RELAP5-3D Validation Using HTTF Data

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Idaho National Laboratory

Next Generation Nuclear Plant

VHTR Technology Development Office

R&D FOR NGNP AND BEYOND

Topics addressed…

- The framework for developing, verifying, validating, and implementing RELAP5-3D to analyze nuclear systems.
- The importance and scope of V&V.
- Development of experimental programs designed to provide data to validate thermal-hydraulic software designed to analyze the behavior of nuclear plants.
- Ongoing development of applicable standards.
- Validation practices
- Concluding comments

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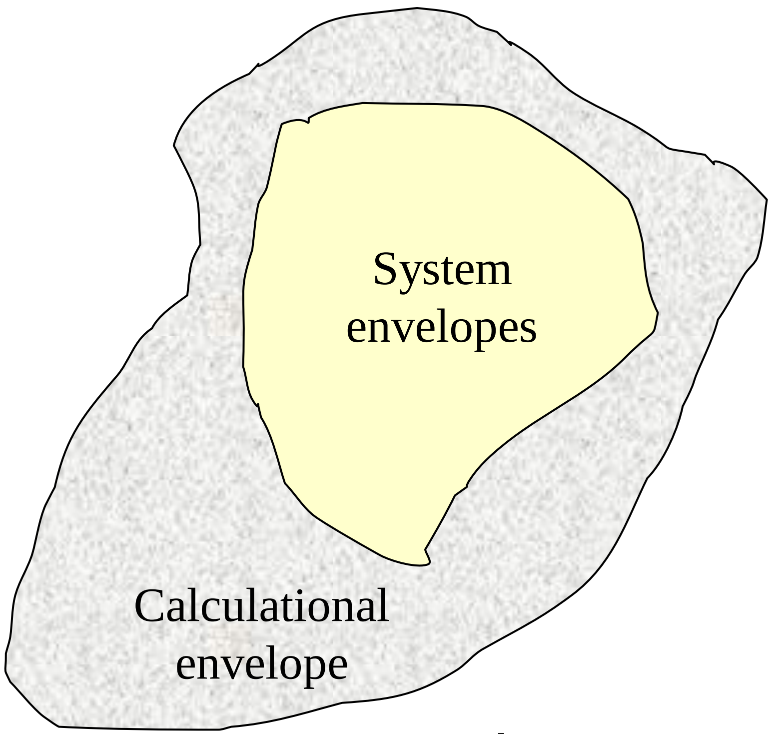
Nuclear Plant System & Calculational Envelopes…

- *System operational envelope:* ***where the plant is designed to operate and produce power plus where the plant may experience various accident scenarios during its lifetime***
  - ***Anticipated operational occurrences***
  - ***Design basis accidents***
  - ***Beyond design basis accidents***
- ***The system envelope is defined on the basis of the plant design characteristics and past history***
- *Calculational envelope:* ***defined by numeric model physics***
- *Objective:* ***Demonstrate calculational envelope encompasses the system envelope***



System envelope = Domain where the plant will operate and also may experience various accident scenarios during plant lifetime.

