DCP_NRC_003265
April 4, 2014

ENCLOSURE 4

Design Centered Working Group ACRS Update 04-09-14:
Changes to Passive Core Cooling System Condensate Return

(Non-Proprietary)

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ACRS Meeting 04-09-14
"Changes to Passive Core Cooling System Condensate Return"

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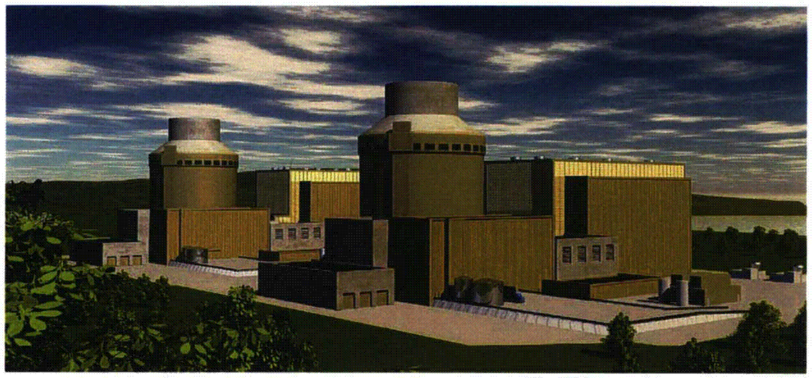
Westinghouse ACRS UPDATE 04-09-14



"Changes to Passive Core Cooling System Condensate Return"

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Purpose

- Explain issue with containment condensate return to In-containment Refueling Water Storage Tank (IRWST) for long-term Passive Residual Heat Removal (PRHR) operation after station blackout event
- Review design changes to improve the containment condensate return to the IRWST
- Review calculations/analysis status that support the long-term PRHR HX decay heat removal operation
  - Each calculations purpose, methodology, and results

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AGENDA*

- Overview of long-term PRHR HX operation*
  - Includes summary of issue, plant changes, licensing actions
- **AP1000** plant safe shutdown systems / operation
- Design changes to improve containment condensate return to IRWST
- Analyses performed to support long-term PXS operation:
  - Each calculations purpose, methodology, and results
- WEC condensate return testing

* Open portion of meeting only includes first item

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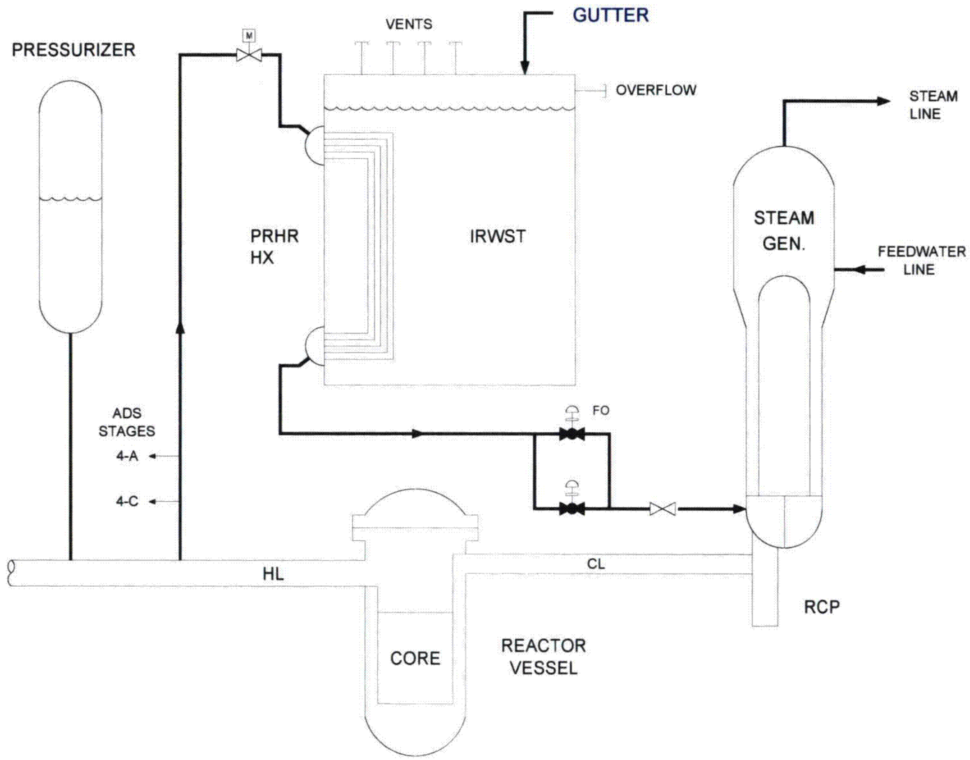
PXS Safety Design Description: non-LOCA Operation

- During non-LOCA events PRHR HX transfers heat from RCS to IRWST
  - Takes ~4 hours for IRWST to heat up to saturation and start steaming
  - Steam is discharged from IRWST to containment through vents in IRWST roof
  - Most steam condenses on containment vessel (CV) and returns to IRWST via gutter



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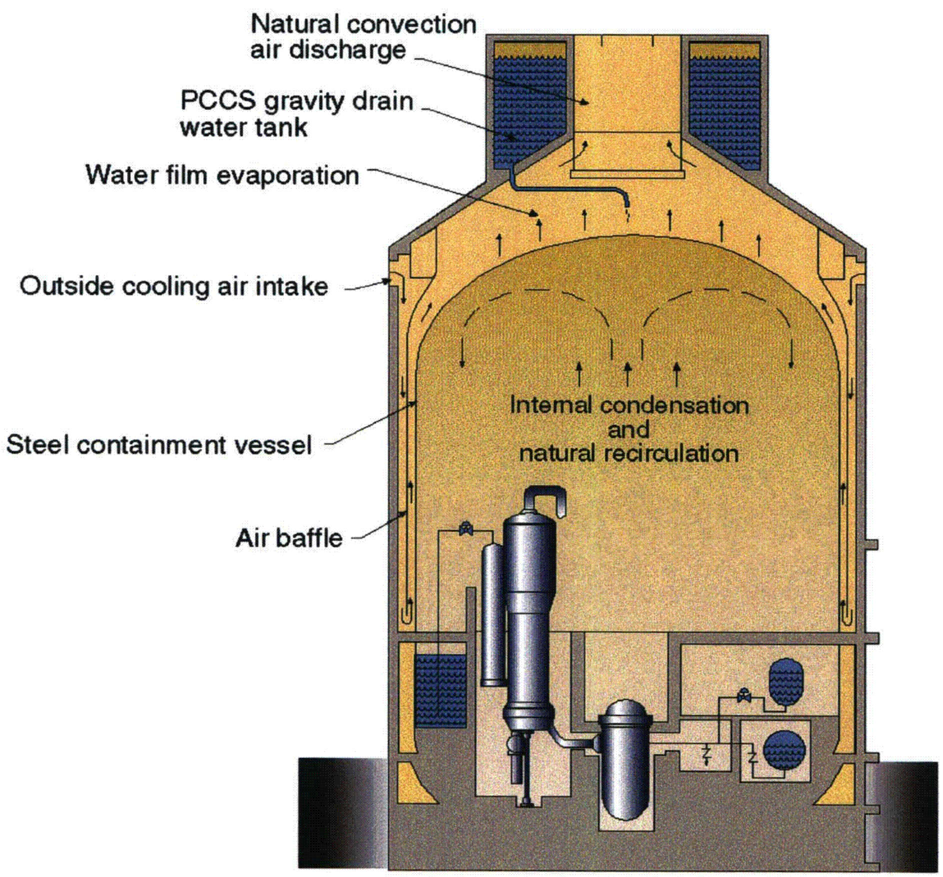
PXS Safety Design Description: non-LOCA Operation

