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IST Data Use in the Evaluation Model

September 16, 2013

(Redacted Version)

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This is a pre-application document and includes preliminary B&W mPower™ Reactor design or design supporting information and is subject to further internal review, revision, or verification.

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Meeting Agenda

- Meeting Objectives
- Summary of Use of IST Data in Evaluation Model Development
- Evaluation Methodology and Interfaces
- IST Testing Program Review
- Conclusions

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Meeting Objectives

- Review Data use in the Evaluation Model Development in order to demonstrate that the designation of IST data as Augmented Quality as defined by the IST QAPP is appropriate
- Review IST Data generation
- Discuss opportunities for NRC review of data
- Discuss any questions from NRC Staff and identify actions to resolve

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Summary of Use of IST Data in Evaluation Model Development

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EM Development

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- IST supports the validation of software used in Safety Analysis Evaluation Methods (RG 1.203)
- The B&W mPower EM is developed under a Quality process, including
  - Expert judgment and elicitation (PIRT)
  - Additional assessments to expand and complete data base
  - Uncertainty, scaling, and importance analysis
  - Methodology guidelines

Establishes the basic principles important for the development, assessment, and review of safety analysis methods

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EM Development Using IST

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Evaluation Methodology and Interfaces

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Integral Systems Safety Analysis

Perspectives on Safety Analysis Methods

- Models & Methods
- Engineering Interfaces
- Traditional Integral Systems Analysis Code and Usage Challenges
- Related Regulatory Highlights
- Evaluation Method Development and Application Process (EMDAP)

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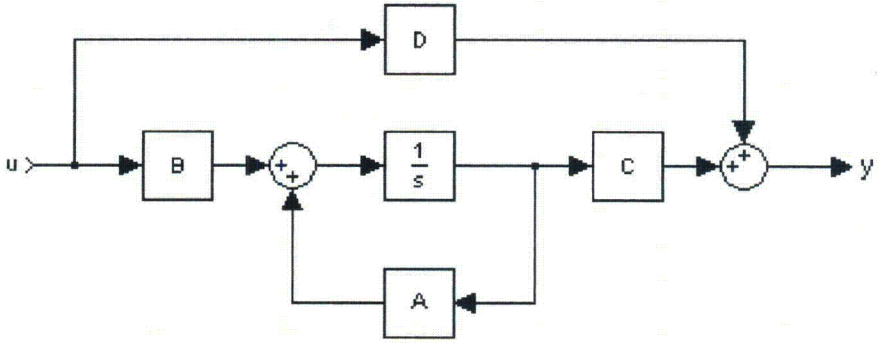
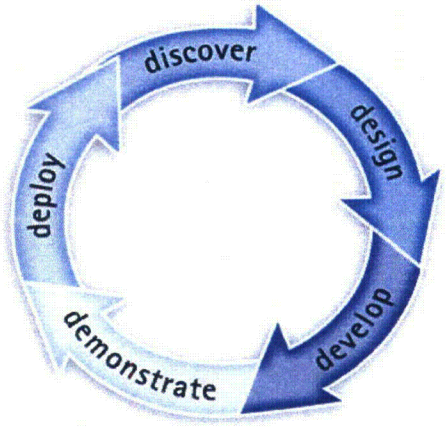
Safety Analysis Models & Methods in Design & Decision-Making

- Design – a plan from function to form
- Model – mathematical principles providing a predictive outcome to a given precondition
- Methodology – a system of rules for resolving technical issues with analysis
- Decision-making – the process for selecting a logical action from competing alternatives