Calculational envelope = Domain of qualification

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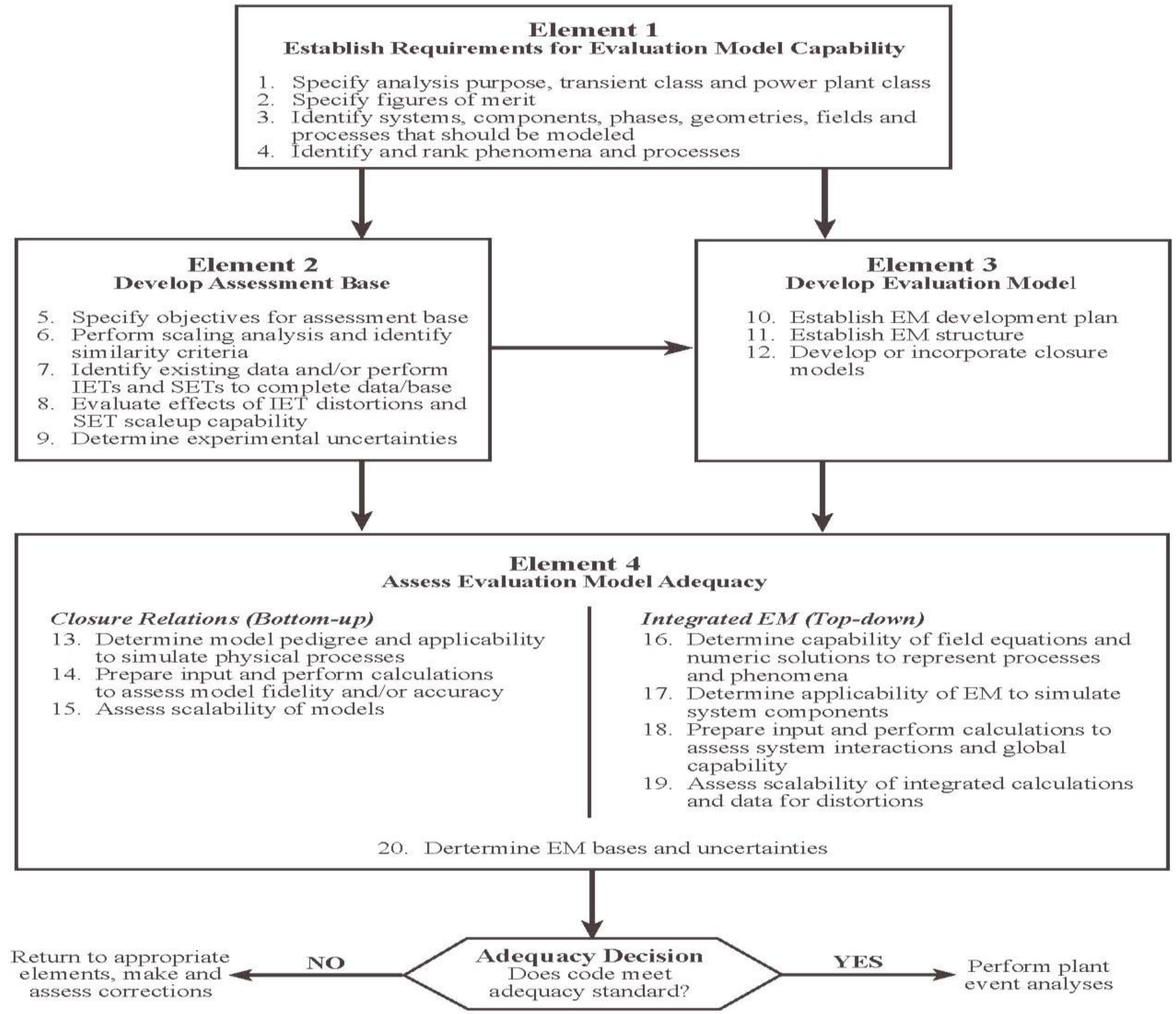
To Determine the Adequacy of Numerical Tools…

