UNITED STATES NUCLEAR REGULATORY COMMISSION

Protecting People and the Environment

Considerations for Advanced Modeling and Simulation Review

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Objective

To bring you into the mind of **a** reviewer:

- How we got where we are (history of simulation review),
- What we currently do (performing a simulation review)
- Considerations for the future.

Can the results of the simulation be trusted with people's lives?

Different types of simulations

Regulatory Oversight

Engineering analysis

Design analysis

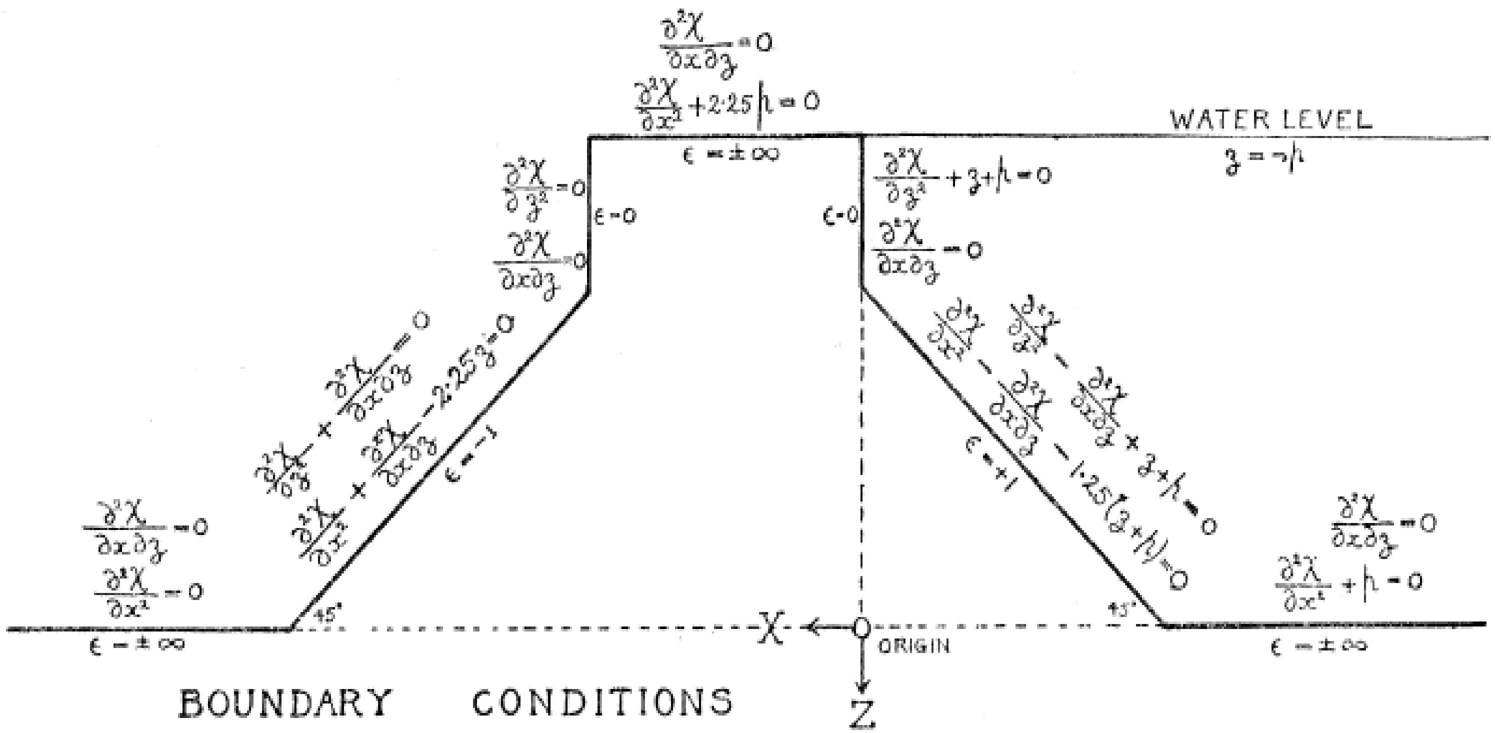
Confirmatory analysis

“Beyond Design Basis”

