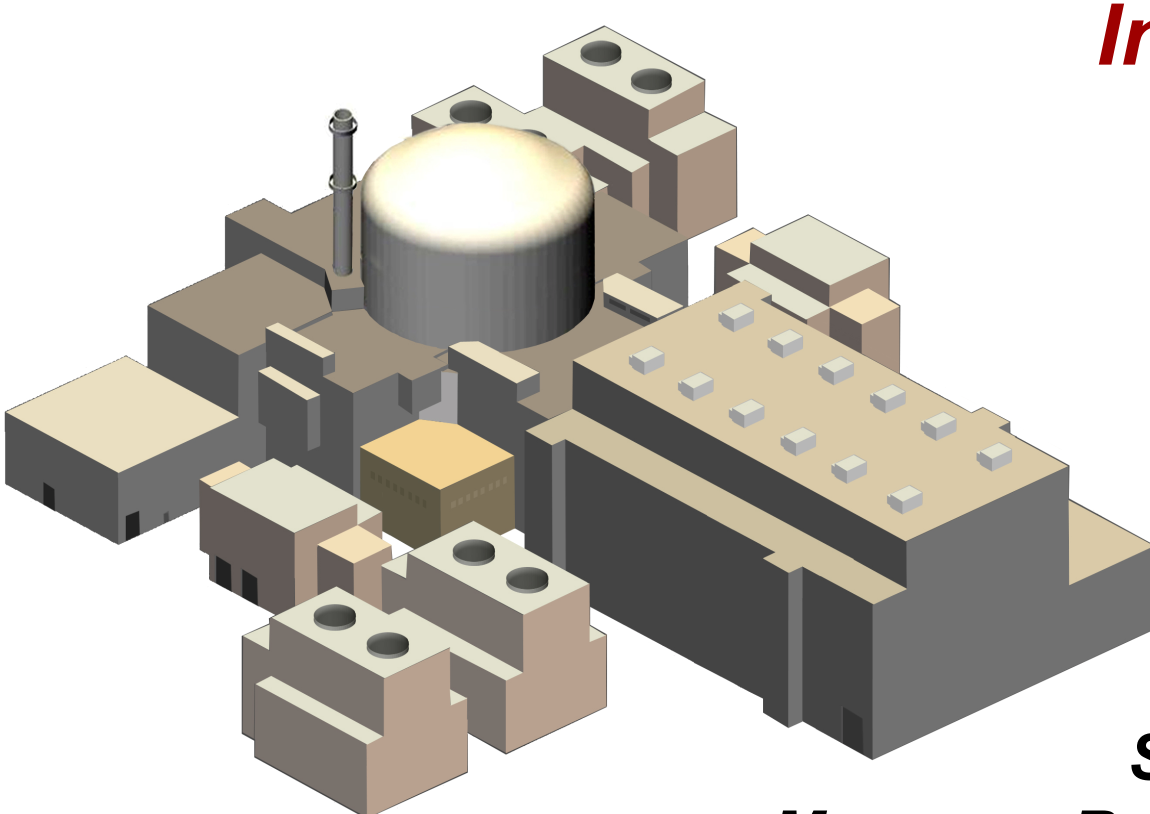
U.S. EPR Containment Meeting

Non-Proprietary

AREVA NP and the NRC
June 19, 2008



Introduction

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Agenda

- > Discuss AREVA responses to April 9, 2008 RAIs (NRC staff)
- > Discuss path forward for containment technical report (AREVA)
- > Describe the evolution of AREVA containment methodology development (AREVA)