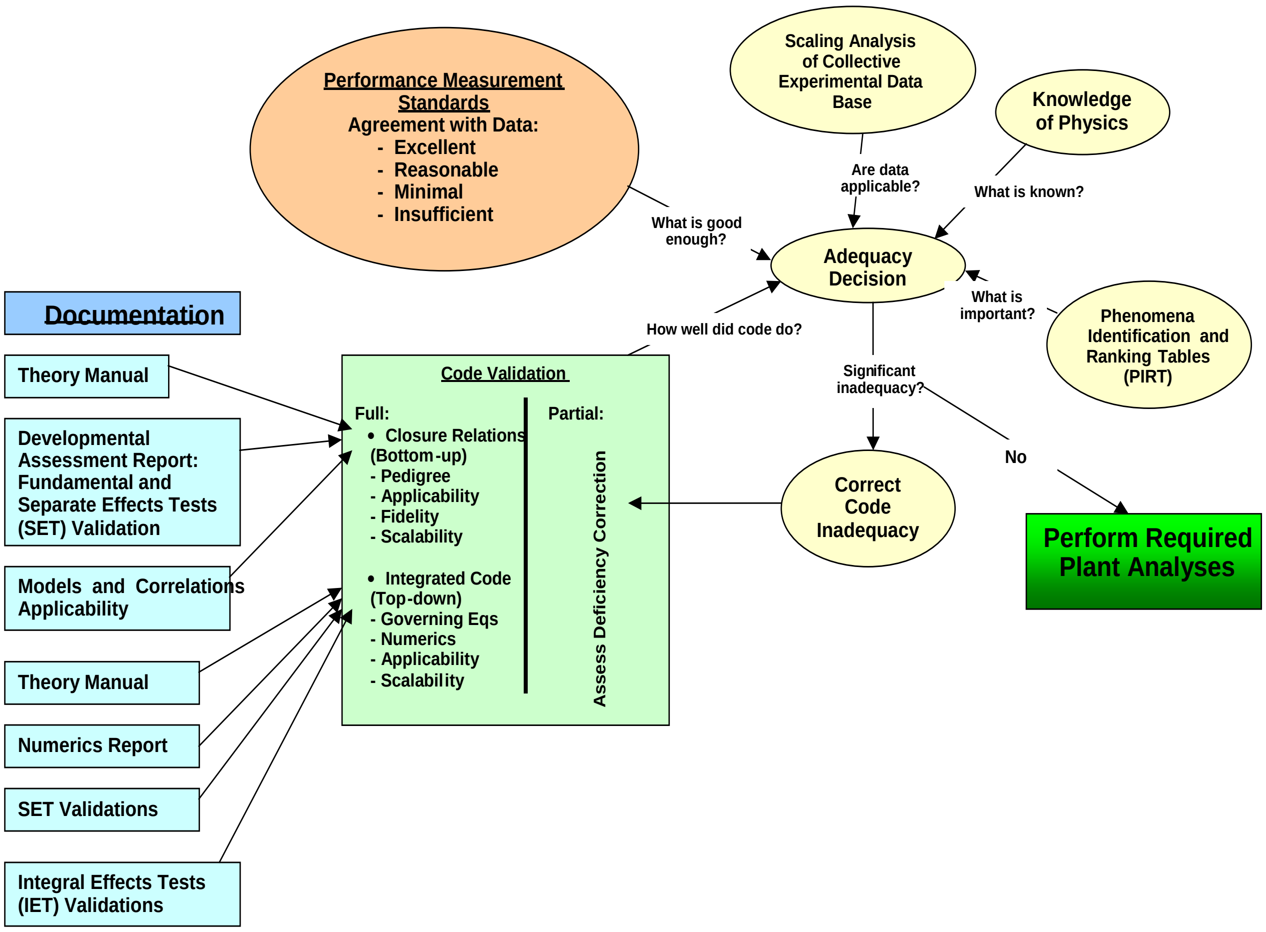
- ***NRC's regulatory Guideline 1.203 breaks process down into 5 pieces:***

1. ***Define requirements***
2. ***Develop assessment base (define data requirements)***
3. ***Develop numerical models***
4. ***Assess adequacy of model***
5. ***Make decision whether good enough.***
6. ***Following completion of process UQ is performed.***



To Determine the Adequacy of Numerical Tools…

- *Practices & procedures used to validate RELAP5-3D follow RG1.203*
- *Element (EL) 1 = PIRT, knowledge of physics.*
- *El 2 = experiment scaling, validation data base.*
- *El 3 = theory, numerics, models & correlations*
- *El 4 = adequacy evaluation*
- *Adequacy decision*



Some of the virtues of RG1.203 are…

- *It identifies the key elements that comprise the path for ensuring numeric tools intended to be used to analyze the behavior of a nuclear system.*
- *To determine whether the software models are adequate for such analyses, it is important to think in terms of the plant operational and accident envelopes, not just single points.*
- *Much work has been done to define how to validate software for a single point, e.g., ASME V&V20 Standard.*
- *Because nuclear systems cannot be used to obtain data throughout it's projected envelope, it is also very important to use a rigorous approach to design experiments which are scaled to the full-sized nuclear system.*

For these reasons, the remainder of this presentation focuses on…

- ***Specifying the scope and magnitude of the validation data base.***
- ***Defining the scaling approach to relate experiments to prototype.***
- ***Defining the integral effects and separate effects experimental requirements.***
- ***Defining the experimental uncertainties.***
- ***Ultimate objectives:***
  1. ***An experimental data matrix that provides the required validation data for numerical models to enable the numeric model validation to be performed and an adequacy decision to be made.***
  2. ***A streamlined approach for performing the validation calculations.***

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Experimental V&V Matrix—DCC, PCC, & SS Scenarios

