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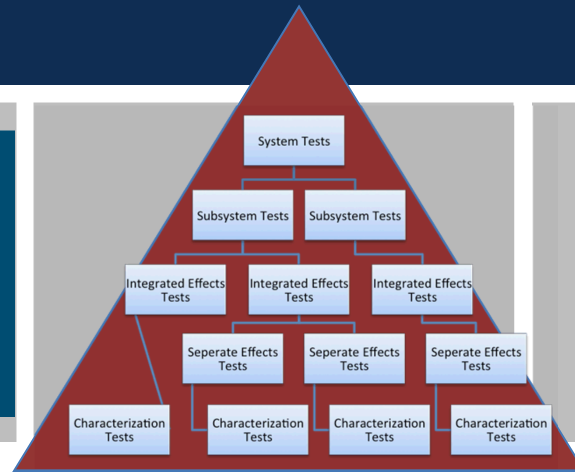

Model Validation Framework

High Fidelity Modeling: Wind Plant Physics and
Modeling Strategic Planning Meeting
Crystal City, VA
February 24-25, 2015

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V&V, UQ, Credibility Processes
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SAND #????

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Outline (15 min + 15 min discussion)

- HFM Objective
- Background on A2e V&V planning
- PIRT: Introduction
- PIRT: Summary of efforts to date
- PIRT: Suggested approach for this meeting
- Discussion

Focus on HFM Objective

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Accurately predict, assess and optimize wind plant performance utilizing High Performance Modeling (HPC) tools developed in a community-based, open-source simulation environment to understand and accurately predict the fundamental physics and complex flows of

- the atmospheric boundary layer,
- interaction with the wind plant, as well as
- the response of individual turbines to the complex flows within that plant

A2e V&V Framework

Why?

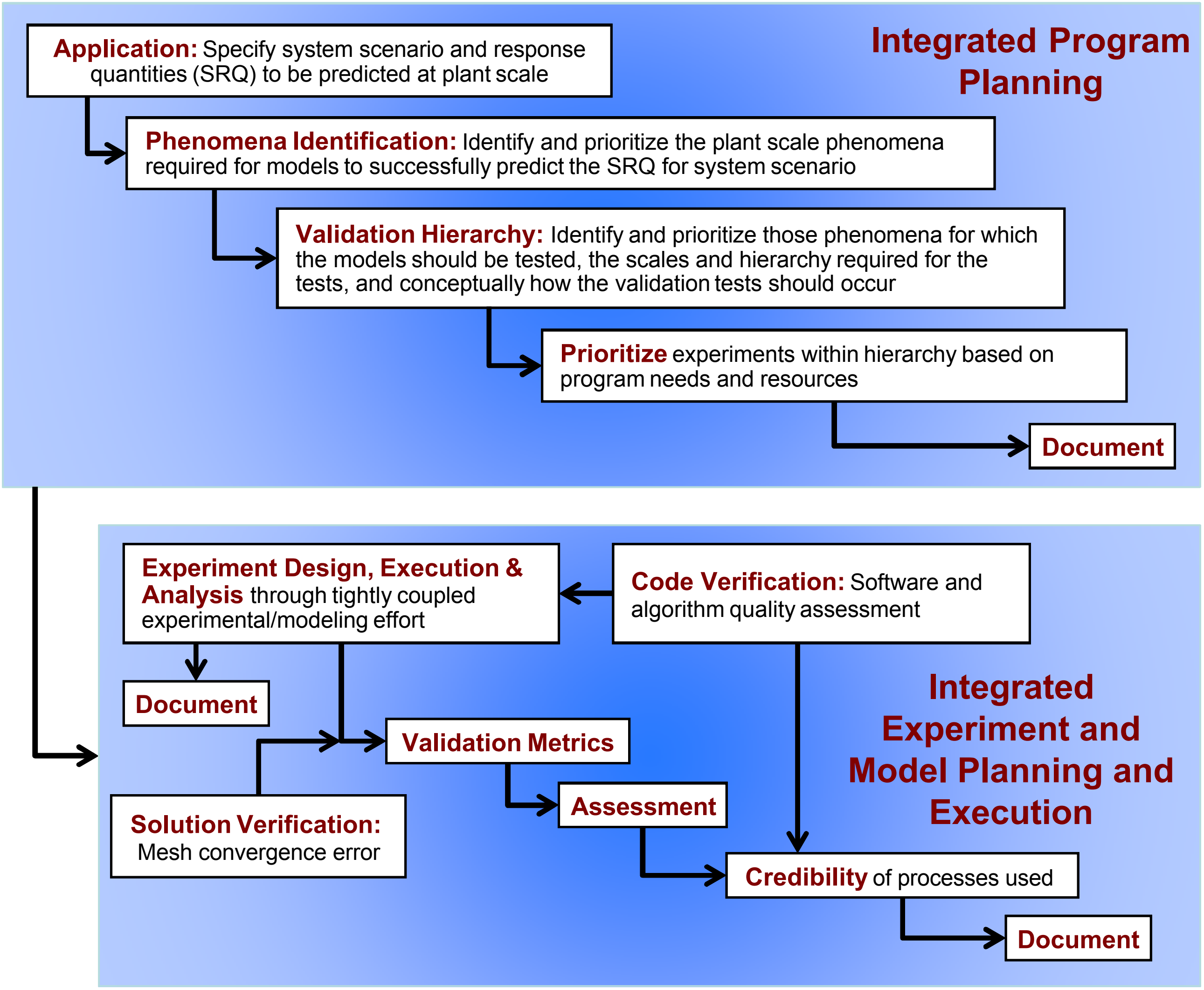
- Provides a structured approach for integrate program planning across scales
- Quantifies prediction uncertainty for use by designers
- Provides structured framework for collaboration