Code model & methods development are unique, and often independent, activities

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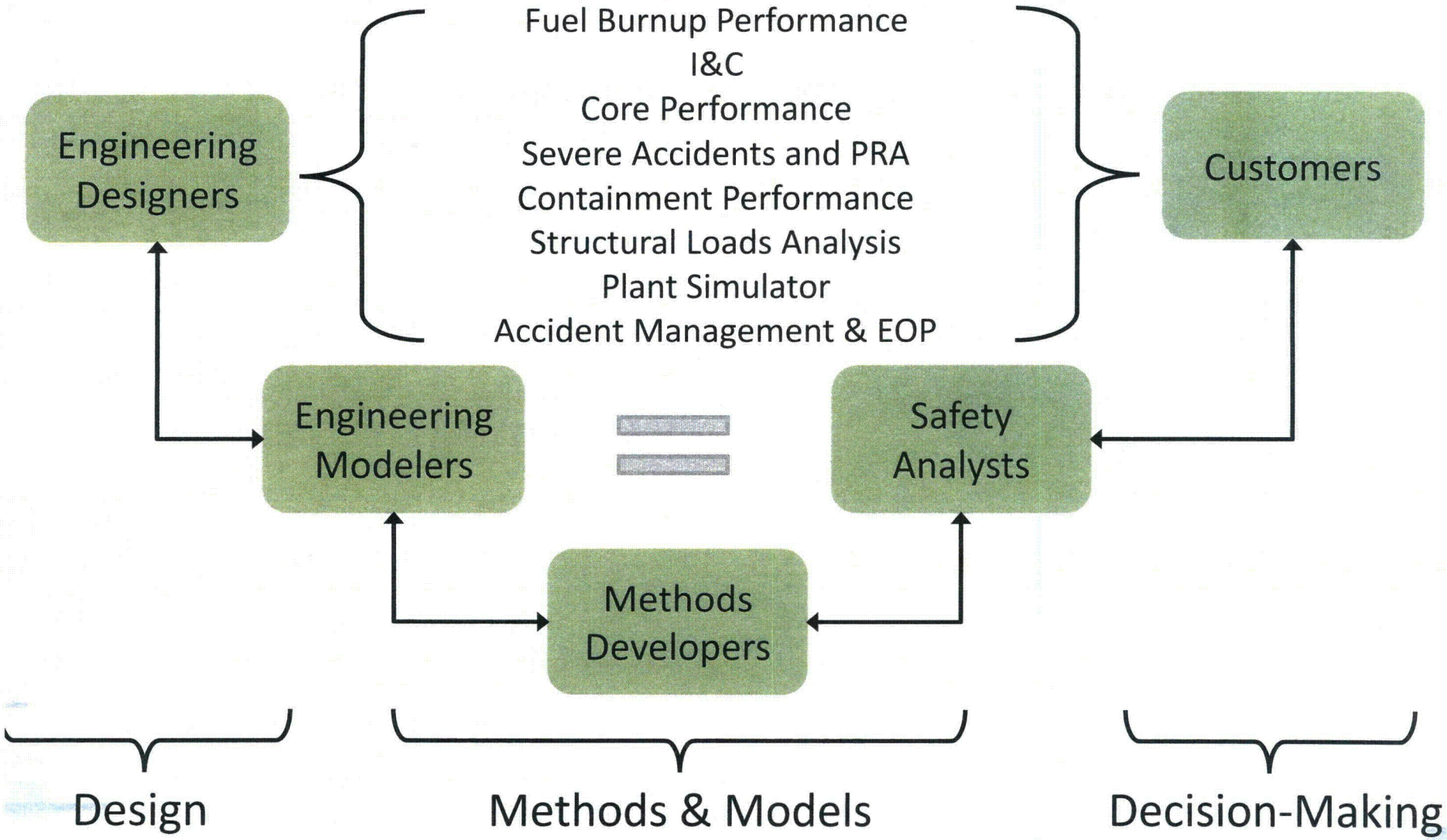
Safety Analysis Interfaces



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Computer Code Application Realities

- Complex systems exhibit multi-physics phenomena (e.g., fluid flow, heat transfer, R_x kinetics, fuel mechanics, containment, chemistry, etc.)
- Such models inherent solution variability
  - incomplete first principles/understanding of phenomena
  - modeling approximations, bifurcations and discontinuities
  - imprecision in the fluid properties (equation-of-state)
  - no optimal spatial resolution to refine non-linear distributed transport phenomena
  - numerical method convergence
- Applications of computer codes are limited
  - finite-difference/volume numerics resolve only to the scale of the control volume/mesh
  - constraints on the range of applicability of individual models
  - inherent code bias and uncertainty

Computer codes rely on a manageable, reduced-order representation of nature

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Data in RELAP5-3D Models

- Internal (source code)
  - Steam tables
  - Correlation parameters
  - Default parameters (may be overwritten by input)
- External (input file)
  - Job control
  - Design description
  - Material properties
  - Equipment performance characteristics

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Regulatory Highlights on Integral Systems Safety Analysis

- 1974, American Physical Society review of LWR Safety Research
- 1975, Water Reactor Evaluation Model
- 1980, TMI Action Plan
- 1987, NUREG-4640, Handbook of Software Quality Assurance Techniques Applicable to the Nuclear Industry
- 1989, Code Scaling, Applicability, and Uncertainty (CSAU) Technical Program Group
- 2000, NUREG-1737, Software Quality Assurance Procedures for NRC Thermal Hydraulic Codes
- **2005, Regulatory Guide 1.203, Transient and Accident Analysis**

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Origins of NPP Safety Analysis V&V*

- American Physical Society, 1974
  - To extend the application of computer codes to large reactors, APS recommended
    - Minimize empiricism
    - Sufficient degree of nodalization
    - Minimize use of arbitrary (tuning) parameters
    - Assess code with a wide range of experiment data
    - Document both code and experimental limitations
    - Independent review of equations, correlations, etc., used in the codes

"Our overall assessment is that LOFT cannot be regarded as a proof test of PWR ECCS behavior. Instead, LOFT represents a very important test bed to examine the behavior of the individual and coupled components during a range of LOCA conditions, as well as to examine our ability to calculate LOCA behavior with advanced codes."

APS identified fundamental requirements for the development of computer codes

* Summarized in NUREG-1230, Compendium of ECCS Research, 1989

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Water Reactor Evaluation Method

- NRC-developed, 1975, NUREG-75/056
  - NRC provided the computer codes (e.g. RELAP4-EM & MOXY), and methods (10 CFR 50 Appendix K LOCA)
  - No general discussion of V&V
    - Appendix K identifies several acceptable correlations
    - Deviations from accepted methods requires validation
  - Latter regulatory statements state that NRC still requires comparisons to data for Appendix K methods similar to those required for the best-estimate option

In absence of sufficient R&D, WREM provided a tight coupling between code models and methods

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NUREG-0737, TMI Action Plan, 1980

- "The analysis methods used by nuclear steam supply system (NSSS) vendors and/or fuel suppliers for small-break loss-of-coolant accident (LOCA) analysis for compliance with Appendix K to 10 CFR Part 50 should be revised, documented, and submitted for NRC approval. The revisions should account for comparisons with experimental data, including data from the LOFT Test and Semiscale Test facilities."
  - LOFT L3-1, L3-2, and L3-6
  - Semiscale S-07-10B

