AREVA

Overview of ANP-10299P, "Applicability of AREVA NP Containment Response Evaluation Methodology to the U.S. EPR ™ for Large Break LOCA Analysis"

AREVA NP and the NRC

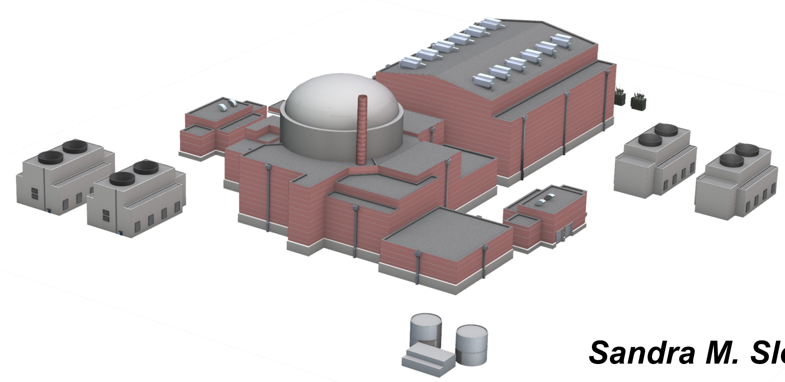
February 26, 2009

™ EPR is a trademark of the AREVA Group

EPR by AREVA

AREVA

Introduction



Sandra M. Sloan

Regulatory Affairs Manager

New Plants

EPR by AREVA

AREVA

Purpose of the Presentation

Provide an overview of the report and establish a starting point for future, more detailed discussions.

AREVA

Agenda

- **MORNING SESSION: PUBLIC Meeting - *non-proprietary***
  - **09:00-09:15** Introduction — NRC/AREVA
  - **09:15-10:45** Report Organization and Contents — Salm
  - **10:45-11:45** Uncertainty Analysis — Martin
  - **11:45-12:00** Opportunity for Public Comment
- **AFTERNOON SESSION: CLOSED Meeting - *proprietary***
  - **1:00-2:30** Mixing Efficiency — Nithianandan
  - **2:30-2:45** Break
  - **2:45-3:30** Sample Problem — Molseed
  - **3:30** Summary and Next Steps — NRC/Sloan
  - **3:45** Actions — All

Presentation Objectives

> Describe the organization and contents of the report
> Outline the approach for demonstrating the applicability of the methodology
> Highlight key sections of the report
> Get preliminary NRC feedback on the report

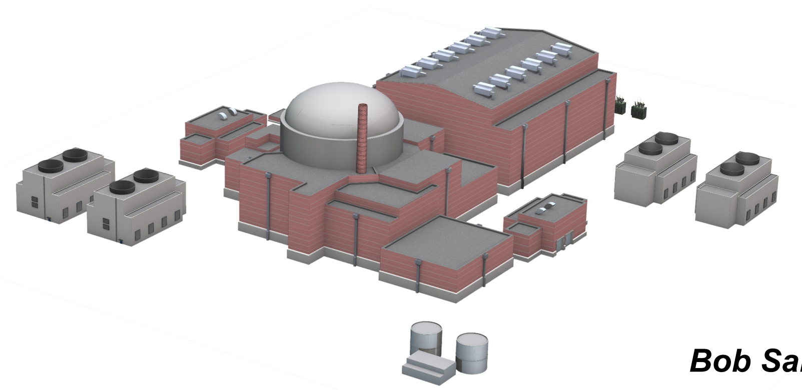
A key outcome will be identification of focus topics and a proposed schedule for future interactions.

Background

> Formal RAIs received
  - April 9, 2008 (RAI-1)
  - October 3, 2008 (RAI-82)
> Last meeting on U.S. EPR containment
  - October 31, 2008
> AREVA submitted technical report
  - January 28, 2009

AREVA

Overview of Containment Technical Report, ANP-10299P



Bob Salm
Manager
New Plants Process & Safety Engineering

EPR by AREVA

AREVA

Presentation Topics

- **Report objectives**
- **Report organization**
- **Report content, section by section**
- **Report conclusion**

EPR by AREVA

Report Objectives

- Present and justify methodology for evaluating U.S. EPR LOCA containment pressure response
  - Revised M&E methodology to address NRC concerns
  - Justification of GOTHIC methodology applicability to U.S. EPR containment design
  - Application of RG 1.203 framework for evaluation model development and assessment process (EMDAP)
- Describe the U.S. EPR containment design, including the CONVECT system, H_2 reduction system and severe accident heat removal system
- Quantify margin provided by conservatisms in EM
- Address most FSAR Chapter 6 containment-related RAIs (Sets 1 and 82)

Report Organization

- Sections
  - 1 – NRC requirements and guidance
  - 2 – US EPR containment design features
  - 3 – EMDAP process and PIRT
  - 4 – Assessment database and scaling
  - 5 – Evaluation model adequacy
  - 6 – Validation and sensitivity analysis
  - 7 – Uncertainty analysis
  - 8 – Modeling and regulatory compliance
  - 9 – U.S. EPR sample problem

Report follows RG 1.203 framework, resulting in a logical, systematic and comprehensive approach

AREVA

Section 1
NRC Requirements and Guidance

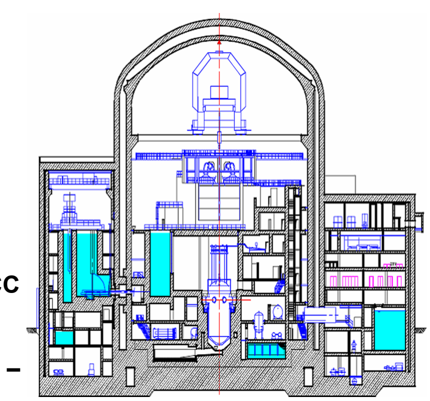
- GDC 50 – Requires containment be designed to accommodate the pressure and temperature conditions following a LOCA
- GDC 38 – Requires a containment heat removal system to rapidly reduce containment pressure and temperature following a LOCA
  - SRP Section 6.2.1.1.A – Provides acceptance criterion that containment pressure be ≤ 50% of the peak pressure within 24 hours after accident

EPR by AREVA

AREVA

Section 2
U.S. EPR Containment Design Features

- Outer shield building
- Inner containment building
- Two zone containment: 1) equipment rooms (inaccessible during operation), 2) surrounding accessible space
- CONVECT system of rupture and convection foils and dampers to connect zones during LOCA
- In containment refueling water storage tank (IRWST) supplies ECC water
- ECCS: 4 trains of accumulators, MHSI, LHSI, RHR, EFW and MSRT – each supplying one RCS loop
  - LHSI/RHR cools IRWST
  - LHSI manually aligned to provide hot leg injection



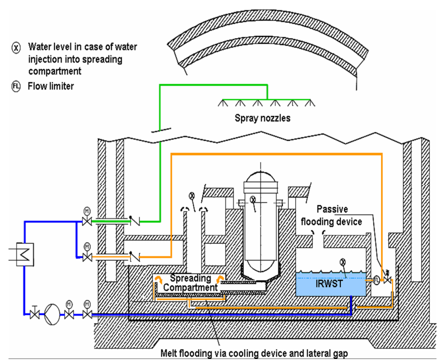
EPR by AREVA

AREVA

Section 2 (cont.)
U.S. EPR Containment Design Features

> **Massive structures provide passive heat sink**
>
> **Hydrogen Reduction System**
>
> **Severe Accident Heat Removal System**

- **Non-safety spray**
- **SAHRS heat exchanger**



EPR by AREVA

AREVA

Section 3
EMDAP Process and PIRT

> **Covers first four steps of EMDAP (RG 1.203)**
>
> **Establishes requirements for evaluation model**
>
> **Presents U.S. EPR PIRT**