- Steam from IRWST increases containment pressure causin actuation of passive containment cooling
- Most of the steam condense: containment vessel (CV)
- Condensate flows down containment walls and back i IRWST via gutter
- Some steam lost to
  - Pressurizing containment
  - Condensation on walls/floo
  - Condensate dripping / splas from CV



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AP1000 Plant Safe Shutdown

- In non-loss of coolant accident events, the PRHR HX will bring the plant to safe shutdown and maintain this condition
  - **AP1000** plant safe shutdown defined as reactor coolant system (RCS) temperature ≤ 420°F in 36 hour
  - This temperature does not represent a plant safety limit
    - If the RCS temperature is somewhat higher it would have no consequences
- In loss of coolant accidents, passive safety injection and ADS will achieve and maintain safe shutdown for an unlimited time
  - With support required for PCS after 72 hours
  - These features also provide diverse safety-related backup to PRHR HX operation

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Technical Issue: Identification

- During detailed design implementation Westinghouse identified the need to revisit the technical basis for the condensate return rate
  - Condensate return rate varies with time
  - Additional mechanisms for condensate loss were identified or better quantified
- Westinghouse initiated a study to fully characterize and quantify condensate return rate
  - Testing performed to quantify losses due to physical features on CV
  - Analysis of thermodynamic behavior during steaming and condensation undertaken

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Technical Issue: Quantification

- Westinghouse test / analysis results:
  - Condensate return rate was lower than assumed in the DCD Chapter 19E shutdown temperature evaluation using the PRHR HX
  - Plant would still be safe, however the Chapter 19E shutdown temperature evaluation would not be bounding
- Decision made to improve gutter system condensate return
  - Use polar crane girder (PCG) and stiffener as intermediate level gutters and add downspouts to transfer directly to IRWST
  - Modify operating deck gutter to reduce losses
  - Allows plant to meet safe shutdown temperature / time (Chapter 19E)

Summary of Licensing Actions

- January 2013
  - Westinghouse confirmed need to change standard design
  - Duke Energy and Westinghouse ISG-011 evaluation confirmed need to inform NRC prior to Levy COL
- January 15, 2014
  - Westinghouse calculations for license submittal complete
    - Containment response analysis for long term PRHR operation
    - Condensate return to IRWST for long term PRHR operation
    - PRHR sizing / performance
    - **AP1000** plant safe shutdown temperature evaluation
- February 7, 2014
  - Levy exemption request update submitted
- March 20, 2014
  - Vogtle pre-submittal meeting held

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COL Applicant/Holder Licensing Basis Impacts

- Part 2 – Final Safety Analysis Report (FSAR)
  - Chapter 1, Table 1.8-201, Summary of FSAR Departures from the DCD
  - Section 3.2, Classification of Structures, Components and Systems
  - Section 3.8, Design of Category 1 Structures
  - Section 5.4, Component and Subsystem Design
  - Section 6.3, Passive Core Cooling System
  - Section 14.3, Certified Design Material
  - Chapter 19E, Shutdown Evaluation
- Part 4 – Technical Specifications
  - Change to Tech Spec bases only

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Closed Meeting Portion

AP1000 Plant Condensate Return to IRWST

Terry Schulz
Consulting Engineer, Westinghouse Electric Co.

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IRWST Steam Condensate Return Summary

- Some **AP1000** plant changes will be made to increase condensate return to IRWST
  - Downspouts from PCG and Stiffener to IRWST
  - Gutter location and design
  - Elimination of many H2 sensor cable support plates in dome
- Testing and analysis confirm that revised design meets safe shutdown cooldown and duration criteria
- Testing, analysis and design changes are undergoing staff audit
- Additional testing will be performed for future margin recovery

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Agenda

- Overview of long-term PRHR HX operation
  - Includes summary of issue, plant changes, licensing actions
- **AP1000 plant safe shutdown systems / operation**
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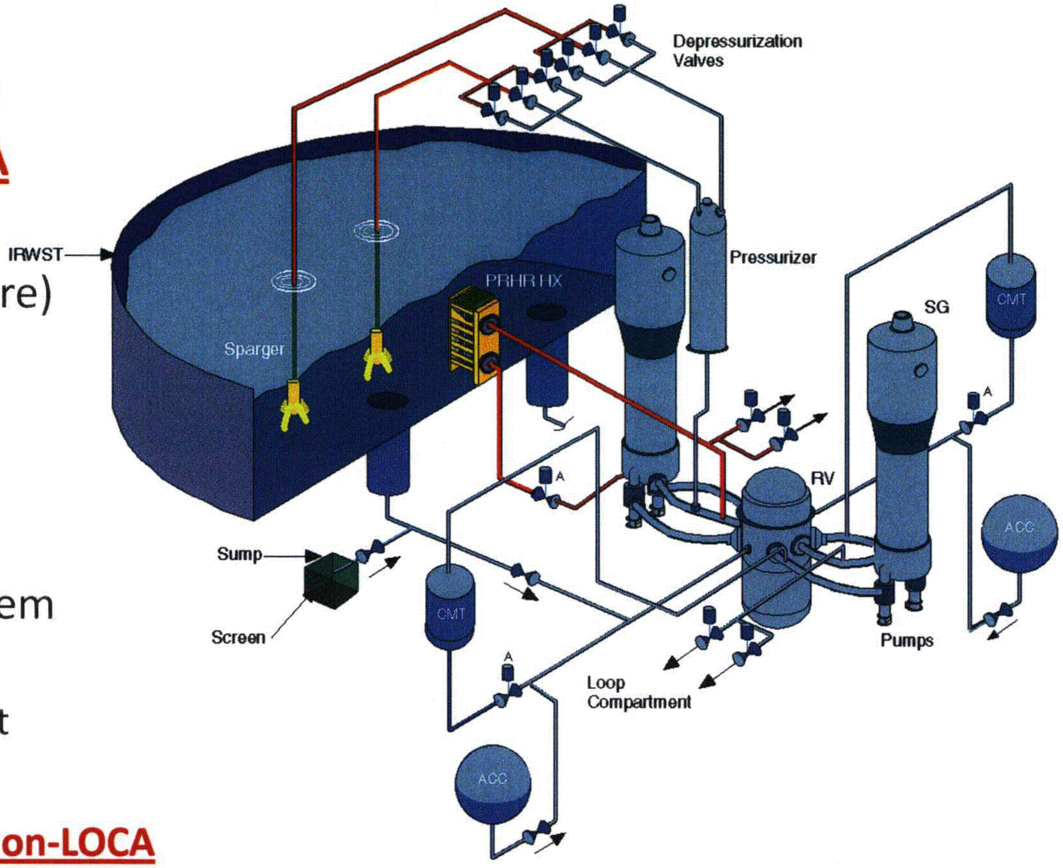
PXS Decay Heat Removal