Foundation of framework

- Framework developed for SNL nuclear weapons program*
- Foundation consistent with various ASME and AIAA V&V Guides, Codes and Standards

How different?

- Framework expanded and refined to address A2e multi-scale planning and prediction
- Framework methodology adapted to a highly collaborative process based on experience



*Trucano, T. G, M. Pilch, W. L. Oberkampf (2002), General Concepts for Experimental Validation of ASCI Code Applications, Sandia Report: SAND2002-0341, Sandia National Laboratories, Albuquerque, NM

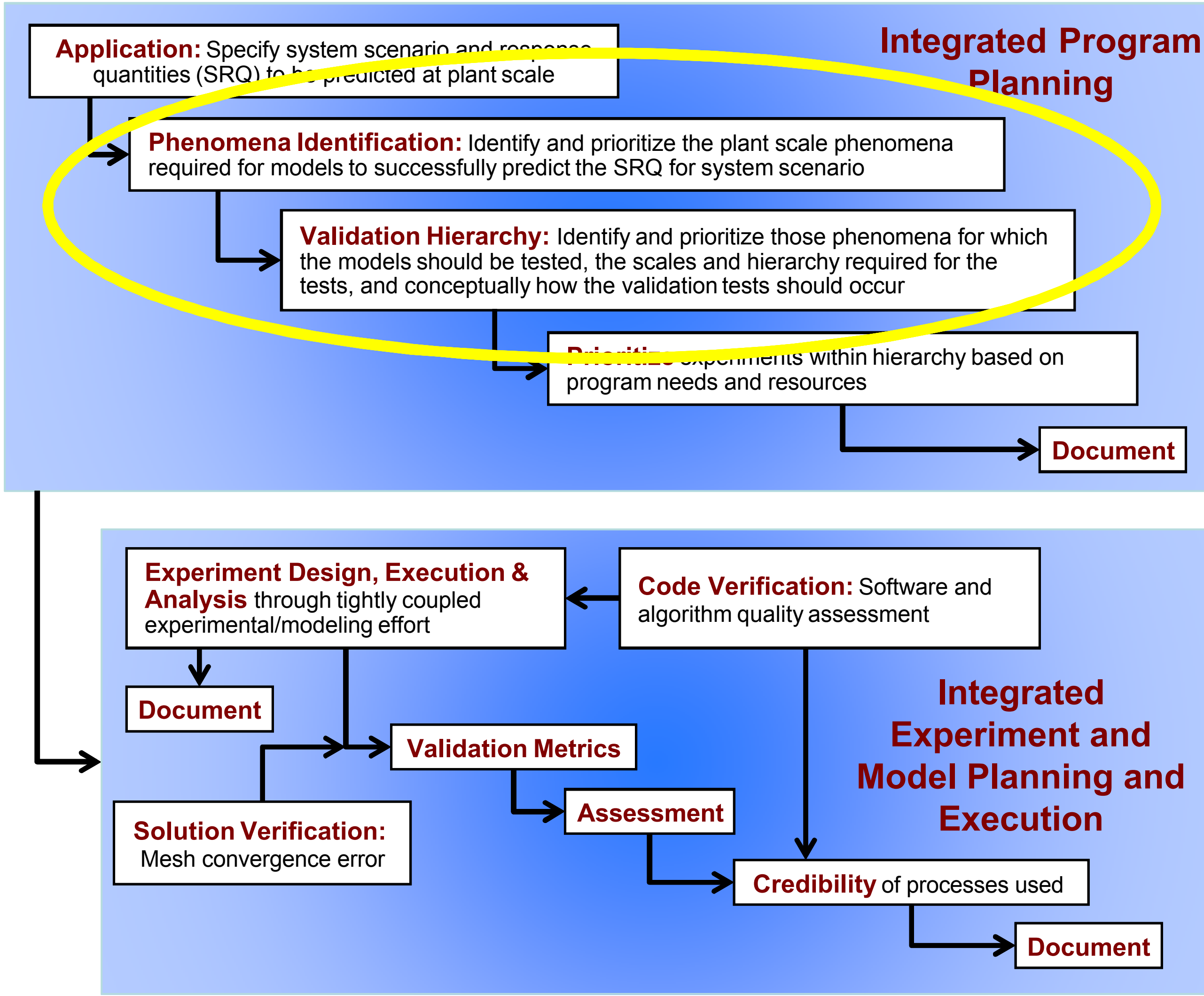
Collaborative Effort!

