SAND2008-0484P

Overview of Computer Codes Used for Certification

KHNP Training Program

Module 13: Packaging and Transportation

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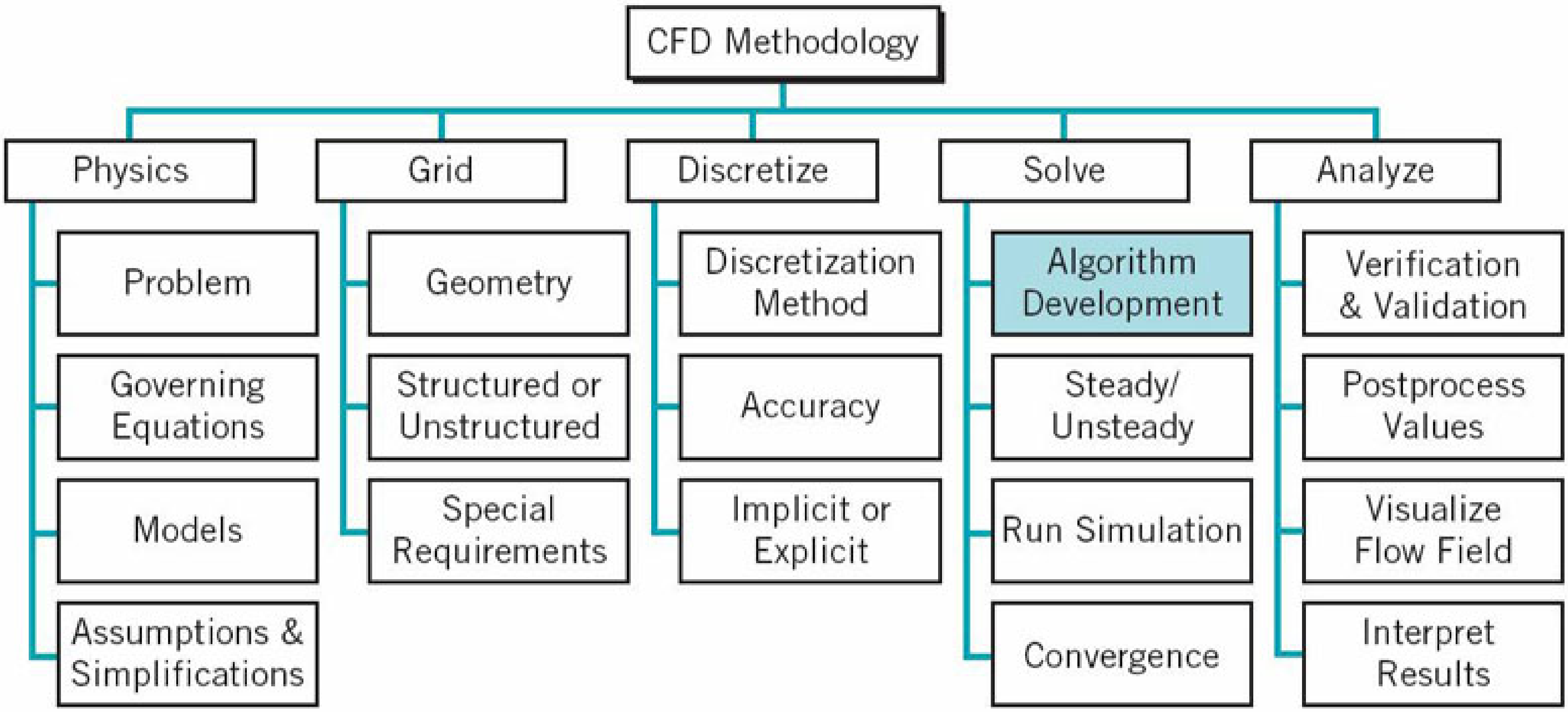
Analysis Methodology

- **Example: CFD**



Benchmarking of Codes

- To have confidence in the codes they must be benchmarked

- This can be done by:
  - Comparison with experimental results,
  - Comparison to the results of other codes, or
  - Comparison to mathematical models