- PRHR HX
  - Natural circ. decay heat removal
  - **Long-term cooling for non-LOCA**
- Passive safety injection
  - Core makeup tanks (High Pressure)
  - Accumulators (Intermediate Pressure)
  - IRWST Injection (Low Pressure)
  - Containment Recirculation
  - Automatic depressurization system
    - Stages 1-3 release to IRWST
    - Stage 4 releases to containment
  - Long-term cooling for LOCA
    - **Backup long-term cooling for non-LOCA**



If PRHR cooling decreased below decay heat, backup core cooling would be provided by passive feed/bleed (safety related)

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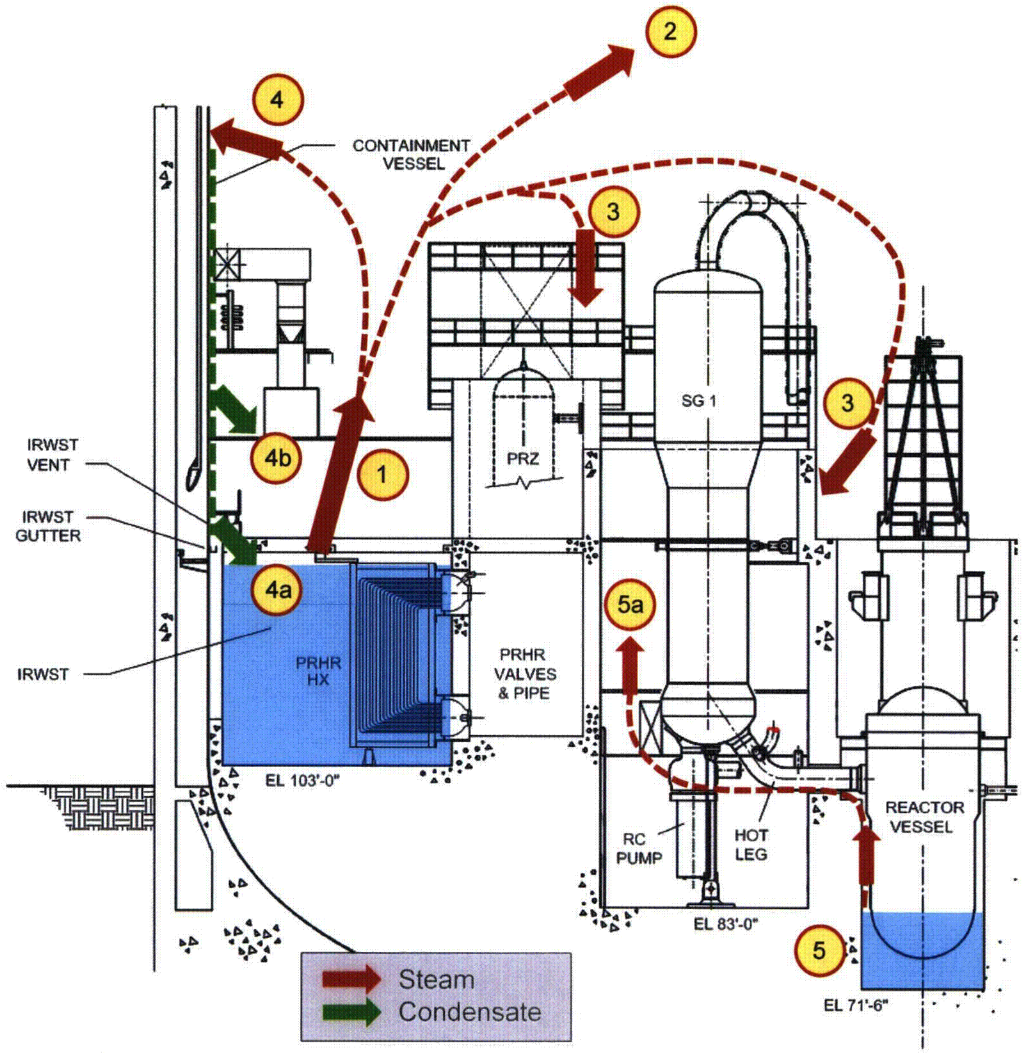
Where Does IRWST Steam Go?

1. Steam leaving IRWST
2. Pressurizes containment
   a. Lost from IRWST
3. Condenses on walls, floors, structures
   a. Lost from IRWST
4. Condenses on CV
   a. Most collected and returned to IRWST
   b. Some splashes / spills off
5. Losses from IRWST collect under RV, contact hot RV
   a. Steam rises up into cont.



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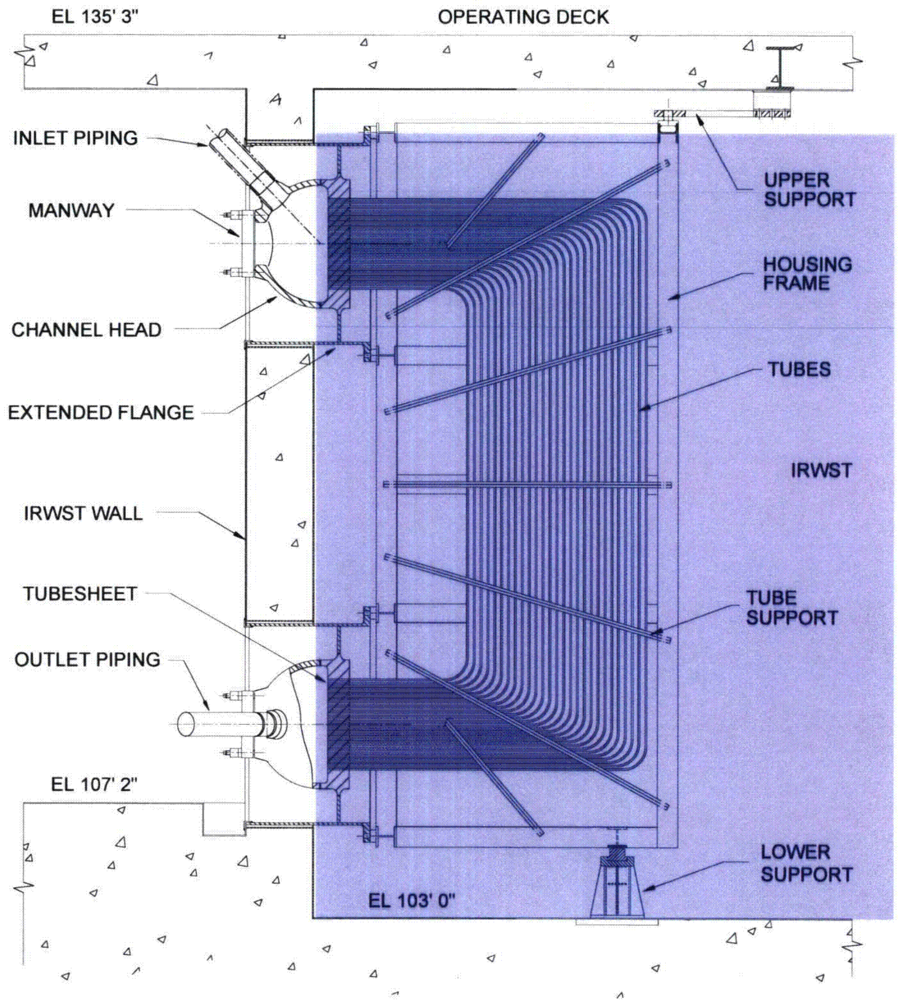
Passive Decay Heat Removal