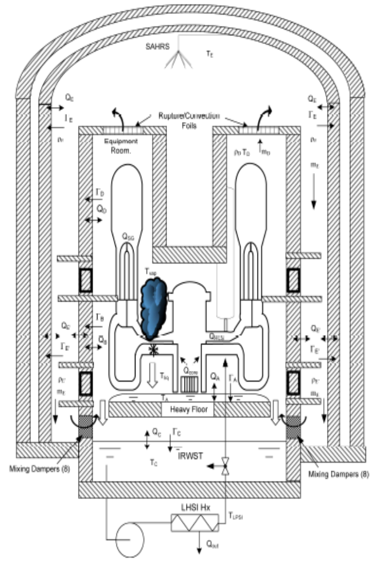
- **Identifies, ranks and assesses state of knowledge of phenomena important to evaluating LOCA pressure response**
  - **Mass and energy release from RCS**
  - **Containment pressure and temperature response**
- **Based on PIRTs developed by experts, including Organization for Economic Cooperation and Development / Nuclear Energy Agency (OECD/NEA)**

EPR by AREVA

AREVA

Section 3 (cont.)
EMDAP Process and PIRT

> Principal mass and heat transfer mechanisms
  - Natural convection and mixing of containment atmosphere
  - Heat transfer to containment structures



EPR by AREVA

AREVA

Section 4
Assessment Database and Scaling

> EMDAP Steps 5 through 9

> Develops equations for scalability analysis

> Describes the code validation database
  - RELAP5-BW – Used to determine mass and energy release prior to assumed reformation of loop seals (limiting pump suction break)
  - GOTHIC – Used to calculate containment pressure and temperature response

> Reviews previous code assessments for applicability
  - Both RELAP5-BW and GOTHIC codes have extensive prior assessment to test data, e.g., Semiscale, FLECHT-SEASET, CCTF, SCTF, UPTF and LOFT, including ISPs
  - This assessment is applicable to U.S. EPR containment analysis

EPR by AREVA

Section 5
Evaluation Model Adequacy

- > EMDAP Steps 10-13, 15-17
- > Both RELAP5-BW and GOTHIC codes were developed under QA programs compliant with 10 CFR 50, App. B
- > Methodology is validated through assessments against representative separate- and integral-effects tests

Section 5 (cont.)
Evaluation Model Adequacy

- > RELAP5-BW adequately predicts medium- and high-ranked PIRT phenomena except two:
  - Hot leg nozzle bypass (gap dynamics)
  - Multi-dimensional mixing in reactor vessel during post-reflood, hot leg injection phase
- > GOTHIC adequately predicts medium- and high-ranked PIRT phenomena except one:
  - Interfacial heat transfer to IRWST liquid
- > Methodology compensates for code limitations through the application of conservative biases and analytical treatments
  - Hot leg nozzle bypass modeled conservatively high in RELAP5-BW based on a separate calculation
  - Multi-dimensional mixing efficiency is determined empirically from test data; a conservative value is input to GOTHIC
  - Interfacial heat transfer to IRWST liquid is conservatively not credited

Conclusion: Methodology is applicable to any PWR with a large, dry containment—including U.S. EPR

AREVA

Section 6
Validation and Sensitivity Analysis

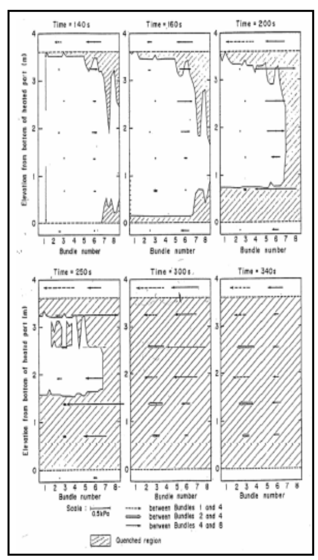
> EMDAP Steps 14, 18 and 19
> Additional benchmarks and studies
> RELAP5-BW assessments against FLECHT-SEASET data
  - Core cooling, quench front progression and integrated carryout rate fraction (CRF) are well-predicted
  - Becker CHF model improves prediction of SG heat transfer to primary side; compares well to FLECHT-SEASET SG heat transfer test data
> Sensitivity study demonstrates the Tagami-Uchida wall condensation heat transfer correlation used in GOTHIC is conservative

EPR by AREVA

AREVA

Section 6 (cont.)
Validation and Sensitivity Analysis

> Hot leg injection mixing/condensation efficiency determined empirically from the UPTF, CCTF, and SCTF test data
  - Produces vigorous circulation and mixing in core and plena
  - Effective at suppressing net steaming
  - Even when two-phase effects are neglected, ECC mixing efficiency is adequate
> Mixing efficiency confirmed for U.S. EPR configuration through CFD analysis with STAR-CD



EPR by AREVA

AREVA

Section 6 (cont.)
Validation and Sensitivity Analysis

- GOTHIC single- and multi-node models are assessed against HDR and BFMC integral-effects containment tests representative of the U.S. EPR design
  - No sprays or fan coolers
  - Multi-compartment configuration (BFMC Biblis)
  - Short-term and long-term phenomena
- Multi-volume models adequately capture both global and local containment thermal-hydraulic phenomena
- Single-volume models adequately capture global phenomena

EPR by AREVA

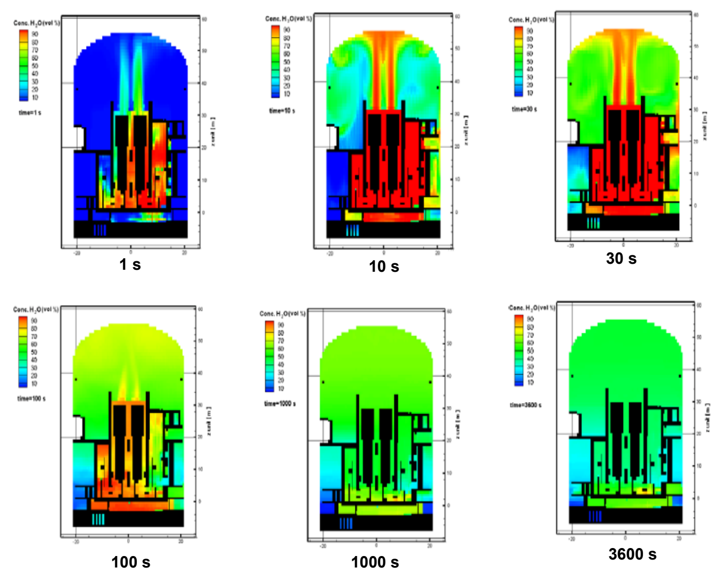
AREVA

Section 6 (cont.)
Validation and Sensitivity Analysis

- GASFLOW 3D CFD code used to assess atmospheric mixing and convection in U.S. EPR containment following a large break LOCA
- Demonstrates:
  - CONVECT system foils and dampers open within 5 s to enable circulation
  - Natural convection is established through steam generator towers
  - Highest gas temperature occurs in the central "non-accessible" area of the containment
  - Released steam distributes throughout the containment
  - Convective flows mix containment atmosphere
  - Containment pressure remains below design value

EPR by AREVA

Section 6
LBLOCA – GASFLOW Steam Distribution



Section 7
Uncertainty Analysis

- Uncertainty analysis follows Code Scaling, Applicability and Uncertainty (CSAU) methodology
- Considers
  - Important phenomena identified in the PIRT
  - GOTHIC user-specified modeling options
  - GRS uncertainty analysis and importance study
- Evaluates a range of values bounding the expected value of the parameter
- Confirms expert assessment in PIRT
- Concludes structure properties and condensation are the dominant phenomena influencing the containment pressure response

AREVA

Section 8
Modeling and Regulatory Compliance

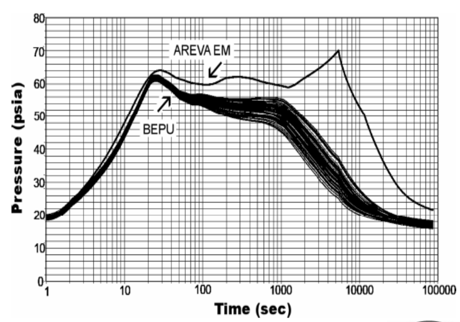
- > Describes the LOCA containment response evaluation methodology applied to the U.S. EPR design
  - Methodology includes codes, biases and treatments
- > Codes
  - LOCA mass and energy release rates
    - Short-term – RELAP5-BW
    - Long-term – GOTHIC
  - GOTHIC predicts containment pressure and temperature response
- > Summarizes methodology compliance with NUREG-0800 Standard Review Plan

