AREVA

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AREVA NP Inc. Presentation Materials for U.S. EPR ACRS Subcommittee Meeting on March 23, 2011

Proprietary and non-proprietary versions of viewgraphs related to the realistic large break LOCA meeting for March 23, 2011 are enclosed. AREVA NP Inc. considers some of the material contained in the enclosed documents to be proprietary. As required by 10 CFR 2.390(b), an affidavit is enclosed to support the withholding of the information from public disclosure.

If you have any questions related to this submittal, please contact me at (434) 832-2369 or by e-mail at sandra.sloan@areva.com.

Sincerely,

Sandra M. Sloan

Sandra M. Sloan, Manager
New Plants Regulatory Affairs

Enclosures

cc: G. Tesfaye, NRC
D. Widmayer, NRC

D077
NRO

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AFFIDAVIT

COMMONWEALTH OF VIRGINIA)
) ss.
COUNTY OF CAMPBELL)

1. My name is Sandra M. Sloan. I am Manager, Regulatory Affairs for New Plants, for AREVA NP Inc. and as such I am authorized to execute this Affidavit.

2. I am familiar with the criteria applied by AREVA NP to determine whether certain AREVA NP information is proprietary. I am familiar with the policies established by AREVA NP to ensure the proper application of these criteria.

3. I am familiar with the AREVA NP information contained in, "AREVA NP Inc. Presentation Materials for U.S. EPR ACRS Subcommittee Meeting on March 23, 2011," and referred to herein as "Document." Information contained in this Document has been classified by AREVA NP as proprietary in accordance with the policies established by AREVA NP for the control and protection of proprietary and confidential information.

4. This Document contains information of a proprietary and confidential nature and is of the type customarily held in confidence by AREVA NP and not made available to the public. Based on my experience, I am aware that other companies regard information of the kind contained in this Document as proprietary and confidential.

5. This Document has been made available to the U.S. Nuclear Regulatory Commission in confidence with the request that the information contained in this Document be withheld from public disclosure. The request for withholding of proprietary information is made in accordance with 10 CFR 2.390. The information for which withholding from disclosure is

requested qualifies under 10 CFR 2.390(a)(4) "Trade secrets and commercial or financial information".

6. The following criteria are customarily applied by AREVA NP to determine whether information should be classified as proprietary:

(a) The information reveals details of AREVA NP's research and development plans and programs or their results.

(b) Use of the information by a competitor would permit the competitor to significantly reduce its expenditures, in time or resources, to design, produce, or market a similar product or service.

(c) The information includes test data or analytical techniques concerning a process, methodology, or component, the application of which results in a competitive advantage for AREVA NP.

(d) The information reveals certain distinguishing aspects of a process, methodology, or component, the exclusive use of which provides a competitive advantage for AREVA NP in product optimization or marketability.

(e) The information is vital to a competitive advantage held by AREVA NP, would be helpful to competitors to AREVA NP, and would likely cause substantial harm to the competitive position of AREVA NP.

The information in the Document is considered proprietary for the reasons set forth in paragraphs 6(b) and 6(c) above.

7. In accordance with AREVA NP's policies governing the protection and control of information, proprietary information contained in this Document has been made available, on a limited basis, to others outside AREVA NP only as required and under suitable agreement providing for nondisclosure and limited use of the information.

8. AREVA NP policy requires that proprietary information be kept in a secured file or area and distributed on a need-to-know basis.

9. The foregoing statements are true and correct to the best of my knowledge, information, and belief.

Sandra M. Sloan

SUBSCRIBED before me this 17th day of March, 2011.

Kathleen A. Bennett

Kathleen A. Bennett
NOTARY PUBLIC, COMMONWEALTH OF VIRGINIA
MY COMMISSION EXPIRES: 8/31/2011
Reg. #110864

KATHLEEN ANN BENNETT
Notary Public
Commonwealth of Virginia
110864
My Commission Expires Aug 31, 2011

Presentation to ACRS
U.S. EPR Subcommittee
Design Certification Application
U.S. EPR Realistic Large Break Loss of Coolant Accident Topical Report, ANP-10278P

Liliane Schor
Eugene Moore

EPR™ by AREVA

AREVA

Topics

- Introduction
- U.S. EPR™ design overview
- AREVA NP realistic large break LOCA (RLBLOCA) EM
- Applicability of RLBLOCA methodology with changes to the U.S. EPR design
  - Phenomenological assessment
  - Unique features of the U.S. EPR design of importance for LBLOCA
    - Whether these features introduce any new phenomena
- Containment model
- Calculation results
- Conclusion

Introduction

- U.S. EPR™ design, a 4-loop PWR with RSGs, is similar to W 4-loop designs
  - Similar operating conditions
  - Same phenomena
  - Within range of applicability of constitutive models
- Methodology is applicable to the U.S. EPR™ design
  - Produce expected results

U.S. EPR™ Plant Comparison

Parameter	*U.S. EPR™*	*Typical 3-loop*	*Typical 4-loop*
Nominal power level, MWt	4,590	2,900	3,455
Number of RCS Loops	4	3	4
Primary volume, ft^3	15,927.3	9,899.9	11,731.1
Volume/Power	**3.5**	**3.4**	**3.4**
Core			
Active fuel length, ft	13.8	12.0	12.0
Average linear heat rate, kW/ft	5.21	5.83	5.65
Peak linear heat rate, kW/ft	13.54	14.05	14.97
Power density, MW/ft^3	3.05	3.41	3.31
RV downcomer			
Volume, ft^3	1,128.5	746.1	773.0
Volume/RCS Volume	**7.1%**	**7.5%**	**6.6%**
RV diameter, ft	13.7	13.0	12.3
Cold leg centerline to bottom of active fuel, ft	20.9	16.7	17.2
Height between vessel nozzles and top of active core, ft	7.1	4.7	5.2

U.S. EPR™ Plant Comparison (cont.)

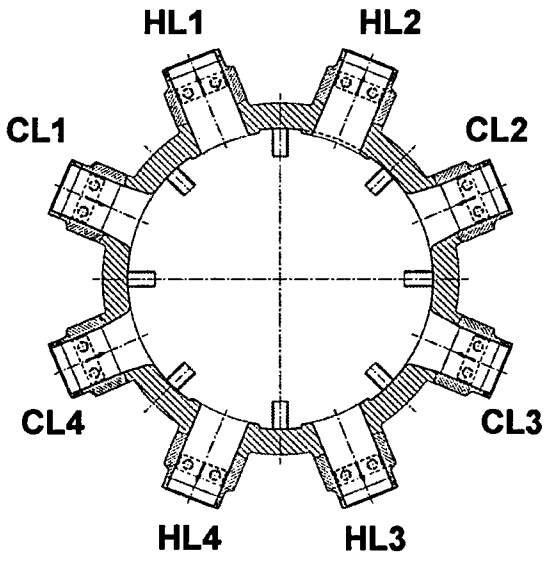
Parameter	*U.S. EPR™*	*Typical 3-loop*	*Typical 4-loop*
Thermal hydraulic RCS flow rate			
Mlbm/hr	176.4	109.2	131.6
Flow rate/Power (kg/MWt-s)	**23.5**	**23.1**	**23.3**
Pressurizer			
Volume (incl. surgeline), ft^3	2,738.8	1,440.4	1,872.9
Volume/RCS Volume	**17.2%**	**9.0%**	**16.0%**
Steam generator			
MFW temperature, °F	446.0	450.0	435.8
Pressure, psia	1,107.1	985.0	854.0
Total Four-SG Mass Inventory, lbm	726,480	325,500	428,000
Mass/Power (lbm/MWt)	**158.3**	**112.2**	**123.9**
Average tube height, ft	36.5	33.2	33.2
SG heat transfer area, ft^2	85,680.7	75,387.0	51,500.0
SG heat transfer area/power (ft^2/MWt)	**18.7**	**26.0**	**14.9**

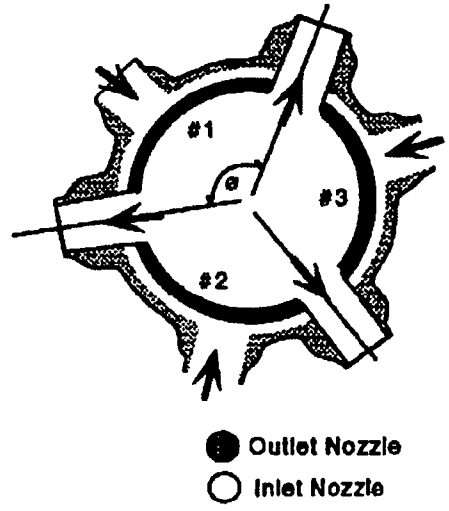
U.S. EPR™ Plant Comparison (cont.)

