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mPower

Safety Analysis and Methods
Redacted

March 22, 2012

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Introduction

- mPower Safety Analysis Methods Development
- Transient Classes
  - mPower Specific Events
  - Events Excluded by Design
- Phenomena Identification and Ranking
  - Key Figures of Merit
- Scaling Analysis
- Code Qualification

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SA&M Responsibilities

Design Basis Accident Analysis (Chapter 15 DCA/CPA)

- Design Basis Accident Analysis
- Radiological Consequences

Containment Analysis (Chapter 6.2 DCA/CPA)

- Containment Analysis
- Combustible Gas Control

Severe Accident Analysis (Chapter 19.2 DCA/CPA)

- Severe Accident Deterministic Analysis
- Severe Accident Phenomenological Evaluation

Best Estimate Design Transient Analysis

- Design Transient Simulation

Code Qualification

- Integrated Systems Testing
- Emergency Condenser Testing

Methods Development

- Design Basis Accident Analysis Methods
- Containment Analysis Methods

Safety Analysis Interfaces

Evaluation Methodology Development and Assessment Process (EMDAP) (RG 1.203)

Establish Requirements

- Identify mPower unique features
- Specify figures of merit
- Identify SSCs that need to be modeled
- Phenomena Identification and Ranking Table (PIRT)

Develop Assessment DB

- Specify objectives of the assessment database
- Perform scaling analysis and identify similarity criteria
- Identify existing data or perform new tests
- Evaluate distortions
- Determine experimental uncertainties

Develop EM

- Establish EM Plan
- Establish EM Structure
- Principal Computer Code Selection

Assess EM

- Determine model applicability
- Perform calculations to assess model accuracy
- Assess scalability of models
- Code Validation
- Evaluate distortion
- Uncertainty Treatment Methodology

Evaluation Model Development Plan

- Per RG 1.203
  - EM purpose & objectives
  - The quality assurance program
  - Transient & accident scenarios
  - Phenomena identification
  - Code selection