EPR by AREVA

AREVA

Section 9
U.S. EPR Sample Problem

- > Instantaneous, double-ended guillotine break in the cold leg pump suction (CLPS) piping
- > As conservatively analyzed, it is the limiting containment pressure response scenario for the U.S. EPR
- > Conservatism of evaluation model (EM) methodology is demonstrated by comparison to best estimate plus uncertainty (BEPU) analysis

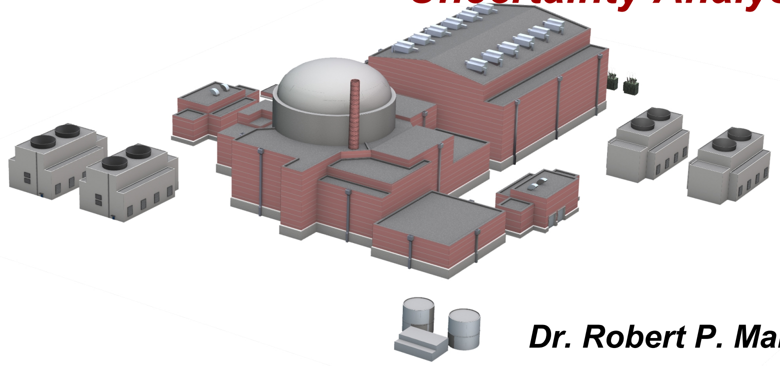


EPR by AREVA

Summary

- ANP-10299P utilizes RG 1.203 framework to present and justify methodology for evaluating U.S. EPR LOCA containment pressure response
- Revised M&E methodology addresses NRC concerns
- ANP-10299P describes the U.S. EPR containment design, including the CONVECT system, H_2 reduction system and severe accident heat removal system
- Best estimate plus uncertainty analysis demonstrates conservatism of EM methodology
- ANP-10299P addresses most FSAR Chapter 6 containment-related RAIs (Sets 1 and 82)

U.S. EPR LBLOCA Containment Response Uncertainty Analysis



Dr. Robert P. Martin
Advisory Engineer
New Plants Process & Safety Engineering

Objectives

> Determine Experimental Uncertainties as Appropriate - EMDAP Step 9

> Determine Evaluation Model Biases and Uncertainties - EMDAP Step 20

> Validate expert judgment in the Phenomena Identification and Ranking Table (PIRT) for U.S. EPR LBLOCA containment response

Quantifying Uncertainties

> Identification of important parameters
  - Separate mass and energy PIRT and containment pressure PIRT specific to U.S. EPR
    - 3-day meeting last July of US and European experts with extensive post-meeting communication to finalize PIRT
    - Began with related PIRTs available in the public domain
  - GOTHIC user-specified modeling options
  - Gesellschaft fur Anlagen- und Reaktorsicherheit (GRS) BEPU and importance analysis performed using data from HDR T31.5

> Emphasis on containment response parameters to support BEPU analysis
  - Uncertainty in mass and energy parameters addressed in Standard Review Plan requirements

Quantifying Uncertainties: Parameter Identification

Phenomena	Model Parameters
Free convection (condensation/evaporation)	Convection and condensation heat transfer coefficients
Structure conduction	Material properties (specific heat, thermal conductivity, material density, gap thickness, structure surface area), temperature initial condition
Pool (IRWST) free convection (condensation/evaporation)	Convection and condensation heat transfer coefficients; pool surface area; heat exchanger process model parameters
Expansion/compression of multi-component gases	Containment initial conditions: volume, pressure, temperature, and humidity; mist auto-conversion threshold (maximum mist density); accumulator nitrogen mass
Blowdown/Spray	Droplet size and containment initial conditions
Intra- and Inter-compartment buoyancy/stratification	Flow resistances, containment internal geometry, break location (total structural surface area in contact with well-mixed atmosphere)
Liquid advection	Water entrainment, revaporization fraction

> **Two-sided parameter uncertainties defined explicitly where data is available, otherwise a one-sided conservative bound identified**

Containment Response Uncertainty Analysis: Sampled Parameters (1/2)

Phenomena	Low Bound	High Bound
Convective Heat Transfer		
Free and Forced Convection	N/A in Single-Volume Model	
Condensation (Uchida)	0.5	1.5
Pool Free Convection		
Direct contact condensation (via pool surface area)	Pool surface area neglected	
LPSI Heat Exchanger	Best-estimate model	
Expansion/Compressions of Gases		
Initial Containment Vapor Space Volume	2,754,237 ft^3	2,810,148 ft^3
Initial Containment IRWST Volume	50,996 ft^3	68,397 ft^3
Initial Containment Pressure	14.5 psia	15.9 psia
Initial Containment Temperature (gas temperature)	59 °F	131 °F
Initial Containment Temperature (structure, accessible area)	59 °F	86 °F
Initial Containment Temperature (structure, inaccessible area)	59 °F	131 °F
Initial Containment Humidity	30 %	70 %
Maximum Mist Density	0.5 g/m^3	1.0 g/m^3

Containment Response Uncertainty Analysis: Sampled Parameters (2/2)

Phenomena	Low Bound	High Bound
Material Properties		
Steel Heat Capacity	0.9	1.1
Steel Heat Conductance	0.9	1.1
Steel Material Density	0.9	1.1
Concrete Heat Capacity	0.7	1.3
Concrete Heat Conductance	0.7	1.3
Concrete Material Density	0.8	1.2
Liner/Concrete Gap Thickness	0.225 mm	3 mm
Blowdown/Spray Phenomena		
Droplet Size	90 microns	120 microns
Temperature Initial Condition	59 °F	122 °F
Local Buoyancy/Stratification		
Flow resistances	N/A in Single-Volume Model	
Containment Internal Geometry	95%	100% (plus basemat)
Liquid Advection		
Water Entrainment	N/A for Single-Volume Model	
Condensate Revaporization	N/A for LBLOCA	

GOTHIC Model for Uncertainty Analysis

> Several key boundary conditions are set at their best estimate or mean values
- Containment free/IRWST volume
- Containment pressure, temperature, humidity
- CCW temperature for three SI trains
- Basemat floor heat sinks credited

> Retained a few conservative assumptions
- Hot leg injection mixing efficiency
- No condensation on surface of IRWST
- Accelerated removal of sensible heat

AREVA

Short-Term Mass and Energy Release

> Mass and energy release calculated with a "relaxed conservatism" model
  - Initiating event is a 100% DEGB (CLPS)
  - Many SRP requirements replaced with BE/nominal values
    - Three LHSI available
    - Nominal operating conditions
    - Best-estimate decay heat (ORIGEN2)
    - HEM critical flow model replaces Moody model
  - S-RELAP5 (code used in AREVA's RLBLOCA EM) applied
    - Greater detail of primary and secondary (4 separated loops)
    - Code options available for applying best-estimate models

EPR by AREVA

AREVA

Propagation of Uncertainties
Objectives

> Generate probability coverage bands for containment pressure for a 24 hour simulation (BEPU analysis)

> Examine sensitivity of containment pressure to model parameters (Importance Analysis)

> Compare BEPU and EM sample problem results of CLPS LOCA to identify the impact of SRP conservatisms

EPR by AREVA

AREVA

Propagation of Uncertainties
Statistical Convolution of Uncertainties

> Apply non-parametric methods to estimate tolerance limits (Wilks' Method)
  - Key advantage of this approach is that a large number of uncertainty contributors can be treated (19 identified in this study)
  - 59 cases, each case involves sampling important phenomena and plant process parameters
  - Sampled parameters assumed to vary randomly on a uniform distribution