- DCD Safety Analysis assumes a constant fraction of steam to atmosphere returned to IRWST
  - Actual losses from the IRWST are larger and vary with time
- Multiple mechanisms exist for condensate losses
- Condensate losses will cause IRWST level to decrease
- As PRHR HX tubes uncover, performance is reduced
  - Safe shutdown temperature can be maintained even with substantial uncovery



AP1000 Plant Safe Shutdown Criteria

- Safe Shutdown temperature (420°F) is a licensing commitment
- This temperature was selected to achieve a safe stable, low-energy condition in the RCS within the PRHR HX capability
  - RCS pressure will decrease to a small fraction of its design pressure
  - 420°F allows pressure across RCS to be ~265 psid (10.6% of RCS design)
    - Assumes RCS drops to saturated pressure, reasonable since no Pzr heaters

Temp (F)	Sat. Pres. (psia)	Delta Pres. (psid)*	Percent RCS
420	310	265	10.6%
425	330	285	11.4%
430	345	300	12.0%
440	380	335	13.4%

* Reduced by 30 psig containment pressure

If RCS temperature slightly exceeded 420°F, Safe Shutdown would not be challenged

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AP1000 Plant Safe Shutdown Criteria

- DCD / FSARs state PRHR HX can maintain safe shutdown conditions for non-LOCA accidents "indefinitely"

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  - Open-loop core cooling using ADS and passive injection is always available as a safety backup to closed-loop PRHR HX cooling

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Systematic Design Process Applied

- IRWST steam condensate return
  - Design activities
    - Define problem
    - Preliminary PIRT, design / analysis, testing
    - Cross functional design review including range of WEC & utility experts
    - Final PIRT (with external review)
    - Second cross functional design review including WEC, utility & external
    - Utility audits
    - Final verified analysis / calc notes
    - Two independent challenge reviews
    - Margin recovery testing (now through 8/14)
  - NRC staff interactions
    - Several information meetings (9/13, 12/13)
    - Audit meetings (1/30/14, 3/18/14)

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Design Changes To Improve Condensate Return to IRWST After Station Blackout

- Changes developed to increase condensate return to the IRWST
  - Use polar crane girder and internal stiffener as intermediate gutters and add down spouts to drain condensate to IRWST
    - Minimizes losses associated with flow over obstacles
  - Optimize IRWST gutter
    - Extended to collect above upper equipment hatch and personnel airlock
  - Change routing of cables to hydrogen sensors
    - Reduces quantity of support plates (obstacles) attached to the containment dome

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Design Changes To Improve Condensate Return to IRWST After Station Blackout

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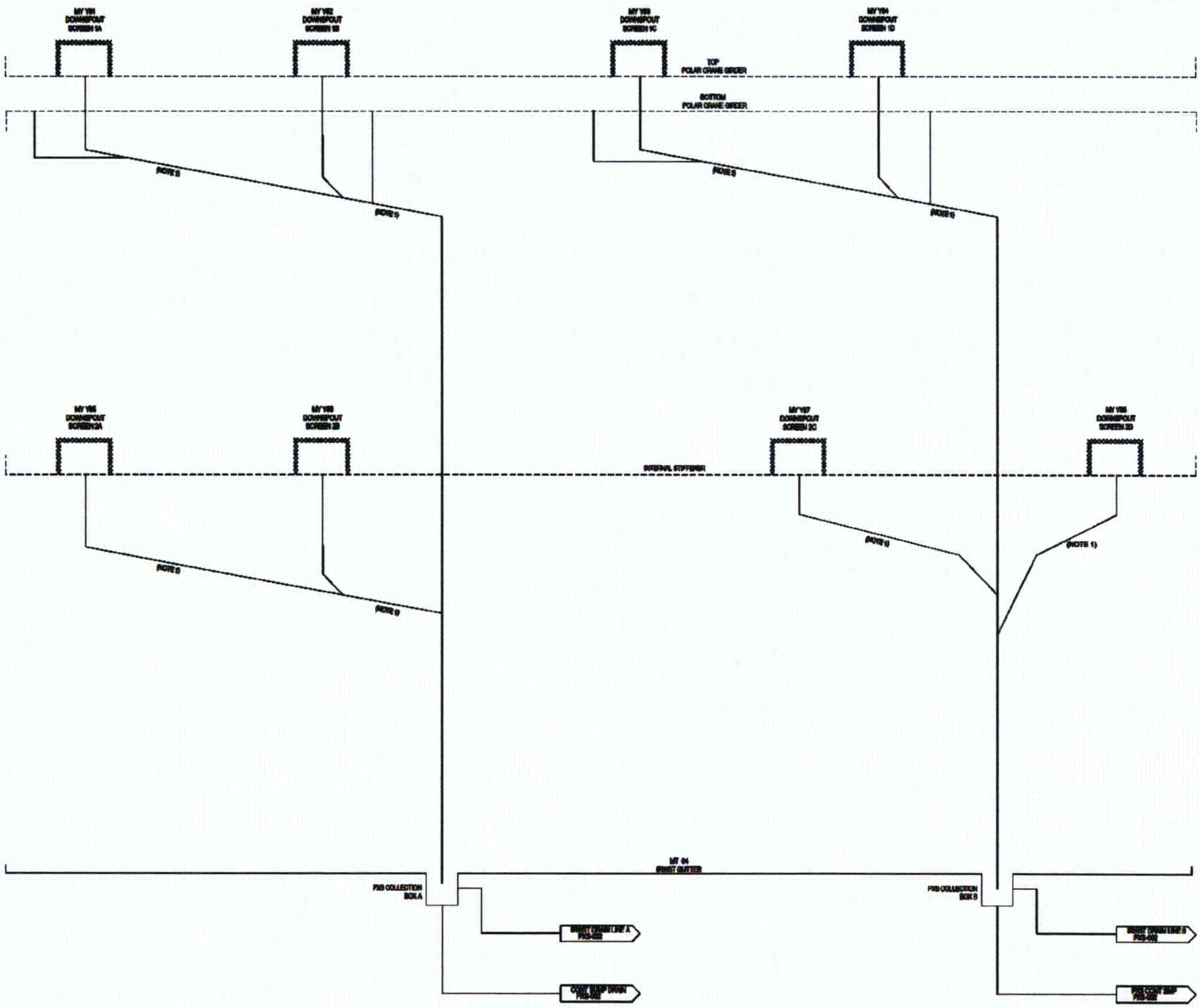
Design Changes To Improve Condensate Return to IRWST After Station Blackout

- Down spouts added at internal stiffener and polar crane girder to direct condensate to IRWST through the collection boxes
- Drain holes plugged
- Rough screens over downspout entrances prevent large objects from entering downspout piping