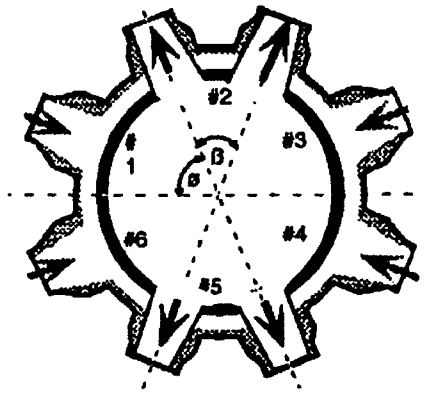
Parameter	*U.S. EPR™*	*Typical 3-loop*	*Typical 4-loop*
Accumulator			
Minimum operating pressure, psia	652.7	599.7	614.7
Empty volume, ft^3	1,942.3	1,450.0	1,350.0
Volume/RCS Volume	**12.2%**	**14.6%**	**11.5%**
Max liquid volume, ft^3	1,412.6	1,029.4	1,095.4
Volume/RCS Volume	**8.9%**	**10.4%**	**9.3%**
Nitrogen volume, ft^3	529.7	420.6	254.6
Volume/RCS Volume	**3.3%**	**4.2%**	**2.2%**
Cold leg area, ft^2	5.1434	4.1247	4.1247
Area/Power	**0.112%**	**0.142%**	**0.119%**
Containment			
Type	"dry"	dry	dry*
Containment free volume, ft^3	2,888,000	2,266,000	2,704,000
Containment volume/Power (ft^3/MWt)	**629**	**781**	**740**

* values from a different reference plant.

U.S. EPR™ Plant Comparison







Westinghouse 3- and 4-Loop

Realistic Large Break LOCA (RLBLOCA)

- Best estimate plus uncertainty methodology in accordance with
  - U.S. Regulatory Guide 1.157, guidance to industry on requirements for developing best estimate methods
  - NUREG-5249, Code Scaling, Applicability and Uncertainty (CSAU) methodology
  - AREVA RLBLOCA methodology, EMF-2103PA
    - Methodology developed for W 3- and 4-Loop Plants and CE 2x4 plants
    - Identified Important LBLOCA Phenomena Documented in Phenomena Identification and Ranking Table (PIRT)
    - Code Models and Correlations assessed for applicability to important phenomena identified in PIRT
    - Conducted extensive assessment to support broad range-of-applicability
      - Assessment matrix included 15 SET Facilities, 2 IET facilities with a total of 136 tests

CSAU Steps

- **Code capabilities**
  - **Phenomena identification and ranking (PIRT)**
  - **Code selection**
- **Assessing and ranging of parameters**
  - **Quantifying the uncertainties and biases to be addressed in the analysis of the chosen scenario with the chosen codes**
    - Establishment of Assessment Matrix

PIRT

PIRT

PIRT (cont.)

PIRT (cont.)

CSAU Steps

- **Code capabilities**
  - **Phenomena identification and ranking (PIRT) ✓**
  - **Code selection**
- **Assessing and ranging of parameters**
  - **Quantifying the uncertainties and biases to be addressed in the analysis of the chosen scenario with the chosen codes**
    - Establishment of Assessment Matrix

Large Break LOCA Computer Codes

- **RODEX3A**
  - **Exposes the fuel rods being modeled through a desired power and burnup history**
  - **Treats both burnup and power-dependent effects**
- **S-RELAP5**
  - **System thermal-hydraulic calculation**
  - **ICECON module within S-RELAP5**
    - Based on CONTEMPT/LT-022
    - Calculates containment pressure which is used to determine the back pressure for flow from the primary system to the containment during the LOCA transient.
  - **RODEX3A subset within S-RELAP5**
    - Calculates only power-dependent effects
      - Obtains values for permanent phenomena from the full RODEX3A exposure analysis at the beginning of the S-RELAP5 analysis, which are treated as constant values thereafter.
      - Power dependent phenomena updated by RODEX3A models in S-RELAP5 throughout both steady-state and transient analyses.

RODEX3A and S-RELAP5
Phenomena modeled by RODEX3A

- The phenomena modeled in the full RODEX3A code can be divided into two general categories
- Burnup-dependent effects:
  - Cladding creep deformations
  - Pellet densification and swelling deformations
  - Fission gas release
- Power-dependent effects:
  - Thermal expansion of pellet and cladding
  - Elastic deformation of cladding
  - Gas pressure in gap
  - Gap width and conductance
  - Fuel and cladding thermal conductivity and heat capacity

ICECON

- Fundamental basis is the CONTEMPT/LT-022 code
  - ICECON adds an ice condenser model
- Compartments modeled may contain two separated regions (vapor and liquid) at different temperatures
- Models allow pool boiling or evaporation and condensation from the vapor regions to be calculated
- The calculated containment pressure is used to determine the back pressure for flow from the primary system to the containment during the LOCA transient.
- The S-RELAP5/ICECON code interface enables ICECON to be run concurrently with S-RELAP5, providing a dynamic calculation of containment pressure that is consistent with the break-mass flow rate and specific enthalpy currently being generated by S-RELAP5.
  - With the concurrent execution of S-RELAP5 and ICECON, a consistent break-pressure boundary condition is always available in S-RELAP5.

CSAU Steps

- **Code capabilities**
  - **Phenomena identification and ranking (PIRT) ✓**
  - **Code selection ✓**
- **Assessing and ranging of parameters**
  - **Quantifying the uncertainties and biases to be addressed in the analysis of the chosen scenario with the chosen codes**
    - Establishment of Assessment Matrix

RLBLOCA Assessment Matrix

RLBLOCA Assessment Matrix

RLBLOCA Assessment Matrix

RLBLOCA Assessment Matrix

RLBLOCA Methodology
Nonparametric Statistics

- Relies on the execution of the code to develop a sampling set of LBLOCA cases
- Each case is defined by randomly sampling values for each PIRT phenomena and plant parameters being treated statistically
  - For every RODEX3A and S-RELAP5 input created, including the ICECON containment input file, each key LOCA parameter is randomly sampled over a range established through code uncertainty assessment or expected operating limits (provided through plant technical specifications, data, etc.).
- A defined number of cases are run with the code to determine that the three acceptable criteria of 10 CFR 50.46 are met with at least a 95 percent probability with 95 percent confidence

U.S. EPR™ RLBLOCA Methodology Sampled Parameters

Phenomenological Parameters

- Film Boiling Heat Transfer
- Stored Energy (centerline temperature)
- Metal-Water Reaction
- Decay Heat Uncertainty
- Biasi CHF
- Tmin (film to transition boiling)
- Break Area and Type
- Break Discharge Coefficients
- Cold Leg Condensation
- Steam Generator Inlet Interphase Friction
- Hot Wall (CHF multiplier)
- Containment Pressure (volume)

Plant Parameters

- Core Power Distributions, $F_{\Delta H}$, F_Q, Axial Shape
- Reactor Coolant System Loop Flow Rates and Core Average Temperature
- Upper Head Temperature
- Pressurizer Pressure and Level
- Accumulator Pressure, Volume and Temperature
- Containment Temperature(s)
- Intact loop receiving pumped SI flow

Sampled Parameters
Example of Uncertainty Range Definition

- **Break discharge coefficient**
  - **HEM critical flow model in S-RELAP5 assessed against tests at the Marviken facility**

[ ]

Sampled Parameters Example of Uncertainty Range Definition

- **Initial RCS mass flow rate**
  - **Lower bound**
    - Based on thermal hydraulic loop flow rate, which corresponds to the worst core cooling conditions
    - Total 4-loop flow rate of 176 Mlbm/hr (478,768 gpm)
  - **Upper bound**
    - Based on mechanical loop flow rate, which corresponds to the maximum flow rate for the mechanical design of components
    - Total 4-loop flow rate of 198 Mlbm/hr (538,648 gpm)
  - **An operational parameter**
    - No particular uncertainty distribution is expected when describing operational variations
    - Uniform distribution used

CSAU Steps

- **Code capabilities**
  - **Phenomena identification and ranking (PIRT) ✓**
  - **Code selection ✓**
- **Assessing and ranging of parameters**
  - **Quantifying the uncertainties and biases to be addressed in the analysis of the chosen scenario with the chosen codes ✓**
    - Establishment of Assessment Matrix