> Method previously employed for RLBLOCA and severe accident analyses

EPR by AREVA

AREVA

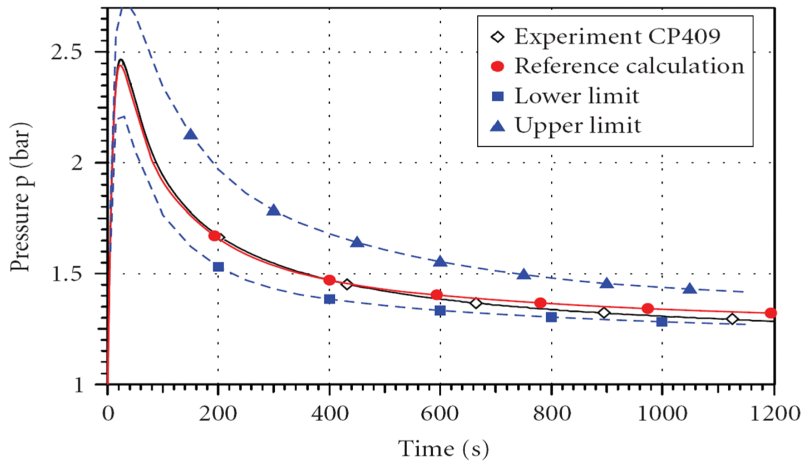
Analysis Precedence
GRS Uncertainty Analysis of HDR T31.5

> BEPU study using HDR T31.5
  - T31.5 – LBLOCA, no sprays or fan coolers
  - Used COCOSYS code for containment response with a fixed mass and energy release
  - Applied an importance analysis

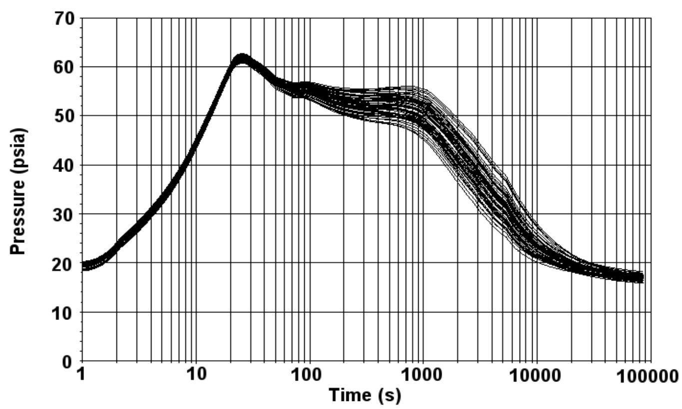
> Uncertainty results showed good agreement with spread of results in ISP-23
  - +/- 10% spread in containment pressure results
  - Importance
    - Short-term: free/forced convection and condensation
    - Long-term: liner thickness and surface area, concrete heat capacity

EPR by AREVA

Analysis Precedence
GRS Uncertainty Analysis of HDR T31.5



Best Estimate Plus Uncertainty CLPS
LOCA Containment Pressure Response



> Containment pressure sensitivity showed
- Low sensitivity during blowdown
- Greatest sensitivity during post-reflood
- Sensitivity steadily decreases as core steaming decreases to zero

Quantifying Phenomenological Importance

> The importance analysis quantifies the sensitivity of an output measure to variations of particular input parameters – assumes
- Best-estimate predictor model: $x_0 = fct(x_1, x_2, x_3, ..., x_n)$
- Linear relationship exists between the dependent variable, x_0, and two or more independent variables, x_i
- Importance is measured in terms of
  - Sample correlation coefficient
  - Standard deviation of the residual (e.g., analysis results)
  - Standard deviation from contributor
- The importance is evaluated by successive evaluation of the multiple-regression model considering the input parameter with the largest sample correlation coefficient

> As with BEPU, importance analysis considers only containment response model parameters

Evaluation of Containment Phenomena: Blowdown Peak Pressure

> Dominant contributors are initial containment pressure and volume

Uncertainty Contributor	Correlation Coefficient	Standard Deviation of Residual	Standard Deviation from Contributor
Blowdown Peak Containment Pressure (η = 61.81 psia)	N/A	**0.524**	N/A
Initial Containment Pressure	0.883	0.246	0.463
Initial Containment Volume	-0.825	0.151	0.195
Initial IRWST Liquid Volume	0.591	0.121	0.089
Initial Temperatures (containment atmosphere, IRWST and structures)	-0.649	0.092	0.079
Concrete Thermal Conductivity	-0.355	0.086	0.033
Concrete Specific Heat	-0.364	0.080	0.031
Surface of Medium Steel	-0.342	0.076	0.026
Steel Density	-0.271	0.073	0.021
Convolution of Important Contributors($\sigma\big|_{est} = sqrt(\sum_{i=1}^{m} Var[x_i])$			**0.519**
Ratio of Estimate to Actual			0.99

AREVA

Evaluation of Containment Phenomena:
Containment Pressure at 10 min

> Condensation heat transfer dominates
- Initial heat sink temperatures
- Uchida

Uncertainty Contributor	Correlation Coefficient	Standard Deviation of Residual	Standard Deviation from Contributor
10 MIN Containment Pressure (η = 51.93 psia)	N/A	**2.014**	N/A
Initial Temperatures (containment atmosphere, IRWST and structures)	0.707	1.424	1.424
Uchida Model Multiplier	-0.548	1.191	0.780
Concrete Specific Heat	-0.534	1.007	0.637
Concrete Thermal Conductivity	-0.551	0.840	0.555
Concrete Density	-0.547	0.703	0.459
Initial Containment Pressure	0.428	0.635	0.301
Steel Specific Heat	-0.405	0.581	0.258
Surface of Horizontal Wall to Inaccessible Space	-0.274	0.559	0.158
Convolution of Important Contributors($\sigma\big|_{est} = sqrt(\sum_{i=1}^{m} Var[x_i])$			**1.935**
Ratio of Estimate to Actual			0.96

EPR by AREVA

AREVA

Evaluation of Containment Phenomena:
Containment Pressure 10 min – 24 hr

> Parameters influencing condensation remain dominant during the first 3 hours

> As concrete heat transfer becomes conduction limited, material property uncertainty becomes important

> Near 6 hrs initial containment pressure becomes important again
- This results from the steam suppression following LHSI hot leg switchover at 90 minutes

EPR by AREVA

Evaluation of Containment Phenomena:
Containment Pressure at 24 hr

> Initial conditions and concrete physical properties dominate

Uncertainty Contributor	Correlation Coefficient	Standard Deviation of Residual	Standard Deviation from Contributor
24 HR Containment Pressure (η = 16.90 psia)	N/A	**0.497**	N/A
Initial Containment Pressure	0.765	0.321	0.380
Concrete Specific Heat	-0.597	0.257	0.191
Initial Temperatures (containment atmosphere, IRWST and structures)	-0.614	0.203	0.158
Concrete Density	-0.498	0.176	0.101
Initial Relative Humidity	-0.562	0.146	0.099
Concrete Thermal Conductivity	-0.616	0.115	0.090
Convolution of Important Contributors ($\sigma_{est} = sqrt(\sum_{i=1}^{m} Var[x_i])$)			**0.484**
Ratio of Estimate to Actual			0.97

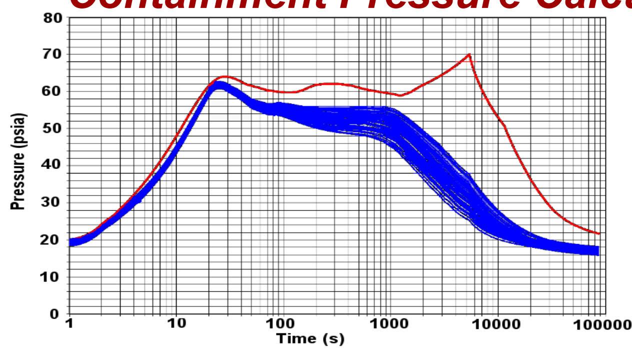
Quantifying Phenomenological Importance
Conclusions