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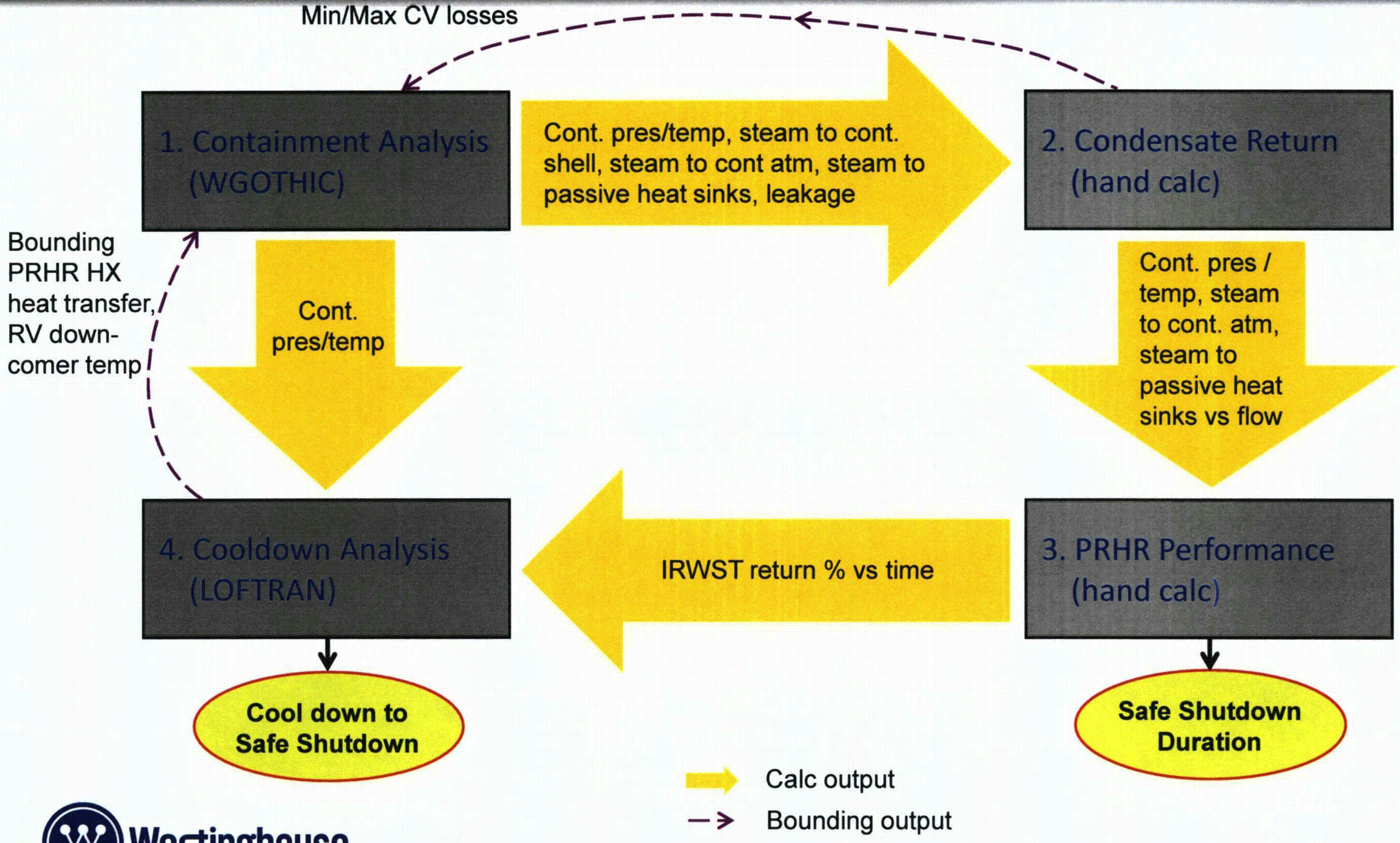
Analysis Approach



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1. Containment Response Analysis for the Long Term PRHR Operation

- Purpose is to quantify IRWST water losses due to:
  - Mass of steam condensing on internal heat sinks
  - Mass of steam in atmosphere
  - Mass of steam lost due to containment leakage
- Approach
  - Start with WGOTHIC containment peak pressure model from DCD Rev 19
  - Methodology was thoroughly reviewed / verified
  - Made changes / additions to models and to inputs to adequately model steam condensate that doesn't return to IRWST

1. Containment Response Analysis for the Long Term PRHR Operation

- Changes made to models to adequately quantify steam condensate that doesn't return to the IRWST

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1. WGOTHIC Containment Model Changes Condensate Hold-up

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1. Containment Response Analysis for the Long Term PRHR Operation

- Sensitivity studies were performed to identify conservative initial conditions and heat transfer assumptions
- Analysis cases were performed with upper and lower bounding PXS condensate spill fractions
- Analysis cases were performed to determine conservative and best estimate IRWST losses
  - Conservative results support justification of no impact to Chapter 15
  - Best Estimate results support Chapter 19 (safe shutdown and PRA)

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1. WGOTHIC Containment Model Changes Containment Heat Sinks, PCS Performance

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1. Containment Response Analysis for the Long Term PRHR Operation

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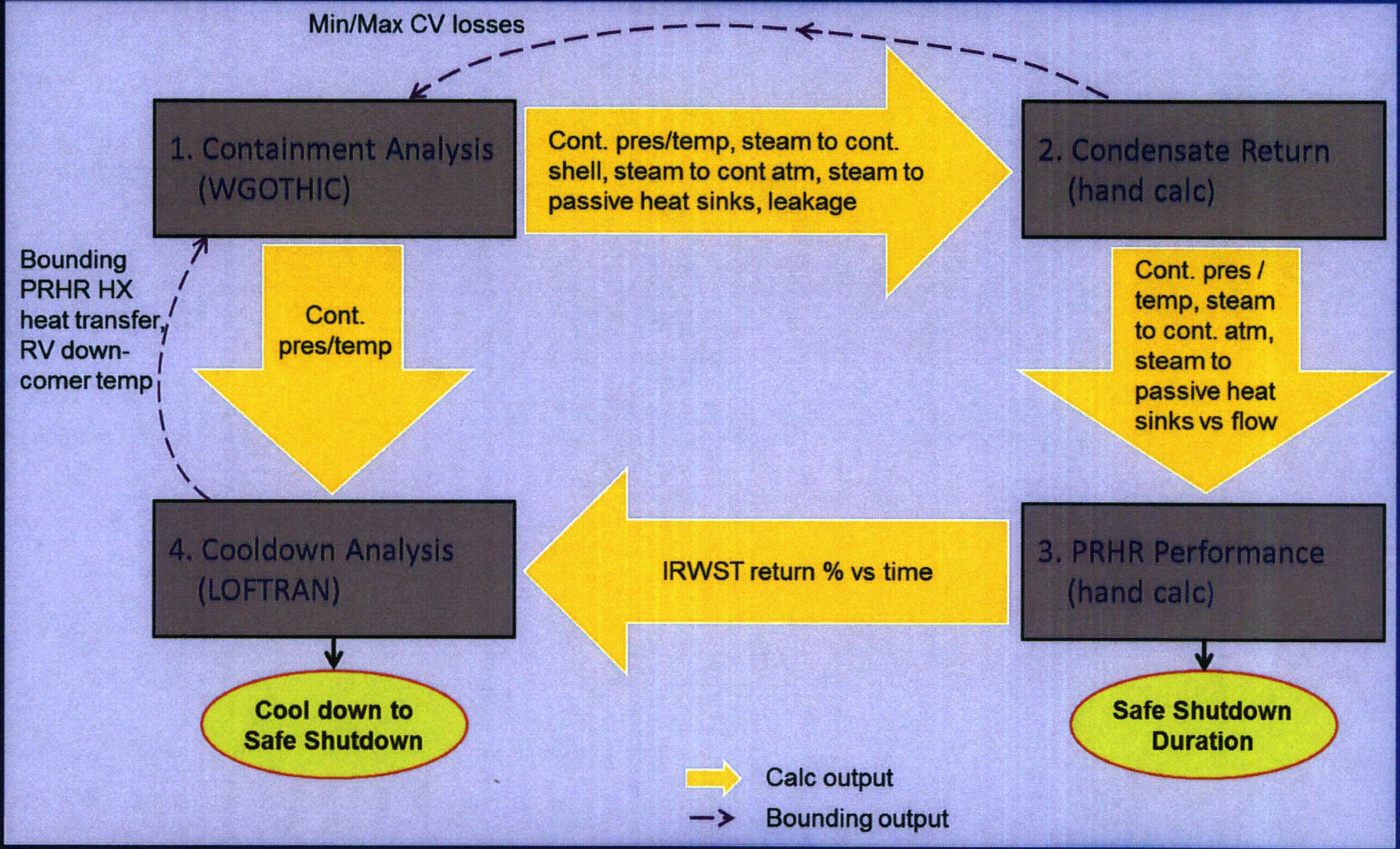
Calculation 2 - Condensate Return to IRWST for Long Term PRHR Operation