  mPower Reactor Accident Analysis Requirements Technical Report MPWR-TECR-005013P

  - Code assessment
  - Uncertainty analysis
  - Scaling analysis

  Separate Technical/ Topical Reports

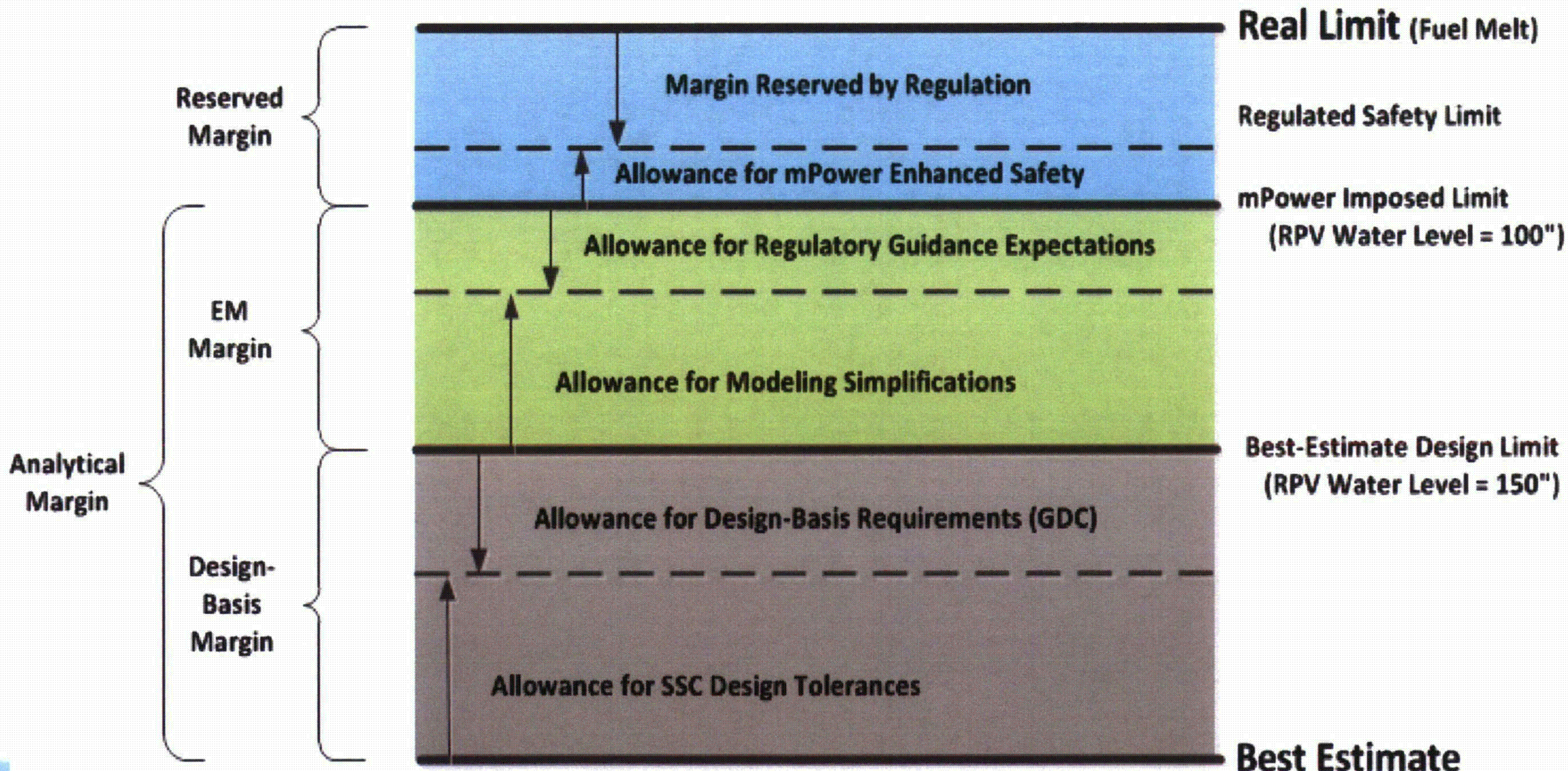
  - Theory manual

  Code Vendor Reports

  - User manuals
    - Guidelines for input model development
    - Guidelines for code use

  Internal Reports

Margin Management



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Transient Class

Accident Category	Examples of Initiating Events for mPower Reactor
Increase/Decrease in heat removal by secondary system	[
Decrease in RCS flow	
Reactivity and power distribution anomalies	
Increase/Decrease in reactor coolant inventory	
Radioactive releases	
Anticipated Transients Without Scram	
Containment pressure and temperature rise	]

[CCI per Affidavit 4(a)-(d)]

B&W mPower^{TM} Reactor Safety Analysis Transient Classification

[

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 [CCI per Affidavit 4(a)-(d)]

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Containment Analysis

Mass and Energy Release Analysis for Postulated Secondary System Pipe Ruptures

- GDC 16 – Containment design
- GDC 38 – Containment heat removal
- GDC 50 – Containment design basis

LOCA Mass and Energy Release Calculation

- GDC 16 – Containment design
- GDC 38 – Containment heat removal
- GDC 50 – Containment design basis

Combustible Gas Control in Containment

- 10 CFR 50.44

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[CCI per Affidavit 4(a)-(d)]

