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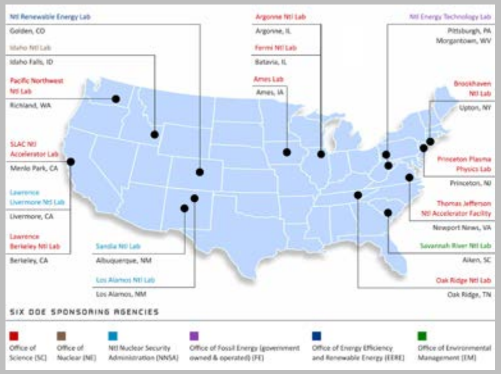

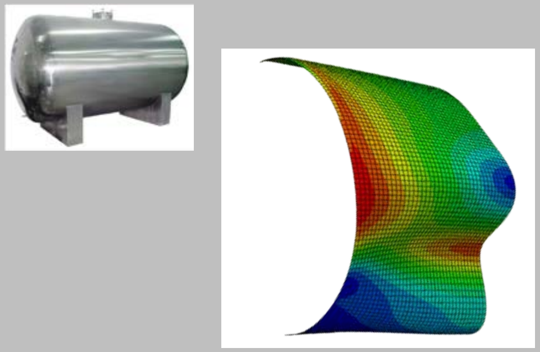

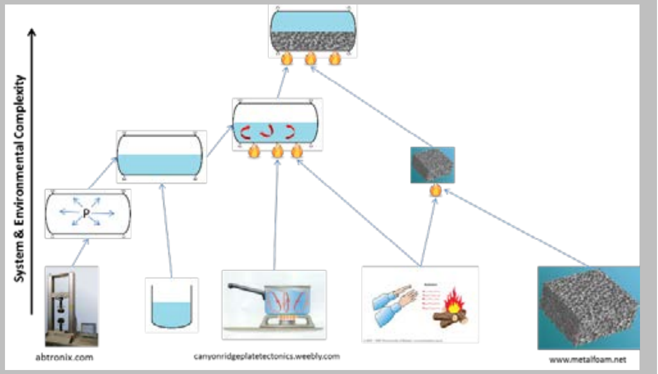

The 2014 Sandia Verification and Validation Challenge Workshop

Ken Hu

8 May, 2014

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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THE WORKSHOP

- How did we get here?
- Goals

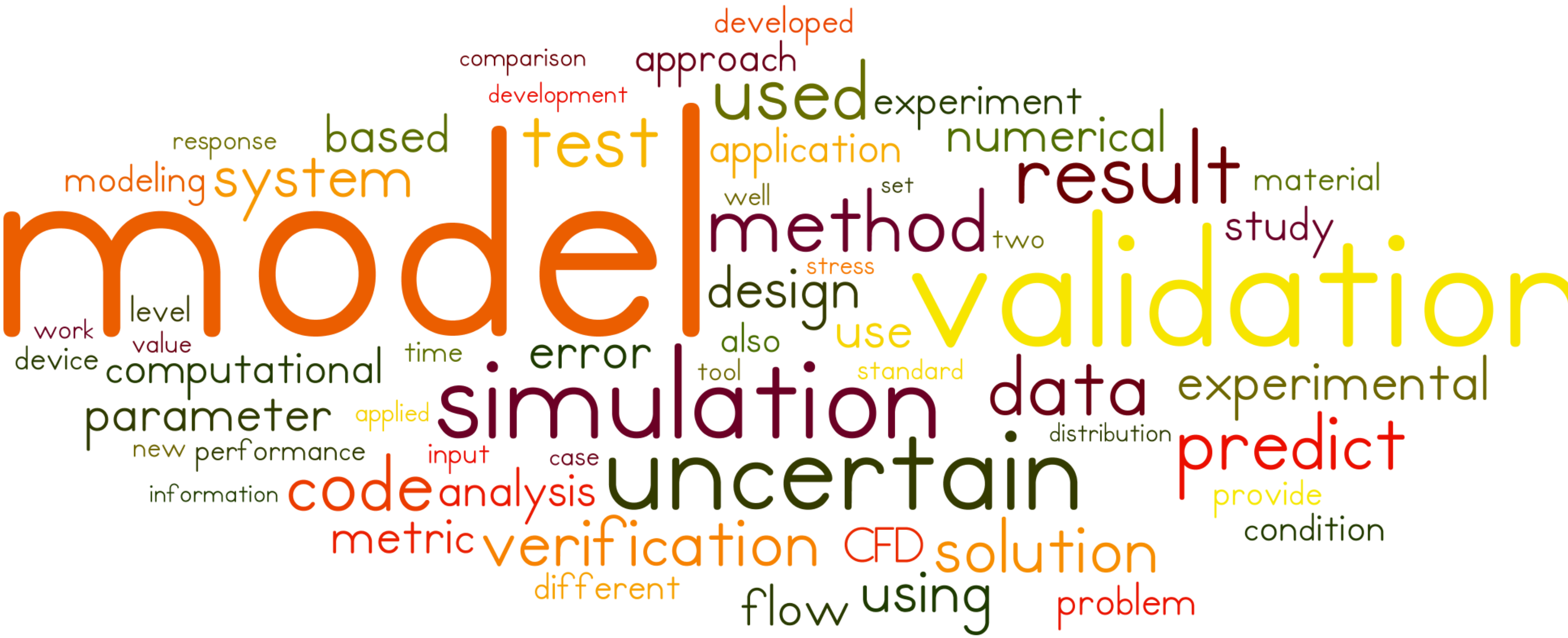
The 2014 Sandia Verification and Validation Challenge Workshop @