> **Short-term:**
- initial conditions
- condensation heat transfer

> **Long-term:**
- initial conditions (due to steam suppression following SI hot leg switchover at 90 minutes)
- structure heat capacity

> **Result consistent with GRS study and the experts' assessment given in the AREVA containment pressure PIRT**

Assessment of Retained Margin
Containment Pressure Calculation



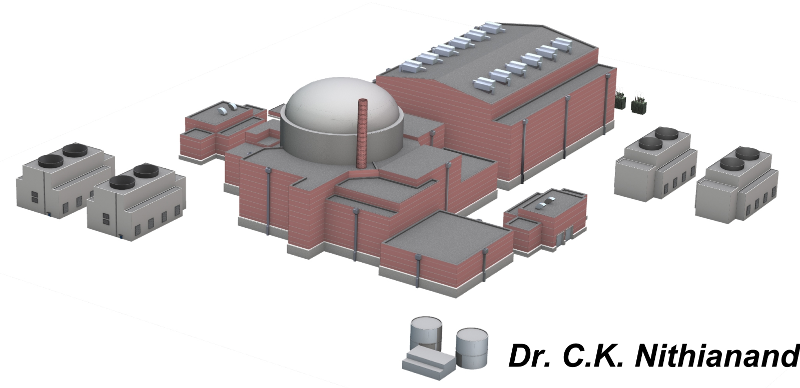
> Large margin due to SRP conservatisms
1. Combined preventive maintenance and single-failure assumption
2. Accelerated removal of sensible heat
3. Conservative decay heat model
4. Moody model

Conclusions

> The BEPU and importance analysis characterize the nature of the U.S. EPR containment pressure response to an LBLOCA
- Mass and energy release uncertainties dominate the event
- PIRT judgments are validated

> Overall methodology has been demonstrated with retained margin

Thermal Mixing in the Vessel During Hot-Leg Injection



Dr. C.K. Nithianandan
Advisory Engineer
Nuclear Analysis

EPR by AREVA

Presentation Objectives

- **Describe how hot leg injection suppresses steaming**
  - **Fluid conditions**
  - **Flow patterns**
  - **Phenomena**
- **Justify the mixing efficiency utilized in U.S. EPR FSAR Chapter 6 analyses**
  - **Test data**
  - **Supporting analysis**
  - **Empirical model**

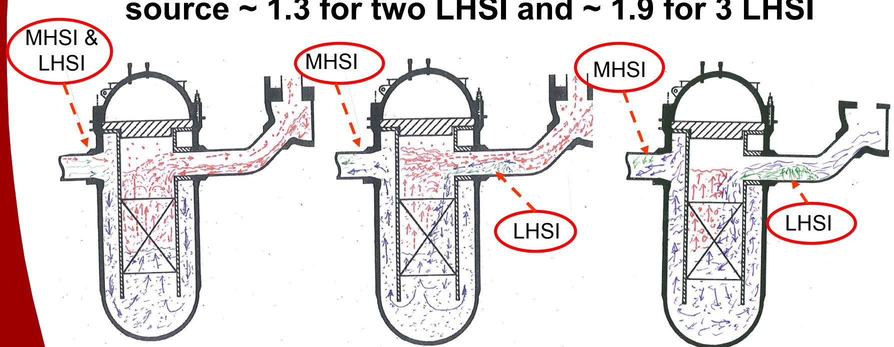
EPR by AREVA

Presentation Outline

- > Steam suppression phenomena during hot leg injection
- > Justification of Upper Plenum (UP) ECC water mixing efficiency
  - Integral-effects tests
    - SCTF
    - CCTF
    - UPTF
  - STAR-CD CFD analysis of upper plenum mixing
    - UPTF test
    - U.S. EPR configuration
  - Empirical upper plenum mixing model
  - Vessel mixing calculation
- > Summary

Expected Vessel Mixing Behavior

- > Hot leg injection = 120 kg/s per hot leg
- > Ratio of ECC sensible heat sink to decay heat source ~ 1.3 for two LHSI and ~ 1.9 for 3 LHSI



BEFORE hot leg inj. | Just AFTER hot leg inj. | Long term (no net steaming)

Mixing Efficiency

> Important phenomena during hot leg injection
- Hot leg mixing
- UP mixing
- Core mixing
- Condensation

> UP mixing efficiency

= 100 * (enthalpy rise / sensible heat) of the ECC water falling into the core region from UP

> Used in GOTHIC long term M&E release

EPR by AREVA

CATHARE 3D Analysis

> Flow recirculation in the vessel (time = 10,000s)

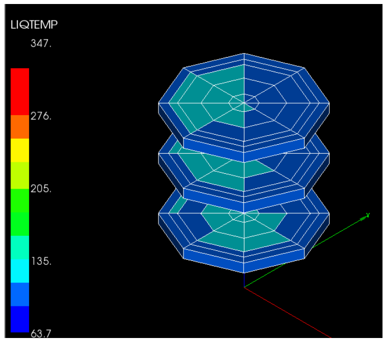
[ ]

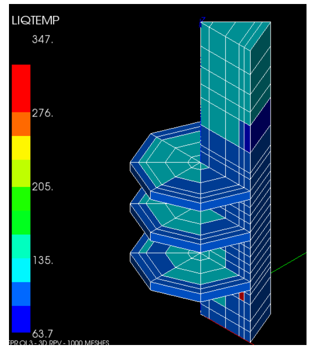
EPR by AREVA

AREVA

CATHARE 3D Analysis

> **Liquid temperature: "hot upward channel" and "cold downward channel"**





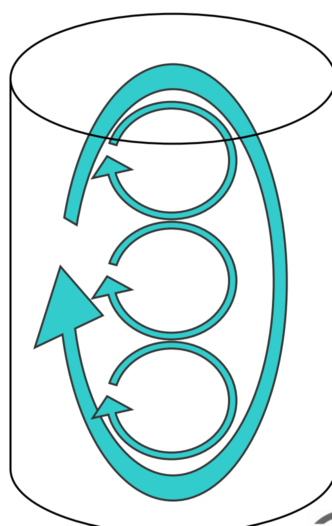
EPR by AREVA

AREVA

CATHARE 3D Analysis

> **Insights:**

- **Efficient mixing occurs in the reactor vessel**
- **Recirculation takes place along entire length of core**
- **Because of efficient mixing in core, steam production is suppressed**



EPR by AREVA

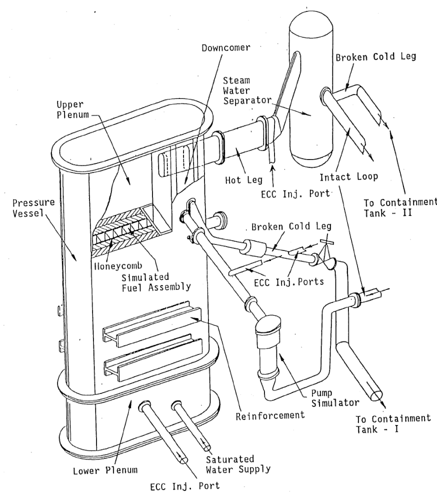
AREVA

SCTF Test Data

scaling ~1:28

> **Evaluated several SCTF CORE-III Combined Injection Reflood Tests**

- **ECC injection in cold leg and upper plenum above bundle 7 & 8**
- **Tests were run past core quench – phenomena past core quench is applicable to U.S. EPR after hot leg injection initiation**
- **For example, Tests S3-SH1 (Run 703) & S3-06 (Run 710) – Core quenched ~ 180 sec.**