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Severe Accidents

Combustible Gas Control

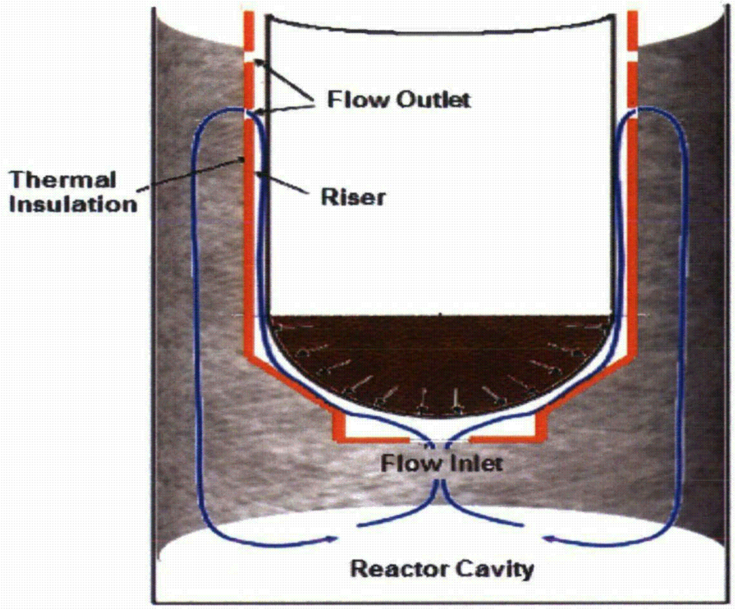
- Accommodate H_2 generation equivalent to a 100 % metal-water reaction of the cladding.
- Limit containment H_2concentration to under 10 % average by volume

Core Debris Coolability

- Provide a means to flood the reactor cavity.
- Provide a means to retain the core debris within the reactor.

Containment Performance

- Preserve the containment's role as a leak-tight barrier for 24 hours following core damage.
- Beyond 24 hours, ensure that the containment continues to serve as a fission product barrier
- Provide path for inventory makeup post 72 hours.



High Pressure Melt Ejection

- Provide an RCS depressurization system
- Provide reactor cavity features that prevent a direct path to the upper containment

Equipment Survivability

- Maintain functionality of systems during relevant severe accident scenarios.

Safety Analysis Transient Classification

mPower Specific Events

- [
-
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-] [CCI per Affidavit 4(a)-(d)]

Events Not Applicable to mPower

- [
-] [CCI per Affidavit 4(a)-(d)]

Comparison to Conventional B&W PWR

- Integral Vessel
  - The whole of the RCS is contained in an integral pressure vessel in a manner eliminating several events common to conventional PWRs, including the large break LOCA.
- Core Power
  - Both core power and average linear power density is lower. While at reduced height, the anticipated fuel product is expected to be otherwise similar.
- RCS Loop Flow and Pressure
  - Reduced RCS loop flow and core fluid velocities (corresponding to reduced power), with total core flow maintaining temperatures within the core and steam generators similar with current PWR operation. RCS pressure is reduced to facilitate optimal component size and shipping constraints.

Comparison to Conventional B&W PWR (cont.)

- Steam Flow and Pressure
  - Because of the power decrease, secondary system steam flow is also reduced, while the secondary pressure is similar. Likewise, the steam generator flow area is proportionally reduced, providing pressure drops and heat fluxes within a range typical of current PWRs with once-through-steam-generators.
- RCS and Pressurizer Volumes and Inventories
  - The parameter of interest is the ratio of component fluid volume to reactor power. The RCS coolant volume to power ratio parameter is larger than current PWRs, providing larger system response for many transients.