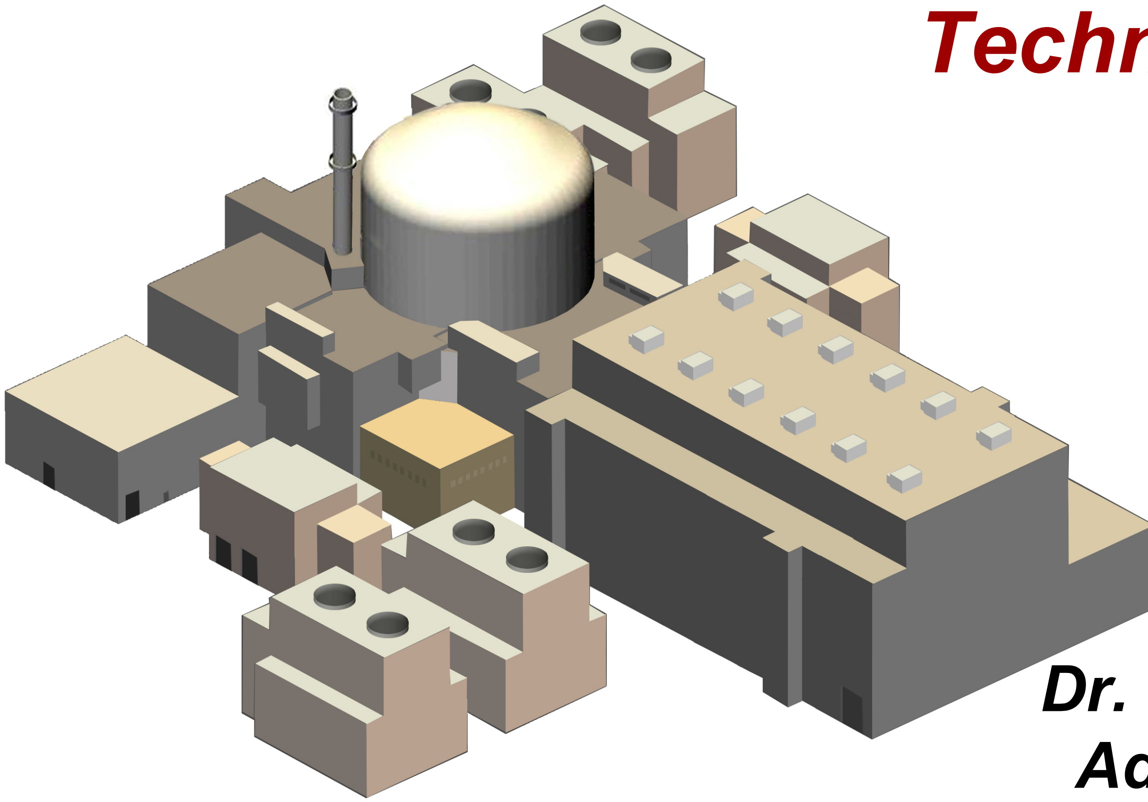
Discussion Goal

To share information regarding AREVA's plans to address NRC containment questions, for the purpose of informing NRC planning and scheduling for the design certification review.

Meeting Objectives

- Discuss responses to RAIs for further explanation and clarity
- Describe the approach, scope, content, and schedule for the containment technical report
  - Obtain NRC feedback on plans for containment technical report
  - Identify opportunities for future meetings and NRC audits of supporting technical information

Overview of U.S. EPR Containment Analysis Approach and Containment Technical Report



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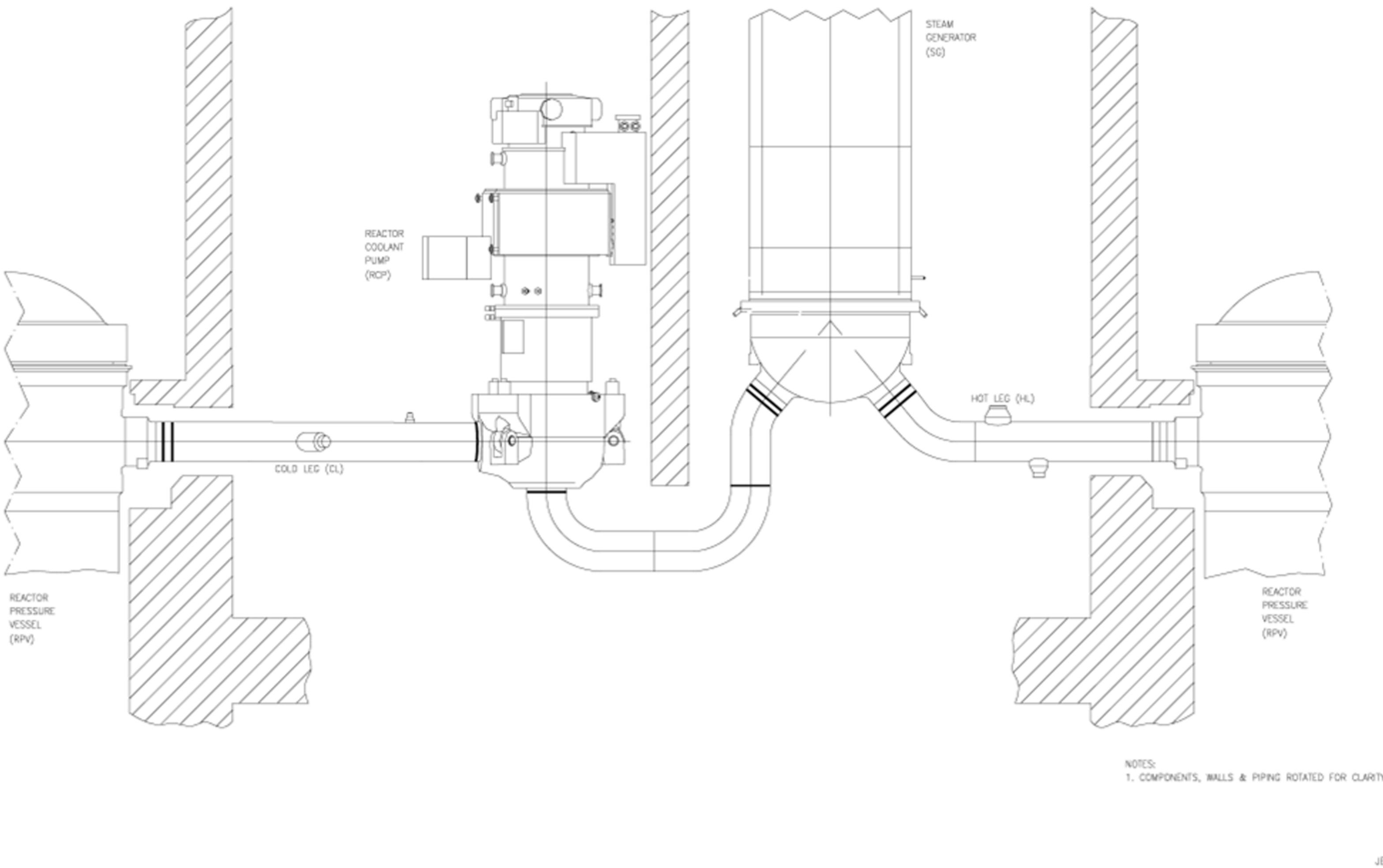
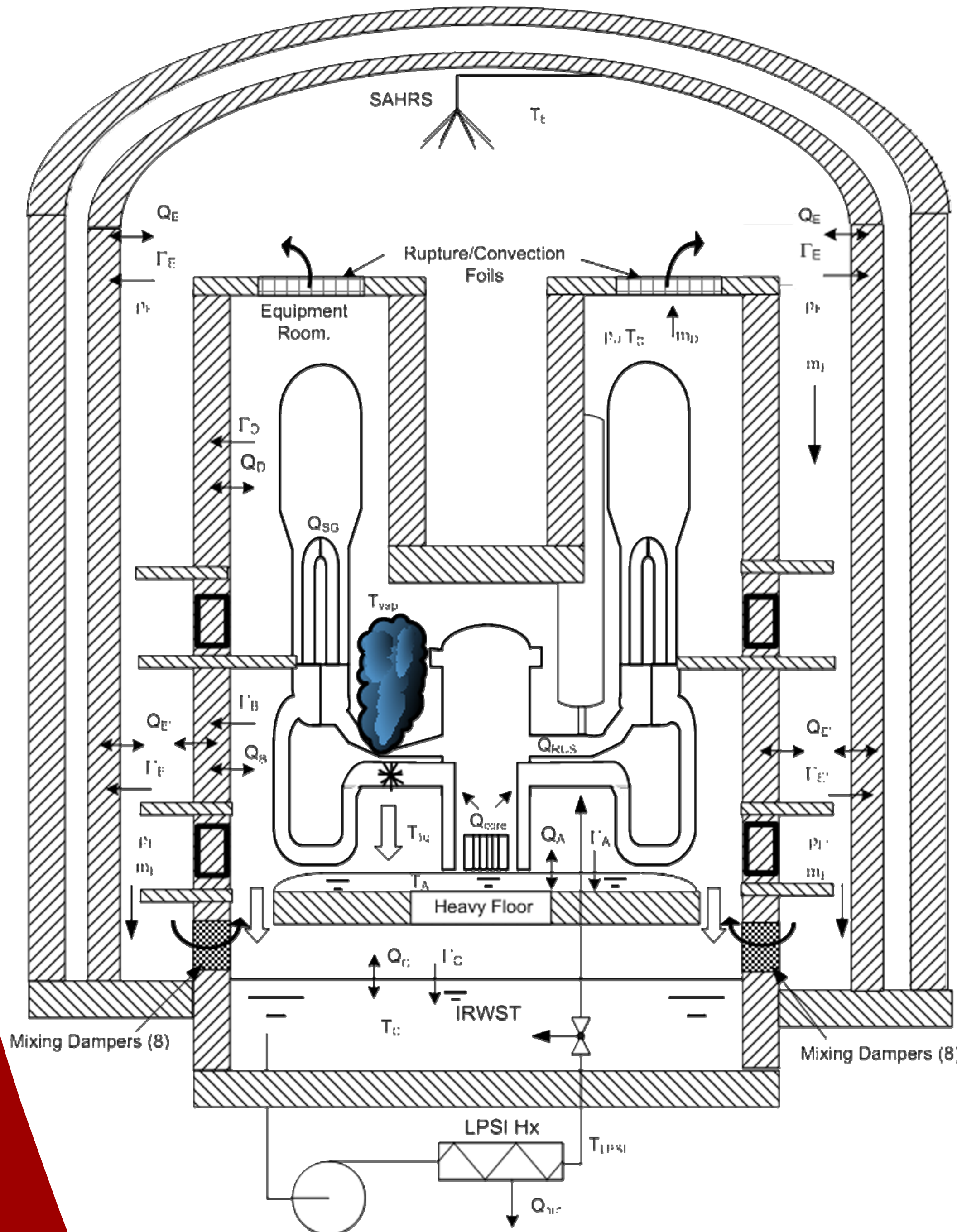
Containment Analysis Approach and Methodology