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2. Condensate Return to IRWST for Long-Term PRHR Operation

- Purpose is to quantify losses from the IRWST

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- Losses due to:
  - Steam to pressurize containment (WGOTHIC)
  - Steam to passive heat sinks (WGOTHIC)
  - Containment leakage (WGOTHIC)
  - Various losses from CV shell
  - Hold up volume on surfaces
- Provides input to PRHR HX calculation in convenient format

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2. Condensate Return to IRWST for Long-Term PRHR Operation

- Losses from CV shell include
  - "Rainout" from center of CV dome

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  - CV plate welds / misalignment in dome

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  - Attachments (support plates) to CV dome and cylinder

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  - Entrance to gutter

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2. Condensate Return to IRWST for Long-Term PRHR Operation

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2. Condensate Return to IRWST for Long-Term PRHR Operation [ ]a,c

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2. Condensate Return to IRWST for Long-Term PRHR Operation

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2. Condensate Return to IRWST for Long-Term PRHR Operation

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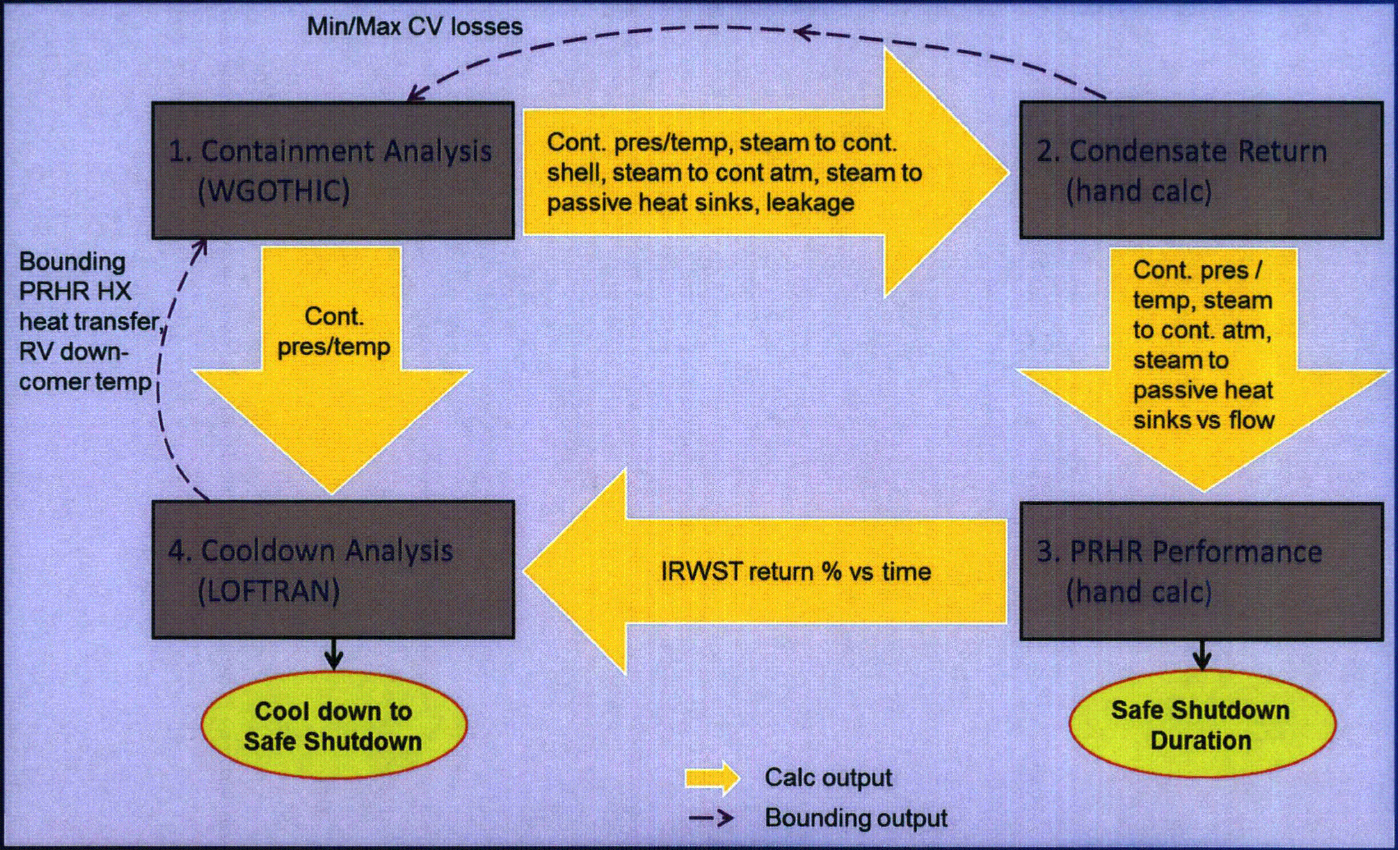
Calculation 3

PRHR HX Sizing / Performance Calculation



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3. PRHR HX Performance

- Purpose
  - Input to RCS cooldown safe shutdown analysis (Calculation 4)
    - Time for IRWST to reach saturation
    - Time to top PRHR HX tube uncovery
    - Condensate return rate vs. time
  - Demonstrate adequate safe shutdown duration
  - Demonstrate no impact to DCD Chapter 15 non-LOCA analysis

3. PRHR HX Performance

- Calculates long-term transient performance, including:
  - RCS cooldown / re-heat (long-term)
    - Sensible and decay heat
  - IRWST heatup / boiloff due to PRHR HX heat input
  - PRHR HX performance based on RCS and IRWST temperature, IRWST water level
  - IRWST steam losses (Calc 2)
    - Steam to containment atm
    - Steam to passive heat sinks (floors, walls, structures)
    - Splashing / dripping from CV

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3. PRHR HX Performance (Cont.)