Assessment of Applicability to U.S. EPR

- U.S. EPR™-specific changes to EM
- Unique U.S. EPR™ design features of importance for LBLOCA
- Phenomenological assessment
  - Reviewed each phenomenon and its treatment within the methodology for applicability to the U.S. EPR™ design

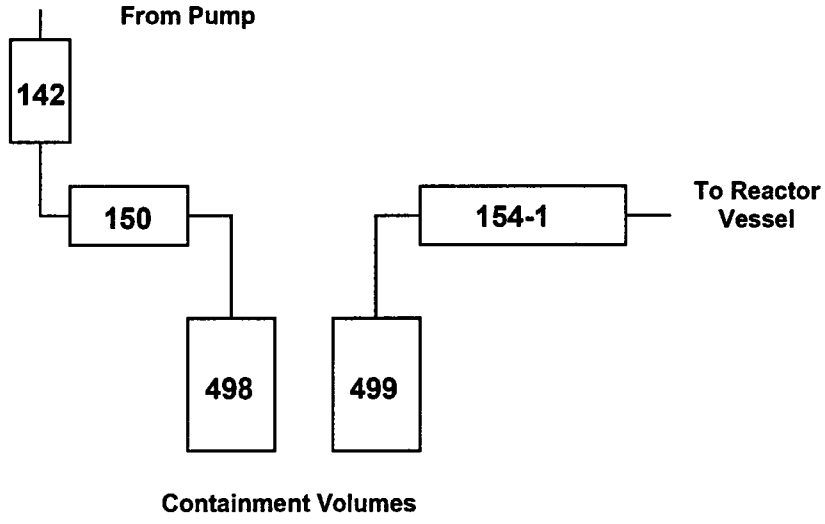
U.S. EPR-Specific Changes to EMF-2103, Rev. 0

- **Core power**
  - **Assumed reactor core power is 4612 MWt (not sampled)**
    - Plant rated power of 4590 MWt + 0.5 percent
    - Does not sample below licensed power level (10 CFR 50, App. K.I.A)
- **Quenching criteria**
  - **Before the rod is allowed to quench, it is required that both the void fraction be less than 0.95 and the cladding temperature be less than the minimum film boiling temperature, T_{MIN}**
- **Modification to the application of Forslund-Rohsenow**
  - **Contribution of the Forslund-Rohsenow model limited to no more than 15 percent of the total heat transfer at and above a void fraction of 0.9**

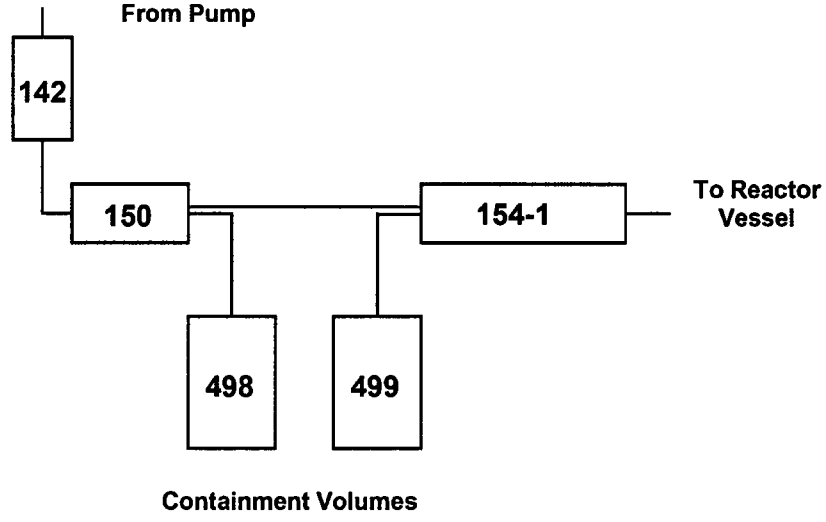
U.S. EPR-Specific Changes to EMF-2103, Rev. 0 (cont.)

- Treatment of split breaks
  - Consistent with RG 1.157, Section 3.1
  - 10% A_{PIPE} < break area < 200% A_{PIPE}, followed by
  - Separate sampling to determine whether DESB or DEGB

Double-Ended Guillotine Break Nodalization



Double-Ended Split Break Nodalization



U.S. EPR-Specific Changes to EMF-2103, Rev. 0 (cont.)

- Increased number of sample cases from 59 to 124
  - U.S. EPR™ RLBLOCA analysis uses a tri-variant application of the Guba correlation
  - 124 cases based on Guba 2003 paper

$$\beta = \sum_{j=0}^{N-p} \frac{N!}{(N-j)!\,j!} \gamma^{j} (1-\gamma)^{N-j}$$

    For β = 0.95, γ = 0.95, and p = 3, the number of cases, N, is 124
  - Using 124 cases enhances the confidence in the results
  - The U.S. EPR™ RLBLOCA analysis extracts the figure of merit for each of the three acceptance criteria, i.e., peak cladding temperature, local oxidation, and total hydrogen generation, from the 124th ordered case using separate ordering for each of the three parameters

U.S. EPR-Specific Changes to EMF-2103, Rev. 0 (cont.)

- **Treatment of offsite power**
  - *Criterion 35--Emergency core cooling. …Suitable redundancy in components and features, and suitable interconnections, leak detection, isolation, and containment capabilities shall be provided to assure that for onsite electric power system operation (assuming offsite power is not available) and for offsite electric power system operation (assuming onsite power is not available) the system safety function can be accomplished, assuming a single failure.*
  - **Loop assumed at transient initiation (t=0 seconds in the transient)**
  - **Only LOOP condition analyzed for U.S. EPR™ RLBLOCA analysis**
    - Automatic RCP trip on low RCP ΔP coincident with SIS signal
    - For non-LOOP cases, the U.S. EPR applies the "RCP Trip on Low ΔP Over RCP and SIS signal"
    - The trip occurs early in the event and presents no challenging or new analysis features
    - Minimal difference in timing of RCP trip between LOOP and non-LOOP cases

U.S. EPR-Specific Changes to EMF-2103, Rev. 0 (cont.)

- Decay heat
  - Uncertainty in the fission-product decay heat based on randomly accessing a Gaussian probability density function with a standard deviation of 2 percent
  - Early blowdown results not significantly affected by decay heat
  - Switched to 2 percent to be more accurate in long term

U.S. EPR-Specific Changes to EMF-2103, Rev. 0 (cont.)

- Downcomer boiling

[ ]

U.S. EPR-Specific Changes to EMF-2103, Rev. 0 (cont.)

- Fuel rod initial stored energy - treatment of average and peripheral assemblies

[ ]

U.S. EPR-Specific Changes to EMF-2103, Rev. 0 (cont.)

- Fuel rod initial stored energy - accounting for thermal conductivity degradation with burnup