As R&D database grew, plant suppliers inherited greater responsibility for the scope of V&V

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NUREG-4640, 1987

- Clarification of 10 CFR 50 Appendix B for Software Use
- Describes software development best-practices
- Defined documentation expectations
  - Software Quality Assurance Plan
  - Software Requirements Specification (SRS)
  - Software Design Documentation (SDD)
  - Software Verification and Validation Plan (SVVP)
  - Software Verification and Validation Reports (SVVR)
  - User Documentation
  - Others (development plan, configuration management, etc.)
- Established expectations for software testing confirms (Section 10.1.3)

Codes are developed to address requirements

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1989 Technical Program Group

- Developed the Code Scaling, Applicability, & Uncertainty (CSAU) Methodology – NUREG-5249
  - Emphasized a Top-Down, Bottom-Up approach
    - Define Plant, Scenarios, and Figure(s)-of-Merit ("Top")
    - Identify Important Phenomena (PIRT)
    - Select code, examine model applicability
    - Identify applicable test programs ("Down")
      - Separate-effects test data from facilities up to full scale, when available, are used to help evaluate code scale-up capability and accuracy. ("Bottom")
      - Integral-effects test data are used to evaluate code overall accuracy ("Up")
  - "These techniques are needed as confirmatory support; however, in practice they have not proven a sufficient basis for determining overall code accuracy."

Birth of Top-Down/Bottom-Up Methodology Framework

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NUREG-1737, 2000

- Quality assurance procedures for development and maintenance of the NRC thermal hydraulic codes
- Introduces qualitative acceptance criteria associated with the adequacy of code prediction
  - "Excellent agreement" – major and minor phenomena and trends are correctly predicted
  - "Reasonable agreement" – major trends and phenomena are predicted correctly
  - "Minimal agreement" – major trends or phenomena are not predicted correctly, some calculated values lie outside the specified or inferred uncertainty bands of the data
  - "Insufficient agreement" – code exhibits major deficiencies

NRC further clarifies expectations for validation

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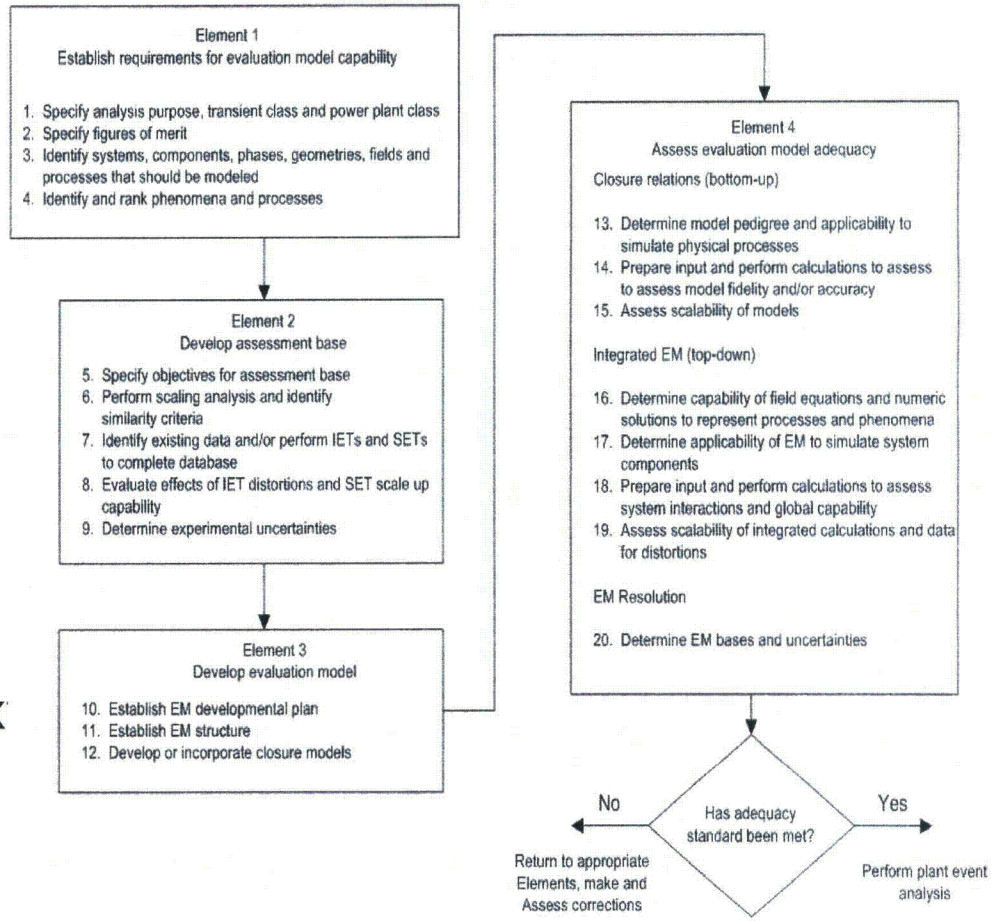
Regulatory Guide 1.203, 2005

- Retains Top-Down/Bottom Up Framework
  - Similar to CSAU
  - Greater emphasis on scaling
  - Identification of uncertainties
  - Quantification of total uncertainty
- Adopted the qualitative V&V acceptance criteria from NUREG-1737
- Appendix B discussed in contex of applying a process



Methodical use of code input & output is a QA requirement

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Methodologies for Decision-Making