(Selected) History

- Foundations Series
- Sandia workshops
  - 2002 – Challenge problem – epistemic uncertainty
  - 2006 – Challenge 2 – connect calibration, validation, prediction
  - 2008 – methods
- AIAA/ USACM/ SIAM/ SEM/ ASME
  - V&V and uncertainty quantification talks & sessions
- ASME V&V Symposium

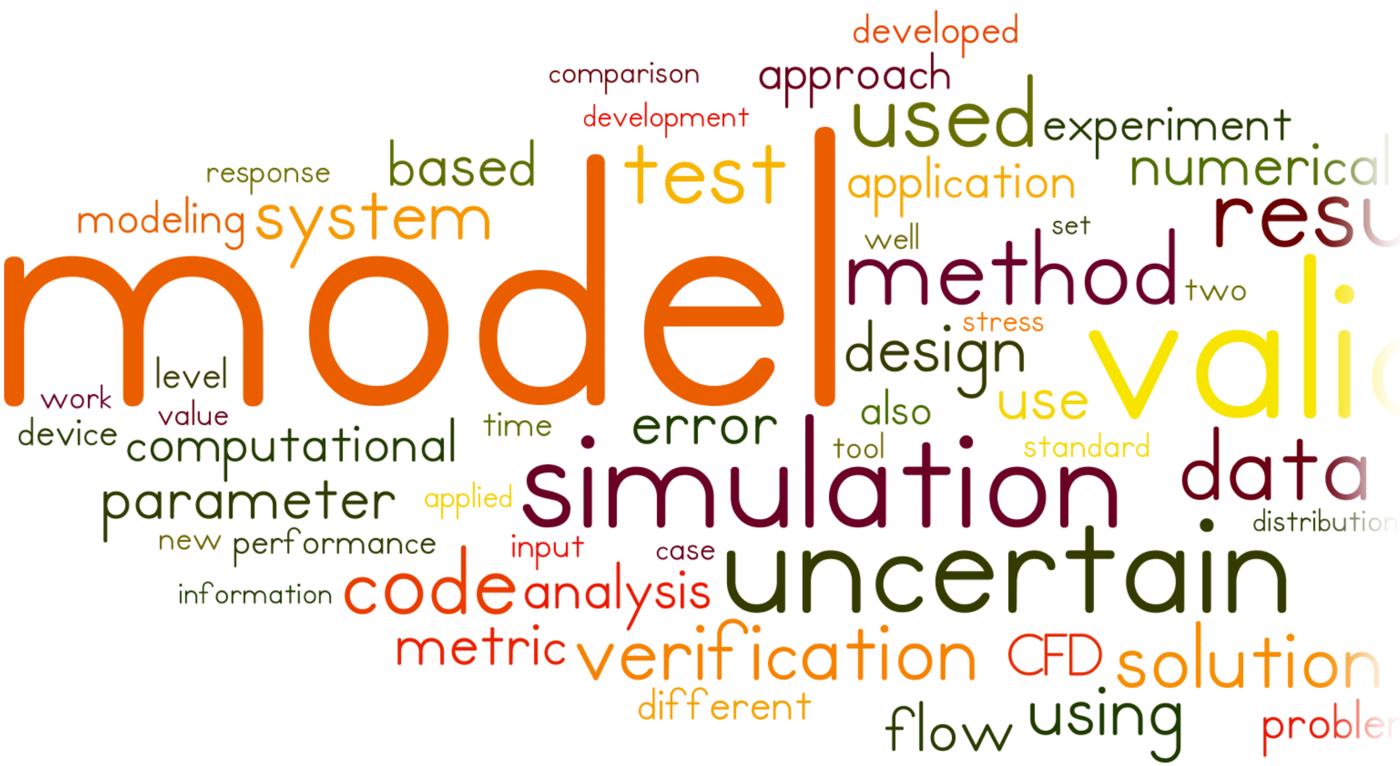
ASME V&V Symposium

- What is the community talking about?
- Three years of abstracts, summarized



ASME V&V Symposium

- What is the community talking about?



model	507
validation	298
uncertain	211
simulation	206
result	165
method	154
data	148
code	139
predict	134
verification	123
solution	121
system	113
design	105
experimental	98
decision	22
credible	13
outcome	12
consequence	5
risk	4
choice	1
action	0
belive/belief	0

What is this all about?

- Thirty+ year history of V&V/UQ work
  - Philosophy, theory, methods, applications
- 2014 – common for simulations to influence decisions

Transition V&V/UQ from R&D to production

- Much discussion centers on methods and demonstration
- Methods are important
- Impact of on project outcomes?

The 2014 Workshop

- Built around a challenge problem
  - Released in Fall 2013
- Participants began work 4-6 months ago
  - Seven participants presenting approaches
  - Two talks on using simulations for decision making
- Final session on Thursday – discussions