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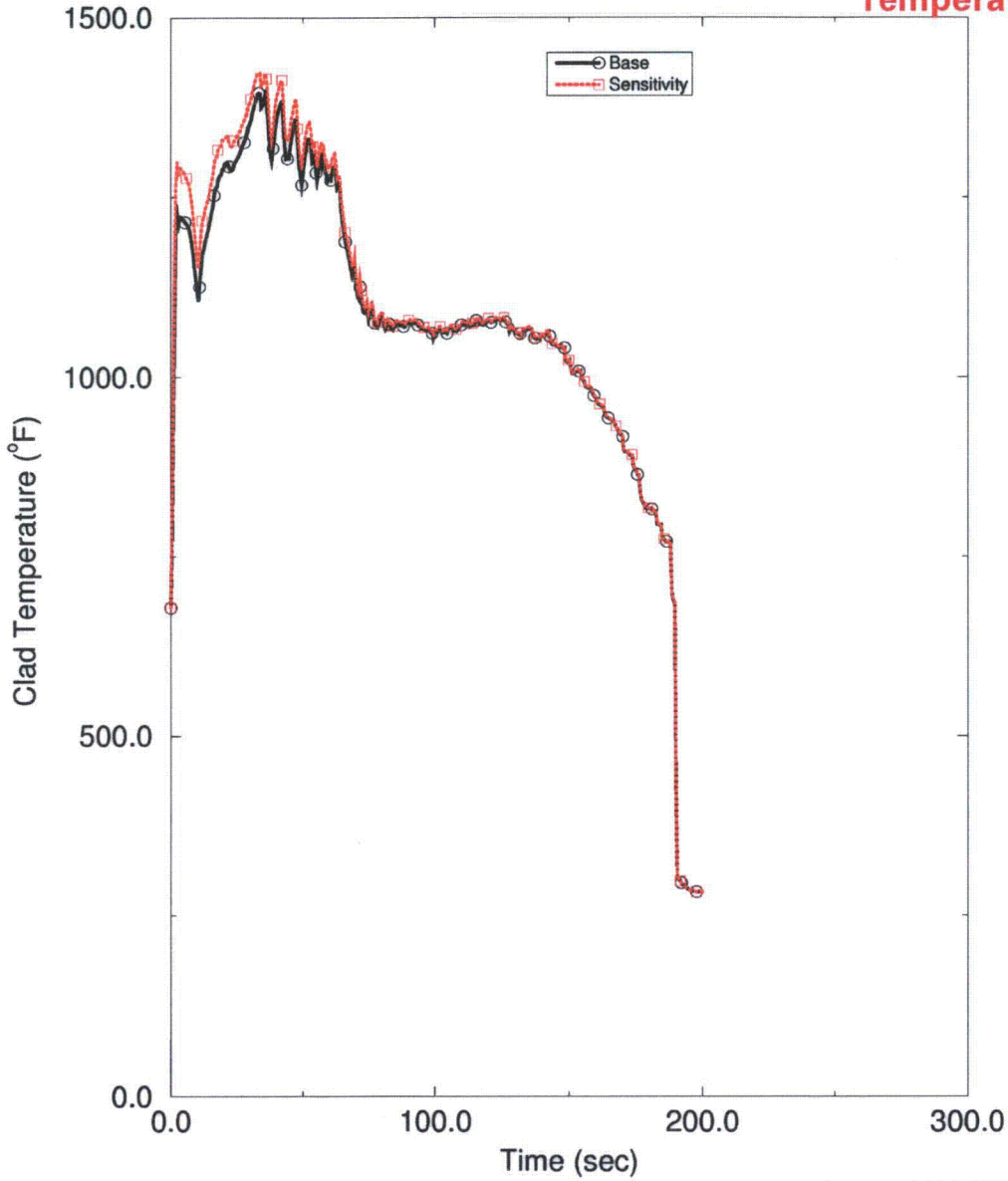
- RODEX3A predictions for centerline temperature assessed relative to data taken at the Halden Reactor Project

PCT Calculation, ANP-10278P, Rev. 0 Case with Modified Centerline Temperature Adjustment



Fuel Rod Initial Stored Energy Treatment – Average and Peripheral Regions

- Using the multiplier in the average core and peripheral assemblies instead of modeling these regions at peak densification produces an increase in centerline temperature of 75°F in the average core and 99°F in the peripheral assemblies.
  - **Sensitivity study with 57°F and 122°F increase in average and peripheral core regions yielded an increase in PCT of less than 20°F**

	Fuel Centerline Temperature	Δ°F (with respect to peak densification)
Average Core		
Original S-RELAP5 Analysis	1747 °F (1225.93 K)	-256
Peak Densification	2003 °F (1368.15 K)	-
Using Multiplier (40.0 GWd/MTU)	2078 °F (1409.8 K)	75
Peripheral Assemblies		
Original S-RELAP5 Analysis	1261 °F (955.93 K)	-159
Peak Densification	1420 °F (1044.26 K)	-
Using Multiplier (60.0 GWd/MTU)	1519 °F (1099.3 K)	99

Assessment of Applicability to U.S. EPR

- U.S. EPR-specific changes to EM✓
  - Estimated net PCT change due to these U.S. EPR-specific changes: + ~200°F (Base of 1425°F)
- Unique U.S. EPR design features of importance for LBLOCA
- Phenomenological assessment
  - Reviewed each phenomenon and its treatment within the methodology for applicability to the U.S. EPR design

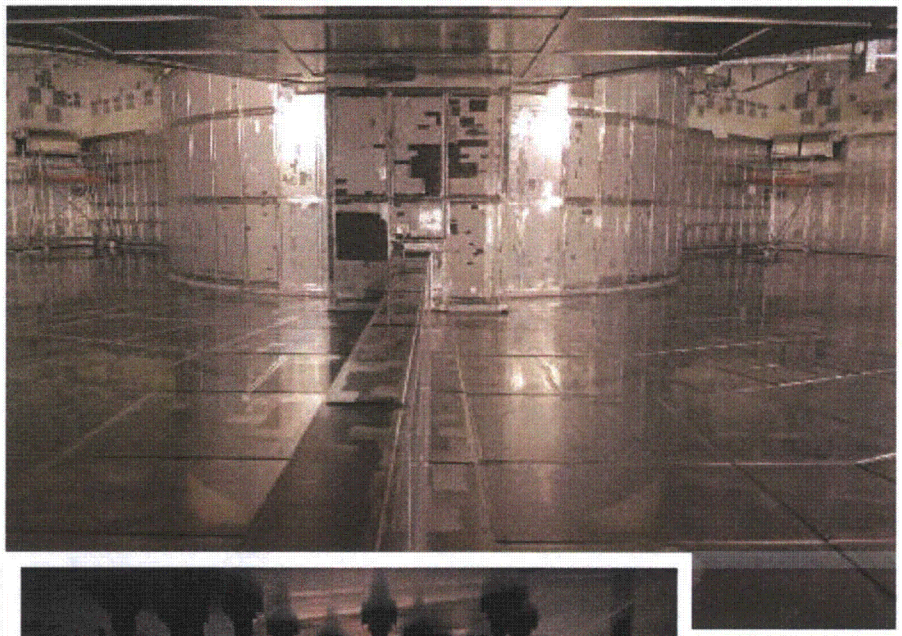
Unique Features of the U.S. EPR design of importance for LBLOCA

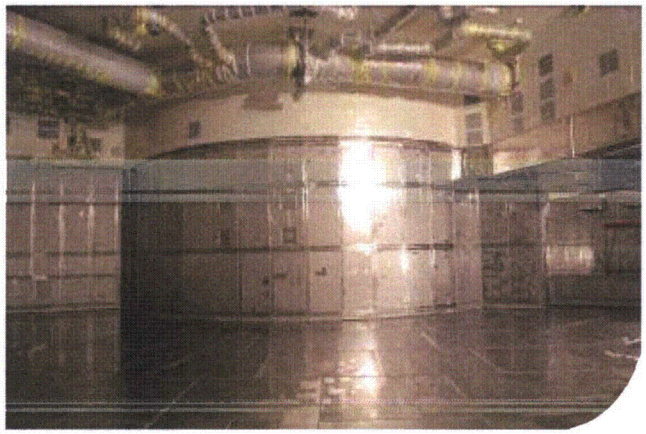
- U.S. EPR LBLOCA analysis relies on passive containment heat sinks for containment heat removal
  - U.S. EPR design does not have fan coolers
    + Containment sprays are reserved for severe accidents
    → Effect is to expect that the U.S. EPR has a higher containment pressure than in current plants

Unique U.S. EPR design features of importance for LBLOCA (cont.)

- In-containment Refueling Water Storage Tank (IRWST)
  - An open pool within the containment building that partly immerses a portion of the containment building structure
  - Functions as both the external water storage tanks and internal sumps of current PWRs

RWST (In-containment Refueling Water Storage Tank)



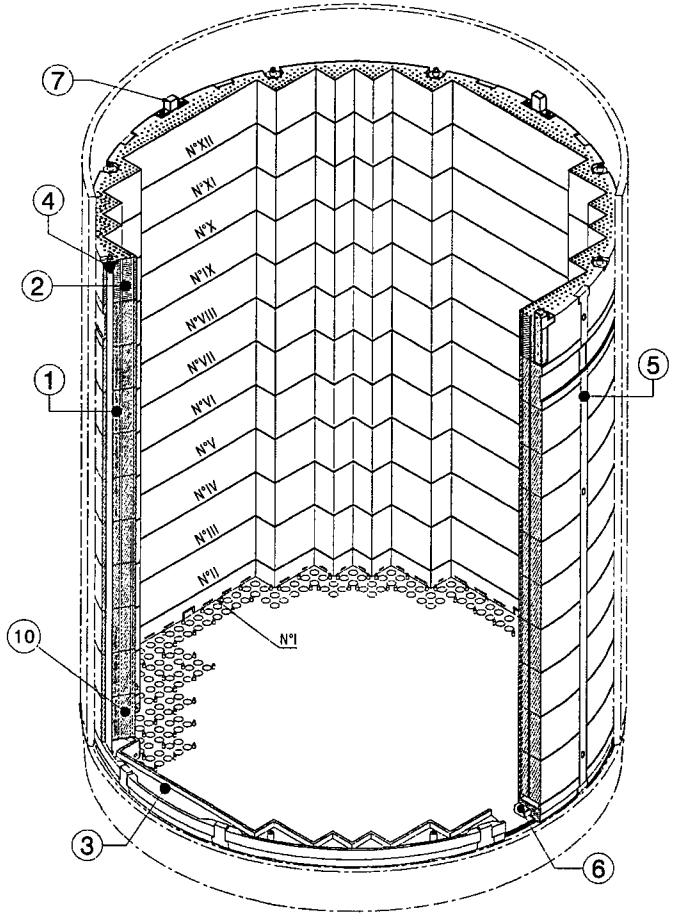


Unique U.S. EPR design features of importance for LBLOCA (cont.)