- RG 1.203 proceduralizes the management of uncertainty
  - Managing compliance
  - Managing intuition (theory)
  - Managing experience (observation)
  - Managing model development/user interface
  - Managing uncertainty quantification and convolution
  - Managing verification and validation
- Evaluation methods for performing process studies of integral system are confirmed by test data, but not developed from test data

Methods development is rigorous

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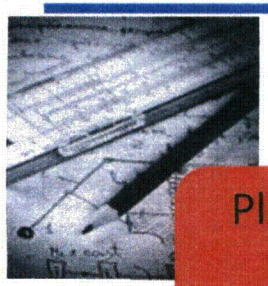
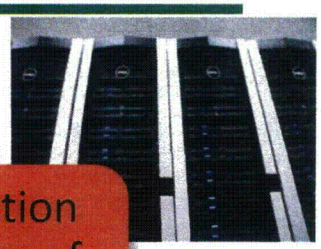
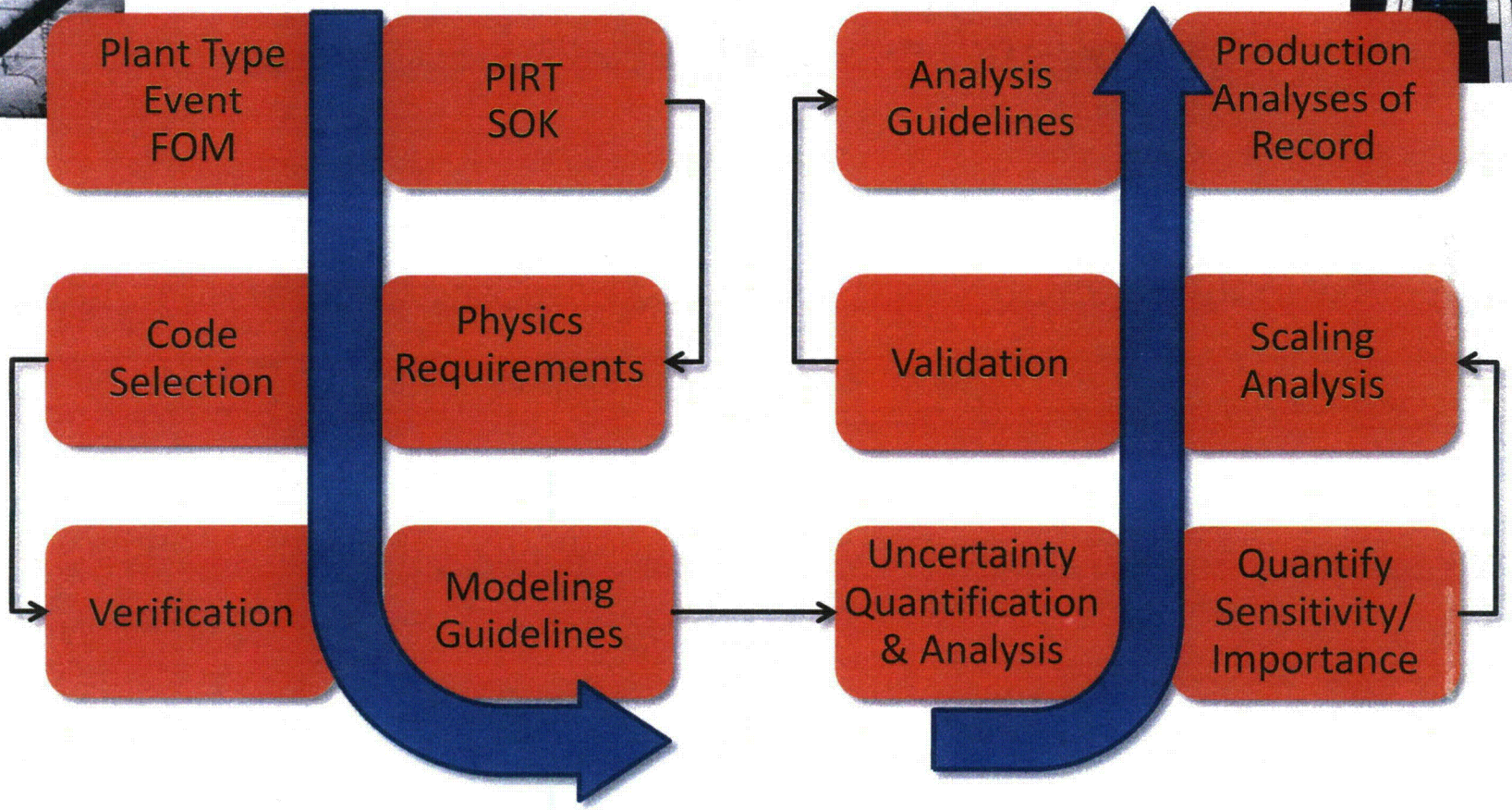
Top-Down/Bottom-Up Methodology