Focus of the Challenge Problem

How to utilize many different methods and synthesize the results?

Open questions in V&V

- How should we think about credibility/ uncertainty/ validity?
  - Can we model these concepts?
  - Can we communicate these concepts?
- How much V&V is required/ useful?
- How does credibility impact decision making?
- How does V&V impact engineering projects?
- Is the community working on the right areas?

A challenge workshop is one way to focus attention on particular questions

Goals for the Workshop

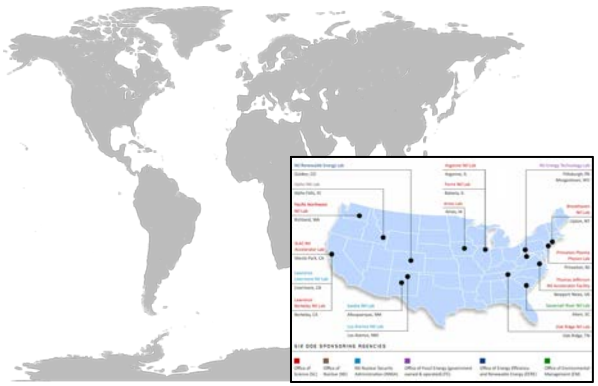
- Pose an "end-to-end" challenge problem
  - Data & models → decision (or recommendation)
- Provide venue for discussions about V&V approaches PLUS "higher-level" issues
  - Express a spectrum of viewpoints about V&V
  - NOT determining the future of V&V work
- Add to community's experience with V&V
- Restart a **workshop series**

THE CHALLENGE PROBLEM

- The story
- The challenge
- Notes about the problem

The Story of Mystery Liquid Company

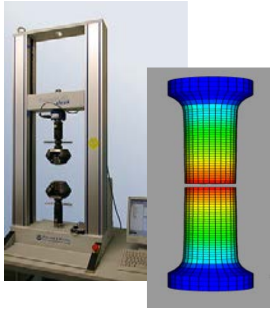
Many storage tanks, holding
Mystery Liquid under pressure



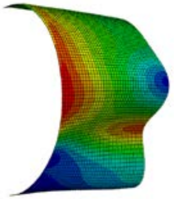
During standard safety testing,
one tank measurement (out of many)
exceeded a safety specification

How should the company respond?
Are the tanks at risk of failure?
Must they be replaced?
No tanks have actually failed, ever.