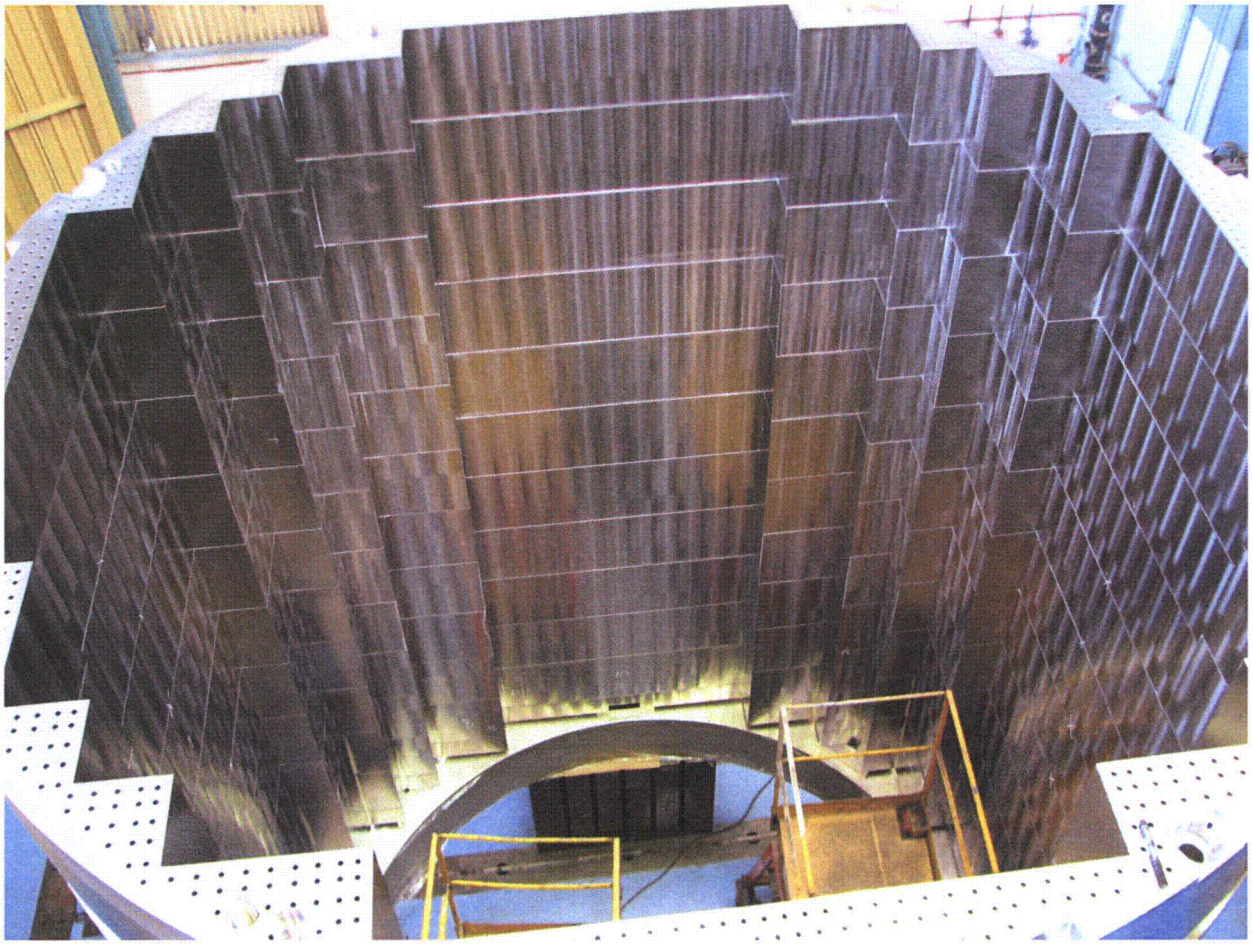
- **MHSI**
  - **Unlike current PWRs, the U.S. EPR design uses MHSI pumps instead of HHSI pumps.**
    - The delayed MHSI has minimal impact on LBLOCA
- **Accumulators**
  - **Higher minimum operating pressure**
- **SIS/RHRS**
  - **A four train system of pumped safety injection. As long as all four trains are available, they are independent.**
  - **If one train down for maintenance, piping cross-connects are opened between 2x2 loops providing multiple injection points for the LHSI**
    - This arrangement ensures that at least one of the cold legs opposite the break receives ECCS flow, even if only two of the four trains is operational (one injecting to the break)

Unique U.S. EPR design features of importance for LBLOCA (cont.)

- **Heavy reflector**
  - An all stainless-steel structure between the multi-cornered periphery of the core and the core barrel
  - Takes the place of the core baffle and eliminates need for thermal shield or neutron pads
  - Metal mass and volume are modeled in S-RELAP5
  - Cooling channels modeled
  - Within capabilities of codes and methods to analyze



OL3 EPR – Heavy Reflector

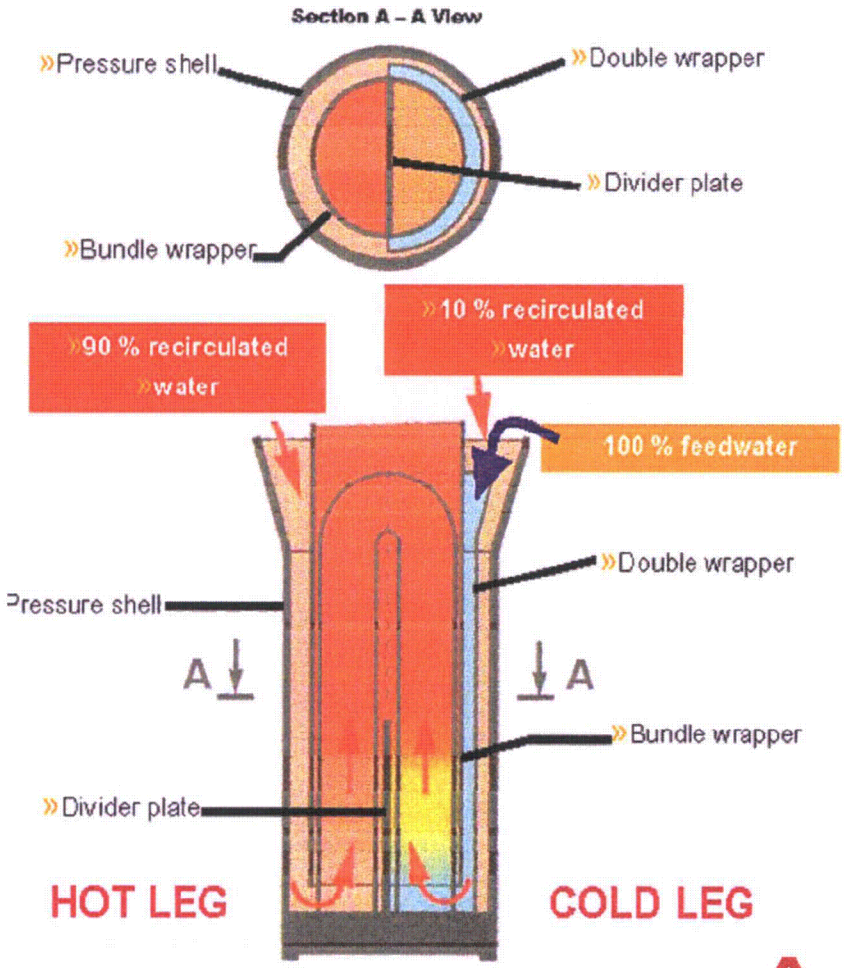


Unique U.S. EPR design features of importance for LBLOCA (cont.)

- **Long core**
  - **Longer active core length**
  - **Methodology does not impose a limit on core height**
    - Length-independent constitutive modeling
- **Partial cooldown**
  - **Steam generator partial cooldown system designed to cool the primary system via the MSRTs, thereby lowering the RCS pressure during various events**
  - **Conservatively not modeled in the LBLOCA model**

Unique U.S. EPR design features of importance for LBLOCA (cont.)