Testing and Methods are Independent

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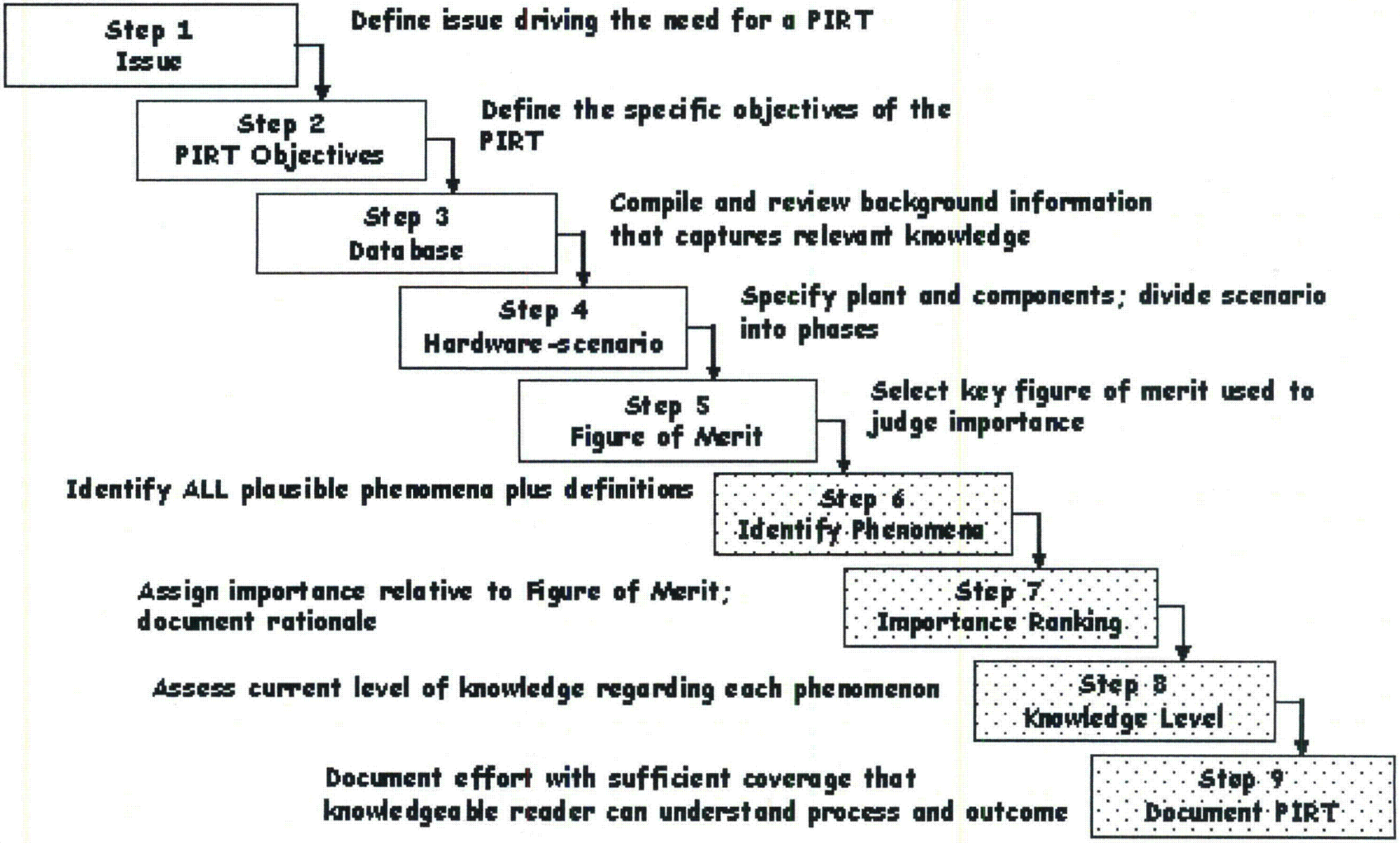
PIRT Process



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Safety Analysis Figures of Merit

Chapter 15 LOCAs/Non-LOCAs

- DNBR (Liquid Level)
- Fuel centerline temperature
- Primary and secondary pressure
- 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

- Highest total effective dose equivalent at exclusion area boundary for any 2-hour period
- Total effective dose equivalent at the boundary of the low population zone (30 days)

Chapter 6 Containment Events

- Containment pressure
- Containment temperature

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Objectives for Assessment Base

- Assessment base serves to
  - Address PIRT conclusions
  - Confirm completeness of computer codes
    - over a range of expected conditions of interest
    - over a range of scales
  - Quantify uncertainties
  - Inform the development of new test programs

Testing builds up the depth and density of data available over the range of applicability