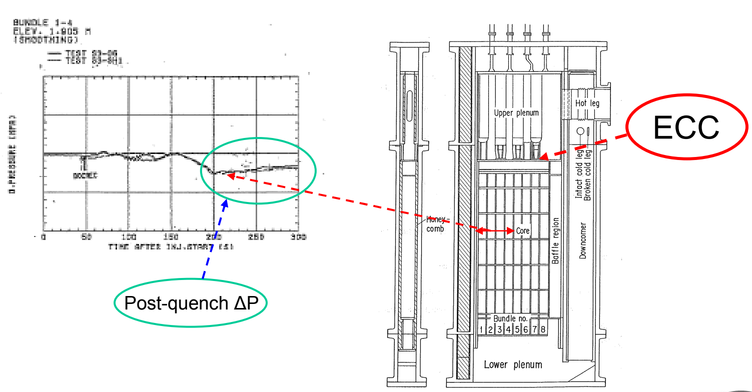
EPR by AREVA

AREVA

SCTF Test Data

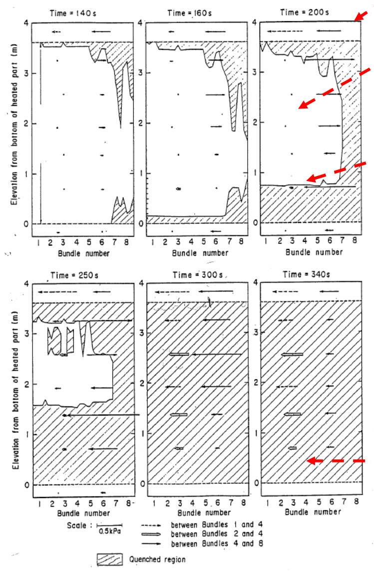
(continued)

> **Tests S3-06 & S3-SH1: horizontal differential pressure in core at 6.25 ft (1.905 m)**



EPR by AREVA

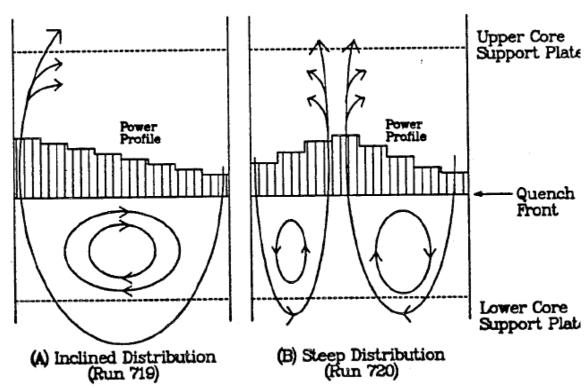
SCTF Test Data
(continued)



> **SCTF Test S3-SH1: direction and magnitude of horizontal differential pressure and quench front propagation**

SCTF Test Data
(continued)

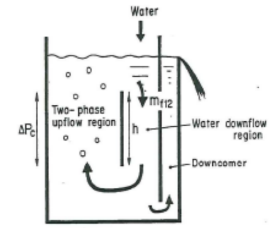
> **Observed flow circulation pattern in SCTF CORE-III cold leg injection tests**



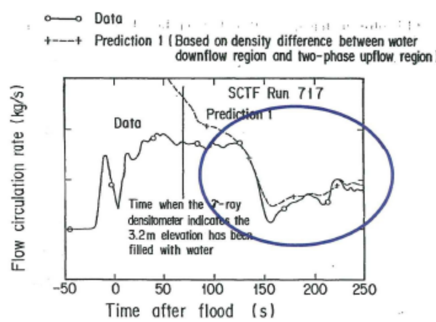
SCTF Test Data

(continued)

> JAERI concluded core circulation during the late reflood phase is determined by the density difference between the water downflow region and two-phase upflow region



$$\Delta P_c = \rho g h - (1/2)\ \rho\ (U_{Bottom}^2 - U_{Top}^2) - (1/2)\ K_c\ \rho U_c^2$$



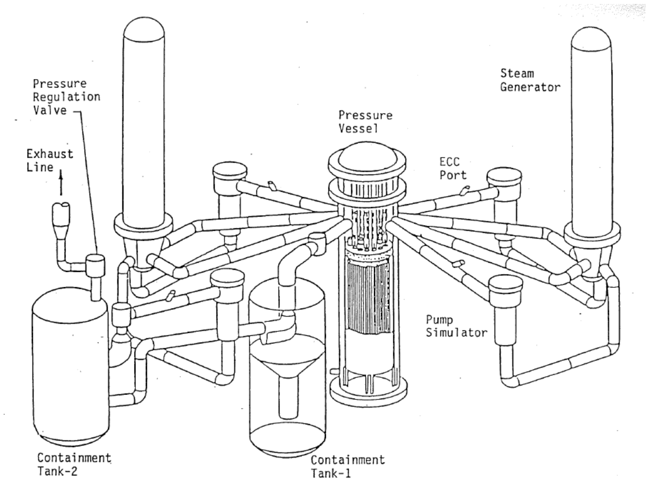
SCTF Summary

> Core circulation develops after core quench
- Subcooled liquid down flow bundles
- Two-phase fluid flows up bundles
- Horizontal crossflow from subcooled to two-phase bundles

> Confirms phenomena involved with circulation and mixing

CCTF Test Data

scaling ~1:28



CCTF Test Data

(Continued)

> CCTF Core-II Test C2-19 (Run-79)

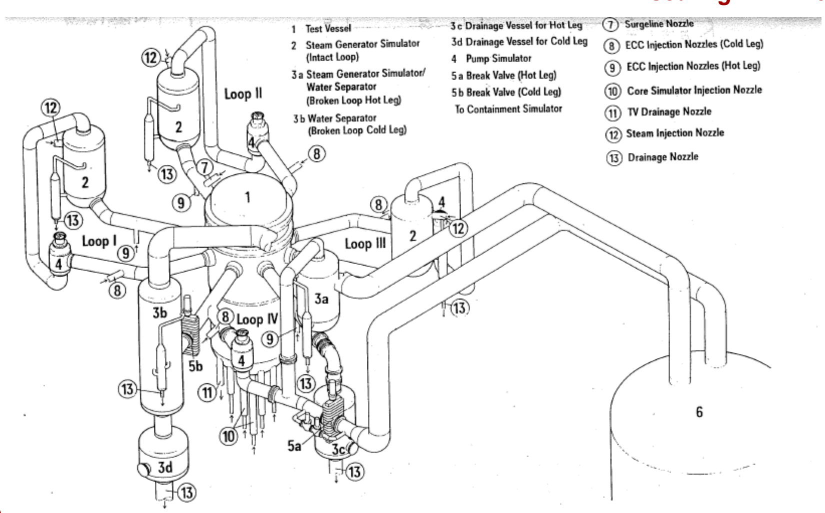
- **Reflood test with combined injection (hot leg - 1 and broken loop hot leg - 4 through the "hutze")**
- **Indication of upflow (red) & downflow (green) bundles at 250 s to 300 s**

CCTF Summary

> Confirms phenomena associated with circulation and mixing

UPTF Test Data

scaling ~1:1.15



UPTF Test Data

(Continued)

> UPTF upper plenum thermal mixing TRAM Test A3

- **Test vessel filled with hot water at least up to the top of the hot leg elevation**
- **ECC water injected into one hot leg; steam/water injected via the core simulator**

UPTF Test Data

(Continued)

> UPTF-TRAM A3 Run 06a: Fuel assembly dummies with indication of water down flow

>Legend:

- **Black – cold water**
- **Gray – warmer water**
- **Clear – hot water**

UPTF Summary
(Continued)

[ ]

> Resulting condensation increases mixing efficiency above that due only to mixing with hot water

Upper Plenum Mixing
STAR-CD Calculation

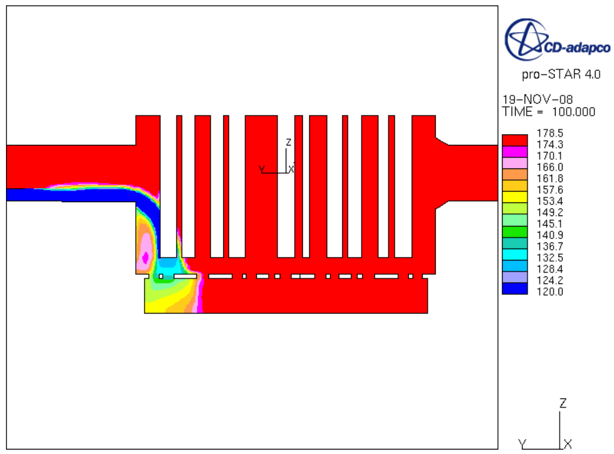
> Two quasi-steady state thermal mixing calculations using CFD code STAR-CD
- Single phase water only
- Base model – U.S. EPR upper core plate (UCP), UP & hot leg geometry