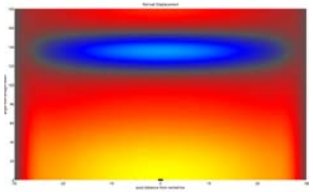
Experimental and modeling efforts are begun



Quarter view



Side view



How will the evidence from experiments and simulations be integrated and used to support the final decision?

Experiments

Tank 0

Tank 0: did not pass a safety test, at removed from field and cut into pieces for measurements and materials testing

Tank dimensions

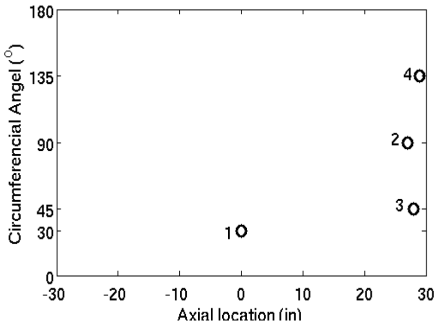
Material Properties

Tanks 1, 2

Tanks 1&2: not part of safety test, removed from field for lab testing

Tank dimensions

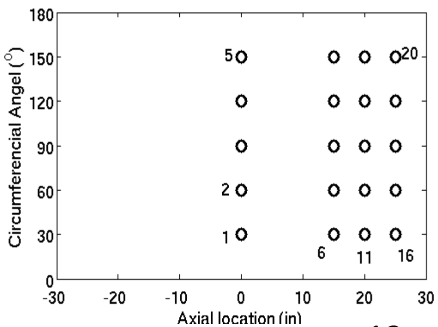
Wall displacement under pressure loading



Tanks 3,4,5,6

Tanks 3-6: not part of safety test, remain in service, tested in the field

Wall displacement under pressure and liquid loading

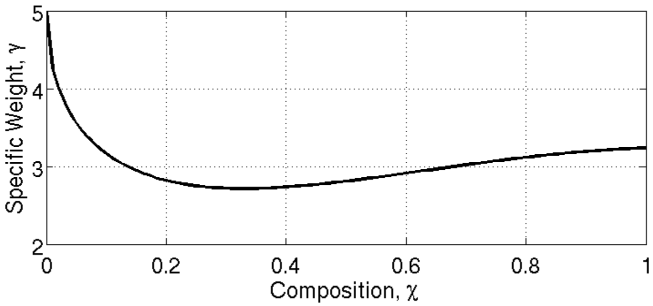


Additional Data

- Specifications from tank manufacturer
  - Tanks are decade(s) old
  - No uncertainty estimates or tolerances

- Data about the Mystery Liquid 
  - Relating composition to specific weight (∝ density)

$$\gamma = \frac{7\chi}{1+0.25(\chi-0.3)^2} - 8\sqrt{\chi} + 5$$



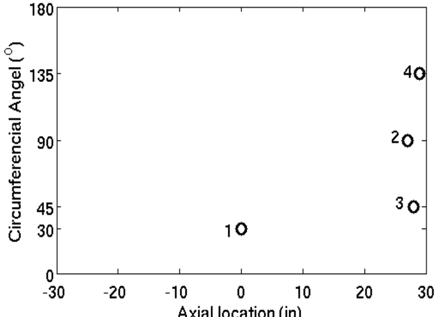
Comments on Data

- Material property data is not supplied
  - Only processed parameter estimates & equation of state
- Number of repeats is limited
- Many uncertainties
  - Data quality: test conditions, measurement devices, data processing
  - Mystery liquid equation of state is imperfect
  - Physical specimens not representative of population