		Depressurized Conduction Cooldown	Pressurized Conduction Cooldown	Air Ingress	Normal operation	INL MIR core bypass	ISU heated core bypass	SNU core bypass	TAMU core bypass	CCNY core heat transfer	TAMU plenum-to-plenum NC	UP LP mixing	INL MIR LP mixing	USU transient mixed convection	INL air ingress	TAMU air ingress
Phenomena	Natural circulation	+	+	+	--	--	--	--	--	p	p	--	--	p	+	+
	Lower plenum mixing	+	+	+	+	--	--	--	--	p	--	p	+	--	+	+
	Upper plenum mixing	+	+	+	+	--	--	--	--	--	p	--	--	--	--	--
	Jet impingement: upper plenum	+	+	+	+	--	--	--	--	--	p	--	--	--	--	--
	Jet impingement: lower plenum	+	+	+	+	--	--	--	--	--	--	p	+	--	--	--
	Core bypass	+	+	+	+	+	p	+	+	o	--	--	--	o	--	--
	Core heat transfer	+	+	o	+	--	p	--	--	p	--	--	--	o	--	--
Test Facilities	INL MIR core bypass	--	--	--	+											
	ISU heated core bypass	--	--	--	+											
	TAMU core bypass	--	--	--	p											
	SNU core bypass	--	--	--	+											
	CCNY core heat transfer	p	p	--	p											
	TAMU plenum-to-plenum NC	p	p	--	--											
	UP mixing in LP	--	--	--	p											
	INL MIR mixing in LP	--	--	--	p											
	USU transient mixed convection	p	p	--	p											
	INL air ingress	--	--	+	--											
	TAMU air ingress	--	--	+	--											
	HTTF integral & separate effects	p	p	p	--											

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Experiments Used to Provide Data to the Experiment Matrix (1)…

- ***Must be scaled,* *using an acceptable methodology, such that the data are in an appropriate range for the plant scenario of interest***
- ***Must have acceptable measurement uncertainties* *to provide a reasonable range of acceptance when the data are used to "judge" whether numerical models are capable of calculating the measured phenomena***

Experiments Used to Provide Data to the Experiment Matrix (2)…

- ***Should be designed as a set to create a "validation pyramid" that is comprised of supporting levels:***
  - ***Fundamental experiments** give data that describes the behavior of the key phenomena in an environment free of extraneous influences, e.g., influences from other phenomena*
  - ***Separate effects experiments** provide data that describes the behavior of key phenomena in typical system components*
  - ***Integral effects experiments** give data that demonstrates the interactions that occur between the key phenomena for the scenarios of interest.*
  - ***The different scales used in the experiments of the validation pyramid provide a check on the measured experimental phenomena scaling***