Predictive Capability Maturity Model

MATURITY / ELEMENT	Maturity Level 0 Low Consequence, Minimal M&S Impact, e.g., Scoping Studies	Maturity Level 1 Moderate Consequence, Some M&S Impact, e.g., Design Support	Maturity Level 2 High-Consequence, High M&S Impact, e.g., Qualification Support	Maturity Level 3 High-Consequence, Decision Making Based on M&S, e.g.. Qualification or Certification
Representation and Geometric Fidelity What features are neglected because of simplifications or stylizations?	• Judgment only • Little or no representational or geometric fidelity for the system and boundary conditions (BCs)	• Significant simplification or stylization of the system and BCs • Geometry or representation of major components is defined	• Limited simplification or stylization of major components and BCs • Geometry or representation is well defined for major components and some minor components • Some peer review conducted	• Essentially no simplification or stylization of components in the system and BCs • Geometry or representation of all components is at the detail of "as built," e.g., gaps, material interfaces, fasteners • Independent peer review conducted
Physics and Material Model Fidelity How fundamental are the physics and material models and what is the level of model calibration?	• Judgment only • Model forms are either unknown or fully empirical • Few, if any, physics-informed models • No coupling of models	• Some models are physics based and are calibrated using data from related systems • Minimal or ad hoc coupling of models	• Physics-based models for all important processes • Significant calibration needed using separate-effects tests (SETs) and integral-effects tests (IETs) • One-way coupling of models • Some peer review conducted	• All models are physics based • Minimal need for calibration using SETs and IETs • Sound physical basis for extrapolation and coupling of models • Full, two-way coupling of models • Independent peer review conducted
Code Verification Are algorithm deficiencies, software errors, and poor SQE practices corrupting the simulation results?	• Judgment only • Minimal testing of any software elements • Little or no SQE procedures specified or followed	• Code is managed by SQE procedures • Unit and regression testing conducted • Some comparisons made with benchmarks	• Some algorithms are tested to determine the observed order of numerical convergence • Some features & capabilities (F&Cs) are tested with benchmark solutions • Some peer review conducted	• All important algorithms are tested to determine the observed order of numerical convergence • All important F&Cs are tested with rigorous benchmark solutions • Independent peer review conducted
Solution Verification Are numerical solution errors and human procedural errors corrupting the simulation results?	• Judgment only • Numerical errors have unknown or large effect on simulation results	• Numerical effects on relevant SRQs are qualitatively estimated • Input/output (I/O) verified only by the analysts	• Numerical effects are quantitatively estimated to be small on some SRQs • I/O independently verified • Some peer review conducted	• Numerical effects are determined to be small on all important SRQs • Important simulations are independently reproduced • Independent peer review conducted
Model Validation How carefully is the accuracy of the simulation and experimental results assessed at various tiers in a validation hierarchy?	• Judgment only • Few, if any, comparisons with measurements from similar systems or applications	• Quantitative assessment of accuracy of SRQs not directly relevant to the application of interest • Large or unknown experimental uncertainties	• Quantitative assessment of predictive accuracy for some key SRQs from IETs and SETs • Experimental uncertainties are well characterized for most SETs, but poorly known for IETs • Some peer review conducted	• Quantitative assessment of predictive accuracy for all important SRQs from IETs and SETs at conditions/geometries directly relevant to the application • Experimental uncertainties are well characterized for all IETs and SETs • Independent peer review conducted
Uncertainty Quantification and Sensitivity Analysis How thoroughly are uncertainties and sensitivities characterized and propagated?	• Judgment only • Only deterministic analyses are conducted • Uncertainties and sensitivities are not addressed	• Aleatory and epistemic (A&E) uncertainties propagated, but without distinction • Informal sensitivity studies conducted • Many strong UQ/SA assumptions made	• A&E uncertainties segregated, propagated, and identified in SRQs • Quantitative sensitivity analyses conducted for most parameters • Numerical propagation errors are estimated and their effect known • Some strong assumptions made • Some peer review conducted	• A&E uncertainties comprehensively treated and properly interpreted • Comprehensive SAs conducted for parameters and models • Numerical propagation errors are demonstrated to be small • No significant UQ/SA assumptions made • Independent peer review conducted

Requirements Cascade

- Application Requirements
  - Hardware Qualification Tests
- Physics Requirements (PIRT)
  - Discovery Experiments
- Mathematical Model Requirements
  - Material & Physics Model Development
  - Calibration Experiments
- Numerical Simulation Tool Requirements
  - Algorithm and Hardware Development
  - Production Code Development
- Verification – Are the mathematical models coded correctly?
  - Verification Problems
  - Verification Metrics
- Validation – Do the mathematical models represent the physics adequately?
  - Validation Data Sets
  - Validation Metrics
- Accreditation – Do the physics represent application adequately?
  - Geometry & Material Model Qualification
  - Accreditation Data Sets
  - Uncertainty Quantification
- Production computing to meet application requirements