Integrated Planning

- Program leaders, modelers, software developers, experimentalist, V&V specialist

Validation Planning

- Domain specific program leaders, modelers, experimentalist, V&V specialist, data acquisition specialist



Backbone of Planning: Phenomenon Importance Ranking Table: PIRT

- Modeling focused
- Consensus based
- Identifies and ranks most important phenomena for an application
- Provides gap analysis of ability to model phenomena
  - Physics gaps
  - Numerical gaps
  - Data gaps
  - Validation gaps
- Gap analysis used for planning, including experimental planning

Phenomenon	Importance at Application Level	Model Adequacy			Planning Priority	Issue	Response including scale
		Physics	Code	Val			
Phenom. 1	Medium	Low	Medium	Low	Medium	Environment source terms inadequate	Source term development followed by validation test at system scale
Phenom. 2	High	Uncertain	Medium	Low	High	Validation required	Validation test for phenomena at laboratory scale using XXX... test facility
Phenom. 3	Medium	Medium	Medium	Medium	Low		
Phenom. 4	Medium	Medium	Low	Medium	High	Mesh not converged	Formalized mesh convergence studies for sub-system to estimate uncertainty
Phenom. 5	High	Uncertain	Medium	Low	High	Validation required	Validation test at laboratory scale using a ... test apparatus
Phenom. 6	High	Low	NA - Data based model	Low	High	Data to calibrate constitutive models required	Look for suitable data in the literature. If such data does not exist, perform experiments at laboratory scale to develop data to calibrate constitutive equations. Validate based on independent experiments at subsystem scale. These experiments should be ...

PIRTs are customizable

Additional columns to identify validation hierarchy added for A2e

Additional rows to identify data needs for A2e

- Initial and boundary conditions
- Site characterization
- Constitutive equations
- Validation data