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3. PRHR HX Sizing / Performance Safe Shutdown Duration (BE)

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3. PRHR HX Sizing / Performance Safe Shutdown Duration (BE)

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3. PRHR HX Sizing / Performance

- DCD/FSAR Chapter 15 non-LOCA evaluation
  - Time of interest for Chapter 15 non-LOCA analysis
    - Longest non-LOCA accident analysis is < 8 hour
    - Limiting safety criterion occurs in < 2.5 hours
  - PRHR HX tubes don't uncover until well after time for longest Chapter 15 non-LOCA analysis

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Chapter 15 non-LOCA analyses are not adversely affected by the decreased IRWST condensate return rates

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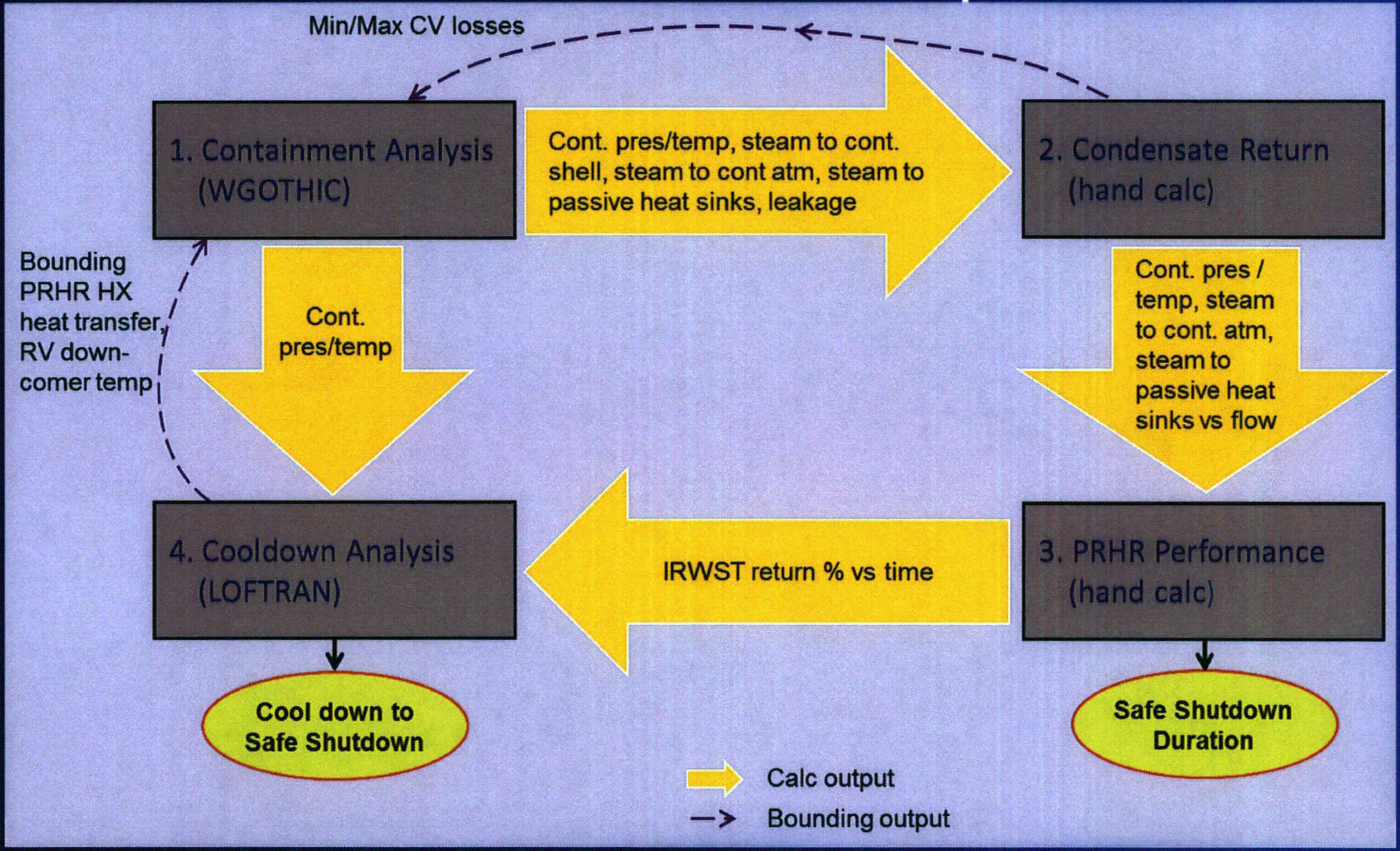
Calculation 4

AP1000 Plant Safe Shutdown Temperature Evaluation



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4. Safe Shutdown Temperature Evaluation

- Purpose
  - Verify the PRHR HX can reduce the core average temperature to long-term safe shutdown temperature of 420°F in 36 hours
- Methodology
  - Based on existing LOFTRAN analysis which supports the DCD Chap 19E (Rev 19)
    - Revised to account for higher / variable steam condensate losses
  - Complete RCS model including models of the PRHR HX, CMTs and the IRWST

4. Safe Shutdown Temperature Evaluation

- Input into Calculation 4 from other calculations
  - Containment pressure vs. time from Calculation 1
    - Used to determine the saturation temperature of the IRWST since containment is pressurizing
  - IRWST condensate return rate vs. time from Calculation 3
    - Fraction of mass returning to IRWST as a function of the mass boiled off
  - Chapter 15 Loss of Normal Feedwater with consequential Loss of Offsite Power analysis used as initiating event
    - This event was selected as it maximizes the heat load to the PRHR HX by reducing the secondary side capability

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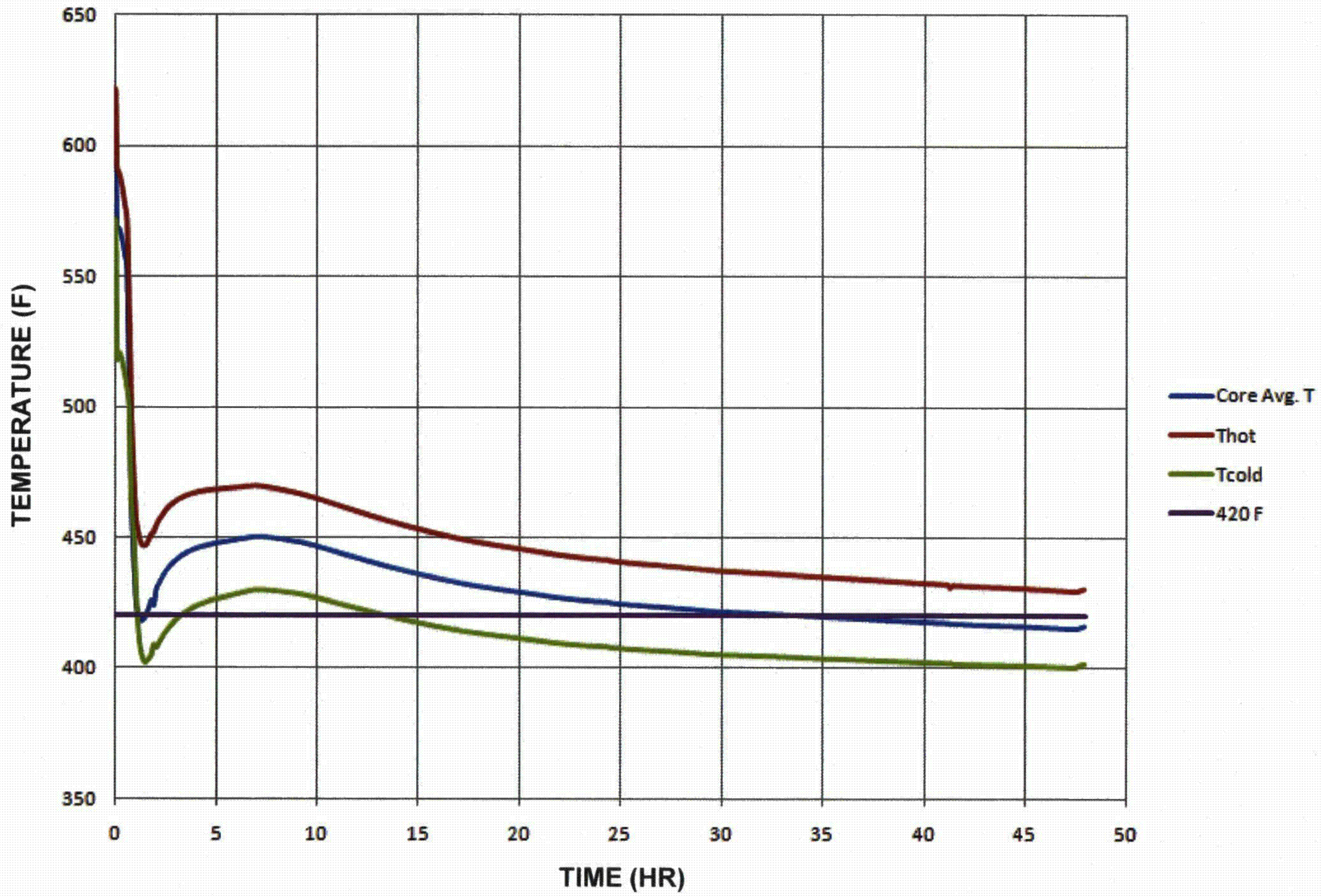
4. Safe Shutdown Temperature Evaluation