- **Steam generator axial economizer**
  - **Physically separates lower half of SG downcomer into a cold and hot half**
  - **S-RELAP5 model noding changes**
  - **LBLOCA insensitive to treatment of SGs**
  - **Within capabilities of codes and methods to analyze**



Assessment of Applicability to U.S. EPR

- U.S. EPR-specific changes to EM✓
- Unique U.S. EPR design features of importance for LBLOCA ✓
- Phenomenological assessment
  - Reviewed each phenomenon and its treatment within the methodology for applicability to the U.S. EPR design

LBLOCA Phenomena
Phase 1 - Blowdown

- **U.S. EPR design introduces no new methodological or phenomenological considerations with respect to:**
  - **Fuel rod stored energy**
    - Except for rod length, treated the very same as existing AREVA fuel
  - **Core departure from nucleate boiling**
    - DNB modeled in S-RELAP5 by the Biasi and Zuber CHF correlations
      - Correlations based on local conditions, unaffected by long core
  - **Core post-CHF heat transfer**
  - **Rewet**
    - RLBLOCA restricts blowdown quench,
    - characterized by a temperature reduction of the PCT node to saturation temperature during blowdown period
  - **Core flow reversal and stagnation**
  - **Critical flow at the break**
  - **Flow split between the loops**

LBLOCA Phenomena
Phase 2 - Refill

- U.S. EPR design introduces no new methodological or phenomenological considerations with respect to:
  - Core post-CHF heat transfer
  - Accumulator Discharge
  - Downcomer entrainment/de-entrainment and countercurrent, slug, and non-equilibrium flow
  - Downcomer 3-D effects
  - Loop flow oscillations
  - Flow split between the loops

LBLOCA Phenomena
Phase 3 – Reflood

- **U.S. EPR design introduces no new methodological or phenomenological considerations with respect to:**
  - **Fuel rod oxidation**
  - **Fuel rod decay heat**
    - Fuel parameters affecting fuel rod decay heat are the same in the U.S. EPR design as for all applicable current PWRs
  - **Core post-CHF**
  - **Core reflood heat transfer and quench**
  - **Core 3-D flow, void distribution and generation**
  - **Core entrainment/de-entrainment**
  - **Upper plenum entrainment/de-entrainment**
    - Distance between top of core and bottom of hot leg nozzles greater in U.S. EPR design (~7 ft) than for current PWRs (~ 3 to 4 ft).
  - **Upper plenum draining and fall-back**
  - **Steam generator steam binding**
  - **RCP locked rotor**
    - Pump seizure is not considered part of a best-estimate LBLOCA scenario and for this reason is not considered in the RLBLOCA EM
  - **Accumulator non-condensable gas**

LBLOCA Phenomena
Phase 3 – Reflood (cont.)

- **Downcomer boiling**
  - **Wall heat release modeling is validated by sensitivity studies (U.S. EPR design and Operating Plants) and through benchmarks against a closed form solution**
    - Axial and radial mesh sensitivity studies conducted using the U.S. EPR design at containment pressure of about 30 psia during reflood phase
      - demonstrate that S-RELAP5 delivers energy to the DC liquid volumes at an appropriate rate, that the noding detail is sufficient to track distribution of steam formed
      - RLBLOCA DC model applicable to U.S. EPR

LBLOCA Phenomena
Phase 3 – Reflood (cont.)

- **Reflood oscillations**
  - **Sensitivity of cladding temperatures to flow oscillations is assessed through both analysis and evaluation of experiments**
  - **LOFT and CCTF**
    - considered in the developmental assessment of S-RELAP5
    - Calculated flow oscillations did not lead to premature quenching of hot fuel rods
  - **S-RELAP5 model of FLECHT-SEASET**
    - Used core flow oscillations at a cycle period and magnitude similar to those seen in the U.S. EPR RLBLOCA analysis
    - S-RELAP5 model predicted higher cladding temperatures when flow oscillations occur
  - **The current treatment of this phenomenon with the S-RELAP5 RLBLOCA methodology is sufficient and conservatively over-predicts cladding temperatures**

Assessment of Applicability to U.S. EPR™

- U.S. EPR-specific changes to EM✓
- Unique U.S. EPR design features✓
- Phenomenological assessment ✓
  - Reviewed each phenomenon and its treatment within the methodology for applicability to the U.S. EPR design

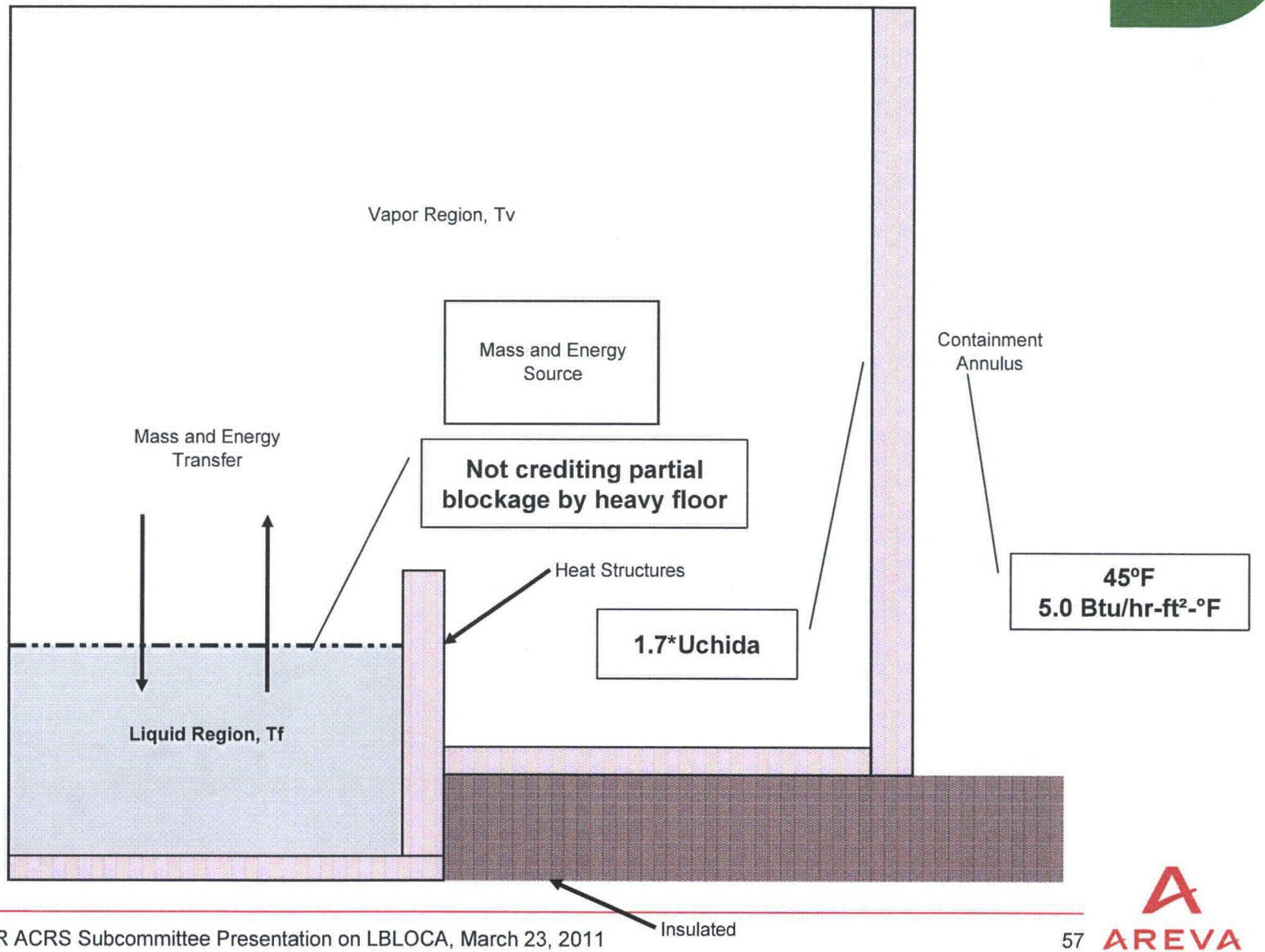
Topics

- Introduction✓
- U.S. EPR design overview✓
- AREVA NP realistic large break LOCA (RLBLOCA) EM✓
- Large break LOCA computer codes✓
- Applicability of RLBLOCA methodology with changes to the U.S. EPR design✓
  - Phenomenological assessment
  - Unique features of the U.S. EPR design of importance for LBLOCA
    - Whether these features introduce any new phenomena
- Containment model
- Calculation results
- Conclusion