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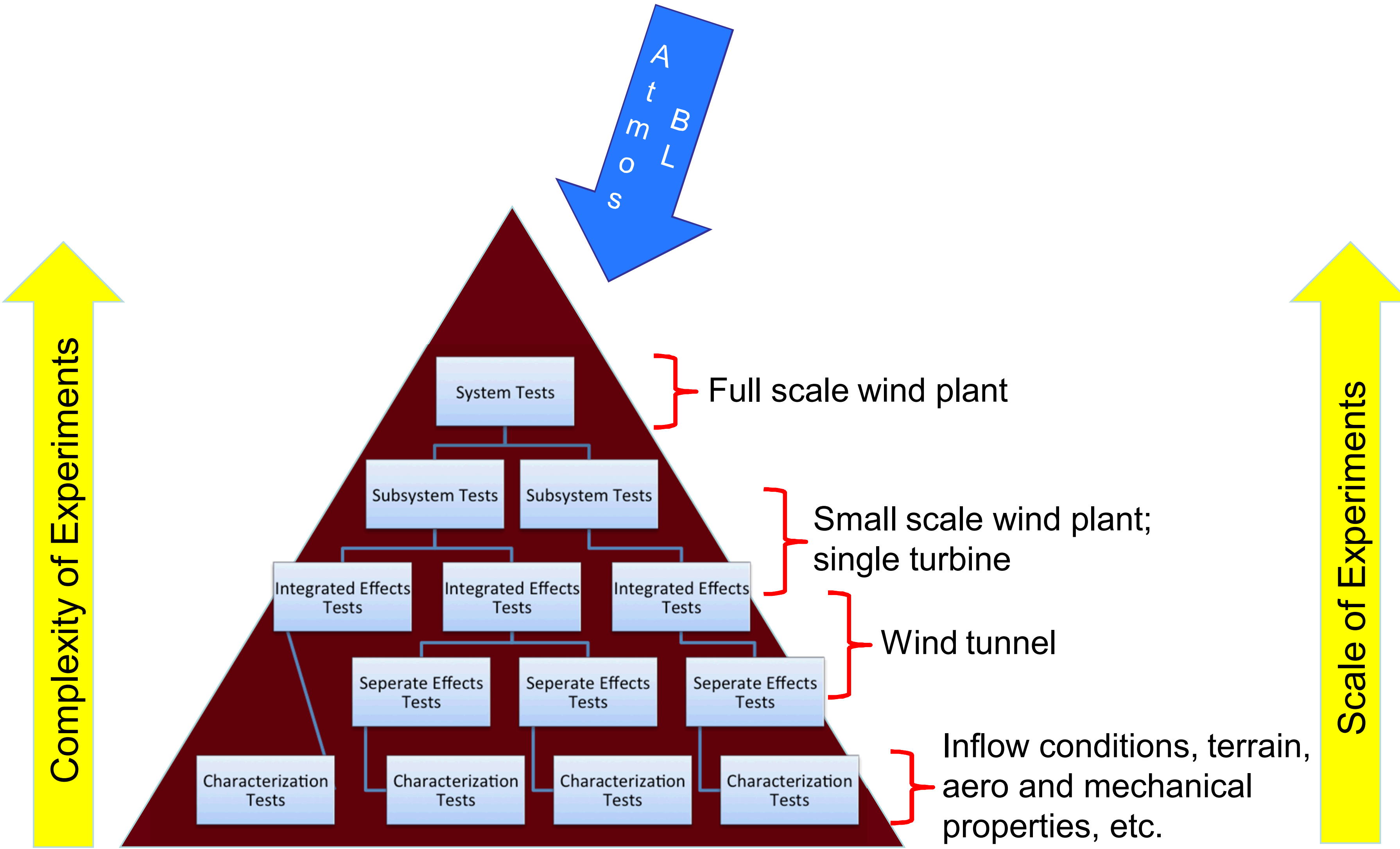