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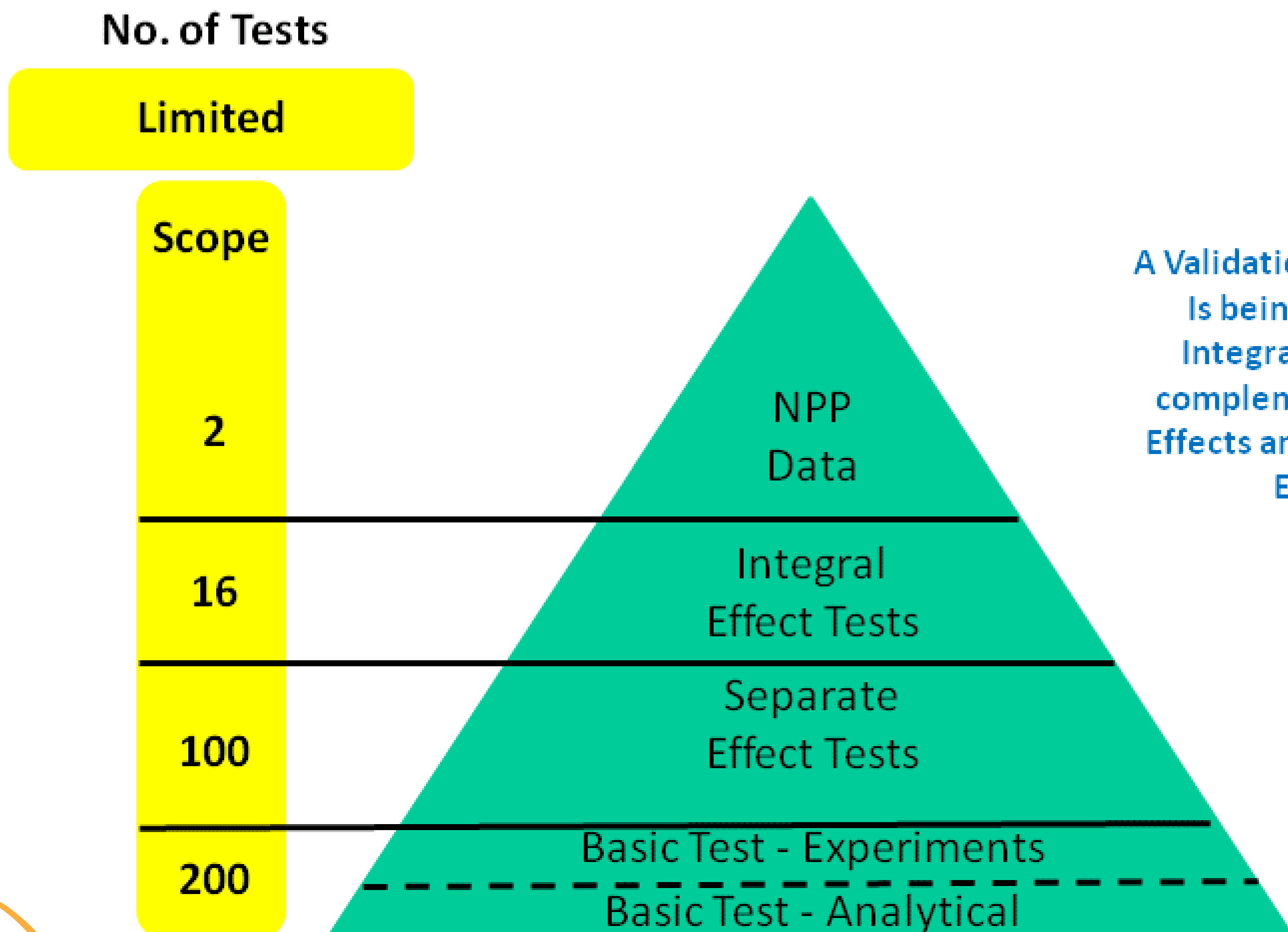
Validation is an In-Depth Activity…



A Validation Triangle Approach
Is being taken: NPP and
Integral Experiments are
complementary to Separate
Effects and Basic Phenomena
Experiments

Thermal-Fluid Phenomena: NEUP Experimental V&V

- Normal operation at full or partial loads
  - Coolant flow and temperature distributions through reactor core channels (“hot channel”)
  - Mixing of hot jets in the reactor core lower plenum (“hot streaking”)
- Loss of Flow Accident (LOFA or “pressurized cooldown”)
  - Mixing of hot plumes in the reactor core upper plenum
  - Coolant flow and temperature distributions through reactor core channels (natural circulation)
  - Rejection of heat by natural convection and thermal radiation at the vessel outer surface
- Loss of Coolant Accident (LOCA or “depressurized cooldown”)
  - Prediction of reactor core depressurized cooldown - conduction and thermal radiation
  - Rejection of heat by natural convection and thermal radiation at the vessel outer surface

Integral Facility[1]/ RCCS[2,3,4]

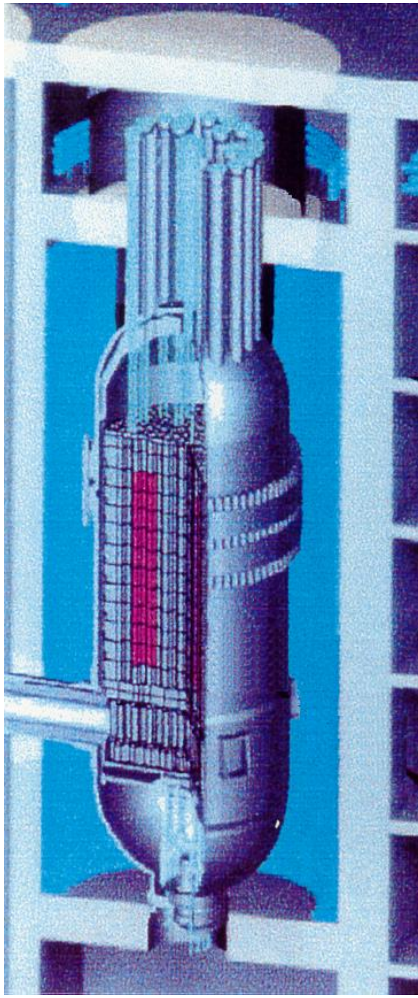
Lower Plenum Exp[5,6]