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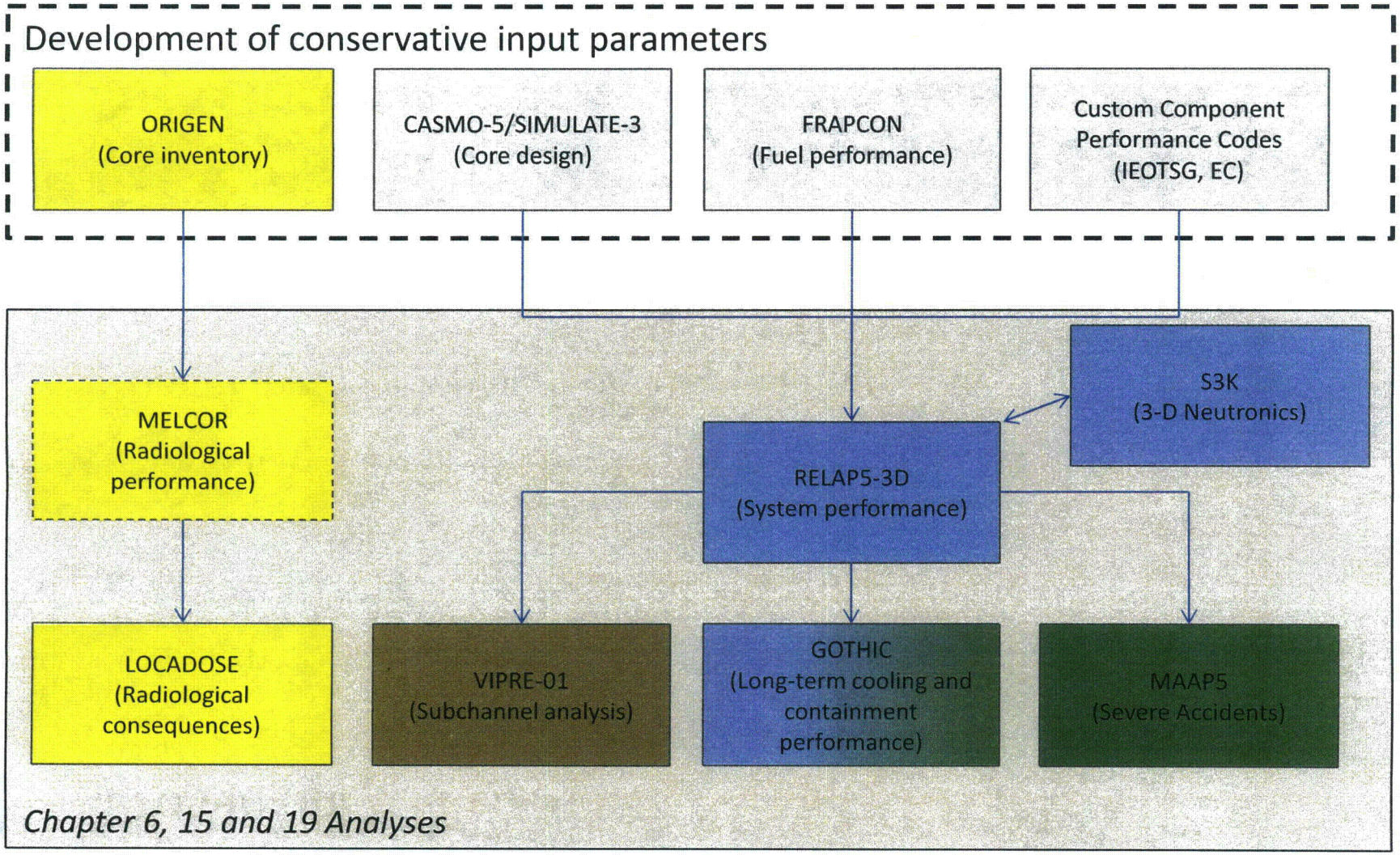
Methodology and Code Usage



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Modeling & Analysis Guidelines

RG 1.203 states a calculational device input model and the related sensitivity studies, assessment reports must achieve the following additional purposes:

- Provide a nodalization diagram and rationale
- Specify and discuss the boundary and initial conditions
- Present and discuss the results of sensitivity studies
- Present and discuss numerical convergence studies
- Provide guidelines for performing similar analyses
- Discuss modifications to the input model resulting from sensitivity studies (if performed)

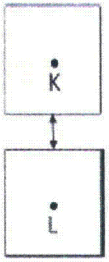
Document No.	Title	Rev. No.
EI-Q03-007	RELAP5-3D Modeling Instructions for Safety Analysis of the B&W mPower Reactor	000

6.2.1 Pressurizer

This section describes the modeling of the pressurizer. The spray valves, heaters, safety valves, and pilot/power-operated relief valves (PORVs) cannot be credited in the DBE analyses unless their realistic operation negatively impacts the analysis figure(s) of merit. Their inclusion is useful for steady-state operation.

A. Technical Basis Discussion

From the PIRT the important phenomena impacting modeling relate to pressurizer performance. The pressurizer conditions during steady-state are well controlled by the use of RELAP5-3D control systems and a pressure boundary condition. These are disabled during transient simulations. During steady-state and transients prior to depressurization, a liquid level is maintained. During depressurization transients, the pressurizer is expected to be in a frothy condition. The flow model for the pressurizer volumes are to be represented as illustrated below:



The relevant contributors to the momentum equation are acceleration (standpipe entrance), body, friction, form and interfacial. Structure stored energy and conduction are the relevant phenomenological contributors to heat transfer.