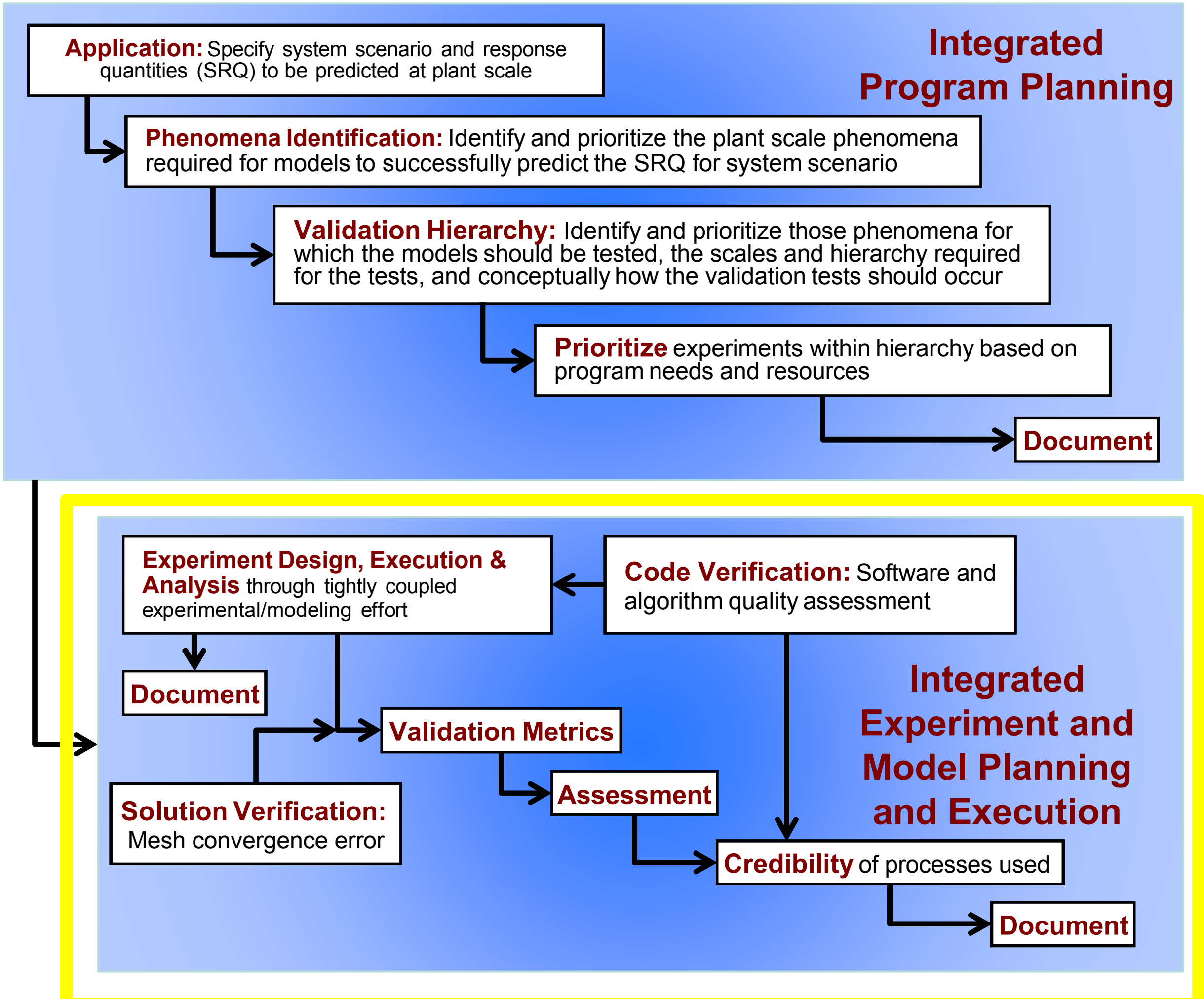
PIRT leads to the Validation Hierarchy