U.S. EPR Reactor Coolant System



U.S. EPR Containment



Containment System Response
LOCA

- Break opening allows RCS inventory to blow down to containment (RELAP5/MOD2 – B&W)
  - Foils on SG compartments rupture and dampers on RCP cubicles open, creating a “one-room” containment and fill the building with vapor
  - Condensation begins on steel and concrete heat structures
  - Liquid begins to pool on the heavy floor and drain to the IRWST
- Core covered by accumulator injection and LHSI flow (RELAP5/MOD2 – B&W)
  - Core sensible heat is transported to containment
  - Broken loop LHSI dumps to heavy floor (cold leg breaks)
  - Condensation on heat structures

Containment System Response
LOCA

- Post-reflood (RELAP5/MOD2 – B&W with a transition to GOTHIC)
  - SI to hot leg at 90 minutes terminates steaming from the vessel (not explicitly modeled in RELAP5)
  - Fully developed recirculation path exists from the IRWST to the RV (through the RHR heat exchangers), out the break onto the heavy floor and through drains back to IRWST
  - Excess safety injection spills on the heavy floor
  - Water leaving the RV will be cooler than the saturation temperature of containment, promoting condensation (conservatively not credited)

LOCA Analysis

> **Long-term mass and energy release**
- Transition from RELAP5 to GOTHIC includes a [

  ]
- The constituent energy sources remaining at the transition time include:
  - Primary system fluid stored energy
  - Primary system passive metal (including core metal)
  - Secondary system stored energy (fluid and metal)
  - Core decay heat

Mass and Energy Release Methodology

> Outlined in Topical Report BAW-10252(P)(A) is based on Appendix K methods utilizing the RELAP5/MOD2-B&W computer code

- BAW-10164(P)(A) – RELAP5/MOD2-B&W – An Advanced Computer Program for Light-Water Reactor LOCA and non-LOCA Transient Analysis
- BAW-10166(P)(A) – BEACH – Best Estimate Analysis Core Heat Transfer, A Computer Program for Reflood Heat Transfer during LOCA
- BAW-10168(P)(A) – BWNT Loss-of-Coolant Accident Evaluation Model for Recirculating Steam Generator Plants

Biasing of key parameters to develop conservative mass and energy release rates discussed in BAW-10252(P)(A).