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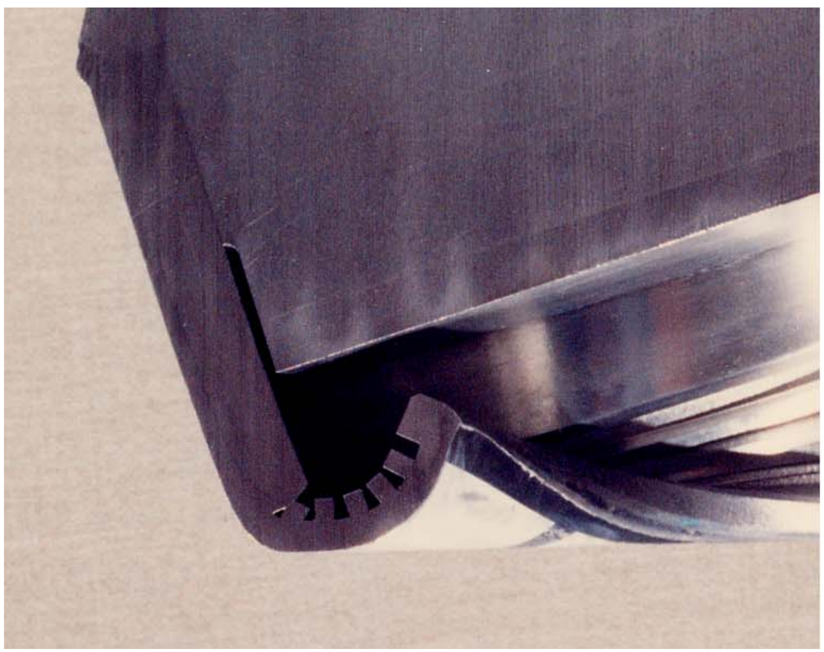
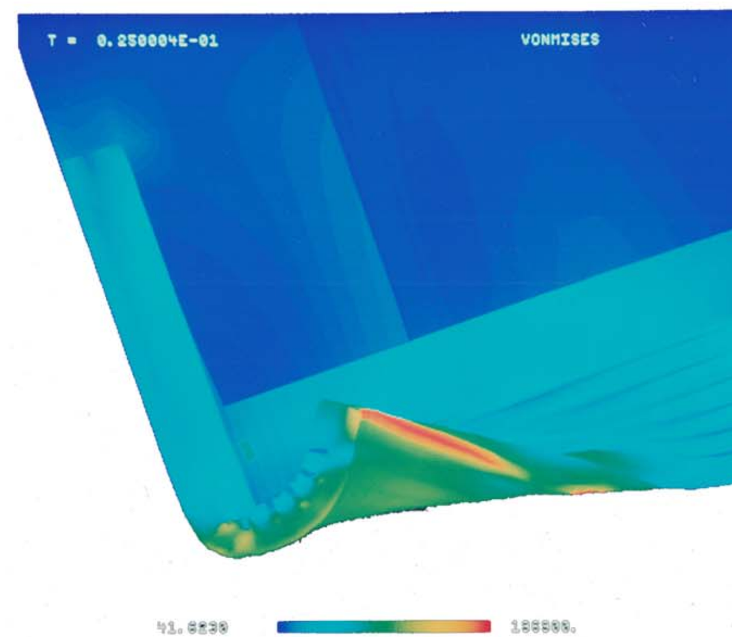
Impact Analyses

- To accurately capture the response of a package during the impact event requires an explicit dynamics code
- Some commercial codes:
  - ABAQUS/Explicit
  - LS-DYNA
- Sandia Codes
  - PRONTO
  - PRESTO