- Summary of results
  - A core average temperature of 420°F is reached at approximately 34.6 hours



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Questions Raised By NRC During Audit

- Questions under discussion
  - Reactor vessel steaming
  - Initial IRWST temperature vs containment structure temperature
  - Containment structure film holdup amount
  - Containment passive heat sinks amounts
  - DCD Chapter 15 impacted
  - Decay heat
  - Operating procedure for ADS post 24 hour
  - Containment vessel dome weld discontinuities
  - CV support plate losses at high temperatures
  - Other more straight forward items

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AP1000 Condensate Return to IRWST PIRT and Testing

Presentation Outline

- Review of previous testing
  - AP600 large scale test
  - Containment testing performed outside Westinghouse
  - **AP1000** condensate return testing – phase 1
- Final PIRT
- Margin recovery testing

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Review of Previous Testing

AP600 Large Scale Test

- Used to provide test data for the qualification of the WGOTHIC computer analysis code
- Prototypic temperatures, pressures and atmosphere conditions
- Also measured the relative condensate return from the containment surface and other areas

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Review of Previous Testing

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Review of Previous Testing

Phase 1 Condensate Return Tests

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- Tested CV vertical wall
  - 55' high and 6' wide
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Review of Previous Testing

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Review of Previous Testing

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Review of Previous Testing

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Final PIRT for Condensate Return

- Phenomena Identification & Ranking Table (PIRT)
  - Follow procedure from Regulatory Guide 1.203
  - Using Westinghouse experts and industry
    - Define scenario / phases
    - Specify Figure of Merit
    - Identify and rank phenomena

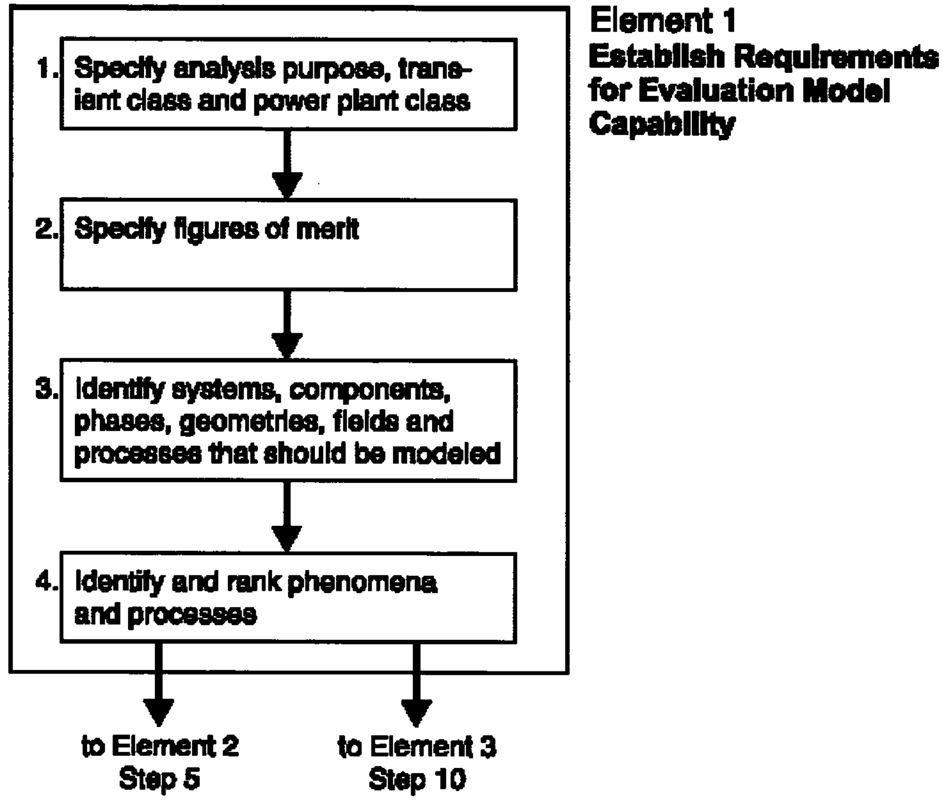

Figure 2. Steps in Element 1

Ref – RG 1.203, pg 8

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Final PIRT for Condensate Return

- Update PIRT from Phase 1

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Final PIRT for Condensate Return

Internal PIRT Committee

- Twelve Westinghouse experts in thermal-hydraulics and safety analysis

External Expert Review

- Dr. Jacopo Buongiorno, Massachusetts Institute of Technology, two-phase flow, boiling heat transfer expert
- Dr. S.C. Yao, Carnegie-Mellon University, two-phase flow, PWR safety analysis expert
- Mr. L.E. Conway, Westinghouse Electric Co. (retired), co-inventor of the AP600/**AP1000** passive containment cooling system
- Mr. Kevin Ramsden, Fauske & Associates, Inc., Chief engineer

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Final PIRT for Condensate Return

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Margin Recovery Condensate Return Testing

- Objective of testing
  - Additional testing will be advantageous to quantify excess conservatism in the current analysis for possible use in the future

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- Test facility design
  - Facility overview
  - Test articles
  - Instrumentation
- Test matrix
- Schedule

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Obstacle Induced Dripping – Attachment Plates

Example attachment plate weld contours

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Obstacle Induced Dripping – Weld Seams

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Test Facility Design Summary

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Test Facility Overview

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Preliminary Test Matrix

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Schedule

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IRWST Steam Condensate Return Summary

- Some **AP1000** plant changes will be made to increase condensate return to IRWST
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