SRP Expectation

PWR Dry Containments

6.1.a. – GDC 16 and 50- The peak calculated containment pressure following a loss-of coolant accident, or a steam or feedwater line break, should be less than the containment design pressure	
6.1.b. – GDC 38 – The containment pressure should be reduced to less than 50% of peak calculated pressure for the design basis loss of coolant accident with 24 hours after the postulated accident	
6.1.c. – GDC 38 – The containment pressure for subatmospheric containments should be reduced to below atmospheric pressure within one hour after the postulated accident, and the subatmospheric condition maintained for at least 30 days.	
6.1.d. – GDC 38 and 50 – For containment response to the loss-of–coolant accident, the analysis should be based on the assumption of loss of off-site power and the most severe single failure in the emergency power system (e.g., a diesel generator failure) the containment heat	

SRP 6.2.1.3 M&E for LOCA Sources of Energy (II.B.1)

10 CFR Part 50 Appendix K, I.A

Reactor Power – The reactor should be assumed to have operated continuously at least 1.02 times the licensed power level; however, a lower core power level – no less than licensed power – could be justified.

Stored Energy in the Core – The steady-state temperature distribution and stored energy in the fuel shall be calculated for the burn-up that yields the highest calculated stored energy.

Fission Heat - Fission heat shall be calculated using reactivity and reactor kinetics. Shutdown reactivity resulting from temperatures and voids shall be given their minimum plausible values, including allowance for uncertainties.

Decay of Actinides – The heat from the radioactive decay of actinides, including neptunium and plutonium generated during operation, as well as isotopes of uranium, shall be calculated in accordance with fuel cycle calculations and known radioactive properties.

SRP 6.2.1.3 M&E for LOCA Sources of Energy (II.B.1)

10 CFR Part 50 Appendix K, I.A

Fission Product Decay – The heat generation rates from radioactive decay of fission products shall be assumed to be equal to 1.2 times the values for infinite operating time in the 1971 ANS Standard. The fraction of the locally generated gamma energy that is deposited in the fuel (including the cladding) may be different from 1.0; the value used shall be justified by a suitable calculation.	
Metal – Water Reaction Rate – The rate of energy release, hydrogen generation, and cladding oxidation from the metal/water reaction shall be calculated using the Baker-Just equation. The reaction shall be assumed not to be steam limited.	
Stored Energy in the Reactor Coolant system metal – Heat transfer from piping, vessel walls, and non-fuel internal hardware shall be taken into account.	

Conservatism in the Model

>

- BTP ASB 9-2 allows for the decay heat multiplier to be reduced to 1.1 times the 1971 ANS standard as early as 1000 seconds

SRP 6.2.1.3 M&E for LOCA Sources of Energy (II.B.1)

10 CFR Part 50 Appendix K, I.A

Stored Energy in the Secondary System – Heat transfer between the primary and secondary systems in the SG shall be taken into account.

Fuel Clad Swelling and Rupture – The prediction of fuel clad swelling and rupture should not be considered.

Break Size and Location (II.B.2)

Containment design basis calculations should be performed for a spectrum of possible pipe breaks sizes and locations to assure that the worst case has been identified.

SRP 6.2.1.3 M&E for LOCA Blowdown Calculations (II.B.3.b)

The initial mass of water in the reactor coolant system should be based on the reactor coolant system volume calculated for the temperature and pressure conditions existing at 102% of full power.

Mass release rates should be calculated using a model that has been demonstrated to be conservative by comparison to experimental data.

Calculations of heat transfer from surfaces exposed to the primary coolant should be based on nucleate boiling heat transfer. For surfaces exposed to steam, heat transfer calculations should be based on forced convection.

Calculations of heat transfer from the secondary coolant to the SG tubes for PWRs should be based on natural convection heat transfer for tube surfaces immersed in water and condensing heat transfer for the tube surfaces exposed to steam.

Conservatism in the Model

- No credit is taken for the controlled depressurization of the secondary system via the safety grade Main Steam Relief Train (MSRT)
  - The safety grade MSRT allows for a controlled cooldown of the secondary system that will remove a significant amount of sensible energy from the secondary system

SRP 6.2.1.3 M&E for LOCA
PWR Core Reflood Calculations (II.B.3.c)

Following initial blowdown of the RCS, the water remaining in the **RV should be assumed to be saturated.**

Justification should be provided for the refill period. An acceptable approach is to assume a water level at the bottom of the active core at the EOB so there is no refill time.

Calculations of the core flooding rate should be based on the ECCS operating condition that maximizes the containment pressure either during the core reflood phase or the post-reflood phase.

Calculations of liquid entrainment should be based on PWR FLECHT experiments.

EPR

SRP 6.2.1.3 M&E for LOCA
PWR Core Reflood Calculations (II.B.3.c)

Liquid entrainment should be assumed to continue until the water level in the core is 2ft from the top of the core.

The assumption of steam quenching should be justified by comparison with applicable experimental data. Liquid entrainment calculations should consider the effect on the carryout rate fraction of the increase core inlet water temperature caused by steam quenching assumed to occur from mixing with the ECCS water.