B&W mPower-specific modeling guidelines are being applied for Safety Analysis

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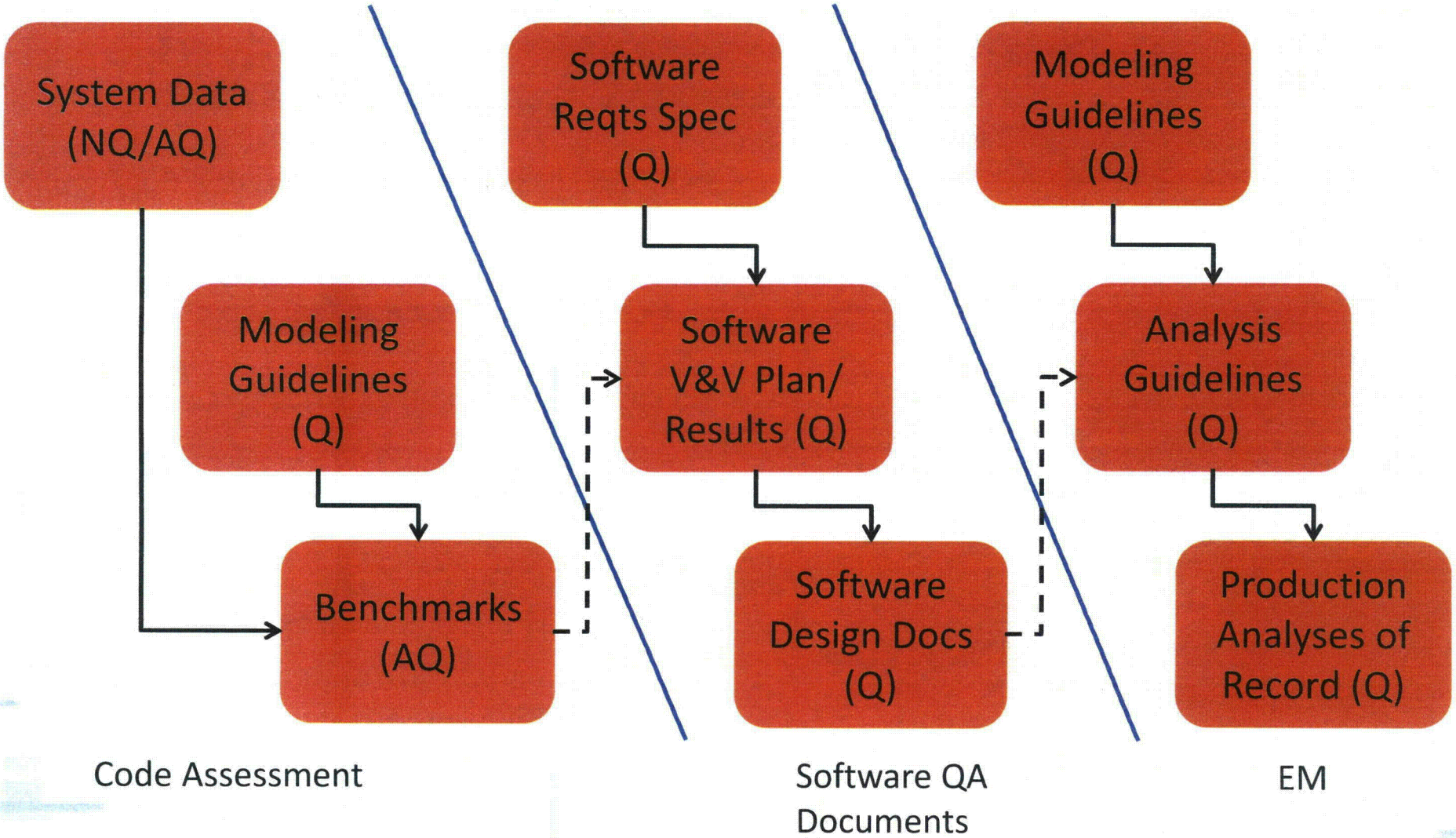
Interface to NUREG-4640



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Database Supporting Operating LWRs

Facility	IET or SET	Descriptions
ACHILLES – UK	IET	Impact of noncondensibles
ARC-19 Tube OTSG	SET	OTSG steady-state and LOFW tests
BETHSY – France	IET 1/100-scale 3-loop	Small breaks and operational transients
CCTF – Japan	IET 1/21.44-scale 4-loop	Refill and reflood phases of a LBLOCA
FEBA - West Germany	SET	Fuel blockages effects
FIST - United States (General Electric)	IET 1/624-scale BWR	LOCAs and operational power transients
FLECHT-SEASET - United States (W)	SET	Core heat transfer during forced/gravity feed reflood
FR2 - West Germany	IET	Fuel rod ballooning and burst behavior
FRIGG – Sweden	SET	Void distributions
GE Level Swell- United States (B&W)	SET	Void distributions during blowdown
GERDA/OTIS - United States (B&W)	IET	Small breaks and natural circulation events, predecisor to MIST
HALDEN – Norway	SET	Fuel behavior
LOBI – Italy	IET 1/700-scale 4-loop	Small breaks and operational transients
LOFT - United States	IET 1/50-scale PWR	Large break LOCA
MIST - United States (B&W)	IET of B&W 2 x 4 design	small break LOCA and operational transients

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Database Supporting Operating LWRs

Facility	IET or SET	Descriptions
MARVIKEN - Sweden	SET	Critical flow and containment response
PKL - West Germany	IET 1/134-scale 4-loop PWR	Small and large break LOCAs
REBEKA - West Germany	SET	Rod ballooning
LSTF (ROSA IV) - Japan	IET 1/48-scale 4-loop PWR	Small break LOCA and operational transients Westinghouse 4-LOOP plant SBLOCA-RELAP5/MOD2-B&W
SCTF - Japan	IET	Multidimensional effects
SEMISCALE - United States	IET 1/1700-scale 4-loop PWR	Full spectrum of breaks
SSTF - United States	SET (BWR vessel)	Multidimensional effects during BWR LOCA
THTF - United States (Westinghouse)	SET	Core heat transfer during forced/gravity feed reflood and SBLOCA tests
TLTA - United States (GE)	IET 1/624-scale BWR	Full spectrum of breaks
UPTF - West Germany	SET (1/1-scale vessel)	ECCS effectiveness
Westinghouse/EPRI – United States	SET	ECCS mixing/condensation in the cold leg

Database credited by LWR vendors for safety analysis is non-safety

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B&W mPower Credited Database for AOO & Small LOCAs (excluding B&W testing)