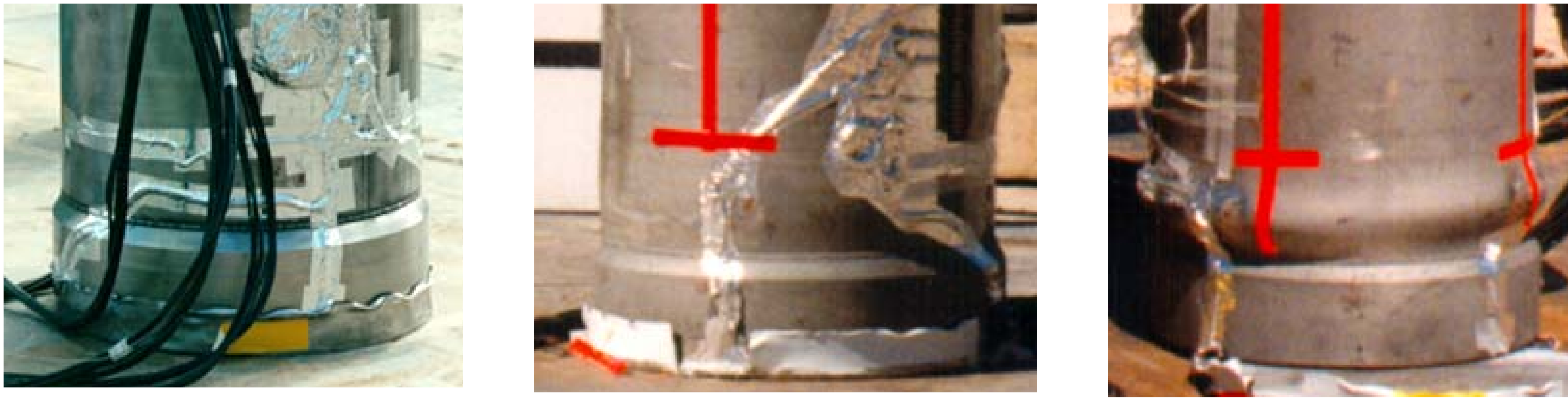
Comparison of Test and Analysis Results

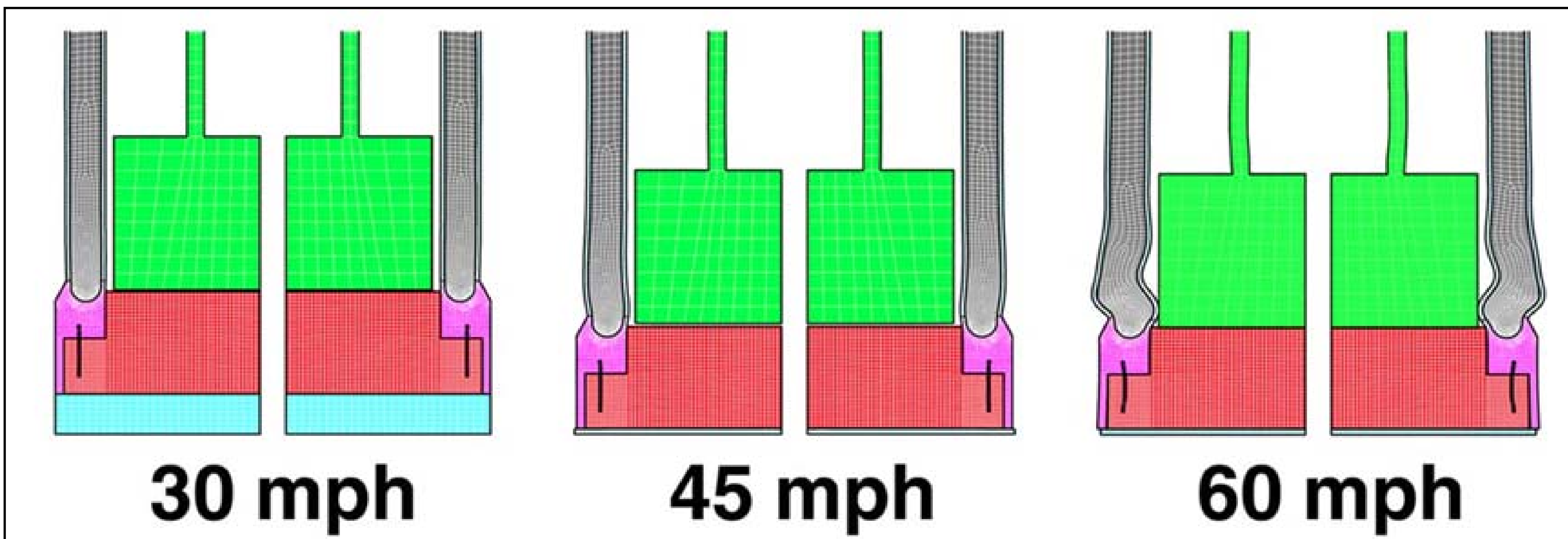
- DHLW notched impact limiter





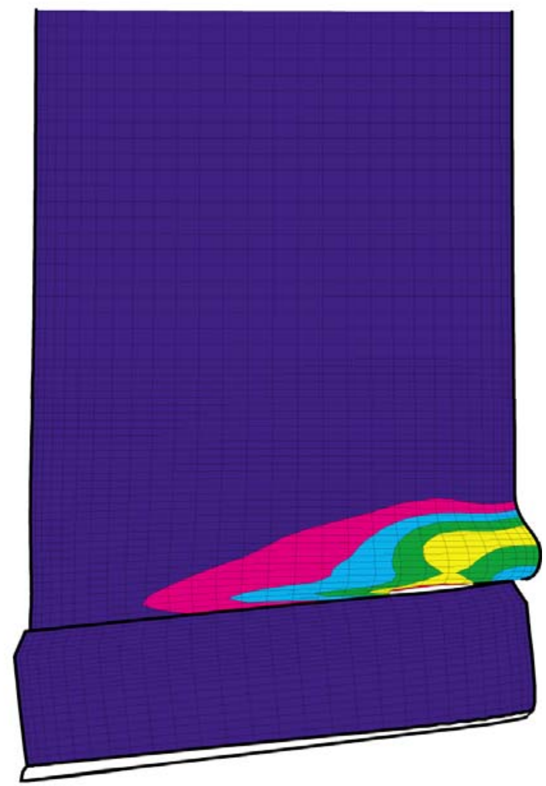
Comparison of Test and Analysis Results
Response to Extra-Regulatory Impacts





Comparison of Test and Analysis Results
Response to Extra-Regulatory Impacts

- Structural evaluation test unit 60 mph corner impact



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Impact Code-to-Code Comparison

- The European Commission sponsored a comparison of explicit dynamics codes used for package analyses