Steam leaving the steam generators should be assumed to be superheated to the temperature of the secondary coolant. (**Cold Leg Breaks only**)

SRP 6.2.1.3 M&E for LOCA PWR Post-Reflood Calculations (II.B.3.d)

All remaining stored energy in the primary and secondary systems should be removed during the post-reflood phase.

Steam quenching should be justified by comparison with applicable experimental data.

The results of post-reflood analytical models should be compared to applicable experimental data.

SRP 6.2.1.3 M&E for LOCA PWR Decay Heat Phase Calculations (II.B.3.e)

The dissipation of the core decay heat should be considered during this phase of the accident. The fission product decay energy model is acceptable if it is equal to or more conservative than the decay energy model given in Branch Technical Position ASB 9-2 in SRP §9.2.5.

Steam from decay heat boiling in the core should be assumed to flow to the containment by the path which produces the minimum amount of mixing with ECCS injection water.

Conservatism in the Model

- Hot leg injection of the ECCS is not explicitly modeled in the RELAP5 calculation
  - The U.S. EPR will switch from cold leg-only ECCS injection to cold leg/hot leg injection 90 minutes following the break to address boron precipitation
  - This switch will introduce a significant amount of SI that will enter the top of the core and terminate steam production

Containment Technical Report

Topics

- > Background
- > Application of Reg. Guide 1.203
  - Element 1 – Establish requirements for evaluation model capability
  - Element 2 – Develop assessment base
  - Element 3 – Develop evaluation model
  - Element 4 – Assess evaluation model adequacy
- > Planned action
  - Analyses
  - Technical report preparation
- > Status of work

Background

> **AREVA met with the NRC to discuss NRC's containment concerns (January 29, 2008)**
- **Atmospheric mixing**
- **Long term cooling to mitigate core steaming**

> **In accepting the U.S. EPR application for Design Certification (February 25, 2008), the NRC stated:**

"During the acceptance review process, the NRC staff has identified one issue that will introduce uncertainty into the review schedule. The U.S. EPR design does not rely on active containment cooling systems for post-accident containment mixing. The NRC staff expects to interact with you to discuss the significance of this issue as the schedule is being developed."

Background

- In April, AREVA received 10 "Requests for Additional Information" (RAIs) prefaced with:

  "The EPR containment design is unlike that of operating PWRs in the US in that it does not include safety related containment sprays or fan coolers and instead relies on other containment heat removal mechanisms to a greater extent than credited in the containment analyses of operating PWRs."

- 2 RAIs have helped AREVA to define the scope of a technical report describing the methods
  - RAI #1 asks that AREVA "seek approval" of the RELAP5 & GOTHIC-based methods within the RG 1.203 framework
  - RAI #2 ask that AREVA demonstrate methods applicability for all phases of a LOCA with an emphasis on post-reflood and phenomena associated with steam quenching

RG 1.203 Transient and Accident Analysis Methods

Element 1
Establish requirements for evaluation model capability

1. Specify analysis purpose, transient class and power plant class
2. Specify figures of merit
3. Identify systems, components, phases, geometries, fields and processes that should be modeled
4. Identify and rank phenomena and processes (PIRT)

Element 2
Develop assessment base

5. Specify objectives for assessment base
6. Perform scaling analysis and identify similarity criteria
7. Identify existing data and/or perform integral (IET) and separate effect tests (SET) to complete database
8. Evaluate effects of IET distortions and SET scale up capability
9. Determine experimental uncertainties

Element 3
Develop evaluation model

10. Establish EM developmental plan
11. Establish EM structure
12. Develop or incorporate closure models

Element 4
Assess evaluation model adequacy

Closure relations (bottom-up)

13. Determine model pedigree and applicability to simulate physical processes
14. Prepare input and perform calculations to assess model fidelity and/or accuracy
15. Assess scalability of models

Integrated EM (top-down)

16. Determine capability of field equations and numeric solutions to represent processes and phenomena
17. Determine applicability of EM to simulate system components
18. Prepare input and perform calculations to assess system interactions and global capability
19. Assess scalability of integrated calculations and data for distortions

EM Resolution

20. Determine EM bases and uncertainties

Has adequacy standard been met?