Plenum-to Plenum Exp[3]

Core Exp[3,5,7]

MIR Exp[8]

Air Ingress Exp[3,8]



[1] Oregon State University, [2] ANL, [3] TAMU, [4] Univ of Wisconsin, [5] City College of NY, [6] Univ of Pittsburgh, [7] Idaho State Univ, [8] INL

Experiment Design…

- ***The H2TS (Hierarchical Two-Tiered Scaling) methodology was developed in 1980s by Zuber and provides the following advantages:***
  - ***It is a method that is systematic, auditable, and traceable***
  - ***Provides a unified scaling rationale and similarity criteria***
  - ***Assures that important processes have been identified and addressed properly and provide a means for prioritizing and selecting processes to be addressed experimentally***
  - ***Creates specifications for test facilities design and operation (test matrix, test initial and boundary conditions) and provide a procedure for conducting comprehensive reviews of facility design, test conditions, and results***
  - ***Assures the prototypicality of experimental data for important processes and quantify biases due to scale distortions or to nonprototypical test conditions***
- ***VHTR experiments designed using H2TS methodology.***

Ref: Zuber, N., 1991, An Integrated Structure and Scaling Methodology for Severe Accident Technical Issue Resolution, NUREG/CR-5809, November, Appendix D, "Hierarchical, Two-Tiered Scaling Analysis."

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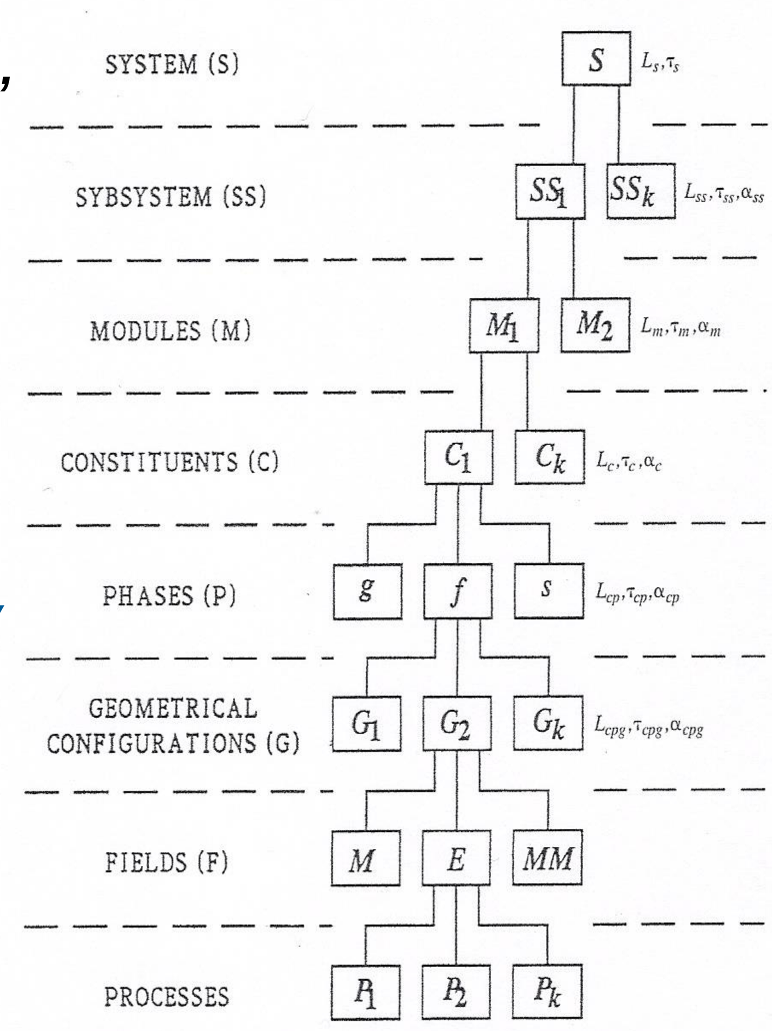
Zuber's H2TS Scaling Methodology…

- ***Decomposes and organizes the system***
  - ***Starting with the whole system***
  - ***Working downward through subsystems, components, until reaching the transfer processes***
- ***Scale measures are assigned at each level***
  Each phase characterized by one or more geometrical configurations. Address the effects caused by the interaction of its constituents which have been identified as important in the PIRT. Similarity criteria developed at appropriate scaling level.
- ***Each geometrical configuration described by 3 field equations (mass, momentum, and energy)***
- ***Includes a top-down (system) and bottom-up scaling analysis—development of similarity criteria for interaction of constituents and specific processes***



