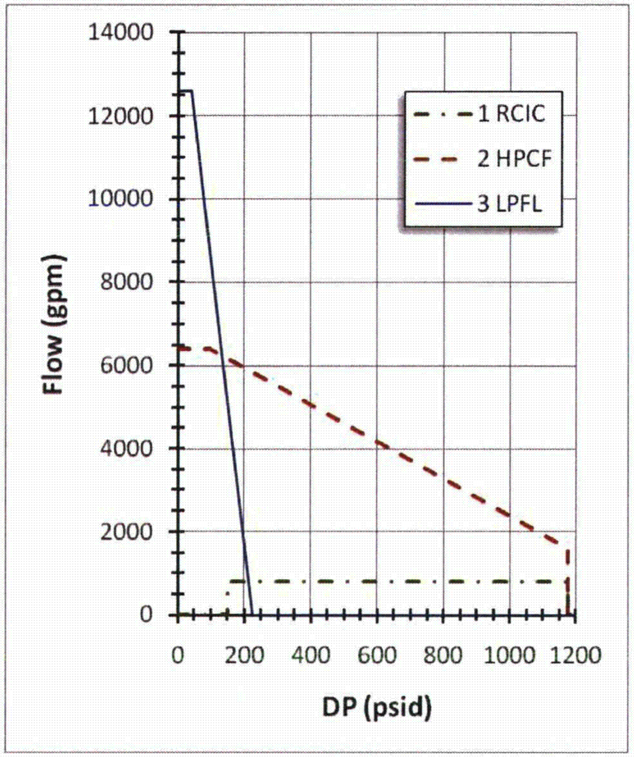
- Recirculation System
  - 10 Reactor Internal Pumps (RIPs) vs. 2 external loops / jet pumps
  - Lower inertia leads to faster coastdown time constant (< 1s vs. ~ 5s)
- No Large Breaks Below Top of Active Fuel (TAF)

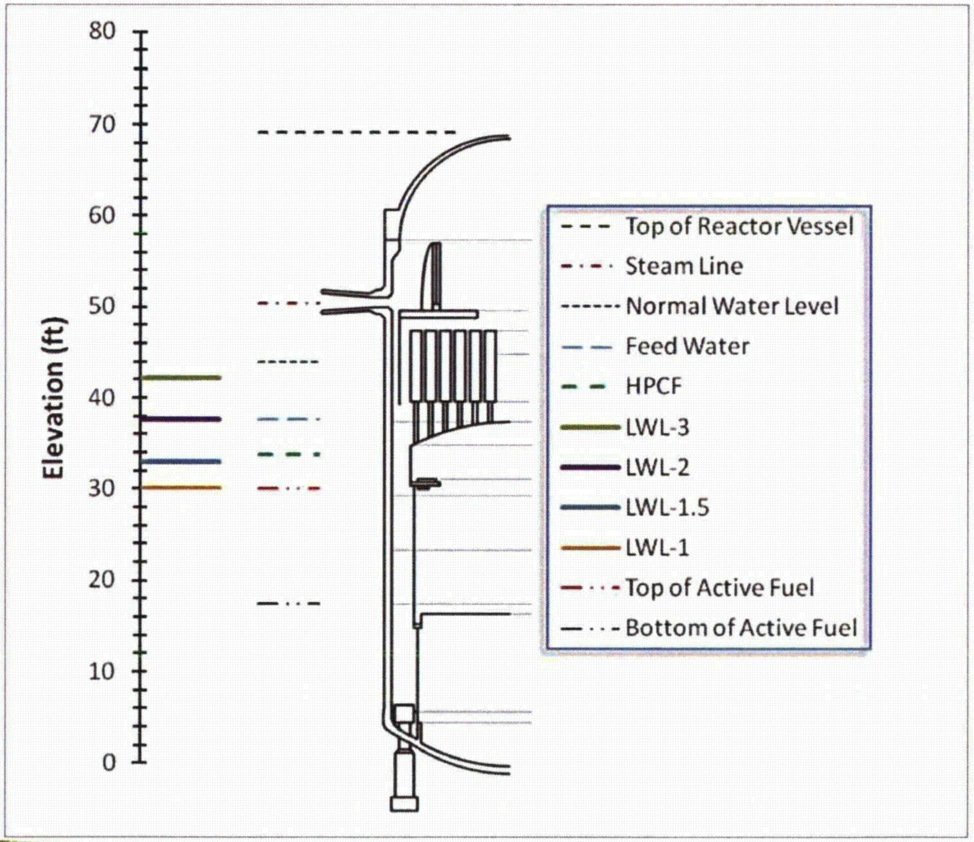
Break	Area	Elev. Above TAF
BWR Recirculation Line Break (double-ended)	7.23 ft^2	-16.7 ft
ABWR Steam Line Break (after MSIV isolation)	1.06 ft^2	20.4 ft
ABWR FW Line Break (vessel side)	0.90 ft^2	7.6 ft
ABWR RHR Suction Line Break	0.85 ft^2	5.8 ft
ABWR HPCF Line Break	0.10 ft^2	3.2 ft
ABWR Bottom Drain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

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 30s 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 using a very conservative definition of the hottest node
  - 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 1s
  - Steam line isolated by turbine control valve (TCV) closure (fast / slow)
  - RIPs connected to MG 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 (4.5s + 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

- Modeling Considerations
  - Fast Coastdown of RIPs Expected to Result in Early Dryout
    - Core noding and pump modeling expected to be important in prediction of dryout
    - Benchmarked FRIGG Transient Dryout Experiments
      - Determined that additional axial nodes were necessary for conservative prediction of decreasing flow tests
    - Used minimum moment of inertia for RIPs
      - Matched minimum pump coastdown time constant