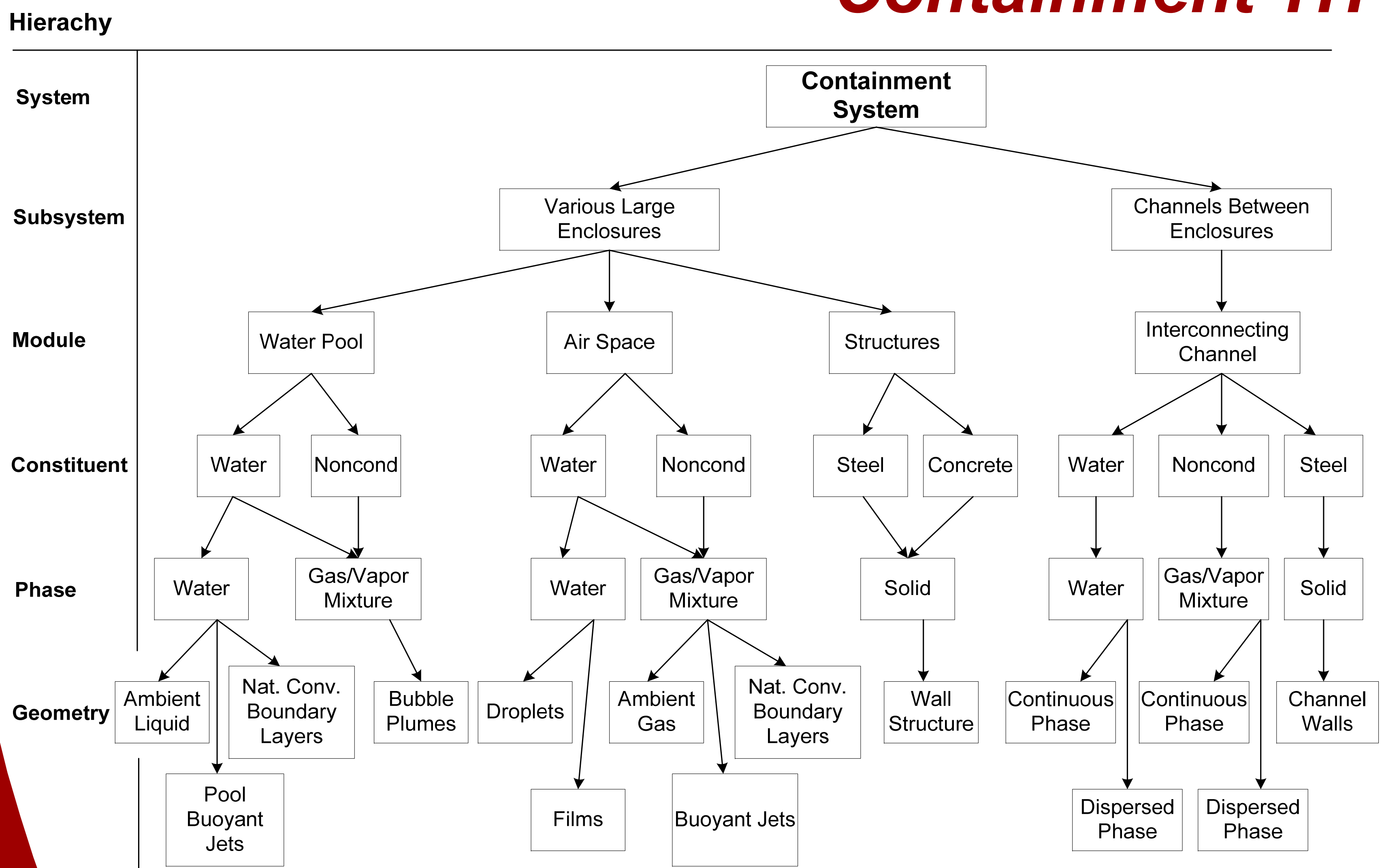
No → Return to appropriate Elements, make and Assess corrections

Yes → Perform plant event analysis

RG 1.203 Element 1
Establish Requirements for Evaluation Model Capability

1. Specify analysis purpose, transient class and power plant class
   - LBLOCA and MSLB Containment Response in the US EPR
2. Specify figures of merit
   - Containment Pressure and Temperature
3. Identify systems, components, phases, geometries, fields and processes that should be modeled
   - Will identify hierarchical relationships (see next slide)

Hierarchical Relationship for Containment TH



*From Peterson, P. F., "Scaling and Analysis of Mixing in Large Stratified Volumes," Int. J. Heat Mass Transfer, 37(Suppl. 1), 97-106, 1994.
(Aerosol contribution neglected as a simplification)

AREVA

RG 1.203 Element 1
Establish Requirements for Evaluation Model Capability

4. Identify and rank phenomena and processes

- **PIRT has greatest merit for BEPU methods applied to complex systems – deterministic containment analysis benefits less**
- **For global P&T plan to reference and summarize:**
  - OECD/NEA CSNI-1999-16, "SOAR on Containment Thermal-hydraulics and Hydrogen Distribution," 1999.
  - Maine Yankee Containment Analysis Methods Submittal, 1996.
- **Principal phenomena with rank (pressure only)**
  - **Free convection (condensation/evaporation) - High**
  - **Structure conduction - High**
  - **Spray/fans - Medium (N/A for U.S. EPR)**
  - **Local buoyancy/stratification - Low/Medium**
  - **Liquid advection (transport only) - Low/Medium**

EPR

RG 1.203 Element 2
Develop Assessment Base

5. Specify objectives for assessment base
   - Confirm appropriateness of the containment design
   - Code V&V
     - over a range of expected conditions of interest
     - over a range of scales
   - Quantify uncertainties
   - Not an effort to design a test program
6. Perform scaling analysis and determine similarity criteria
7. Identify existing data and perform IET and SET benchmarks

RG 1.203 Element 2
Develop Assessment Base

6. **Scaling basis**
   - Containment TH
     - Grashof and Prandtl #s
   - RCS TH
     - Froude, Reynolds and Weber #s
7. **Experimental basis**
   - Several tests address this issue:
     - HDR, CVTR, BMC, NUPEC,etc
   - Break/Energy Flow
     - Edward's Pipe (SET), Marviken (SET), Semiscale/LOFT (IET)
   - Steam/Water Mixing & Counter-Current Flow
     - UPTF, PKL, W/EPRI 1/3