- Examined ABAQUS/Explicit, LS-DYNA, LUSAS, H3DMAP, DYNA, and PRONTO
- 3 Benchmark problems
  - A concentric steel and lead cylinder with side impact
  - A corner impact of a steel cube
  - An end impact of a steel-lined wood impact limiter
- All codes produced similar results

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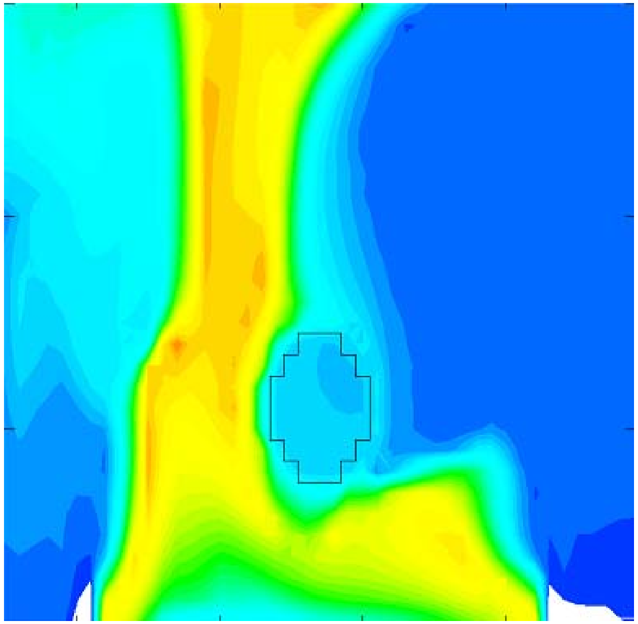
Thermal Analyses

- To accurately capture the response of a package during thermal events may require more than one type of code
- Some commercial codes:
  - ANSYS
  - MSC PATRAN/Thermal
  - ABAQUS
  - FLUENT
  - CFX
- Sandia Codes
  - FUEGO
  - VULCAN
  - CALORE
  - CAFE