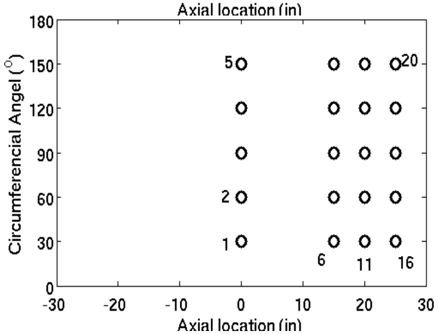
Data – summary

- Dimensions
  - Radius
  - Wall thickness
  - Length
- Material data
  - Young's modulus
  - Poisson Ratio
  - Yield stress
  - Composition vs. specific weight

- Wall displacement (normal to surface)
  - Various locations
  - Various loading

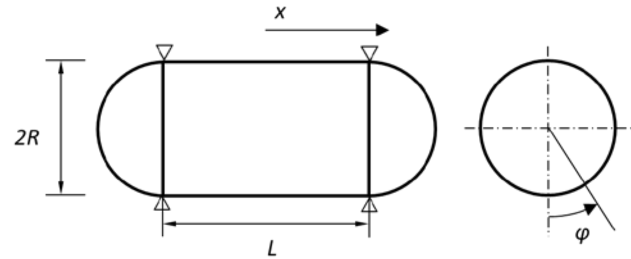


Pressure Only



Pressure and Liquid

Simulations

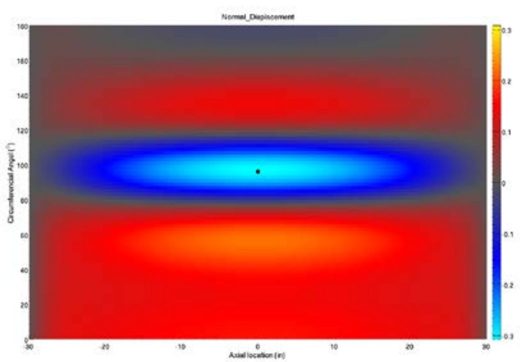


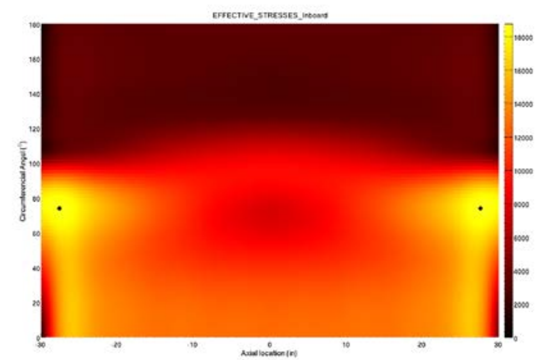
- Model and code implementation were supplied
  - Treated as a finite element model
  - 4 meshes

$$[d,\sigma] = \mathcal{M}(R, L, \tau, E, \nu, P, H, \gamma, m)$$

displacement (d), stress (σ); Tank Dimensions (R, L, τ); Material properties (E, ν); Pressure (P); Liquid properties (H, γ); mesh (m)