RG 1.203 Element 3
Develop Evaluation Model

- U.S. EPR analytical methodology based upon GOTHIC
  - BAW-10252(P)(A) - Analysis of Containment Response to Postulate Pipe Ruptures Using Gothic, Revision 00, December 2005
    - Code description
    - Code validation
    - Analysis approach
    - Sample problems
- RELAP5/BW for mass and energy release
  - BAW 10164(P)(A) – RELAP5/MOD2-B&W – An Advanced Computer Program for Light-Water Reactor LOCA and non-LOCA Transient Analysis
  - BAW-10166(P)(A) – BEACH – Best Estimate Analysis Core Heat Transfer, A Computer Program for Reflood Heat Transfer during LOCA
  - BAW-10168(P)(A) – BWNT Loss-of-Coolant Accident Evaluation Model for Recirculating Steam Generator Plants

RG 1.203 Element 4
Assess Evaluation Model Adequacy

> Demonstrate capability of evaluation model

> Address uncertainties
- Code applicability
- Code use
- Code performance
- Code scalability

Planned Action - Calculations

- GOTHIC applicability studies
  - Reference original calculational bases demonstrating model validation and applicability, as appropriate
  - Prepare analyses of existing GOTHIC benchmarks (e.g., ISPs). Supplement benchmarks with new test program studies, where possible.
  - Assess code uncertainty through a code-to-code study with WAVCO to address user effect uncertainties, other code-to-code comparisons, as necessary
  - Employ a GOTHIC-only uncertainty analysis incorporating uncertainty parameters derived based on AREVA experience and others. Quantify uncertainty importance with respect to both short-term peak and long-term 50% peak.
- Characterize nominal (reduced-conservatism) LBLOCA containment response
  - Prepare a single RELAP5/BW calculation incorporating nominal estimates for break model description and expected EOPs (inc. hot leg injection). Carry M&Es through GOTHIC calculation. Present containment pressure response comparison against DC project results.
- CFD
  - Provide a GASFLOW analysis illustrating atmospheric mixing with state-of-the-art analysis tool

Planned Action - Calculations

> Phenomenological studies
  - M&E model studies
    - Reference original calculational bases demonstrating model validation and applicability as appropriate
    - Demonstrate that AREVA's M&E model is applicable for containment response
  - Examine role of IRWST as either heat sink or steam/evaporation source. Examine uncertainty regarding pool stratification.
  - Examine role of various major surfaces to actively participate in condensing of steam
    - Quantify impact of heavy floor
    - Examine GASFLOW steady-state containment flow results to assess the degree to which all surfaces participate in condensation driven natural circulation
  - Examine Uchida vs. best-estimate MDLM condensation heat transfer
  - Examine impact of using the severe accident heat removal system sprays

Planned Action – Technical Report
(consistent w/ RG 1.203)

> Introduction
- Regulatory Requirements and Guidance (e.g., SRP, GDC, RG 1.203)

> Description of US EPR Containment Design
- Unique U.S. EPR Containment Elements
- Containment Pressure Mitigation Strategy (e.g., hot leg injection, large containment surface area, mixing dampers/rupture foils, IRWST, LHSI heat exchanger)

> Phenomenological Assessment and Importance
- OECD/NEA CNSI-99-16 and PIRT for Maine Yankee Containment Analysis

> Review of Applicable Containment Test Data
- Containment Test Facility Description/Test Program Details
- Hot Leg ECCS Injection
- Scaling Topics
- Conclusions from Data Review

Planned Action – Technical Report
(consistent w/ RG 1.203) (continued)

> **Code Applicability**
- Overview of the current state-of-the-art
- RELAP5-BW
- GOTHIC

> **Analysis Methods**
- Overview
- Nodalization
- Treatment of phenomenological uncertainties
- Pressure and temperature

> **Validation and Sensitivity Analysis**
- Mix of old and new calculations

> **Sample Problem (calculations as prescribed by SRP)**

> **Conclusions**

Status of Technical Report Development

- Technical report outline has been defined
- Met with European counterparts in Offenbach, Germany (May, 2008)
  - Acquired basis documents developed during vendor/regulator dialogue
  - Began transferring containment test data
  - Compared notes with regard to analysis methods
  - Acquired WAVCO code and detailed EPR model to investigate TH behavior on a finer resolution
  - Commissioned GASFLOW study

Status of Technical Report Development (continued)