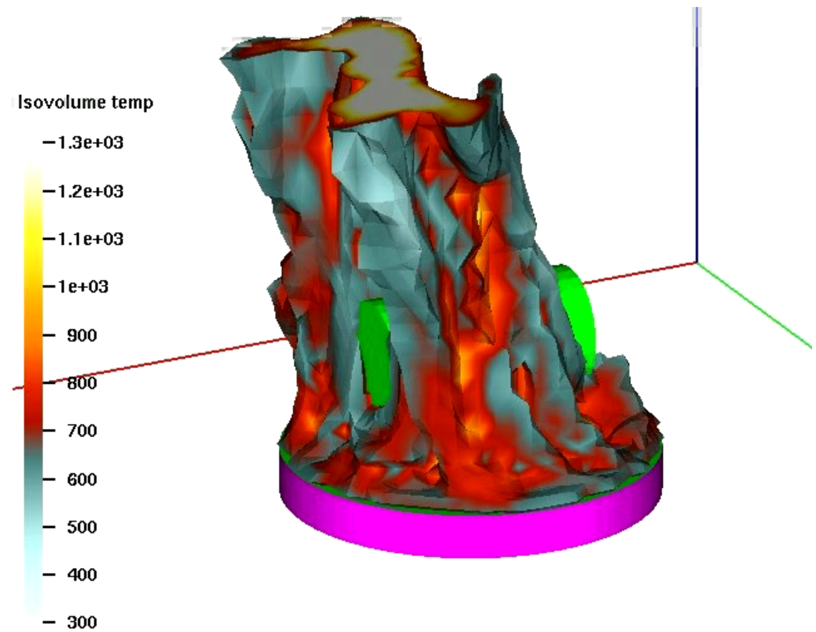
Linking Analysis to Testing

Comparison of CAFE analysis to test

- Truck-cask-size calorimeter



CAFE Fire Simulation – Code Benchmarking
Large Calorimeter Fire Test

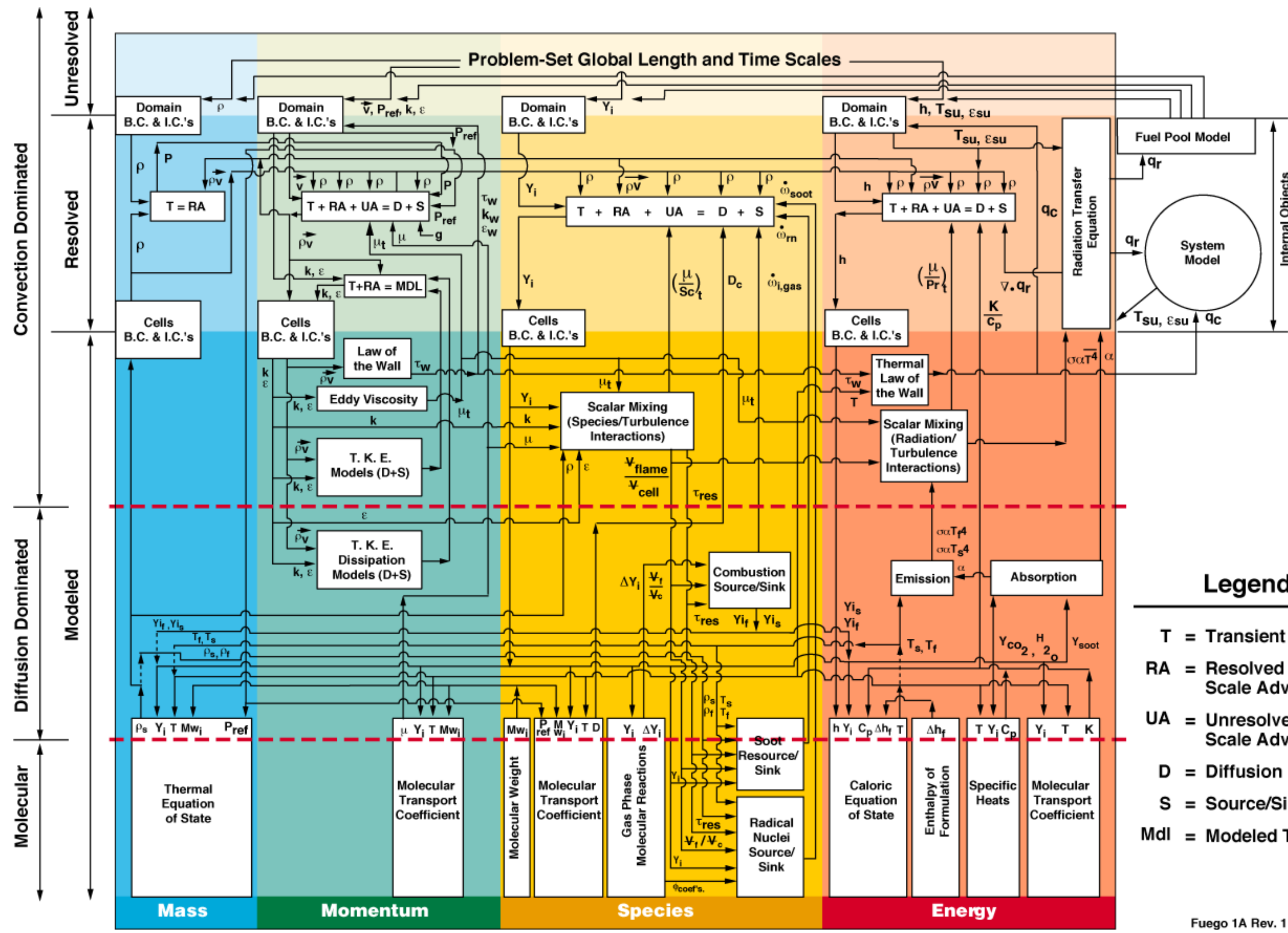


Formal V&V Process

- **The next slides will cover the verification and validation process being used for the Sandia fire code FUEGO**