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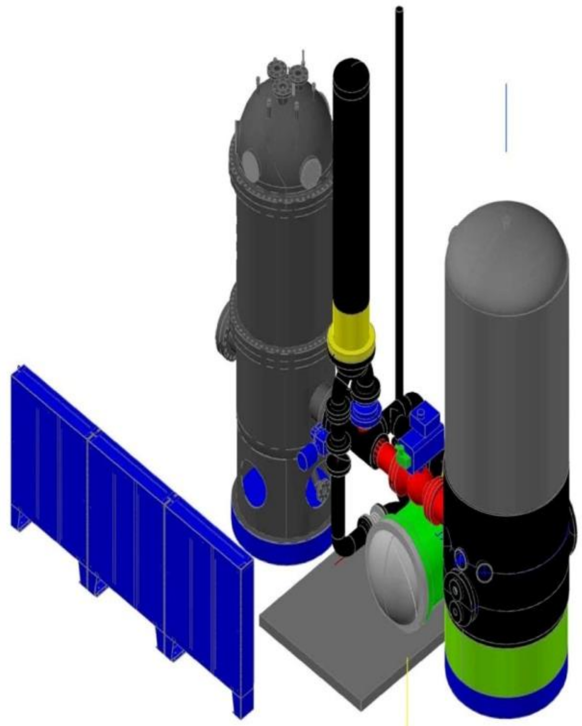
Application of H2TS Methodology to Separate-Effects and Integral-Effects Experiments

SYSTEM	VHTR					
SUBSYSTEM	REACTOR COOLANT SYSTEM				REACTOR CAVITY COOLING SYSTEM	
CONSTITUENTS	Helium	Helium Air	Helium Air	Reactor Vessel • Metal • Graphite	Reactor Cavity Helium, Air, Metal	Cooling Duct External Air
GEOMETRICAL CONFIGURATIONS	• Volume • Break Size	• Elevation • Lengths	• Elevation • Lengths	• External Surface Area • Graphite Reflector	• Cavity Volume • Panel Surface Area	• Duct Elevation • Lengths
FIELDS	Mass Energy	Mass Energy	Mass Momentum Energy	Energy	Mass Energy	Mass Momentum Energy
PROCESS TO BE SCALED	Primary System Blowdown	Air Ingress	Gas Natural Circulation	Radiation Heat Transfer, Core Heat Conduction	Gas Temperature, Gas Pressure, Heat Transfer Rate	Natural Circulation, Heat Removal Rate



Scaling Choices…

Preserving kinematic similarity	$\left(\frac{a_i}{a_c}\right)_R = 1$
Preserving friction and form loss similarity	$(\Pi_F)_R = 1$
Elevation and length scale ratio	$(L)_R = 1:4$
Diameter scaling ratio	$(D)_R = 1:4$
Pressure scaling ratio (full pressure)	$(P_0)_R = 1:8$