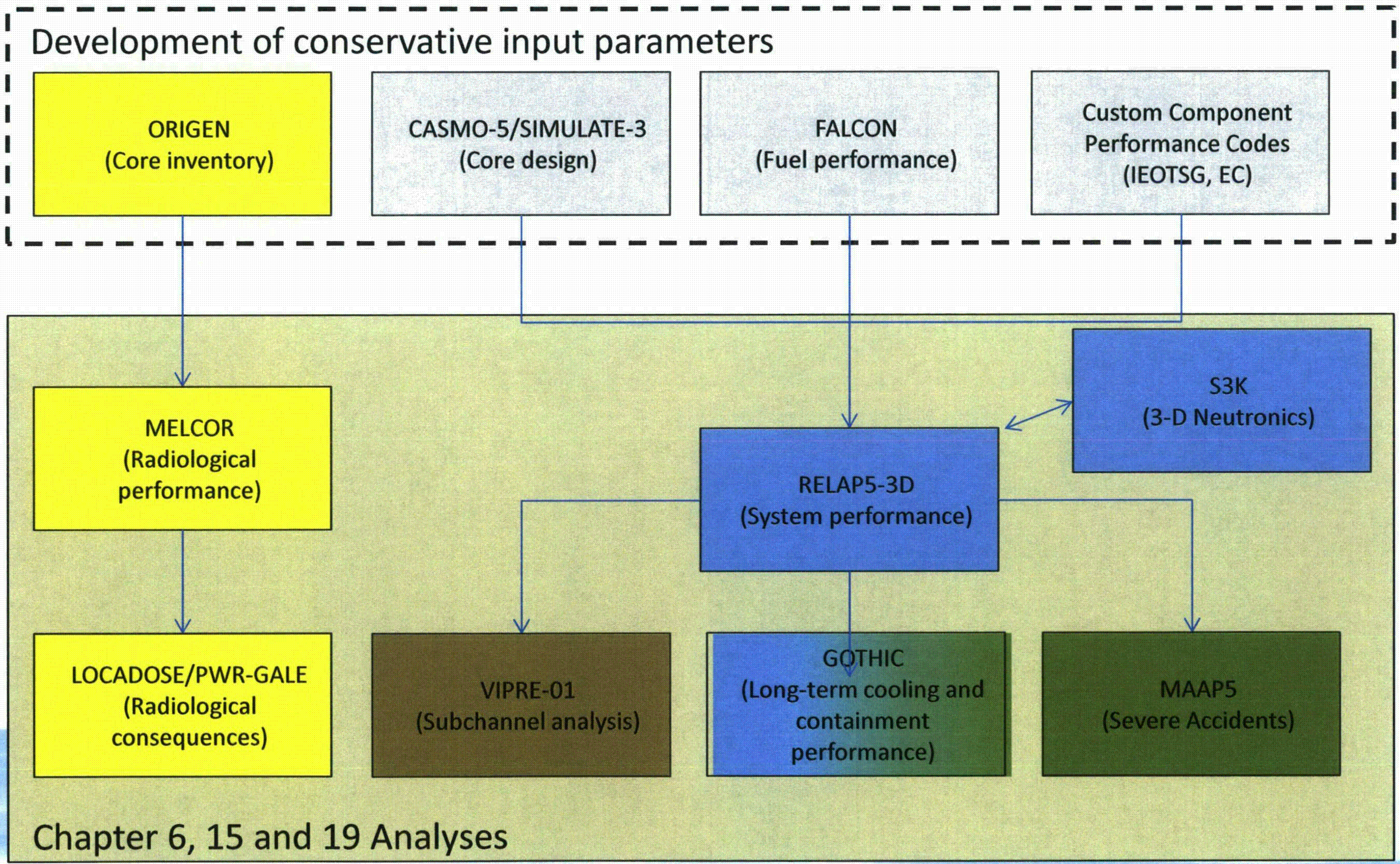
Specify Figures of Merit

- Chapter 15 LOCAs/Non-LOCAs
  - DNBR
  - Fuel centerline temperature
  - Primary and secondary pressure
  - RPV liquid level
  - Break mass & energy for containment analysis
- Chapter 15 Reactivity Initiated Events
  - Fuel enthalpy (also feeds into source term assumptions in radiological)
- Chapter 15 Radiological Events
  - A person located at any point on the boundary of the exclusion area for any 2-hour period would not receive a dose in excess of 25 rem
  - A person located at any point on the outer boundary of the low population zone would not receive a dose in excess of 25 rem
- Chapter 6 Containment Events
  - Containment pressure
  - Containment temperature
- Chapter 19 Severe Accidents
  - Hydrogen concentration
  - Core melt stabilization
  - RPV pressure
  - Containment pressure

Phenomena Identification and Ranking (PIRT)