At any axial distance x, and angle φ



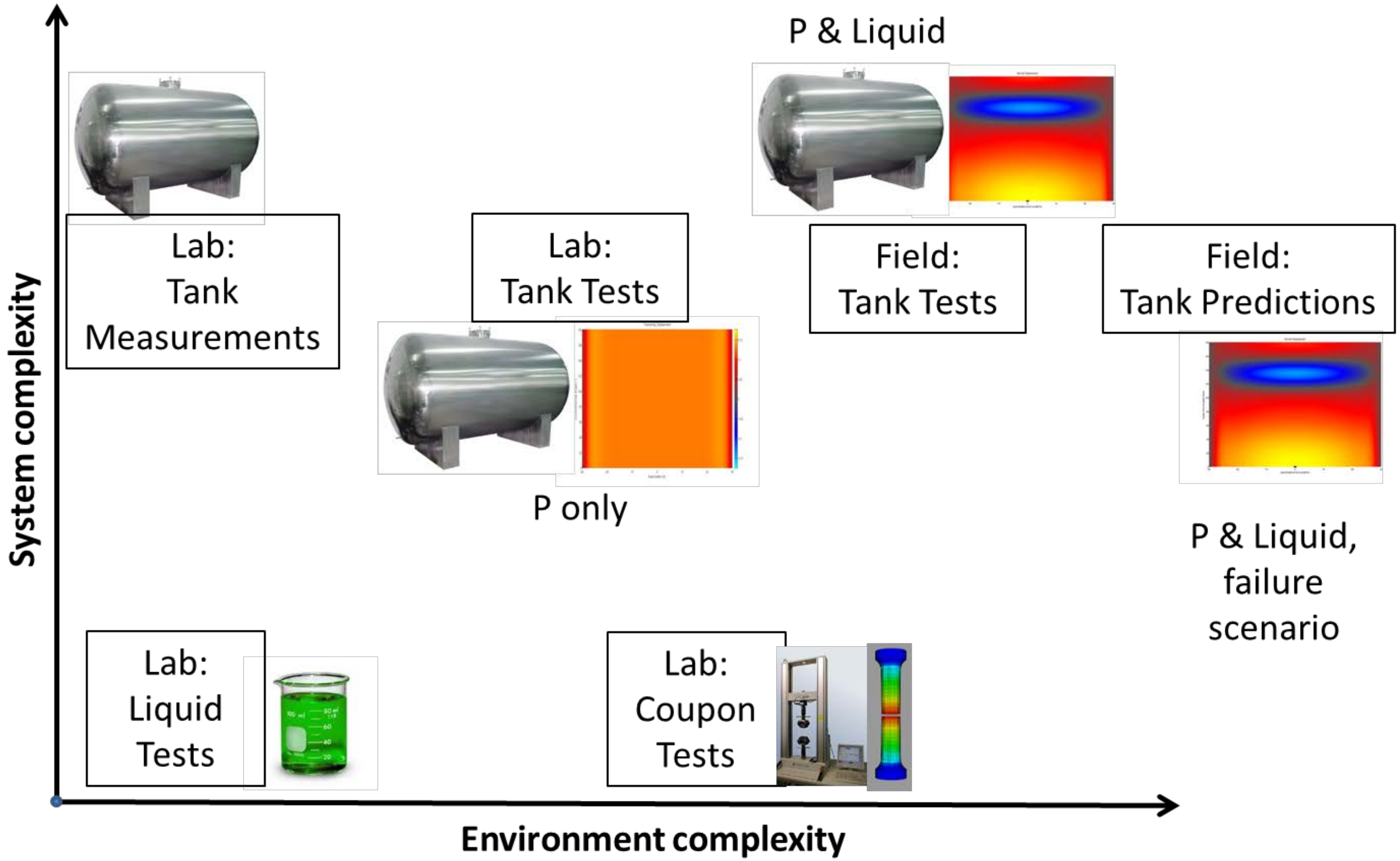


The Challenge

- **Predictions + uncertainty**:
  - The ultimate product of this study will be prediction of Probability of Failure for two scenarios. In addition to a best estimate of Probability of Failure, we expect to produce uncertainty estimates.
- **Credibility Assessment**:
  - In addition to the predictions, we need to know the credibility the predicted Probability of Failure.
- **V&V Strategy**:
  - The key to providing a good credibility assessment is a logical and clearly defined strategy to gather evidence that the predictions are accurate.

Strategies/ Approaches

- How are data and simulations used?
- Need a framework for describing an "approach"



Analysis Hierarchy

- A POSSIBLE way to communicate analysis strategy
- System/ hardware levels
  - Full system (tank)
  - Material (test coupons, etc.)
- Environments
  - Uniaxial tension
  - Gas Pressure
  - Liquid load
- Match test data and simulations to nodes
- Strategy = how to use data and simulation at nodes
- Ex: calibration, validation, uncertainty characterization, solution verification, uncertainty quantification, prediction, etc.