SIERRA/FUEGO/SYRINX
Math Model Connectivity

Vulcan/Fuego-Level 1 Mathematical Model Coupling



Legend

T = Transient

RA = Resolved Scale Advection

UA = Unresolved Scale Advection

D = Diffusion

S = Source/Sink

Mdl = Modeled Terms

Fuego 1A Rev. 1 8/20/98

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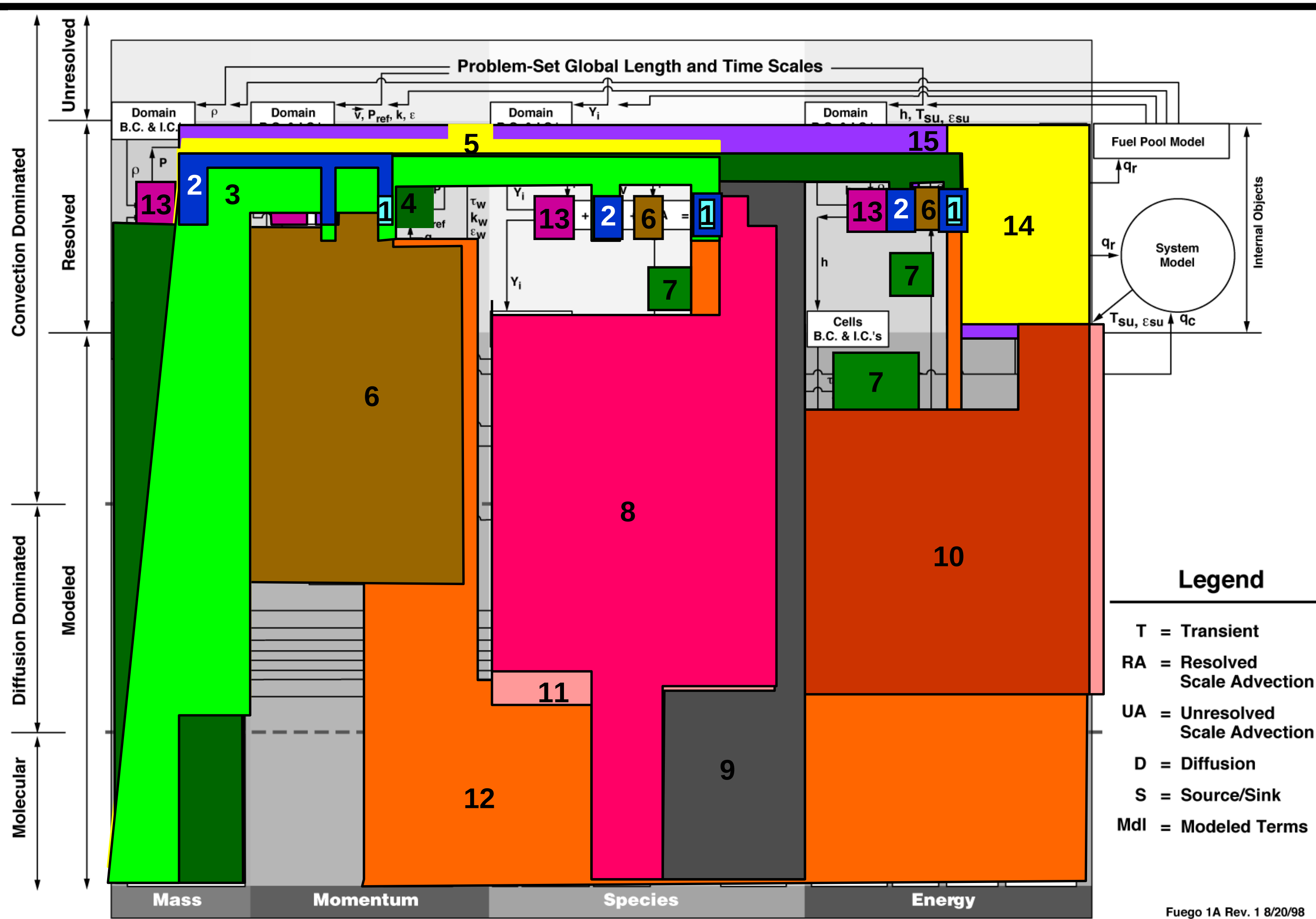
Verification Suite Coverage of Math Models in Fuego