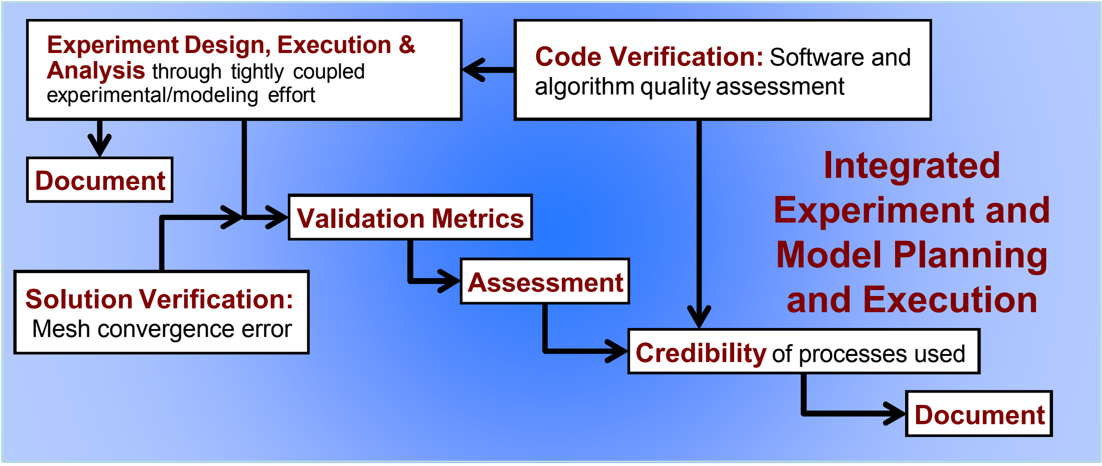


Validation experiments follow program planning



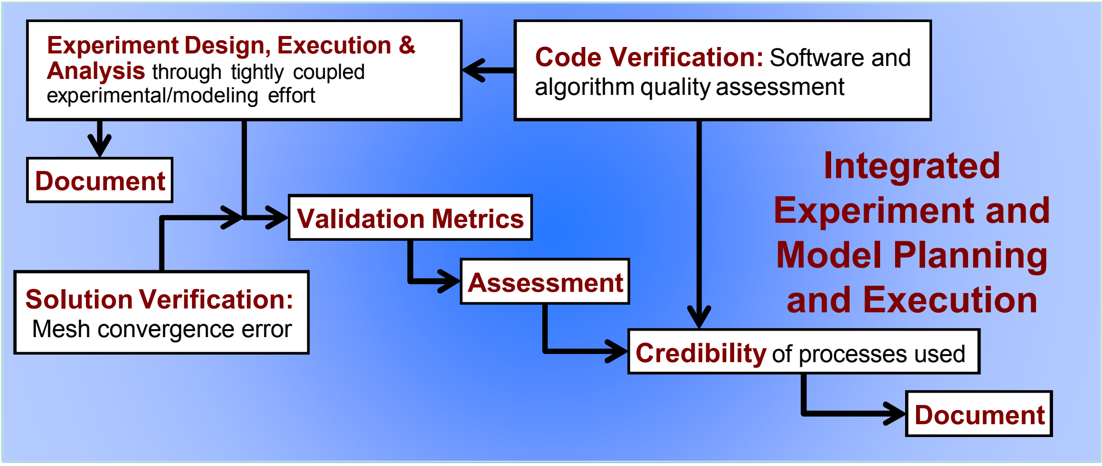
Validation experiments follow program planning

- Validation is a process of characterizing model error, not a binary statement of model validity
- A useful metric is the signed difference between experimental data and model predictions and the uncertainty in this difference – most customers ask for this
- The validation quantities of interest should be chosen to support overall program goals and program quantities of interest
- Validation experiment should be unambiguously modeled, requiring attention to data needs of the model
- The uncertainty in these quantities of interest, measured and predicted should be estimated



Validation Experiment Design

- Experimental design - collaborative effort between the experimentalist, modelers, data acquisition and V&V specialists
- The most successful validation exercises are those that are modeled during their design process
- The least successful validation exercises are those for which the data is "thrown over the fence"
- Data uncertainty and model prediction uncertainty should be quantified to support the uncertainty quantification component of validation



Status: Existing PIRT development

- Initiated PIRT development at beginning of FY15
- Continued development at various meetings
  - Wind Tunnel V&V Meeting, University of Minnesota, Fotis Sotiropoulos – host, Oct. 2, 2014
  - A2e XPIA Meeting, Univ. of Colorado at Boulder, Julie Lundquist - host, meso to plant scale, Nov. 13-14, 2014
  - A2e Verification & Validation Planning Meeting, Scott Schreck – host, National Wind Technology Center, all scales, Dec. 4-5, 2014

PIRT – HFM focus (this meeting)