- LOFT L6-1, L6-2, L6-3, & L6-5
  - Address 15.1, 15.2, & 15.3 categories
- LOFT L3-1, L3-2, L3-3, L3-6, & Semiscale S-7-10B
  - Address 15.6
- LOFT L9-2 & L9-3
  - Address 15.8, natural circulation
- Others inherited from INL Developmental Assessment
  - Marviken, GE Level Swell, Christensen Test 15, Bennett heat tube tests, ORNL THTF tests, RIT Tube Test, Dukler-Smith flooding, MIT pressurizer test, Model Boiler 2 Test 1712
  - Thought problems (e.g., fill/drain, water over steam, water faucet, core power/decay heat, point kinetics ramp)

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B&W mPower Testing and Safety Analysis Interface

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Use of IST Data

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Confirm that RELAP5-3D adequately predicts important phenomena

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Use of IST Data

- IST RELAP model development and benchmarking process [[ ]
- IST data [ ]

Use of IST Data is Not Safety-Related

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Safety Analysis & Methods and IST Interface

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Examples of Safety-Related Test Programs for B&W mPower

- CHF Testing (Stern Labs)

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  - Test data procured to Appendix B/NQA-1 reqts
- Other safety-related tests

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Applied quality program consistent with application

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IST Testing Program Review

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Systems Included in the IST

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Current Status

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IST QAPP [ ]

- The IST Quality Assurance Program Plan (QAPP) represents the top-level IST QA document
- Defines which of the 18 criteria implemented through the B&W mPower Quality Assurance Program Description (QAPD) flow down to the IST

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IST QAPP (cont)

- Documents commitments / exceptions for the 12 QA criteria implemented at the IST , as addressed by Part III, Section 1 (Non-Safety-Related SSCs - Significant Contributors to Plant Safety) of the B&W mPower QAPD.
- Defines the set of controls that collectively establish the IST augmented-quality (IST-AQ) designation for selected IST testing and test data.

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B&W mPower QA Oversight at the IST

- IST QAPP specifics relative to the QAPD toward achieving IST- AQ
  - IST Staff are under the B&W mPower Indoctrination & Training Program
  - Test Procedures are developed under the IST QAPP
  - M&TE is controlled under the IST QAPP
- Other B&W mPower QA Program attributes implemented at the IST that contribute to IST-AQ include:
  - Organization, Management Assessment, Procurement Processes, Software Control, Procedure Control, Document Control, Test Controls, Non-Conformance Control, Corrective Actions, QA Records
- B&W mPower QA performs Internal Audits and Internal Surveillances of the entire B&W mPower QA program which includes the IST activities

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Quality Designations of IST Programs

- IST Non-Quality Programs:

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- IST Augmented Quality-Related Programs:

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IST Configuration Control

- IST Conduct of Engineering manages changes to the IST Technical Baseline
  - Design Change Packages
  - Temporary Modifications to existing system configuration
  - Control of Engineered Equivalent Determinations for replacement components
  - Technical Baseline is controlled procedurally

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IST M&TE Control [ ]

- Approved procedure establishes controls for measuring and test equipment (M&TE) - both Calibrators and Instruments.
- Four subordinate IST M&TE procedures exist to control the calibration of specific types of M&TE Instruments used at the IST.
- The IST performs on-going calibrations of vendor-supplied M&TE Instruments using standards-traceable M&TE Calibrators (calibrated externally to the IST by an accredited vendor), vendor-supplied calibration data, and IST-defined
- Calibration activities ensure the instruments are within the high accuracy standards required by the IST for data generation
- [

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IST Test Control [ ]

- IST Conduct of Testing Program controls the testing in accordance with the requirements of the Technical Specification provided by the Design Organization
- Provides governing interface between IST plant operations and testing
- Contains requirements for test sequence documentation preparation and review
- Defines the strategy to pedigree IST instrument calibration and qualification of hardware, firmware, and software
- Details methods of test data retrieval, review, and transfer to the Design Organization

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IST Data Acquisition System Configuration

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IST Summary

- IST fully operational and testing is well underway
- Augmented Quality program operative
- Completed steam generator performance [ ] tests
- [ ]

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IST Test Results

- Test results are compiled, reviewed and approved by the IST organization [

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Conclusions

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IST Data

- High quality test data is being generated according to the IST QAPP (Augmented Quality)
- IST Data is used in the IST RELAP5 Model to support the Evaluation Methodology per RG 1.203
- [

  ]
- IST test data is not safety-related

Quality of IST Data is Commensurate with Use

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[Proprietary per Affidavit 4(a)-(f)]

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NRC Pre-application Review Opportunities

- IST QA Inspection/Audit
  - Discussion of QA inspection has been premature
  - IST Data Use should be reviewed in context of EM development
- EM Development pre-application "Audit"
  - Similar to PRA audit recently conducted to familiarize NRC staff with the EM Development
- Opportunity to observe testing in progress

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NRC Review Opportunities

- Accident Analysis Methodology Topical Report
  - Contains the EM in accordance with RG 1.203
  - Describes the EM database
  - Scheduled for Submittal in July of 2014
  - Will be referenced by the GmP DC Application thereby creating the regulatory requirement for reporting any defects or non-compliance through the B&W mPower CAP and under 10 CFR 21 as necessary

NRC has opportunity to review IST Data generation and use in the context of the EM Topical Report review and has adequate regulatory oversight over use of the data in the EM Development

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