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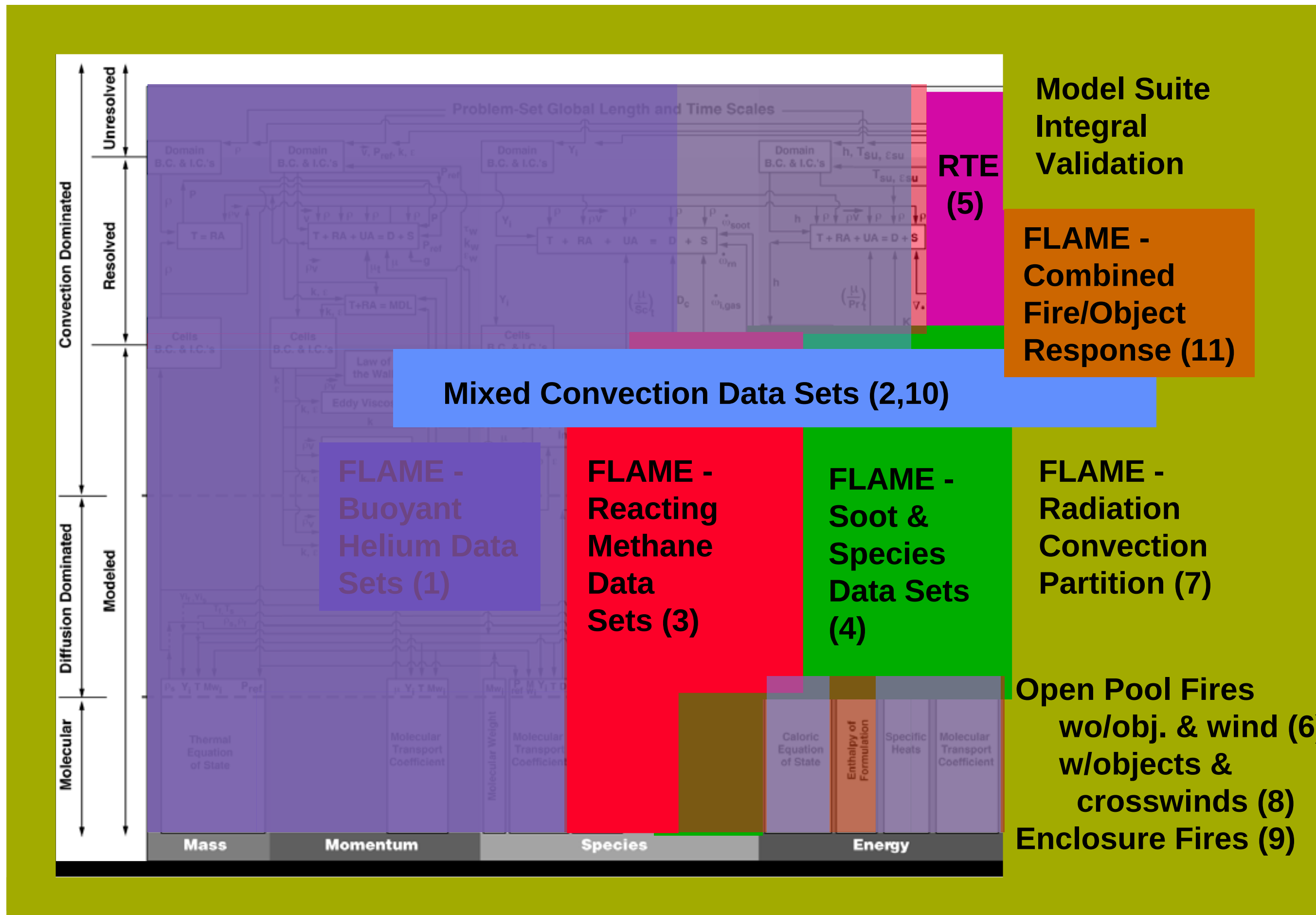
Validation Suite Coverage of Math Models in Fuego

Validation plan

- provides full coverage of all mathematical models
- builds from simple to full physics coupling



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