- HFM focused group – will have a different perspective

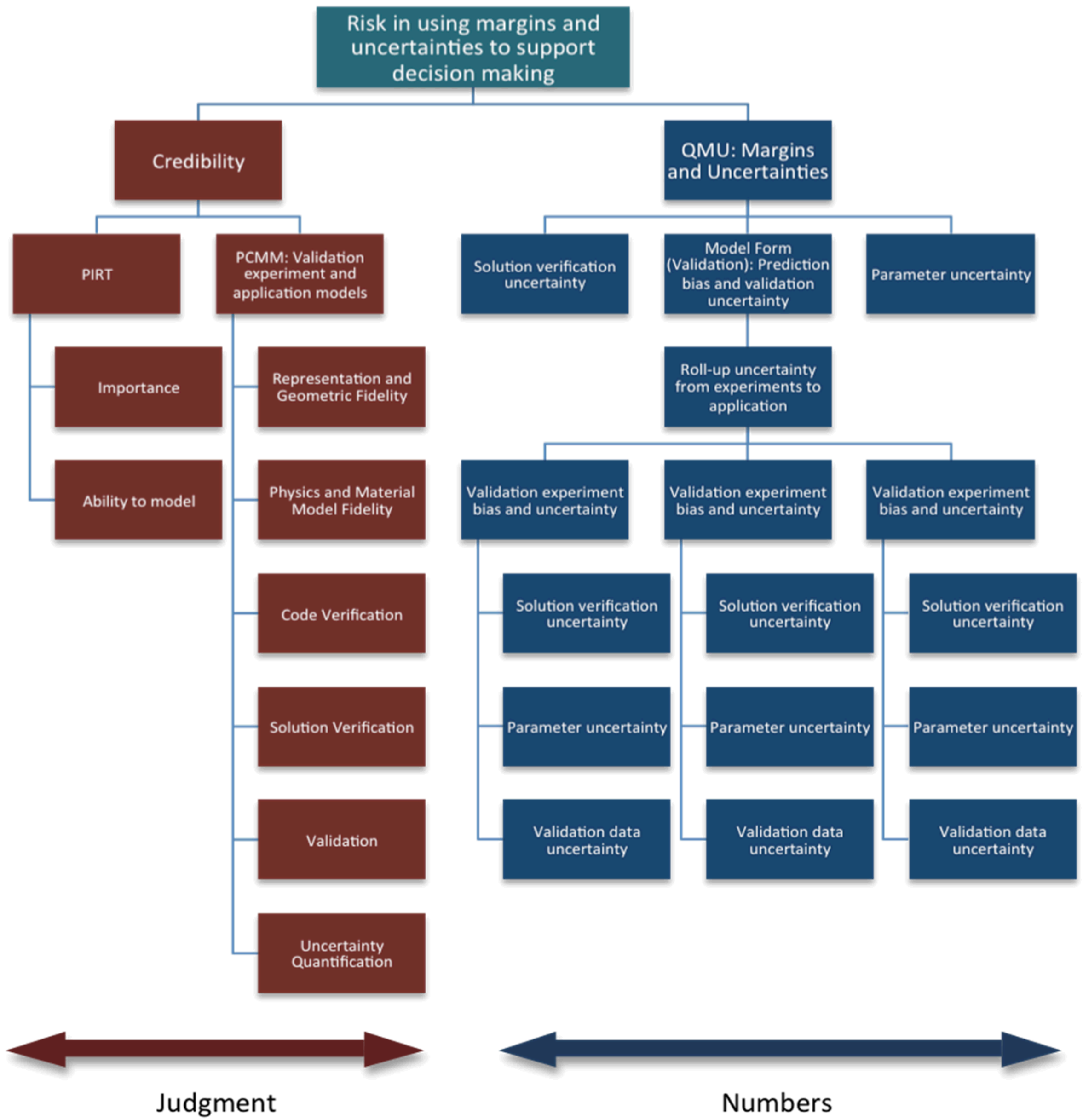
- This is your PIRT, but you may find that the work already performed may be useful
  - A copy of the existing PIRT, including gap analysis of the more important phenomena has been provided for your information
  - A copy of the existing PIRT showing the identified phenomena, but blank otherwise, has also been provided
  - Suggest that you start with the blank version and add/modify phenomena as needed
  - You can then address importance of phenomena at application level, address model adequacy ratings, issues and comments
  - Perform computational simulation gap analysis
  - Define validation requirements as well as data needs/types (including site characterization, initial and boundary conditions, …)

Example*

Phenomenon	Importance at Application Level	Model Adequacy		
		Physics	Code	Val
Turbine scale flow				
Blade Aero / Wake Generation				
Blade load distribution effects and rotor thrust	H	M	L	L
Tip and root vortex development	H	M	L	L
Boundary layer state (roughness, soiling, bugs, erosion)	L	L	L	L
Boundary layer state (Re)	L	M	L	L
Rotational augmentation	H	M	L	L
Dynamic stall	H	L	L	L
Unsteady inflow effect (turb. intensity, spectra, coherence; veer, shear)	H	L	L	L
Blade flow control	L	L	L	L

*See Chapter 3 in supplied document for PIRT guidelines

Discussion



Risk in using margins and uncertainties to support decision making
Credibility
QMU: Margins and Uncertainties
PIRT
PCMM: Validation experiment and application models
Solution verification uncertainty
Model Form (Validation): Prediction bias and validation uncertainty
Parameter uncertainty
Importance
Ability to model
Representation and Geometric Fidelity
Physics and Material Model Fidelity
Code Verification
Solution Verification
Validation
Uncertainty Quantification
Roll-up uncertainty from experiments to application
Validation experiment bias and uncertainty
Validation experiment bias and uncertainty
Validation experiment bias and uncertainty
Solution verification uncertainty
Solution verification uncertainty
Solution verification uncertainty
Parameter uncertainty
Parameter uncertainty
Parameter uncertainty
Validation data uncertainty
Validation data uncertainty
Validation data uncertainty
Judgment
Numbers