- Preliminary PIRTs
  - SB LOCA – Ortiz, Ghan, NUREG/CR-5818
  - Non-LOCA – Greene, et al., ICONE 9, 2001
  - Containment – OECD/NEA CSNI-1999-16
- Final PIRTs
  - SBLOCA – DEGB in mid-flange attached pipe
- Plans
  - Long-term Non-LOCA events (±ΔT, ±Vol, -Flow)
  - Short-term Non-LOCA events (reactivity anomalies)

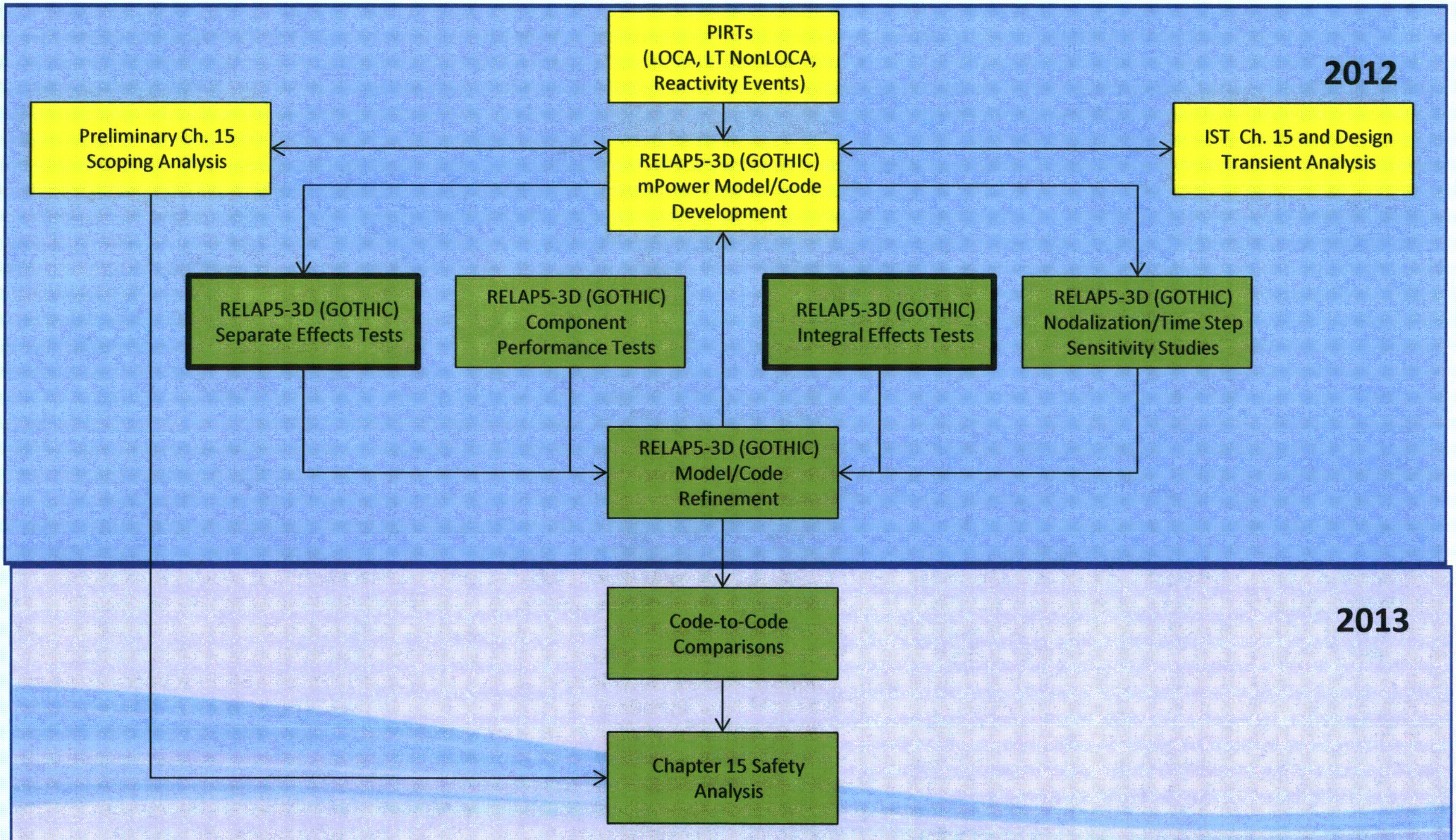
Methodology and Code Usage



Objectives for Assessment Base

- Assessment base serves to
  - Address PIRT conclusions
  - Confirm appropriateness of the design
  - V&V computer codes
    - over a range of expected conditions of interest
    - over a range of scales
  - Quantify uncertainties
  - Contribute to IST test program