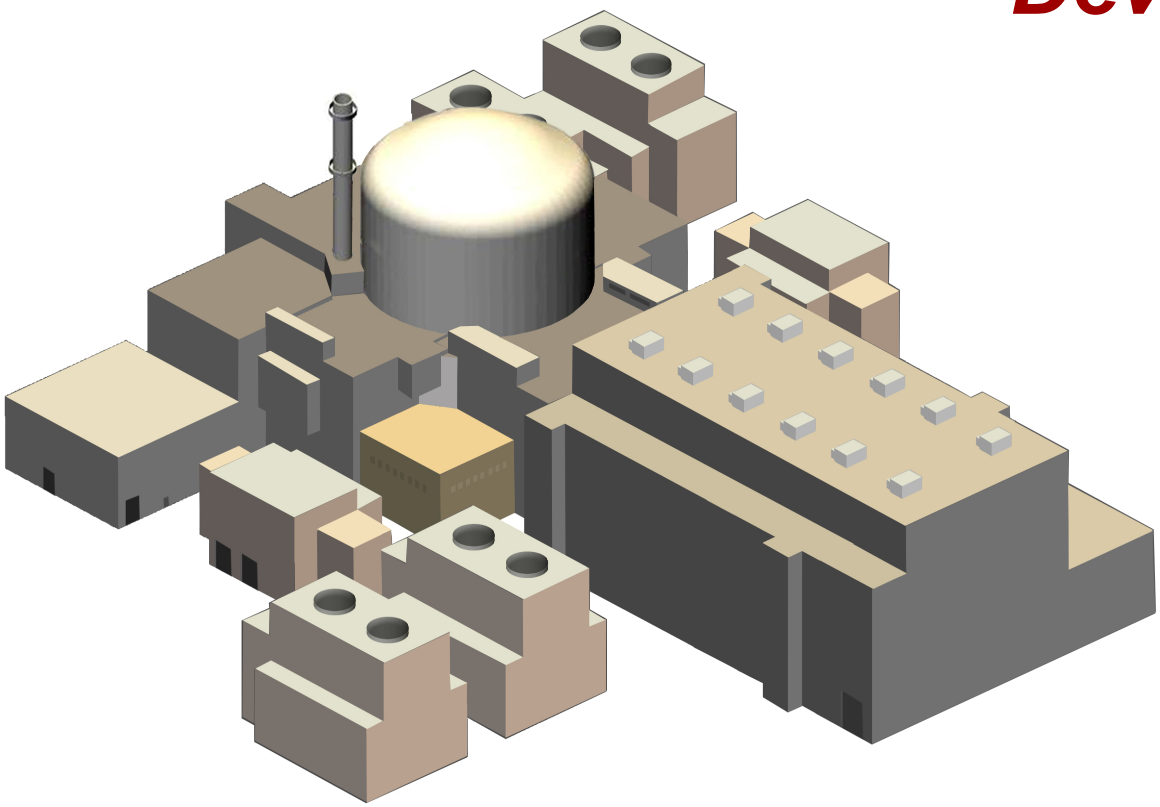
- > **Expanded containment analysis team to perform studies for technical report**
  - **Several test program benchmarks begun**
  - **WAVCO study has begun**
  - **"Reduced Conservatism" analysis begun**
  - **Phenomenological studies begun**

- > **Scaling study commissioned**

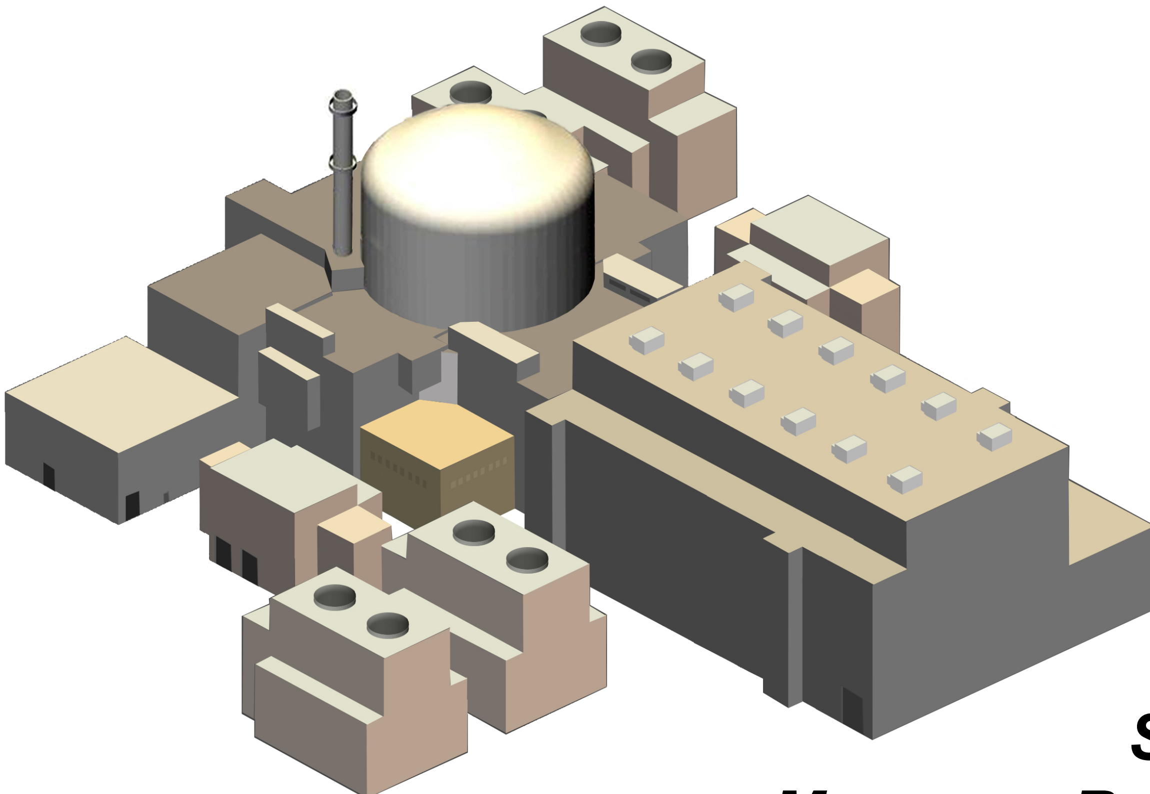
Summary

- NRC requests more information on the application of AREVA containment analysis methods to the U.S. EPR
  - Atmospheric mixing
  - Mitigation of core steaming
  - Mass and energy release prediction
- AREVA plans to follow the SRP and RG 1.203
- AREVA plans to preserve a deterministic approach
  - Prepare an applicability technical report
  - Run several analyses

Discussion of Evolution of AREVA Containment Methodology Development



Next Steps



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AREVA

Next Steps

- > AREVA to continue development of containment technical report, according to plan outlined
- > AREVA to keep NRC apprised of progress and identify appropriate opportunities for future meetings and NRC audits of supporting technical information
- > AREVA to submit containment technical report by January 28, 2009

EPR