ICECON Containment Model

- **Modeled as a "dry" containment, which has capability to model liquid pool**
- **Assumptions to further reduce containment pressure**
  - **Nominal surface area of containment heat structures conservatively increased by modeling heat structures representing basemat floor in contact with containment atmosphere**
  - **All nominal heat-transfer surface areas are increased by 10 percent**
  - **A passive heat sink representing uninsulated systems and components added to the U.S. EPR ICECON model**
    - In accordance with NUREG-0800, Branch Technical Position (BTP) 6-2
  - **Minimizing insulating effects on exposed surfaces of heat structures**
    - Air gap between containment liner and concrete is neglected
    - Paint layer such as on containment walls assumed to have material properties of steel
  - **Liquid dropout**
    - In RLBLOCA EM, the only liquid mass that is transferred to the pool is the calculated condensate.
    - U.S. EPR models liquid dropout to the pool in the post-blowdown period

ICECON Containment Model



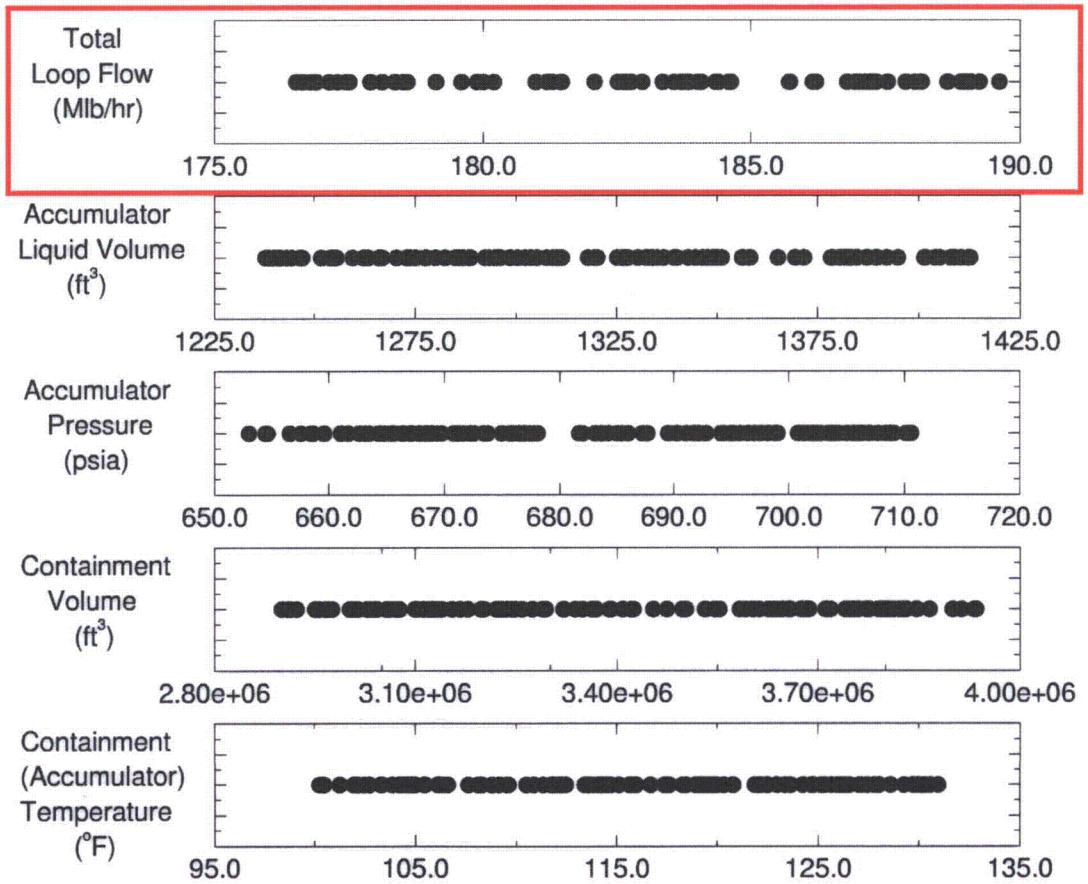
ICECON Containment Model

- **Containment free volume**
  - **Sampling range for containment volume comprises the following:**
    - Lower bound: Nominal containment free gas volume
    - Upper bound: (Nominal containment free gas volume) + (Nominal IRWST water volume) + (internal structure volume except for internal tanks and equipment)
- **Effect of containment pressure on PCT was determined to be small**
  - **Sensitivity study increasing sampled containment volume by 60 percent yielded around a 10 psi drop in containment pressure**
    - PCT case (Rev. 0) increased by 26°F
      - A lower PCT case (Rev. 0) increased by 65°F
  - **Conservative bias towards low containment pressure is reasonable**
- **ICECON model containment pressure calculation is conservative with respect to equivalent single and multi-node GOTHIC models**

Topics

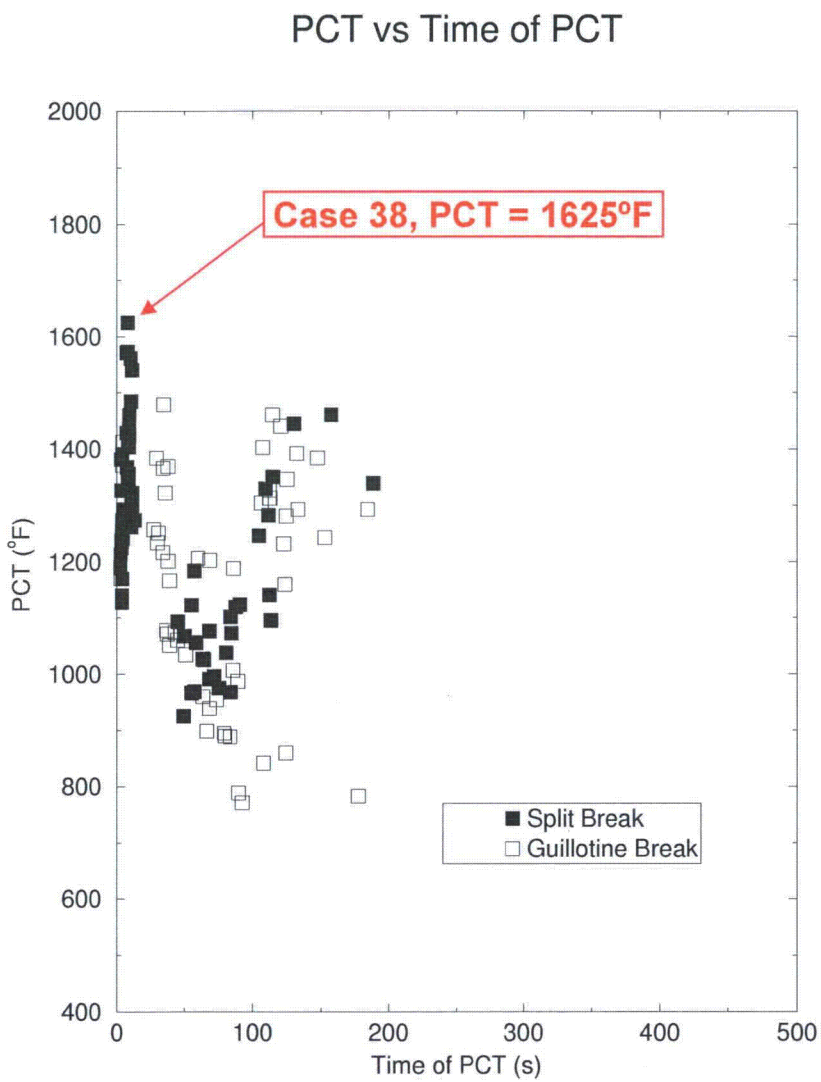
- Introduction✓
- U.S. EPR™ design overview✓
- AREVA NP realistic large break LOCA (RLBLOCA) EM✓
- Large break LOCA computer codes✓
- Applicability of RLBLOCA methodology with changes to the U.S. EPR™ design✓
  - Phenomenological assessment
  - Unique features of the U.S. EPR™ design of importance for LBLOCA
    - Whether these features introduce any new phenomena
- Containment model ✓
- Calculation results
- Conclusion