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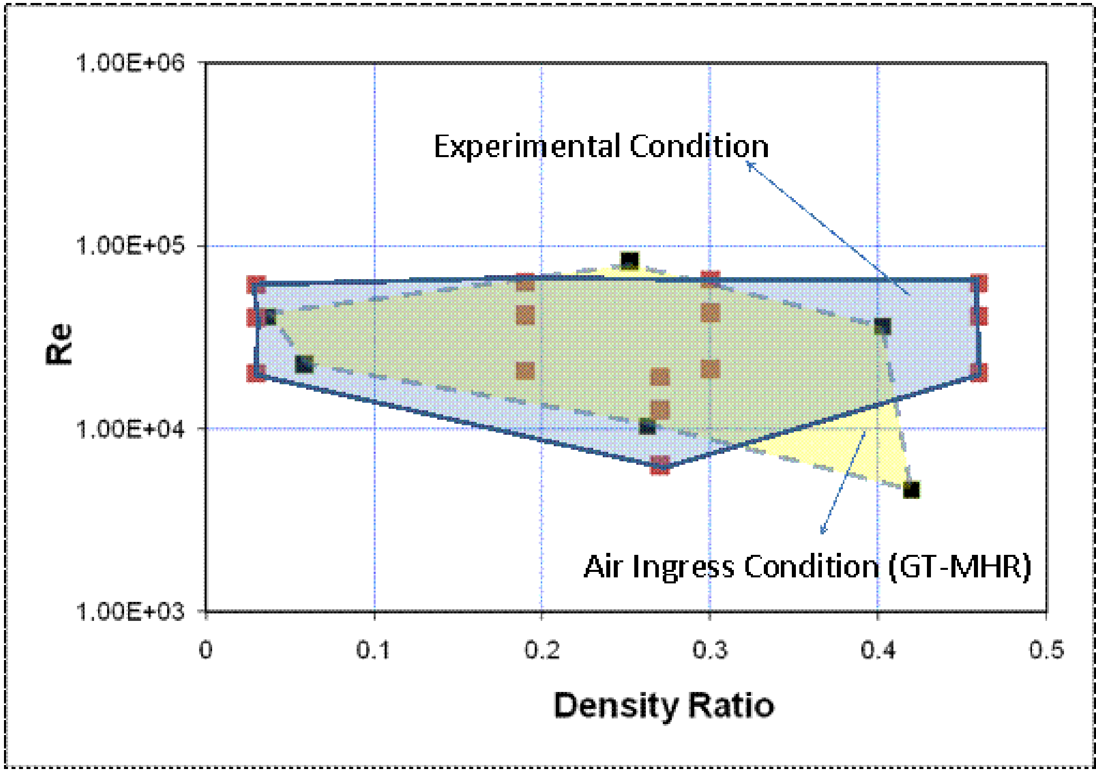
Separate Effects Experiments Designed to Match Key Phenomena Ranges of Prototype…

- ***Designed to capture key phenomena***
- ***Scaled to provide direct link between subscaled experimental facility and prototypical plant***
- ***Low, quantified uncertainties***
- ***Experiment design should consider decomposition of behavior in system component to lowest level that can be modeled by software to ensure each component is properly being calculated by software physics***



Courtesy C. Oh

Tools Available for Evaluating Validation Calculations: References…

- ***References:***
  - *R. Kunz, G. Kasmala, J. Mahaffy, C. Murray, "On the Automated Assessment of Nuclear Reactor Systems Code Accuracy," Nuclear Engineering and Design Journal, accepted for publication.*
  - *M. Lazor, Evaluation of Assessment Techniques for Verification and Validation of the TRACE Nuclear Systems Code, 2004, M.Sc. Thesis, Pennsylvania State University.*
  - *F. D'Auria, N. Debrecin, G. Galassi, "Outline of the Uncertainty Methodology Based on Accuracy Extrapolation," Nuclear Technology, 1995, Vol 195, January.*
- ***Techniques discussed and used in these references are candidates for performing validations.***

Tools Available for Evaluating Validation Calculations: Validation Analysis (1)…

- ***Approximation theory based methods*: mathematical techniques that give functional approximations to the data.***

- ***Time series data analysis methods*: estimate properties of measured or computed processes from a time series of repeated successive observations which may or may not be independent.***

- ***Basic statistical analysis methods: incorporate approximation theory and time-series data analysis methods but describe random data in a fashion not dependent on the spatial or temporal ordering of data.***

* *Applicable to successive data.*

Tools Available for Evaluating Validation Calculations: Validation Analysis (2)…

- ***Trend removal & time windowing*: used to analyze non-stationary data; pre-processing techniques to allow application of time series data analysis and statistical methods.***

- ***Time frequency methods: short Fourier transforms and wavelet transformations.***

- ***Pattern recognition methods: used to extract useful information from noisy data sets***

- ***Multi-variate analysis methods: characterize the dependent variable with respect to multiple independent variables.***

** Stationary data = data with a constant mean or autocorrelation function, i.e., adjacent sections of time trace have the same statistical measures.*

Summary of Process…

- ***Objective of NGNP methods is to validate numeric models that are capable of calculating VHTR behavior throughout its system operational/accident envelope***
- ***For the NGNP, a rigorous process is used to design experiments that will provide validation data for RELAP5-3D.***
- ***The process is based on the H2TS methodology***
- ***Experimental and validation matrices are defined***
- ***Both separate-effects and integral-effects experiments are underway***
- ***Validation of numeric models is also proceeding***
- ***The NGNP approach is compatible with NRC guidelines and practices—as used to qualify numeric models for Generation III+ systems***