Prediction

- Failure is considered likely if predicted stresses are greater than the yield stress

1. Estimate the probability of failure at the conditions of the safety test (nominal pressure, liquid height, and composition)
2. Find the boundaries of “safe operating conditions” where probability of failure $< 10^{\{-3\}}$

- Include or account for uncertainty

Credibility

- Are the simulation predictions credible?
- **After the analysis, are you ready to make a recommendation of whether to replace the tanks?**
- How do you communicate the results, uncertainty, and credibility?
- How does each V&V task contribute to the credibility of the predictions of interest?
- Does the V&V strategy as a whole add credibility?
- What is the impact of extrapolation from the validation domain?

Problem scope

- Problem statements specifies:
  - Model & code
  - Experiments & measured data
  - Quantities of Interest – wall displacement and stresses
  - Final analysis – probability of failure (based on stress)
- Code is supplied
- Participants cannot modify any of the above

- Scope is huge – develop a strategy, apply methods, integrate all the information…

Known model issues

- The model only includes the center section (cylinder)
- No end caps → very different boundary conditions
- No capability for spatial variability of inputs
- Known mesh dependence
- These model limitations have unknown effects on the ability to accurately compute the responses.

Problem Features

- Relevant: Multiple levels → V&V hierarchy
- V&V/UQ topics: calibration, solution verification, experimental and modeling uncertainty, uncertainty quantification, validation, aggregation, extrapolation to "application" domain
- 'End-to-end' problem
  - Data+models → prediction, uncertainty, credibility
    → Decision informed by Modeling and Simulation

THEMES FOR DISCUSSION

- Gather topics during talks
- How to advance the field?
- Future workshops?

Questions for participants

- Estimate the time commitment from your group
- Estimate the number of runs and the computational cost
- Discuss how you dealt with the scope of the problem
- **If the decision maker asked for your professional opinion: are the tanks safe? What is your answer and why?**
- How would you improve your analysis?
- Would you suggest any changes to this problem or future problems?

Starter Topics

- Scope of V&V is huge
  - Too much for a single person
  - What is the most important? How to decide?
- Credibility Culture
  - Whose job is V&V?
  - How IS V&V used?
  - How SHOULD V&V be used?
- Next steps?
  - For workshops, for challenge problems.

Acknowledgements

- Sandians – Brian Carnes, Vicente Romero, George Orient, Adam Hetzler, the Dakota team, and others
- ASME organizers, especially the V&V 20 committee
- Participants
- Many colleagues for their suggestions and help

More info:

- Website: https://share.sandia.gov/vvcw
  - Full problem statement
  - Summary handout
  - This presentation
- Email: vvcw@sandia.gov
- These will be active through FY15, then will migrate to an archive location

2014 V&V Challenge: Problem Summary

This handout provides a summary of the challenge problem - the goal is allow the reader to follow workshop presentations. For the full problem statement, the code and data, and all other information about the workshop, visit the website: https://share.sandia.gov/vvcw/.

Backstory

MysteryLiquid Co. maintains a large number of storage tanks that hold a Mystery Liquid under pressure. The weight of the contents plus pressurization causes deformation of the tank walls.

During a standard safety inspection, one tank produced out-of-spec measurements when a large load was applied. Given that the tank is out of spec, we wish to know if there is a real chance of physical failure.

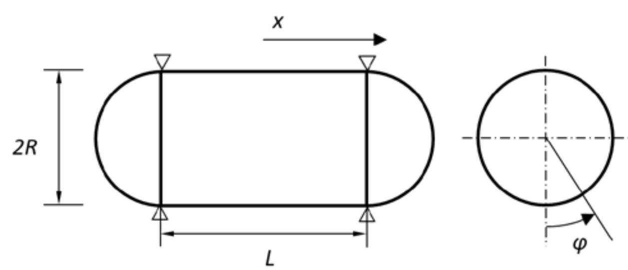
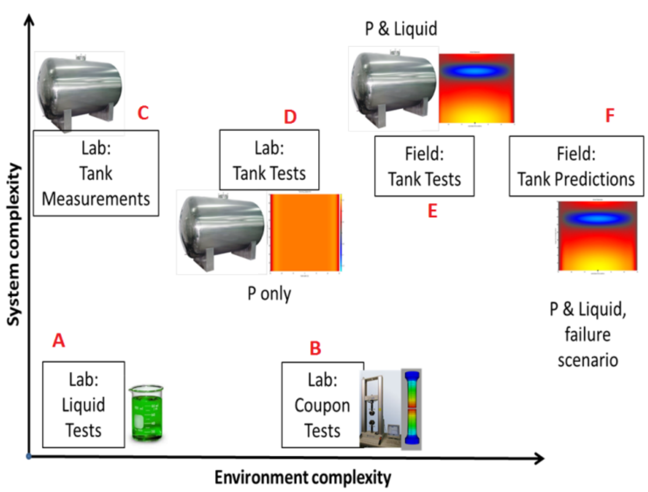