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	Break + Failure of 1 EDG
FW Line (RCIC side)	--	1	2	8	Break + 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	Break + Failure of 1 EDG
Drain Line	1	1	2	8	Failure of 1 EDG

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Break Spectrum Results

Break Location	PCT °F	Minimum Inventory (Mlb)
HPCF Line	1306	0.291
MS Line (inside containment)	1213	0.358
MS Line (outside containment)	1234	0.532
FW Line	1310	0.272
RHR Suction Line	1310	0.291
RHR Injection Line	1305	0.470
Drain Line	1306	0.545

* PCTs occur during pump coastdown before actuation of ECCS; PCT Limit 2200°F

LOCA Methodology Summary

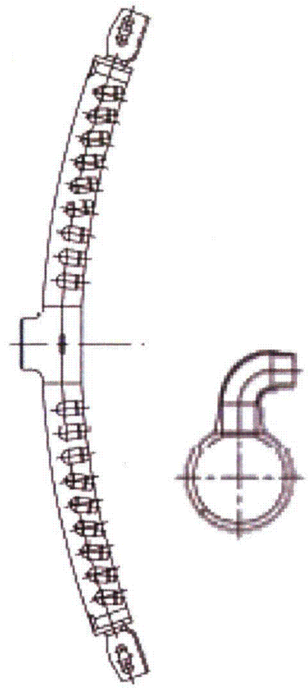
- Evaluation model is very conservative:
  - Hot assembly power
  - RIP coastdown
  - Other App. K requirements
- PCT occurs before actuation of ECCS
  - ABWR LOCA is a benign event, similar to ‘loss of flow’
- Core uncovery limited to some low power assemblies for HPCF break only but does not lead to PCT
- The model is applicable to the ABWR

Response Question from ACRS Subcommittee Meeting

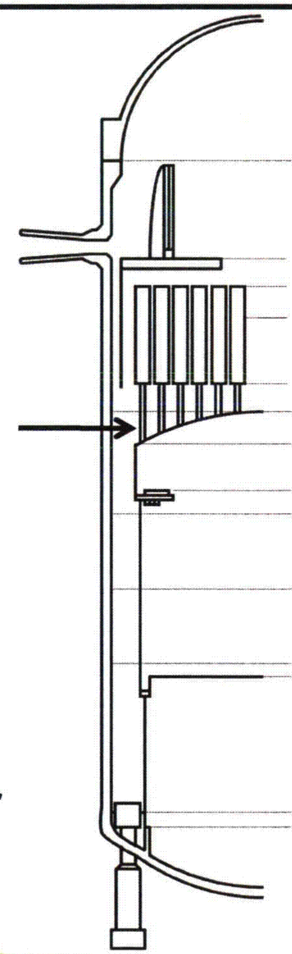
- HPCF Line Break
  - Results in partial uncovery of some low power assemblies
  - LPFL injects into steam environment after ADS actuation
  - GOBLIN, a thermal equilibrium code, forces complete condensation at the injection location
  - *ACRS SC Question: Could incomplete condensation result in asymmetric subcooling at core inlet and result in more uncovery?*

Response Question from ACRS Subcommittee Meeting

- LPFL injection:
  - Into one of the two FW lines (3 spargers per line) and one of the two LPFL spargers
  - Injection toward the shroud head dome
  - Injection velocity ~ 5 – 25 ft/s, depending on the sparger
  - Injection made along a minimum of 180° of circumference



LPFL Sparger



Response Question from ACRS Subcommittee Meeting

- LPFL Injection Interaction
  - Injected water will impact the shroud dome and separator standpipes, flow downward along the shroud dome and shroud, and into the boiling mixture in the lower downcomer
  - The water then flows downward through the idle RIPs and into the boiling water in the lower plenum
  - Any water in the lower plenum that remains subcooled will settle to the bottom due to its higher density, where it will subsequently be heated by the reactor vessel and the control rod structures filling the lower plenum

Response Question from ACRS Subcommittee Meeting

- LPFL Injection Interaction
  - Core flow is driven by two-phase natural circulation
    - Very unlikely that coolant entering the core would be subcooled (RIPs are idle and flow rates are very low)
  - However, water entering the boiling mixture in the lower downcomer might be subcooled due to incomplete condensation / heatup
    - Mixing would reduce the boiling in the lower plenum
  - A sensitivity study was performed to assess this effect
    - The LPFL injection location was moved to a location below the two-phase mixture in the downcomer assuming no heatup

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Response Question from ACRS Subcommittee Meeting

- Results of the study:
  - The hot assembly is unaffected – PCT (1306°F) occurs during pump coastdown and there is no subsequent uncovery
  - Some low power assemblies might see ~ 1 ft additional uncovery due to reduced two-phase swell caused by the mixing of subcooled water with the boiling mixture in the lower plenum and downcomer
  - The peak cladding temperature in the low power assemblies (~ 660°F) remains well below the PCT in the hot assembly, which is well below the LOCA limit (2200°F)
  - Ultimately the core is recovered as the injection flow exceeds the break flow

Conclusions

- Evaluation model is very conservative
- Potential for subcooled water entering the core is unlikely
- Effect of assuming subcooled water entering the mixture in the downcomer has some effect on local results, but does not change overall results
  - PCT occurs in hot assembly before actuation of ECCS
- The model is applicable to the ABWR

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