1. Simulation of UPTF Test 6a
   - Base model modified – sharp edge hot leg nozzle, "hutze", distance between UCP & HL
   - ECC flow rate = [ ]
2. U.S. EPR case
   - Base model
   - ECC flow rate = 120 kg/s in two adjacent hot legs
   - System pressure = 43.5 psia (3 bar)

Upper Plenum Mixing

STAR-CD Calculation *(Continued)*

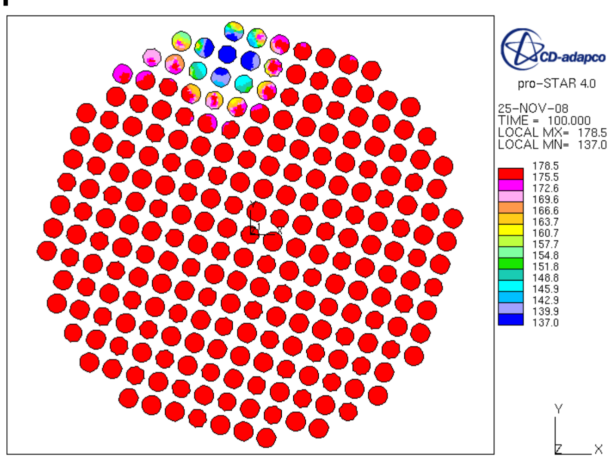
> Thermal mixing pattern of the ECC water in UPTF hot leg and UP at 100 s



Upper Plenum Mixing

STAR-CD Calculation *(Continued)*

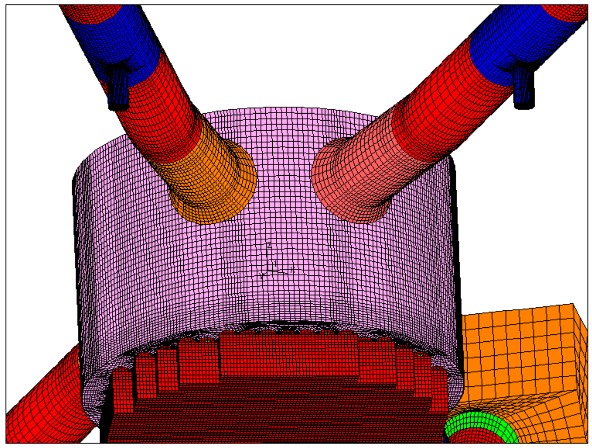
> Thermal profile of the water on the UPTF UCSP at 100 s



Upper Plenum Mixing

STAR-CD Calculation *(Continued)*

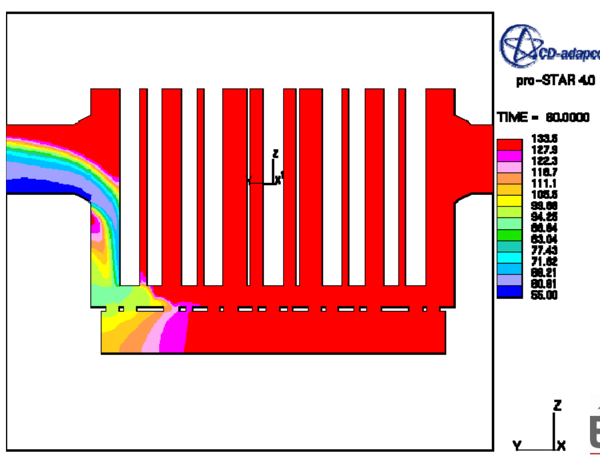
> CFD model for U.S. EPR upper plenum thermal mixing calculation



Upper Plenum Mixing

STAR-CD Calculation *(Continued)*

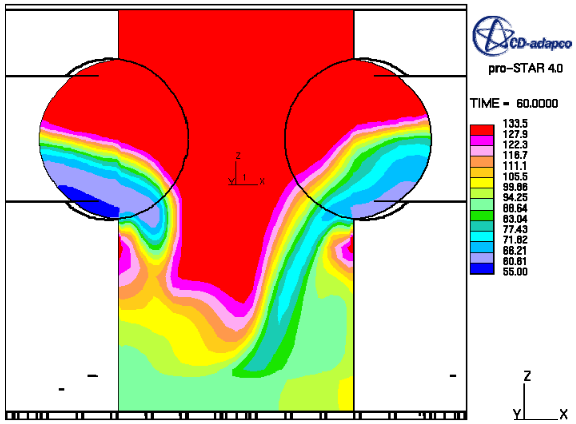
> Fluid temperature distribution in U.S. EPR for ECC injected hot leg nozzle and upper plenum at 60 s



Upper Plenum Mixing

STAR-CD Calculation (Continued)

> Fluid temperature distribution in U.S. EPR at 60 s in the two hot legs receiving LHSI and in upper plenum just below these hot legs

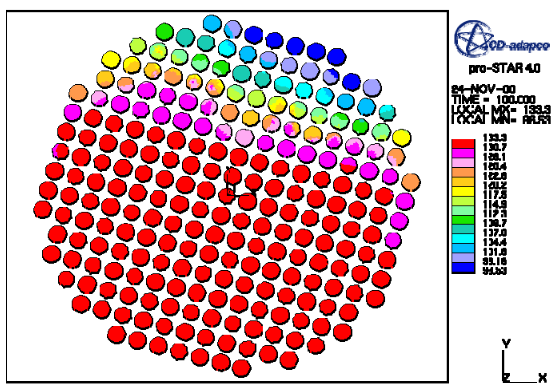


Upper Plenum Mixing

STAR-CD Calculation (Continued)

> Fluid temperature distribution in U.S. EPR on UCSP at 100 s

- Cold water spreads in the UP over more than four rows of fuel assemblies
- Minimum thermal mixing efficiency is [ ]



Upper Plenum Mixing Summary
STAR-CD Calculation

> Benchmark of UPTF Run 6a demonstrates the CFD model can predict single-phase thermal mixing in upper plenum

> Analysis of U.S. EPR configuration shows cold ECC water spreads in upper plenum over more than four rows of fuel assemblies

- Calculated minimum mixing efficiency is [ ]
- Actual efficiency is greater because STAR-CD calculation is single-phase and neglects core mixing and condensation

Upper Plenum Mixing Efficiency vs. Hot Leg Injection Rate

> Based on semi-empirical wall plume model correlated to the mixing efficiencies measured in UPTF TRAM Test A3 and CCTF Core-II Run 79

[ ]

AREVA

Summary

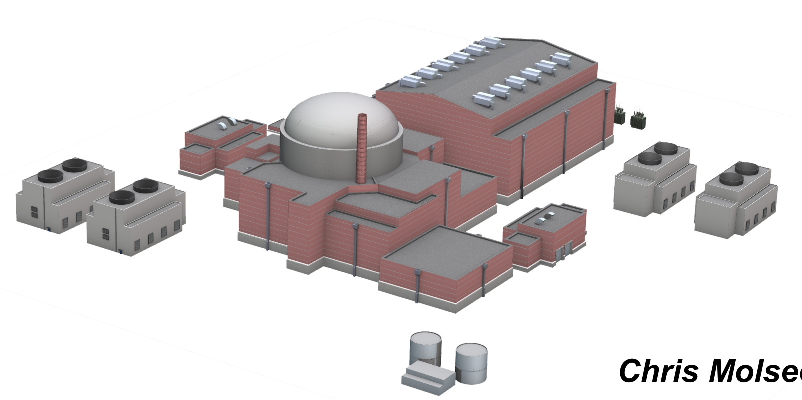
- > **Hot leg injection suppresses net steaming from the core by promoting circulation and mixing in the core and vessel plena**
  - **Predicted by CATHARE 3D analysis**
  - **Confirmed by two-phase, integral-effects test data from SCTF, CCTF and UPTF**
- > **Test data and CFD analysis justify conservative UP mixing efficiency used for U.S. EPR FSAR Chapter 6 analyses**
  - **Two-phase data justifies an ECC mixing/condensation efficiency of [ ]**
  - **Conservatively neglecting condensation, core mixing, the UP single-phase liquid mixing efficiency is**