U.S. EPR Analysis Results: Scatter Plots



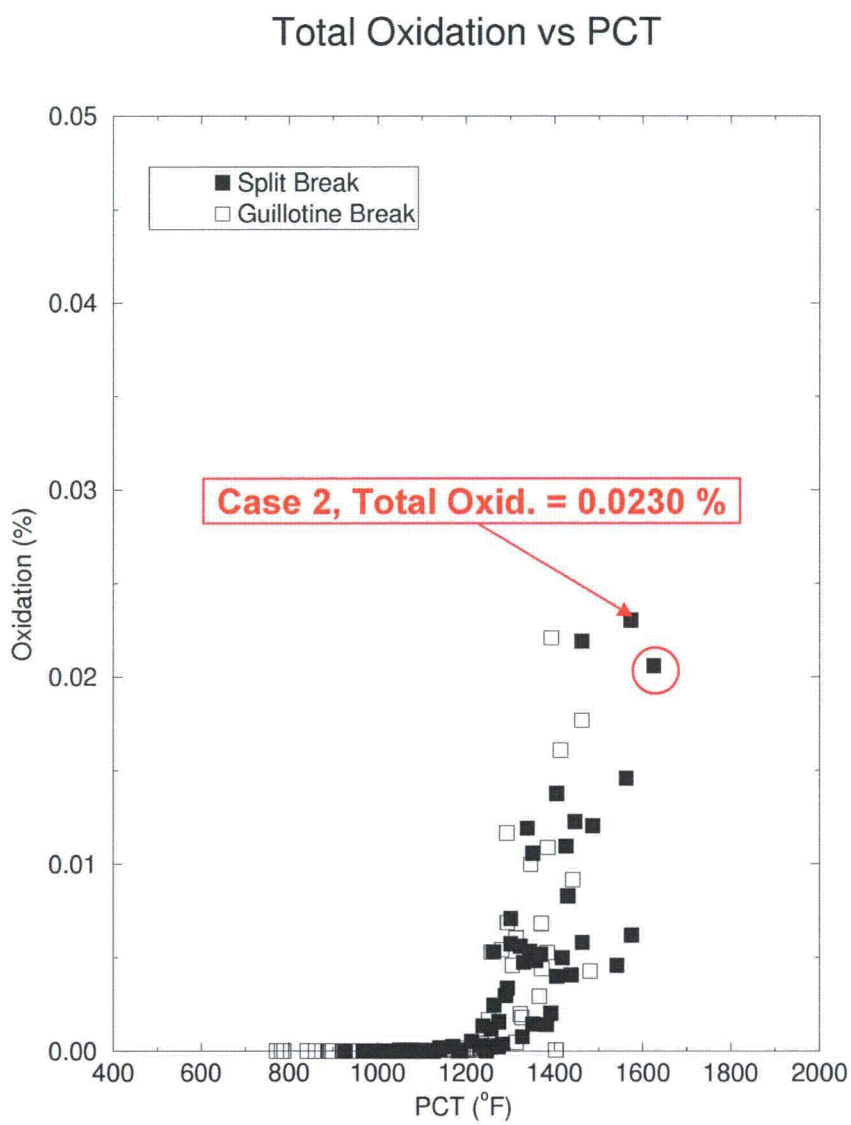
Denotes highest PCT case in each analysis

Acceptance Criteria:
PCT shall not exceed 2200°F



Denotes highest PCT case in each analysis

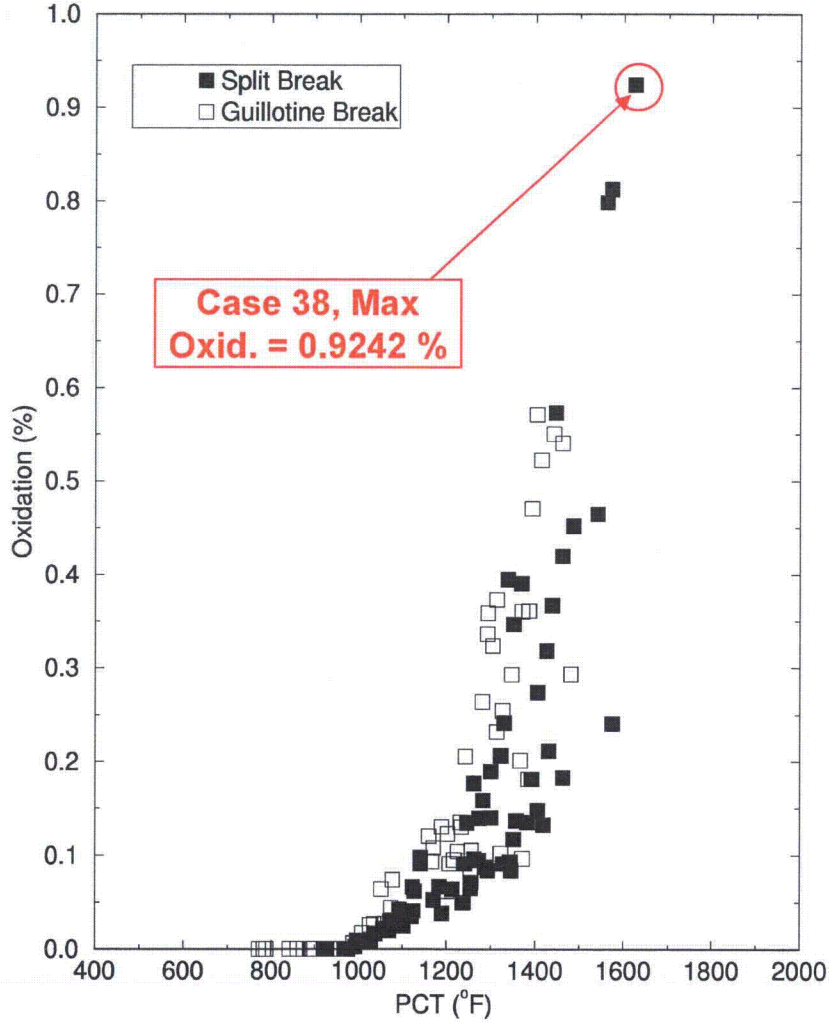
Acceptance Criteria:
Total percent oxidation of less than 1%



Denotes highest PCT case in each analysis

Acceptance Criteria:
Maximum cladding oxidation shall not exceed 17 percent total cladding thickness before oxidation.

Maximum Oxidation vs PCT



Review of RLBLOCA EM SER Restrictions

- Item 1: no significant occurrence of CCFL violation in the downcomer for this evaluation
- Item 2: hot leg nozzle gaps were not modeled
- Item 3: blowdown clad rupture
  - The U.S. EPR analysis LHGR is consistent with 3-loop sample problem LHGR
- Item 4: top slot breaks
  - a separate analysis demonstrates that, when the loop seals are full, the mixture level is always above the top of the active fuel; hot leg injection at 60 minutes.
- Item 5 (3 & 4-loop RSGs), Item 6 (EM applies only to bottom reflood plant)
- Item 7: blowdown quench occurred in one nonlimiting case (break area close to SBLOCA)
- Item 8: core quench initiated at the bottom of the core and proceeded upwards
- Item 9: addressed outside the scope of the RLBLOCA topical report as part of the long-term cooling evaluation.

Conclusions

- The approach described in ANP-10278P, Rev. 1 includes a description of U.S. EPR-specific changes to the RLBLOCA EM.
- ANP-10278P, Rev. 1 is applicable to the U.S. EPR design.

Nomenclature

Abbreviation	Definition
CCFL	Counter Current Flow Limit
CHF	Critical Heat Flux
CSAU	Code Scaling, Applicability, and Uncertainty
DC	Reactor Vessel Downcomer
DEGB	Double-Ended Guillotine Break
DESB	Double-Ended Split Break
DNB	Departure from Nucleate Boiling
ECC	Emergency Core Cooling
EM	Evaluation Model
HT	Heat Transfer
HTP	High Thermal Performance
IET	Integral Effects Test
IRWST	In-Containment Refueling Water Storage Tank
LBLOCA	Large Break Loss of Coolant Accident
LCO	Limiting Condition for Operation
LHGR	Linear Heat Generation Rate
LHSI	Low Head Safety Injection
LOCA	Loss of Coolant Accident
LOOP	Loss of Offsite Power
MFW	Main Feed Water
MHSI	Medium Head Safety Injection
MSRT	Main Steam Relief Train
OL3	Olkiluoto 3
PCT	Peak Clad Temperature
PIRT	Phenomena Identification and Ranking Table
PWR	Pressurized Water Reactor
RCP	Reactor Coolant Pump
RCS	Reactor Coolant System
RHRS	Residual Heat Removal System
RLBLOCA	Realistic Large Break Loss of Coolant Accident
RSG	Recirculating Steam Generator
RV	Reactor Vessel
SET	Separate Effects Test
SG	Steam Generator
SI	Safety Injection
SIS	Safety Injection System