Figure 1: Side view and axial view of tanks

The out-of-spec tank and its two neighboring tanks were taken out of service and underwent testing. In addition, four tanks, in four different locations, each underwent multiple tests while still in service. The company has commissioned a modeling study to complement these experimental tests. The assumption is that the historical safety margins are being violated, and we need to better understand the margin to failure. The goal is to determine whether the remaining tanks must be retired immediately.

The Problem



(A) Mystery Liquid – known relationship between composition and specific weight

(B-E) Out of spec tank (T0) and two neighbors (T1, T2) are taken to a lab for tests. Four more tanks are tested while in service (T3-T6)

(B) T0 is cut up for material tests – Young's modulus, Poisson's Ratio, Yield stress

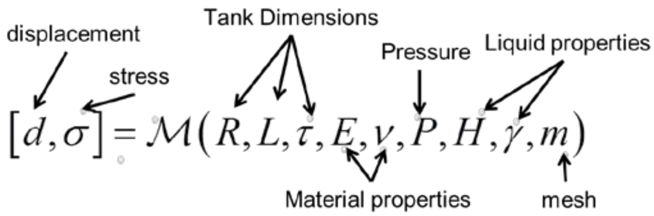
(C) Tank dimensions are measured – radius and length from T1, T2 and wall thickness from T0

(B,C) Manufacturer gave specs for dimensions and material properties (decades ago, when tanks were new)

(D) T1, T2 are pressurized – displacements are measured at 4 locations (6 tests on each tank)

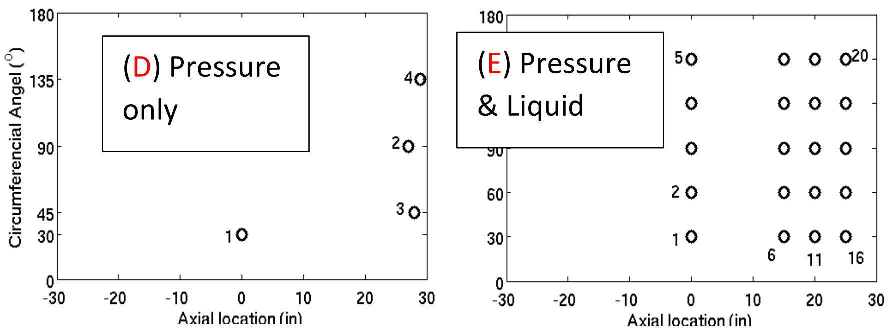
(E) T3-T6 are in service w/ moderate pressure and liquid loads - displacements are measured at 20 locations (3 tests on each tank)

(F) Make predictions of stress for the tanks, at extreme pressure and liquid loading levels
Loading (Pressure, liquid height, and composition) can be measured during tests, but with uncertainty. Also, displacements have significant measurement uncertainties. Tank failure has been correlated to yield stress – when predicted stress in the tank wall exceed yield stress, the tank is considered “failed”.



A model & code are provided to compute displacement and stress. Four meshes were created, at various levels of refinement. The model has known limitations – it includes only the cylindrical section, with no end caps.

The failure model comes from yield stress data (B). Other dimensions and material properties come from manufacturer data and tests (A, B, C). The loading information for each experiment is given (D, E), along with measured displacements (locations shown below).



The model can predict displacements at any location, plus stresses.

The Challenge

Based on the model and available data, develop an analysis strategy to predict failure probabilities for two loading scenarios. Assess the credibility of the predictions, and make a recommendation of whether to retire the tanks.

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