[ ]

EPR by AREVA

AREVA

Sample Problem



Chris Molseed

Supervisor, Containment Analysis

New Plants Process & Safety Engineering

EPR by AREVA

Overview

- > Introduction
- > Short-term mass and energy release
  - Sources of energy
  - Refill
  - ECCS injection
  - Partial cooldown
- > Transition from RELAP5-BW to GOTHIC
- > Long-Term mass and energy release
- > Results

Introduction

- > Sample problem is an adaptation of the AREVA methodology developed for the installed base
  - Emphasis on specific U.S. EPR design features
  - Incorporating the guidelines of the Standard Review Plan
- > Cold Leg Pump Suction (CLPS) break, the most limiting break location for U.S. EPR for this EM

AREVA

Short-Term Mass and Energy Release

- Short-Term Mass and Energy Release (MER) includes the blowdown, refill and reflood phases
- MER methodology based on Appendix K methods utilizing the RELAP5/MOD2-B&W computer code
  - Inputs biased to produce conservative MER
  - Maximize stored energy
  - Accelerate sensible energy removal

RELAP5/MOD2-B&W has undergone extensive benchmarking and development during these three phases of a LBLOCA

EPR by AREVA

AREVA

Short-Term Mass and Energy Release Sources of Energy

- RELAP MER includes the following energy sources

  [ ]

  - Primary system fluid energy
  - Primary system stored metal energy
  - Secondary system fluid energy
  - Secondary system stored metal energy
  - Metal water reaction

EPR by AREVA

Short-Term Mass and Energy Release -Refill Phase

> Accelerated refill phase

[ ]

> Conservative modeling advances heat transfer from the fuel elements to the core fluid

Short-Term Mass and Energy Release ECCS Injection

> U.S. EPR Safety Injection System
- Four trains of Medium Head Safety Injection (MHSI)
- Four trains of Low Head Safety Injection (LHSI)
- Four accumulators

> Sample problem includes only 2 out of the 4 Safety Injection (SI) trains

> LHSI trains are cross-connected (while in preventative maintenance)

AREVA

Short-Term Mass and Energy Release Partial Cooldown

> U.S. EPR includes a safety related means to depressurize the secondary system via the Main Steam Relief Train (MSRT)

- SI signal initiates a controlled cooldown
- 180 ºF per hour
- Target secondary side pressure of 870 psia

> Partial cooldown logic ensures the primary system pressure falls below the MHSI shutoff head in the event of a LOCA

Partial cooldown removes energy from the secondary system reducing the stored energy contribution

EPR by AREVA

AREVA

Transition from RELAP to GOTHIC

> Long-term phase is best described as a quasi-steady-state or "boiling pot"

> Transition coincides with the end of the partial cooldown and assumption of loop seal formation

> Simplified model capable of predicating mass and energy release rates

EPR by AREVA

Transition from RELAP to GOTHIC

[ ]

This assumption addresses the requirement presented in Standard Review Plan Acceptance Criteria 6.2.1.3 (1)(C)(v)

Long-Term Mass and Energy Release

> For a Cold Leg Pump Suction (CLPS) break the GOTHIC RCS model calculates steam release based on a simple, but conservative model

[ ]

Long-Term Mass and Energy Release

> GOTHIC RCS node includes the following heat sources:
- Core decay heat [ ]
- Primary system fluid stored energy
- Primary system metal stored energy
- Secondary system stored energy (metal and fluid)
- SI pump heat

GOTHIC Long-Term Model Prior to LHSI Realignment

[ ]

AREVA

Long-Term Mass and Energy Release
Hot Leg Injection

> At 90 minutes the operators realign the LHSI system to the hot legs

> A fraction of the LHSI continues to be delivered to the cold leg and to the IRWST (i.e., as part of the recirculation process for cooling the IRWST)

> MHSI pumps continue injection into the cold legs only

EPR by AREVA

AREVA

Long-Term Mass and Energy Release
Hot Leg Injection

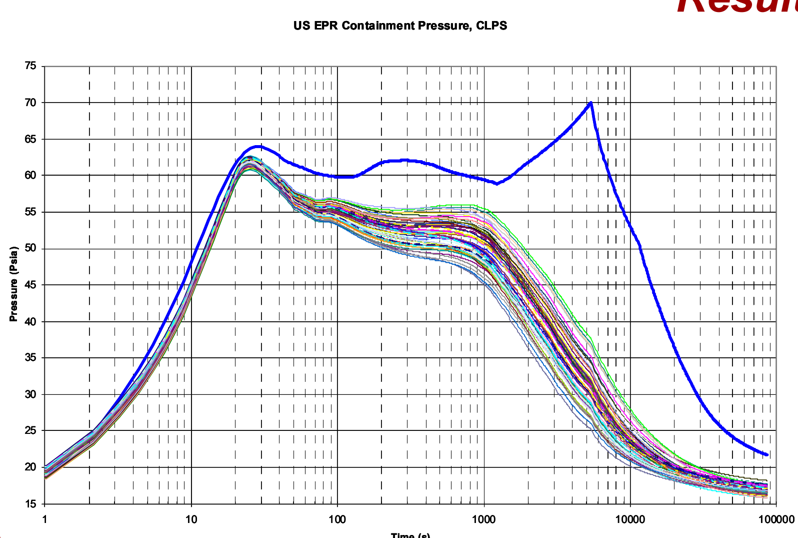
[ ]

EPR by AREVA

GOTHIC Long-Term Model after Actuation of HL Injection

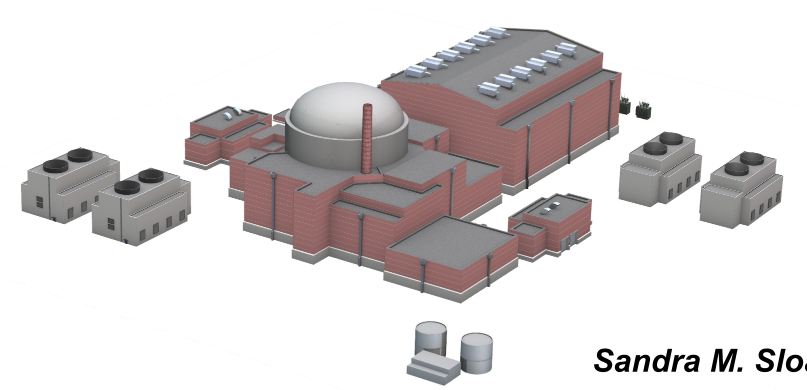
[ ]

Results



AREVA

Summary and Next Steps



Sandra M. Sloan
Regulatory Affairs Manager
New Plants

EPR by AREVA

AREVA

Highlights

> *Described the contents of the report*
> *Demonstrated the applicability of the methodology*
> *Systematically quantified uncertainty*
> *Explained mechanisms for cessation of steaming*
> *Demonstrated margins in the methodology*

Systematic and comprehensive approach used to demonstrate applicability and conservatism of the approach

EPR by AREVA

Next Steps

PURPOSE of MEETING

Provide an overview of the report and establish a starting point for future, more detailed discussions.

- **Complete RAI 1 & 82 responses consistent with already established RAI-82 supplemental response dates (5/22, 6/23)**
- **Identification of focus topics**
- **Format**
  - **Audits**
  - **Meetings**
  - **Presentations**
- **Schedule for future interactions**

Adjourn

> ***Ciao!***