Code Validation



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Evaluation Model Adequacy

- Evaluation Model Adequacy
  - Assessment of RELAP5 and GOTHIC to show that they predict medium- and high-ranked PIRT phenomena
  - Otherwise, methodology is made to compensate for code limitations
    - Provide benchmarks that shows the code adequately models the process or phenomena (i.e., inherent code conservatism)
    - Use a model known to be conservative (e.g., ANS-73 for decay heat)
    - Use event-bounding conditions
    - Apply a conservative bias to compensate for absence of data or for significant uncertainties that exist.

IST Test Plan

- Component Testing
  - Steam generator testing (Forced Flow and Natural Circulation)
  - Pressurizer control testing
  - Decay heat removal system (ECCS, non-safety systems)
  - Pump
- Normal Operations Testing
  - Startup
  - Steady-state
  - Power ramps
  - Shutdown
  - Natural circulation testing at decay heat and low power levels
- Safety Related Testing (Based on Safety Analysis Requirements)

Uncertainty Analysis

- Uncertainty quantification
  - Model uncertainty for important model parameter
    - Best-estimate (probability distribution)
    - Deterministically (bias)
- Best estimate plus uncertainty
  - For better estimate of margin to limit
- Importance analysis
  - To confirm the dominant phenomena identified in PIRT

Scaling Analysis

- Perform Scaling Analysis and Identify Similarity Criteria
  - Develops equations for scalability analysis to validate the adequacy of the benchmarks
    - Integral system scaling (e.g., natural circulation)
    - Mass and energy inventory scaling (e.g., flow between components)
    - Local scaling (e.g., gravity driven flows)
  - RCS TH
    - Resistances (Froude #), heat transfer (Reynolds #), natural convection (Richardson #, Grashof #)
  - Containment TH
    - Natural convection (Grashof #) and heat transfer (Prandtl #)

Code Scaling Distortion Evaluation

- Evaluate Scale Integrated Effects Test (IET) Distortion/Separate Effects Test (SET) Scaleup
- Verify alignment with trends/magnitudes of figures-of-merit between experimental and code results
- Assess importance of any distortion, as necessary either
  - Disposition impact
  - Quantify and apply a code scaling bias

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Methods Development

Deterministic approach

- All heat sources accounted for conservatively (initial power level, decay heat, passive heat sinks)
- Worst time in life (peaking factors, reactivity feedback)
- Highest worth rod stuck out of core
- Conservative discharge model applied for breaks
- Spectrum of break sizes and locations
- Single active failure criterion
- Delays in protection system functions

Conservative methodology chosen to reduce overall analysis timeline

Pre-application submittals to NRC

- Accident Analysis Methods Technical Report (2011)
- LOCA Methodology Topical Report (2Q 2013)
- Non-LOCA Methodology Topical Report (3Q 2013)
- Containment Methodology Topical Report (3Q 2013)

Summary

- Codes and Methods
  - Use of industry standard accident analysis codes
  - Code validation strategy driven by PIRT
  - Codes validated with focus on SBLOCA phenomena and Integrated Systems Test
  - Code modifications incorporated when necessary (e.g. IEOTSG heat transfer correlation)
  - Deterministic methodology due to expected large safety margins

- SRP Assessment
  - Certain Chapter 15 events not applicable due to mPower specific Core, RCP and CRDM designs
  - Additional Chapter 15 events identified due to mPower specific ECCS design