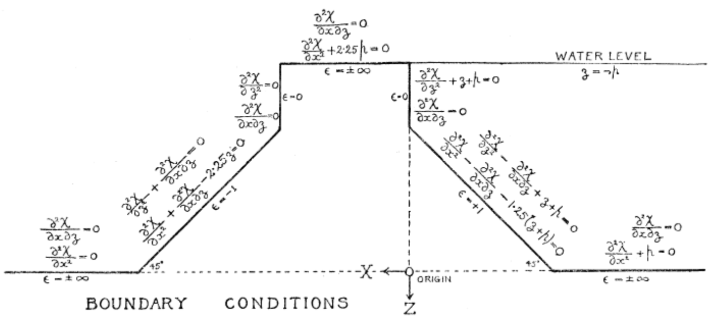
Supporting analysis

Safety Analysis

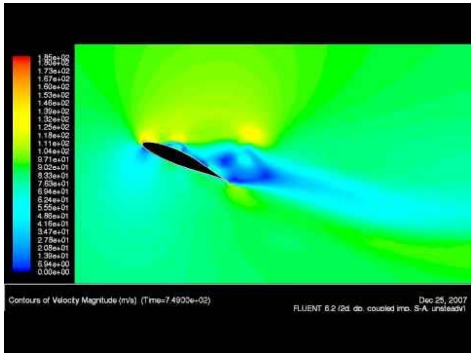
History of Simulation Review



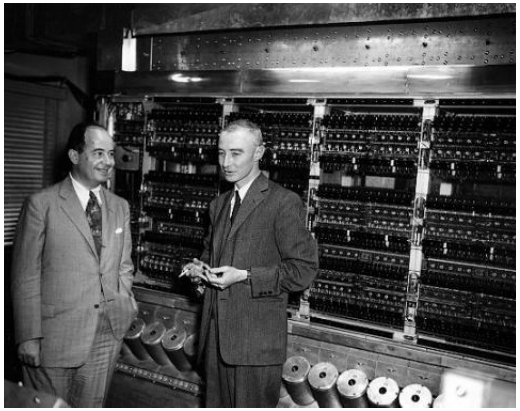
History of Simulation



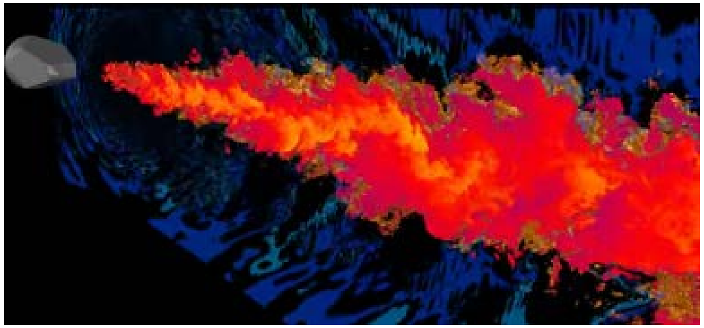
1911



1967



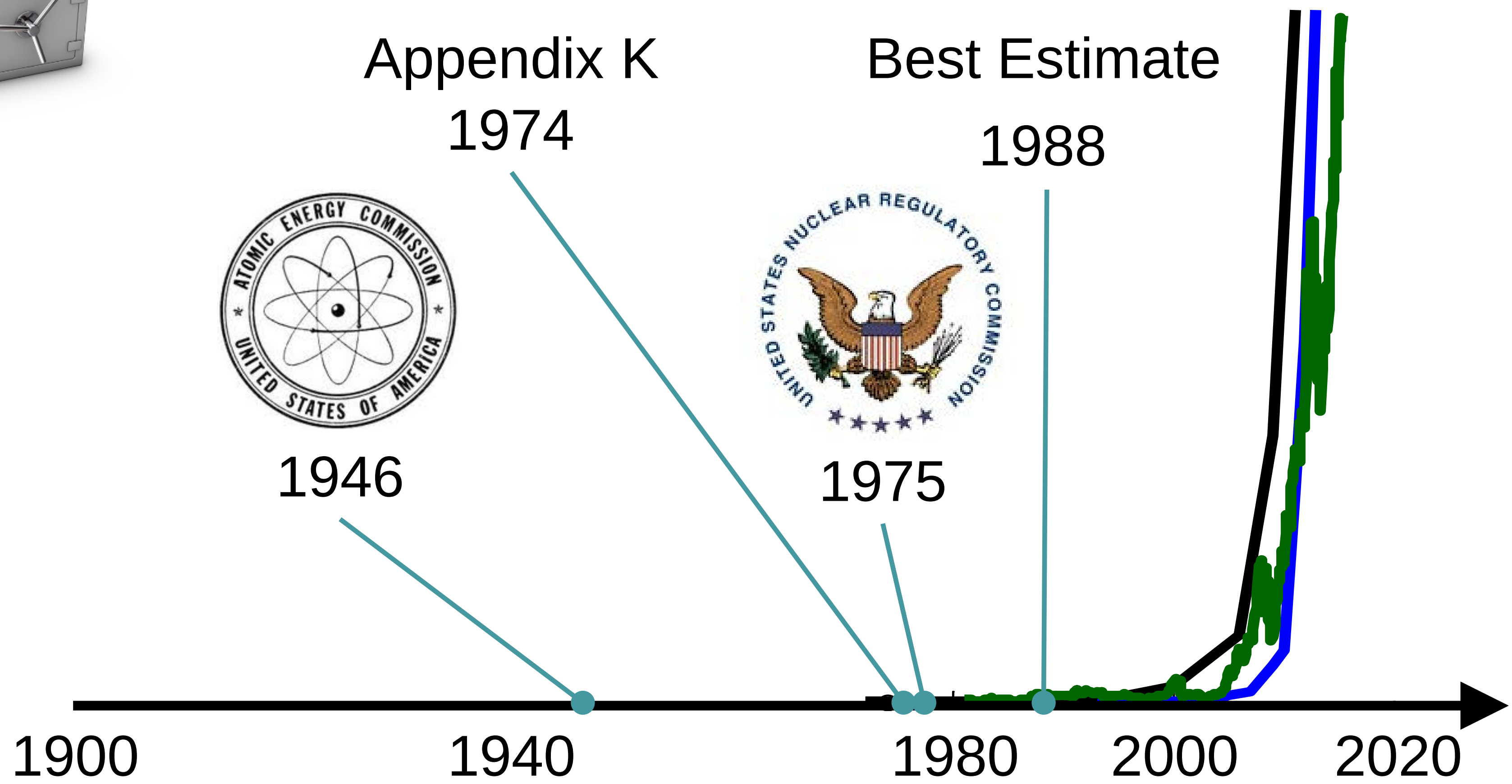
1951



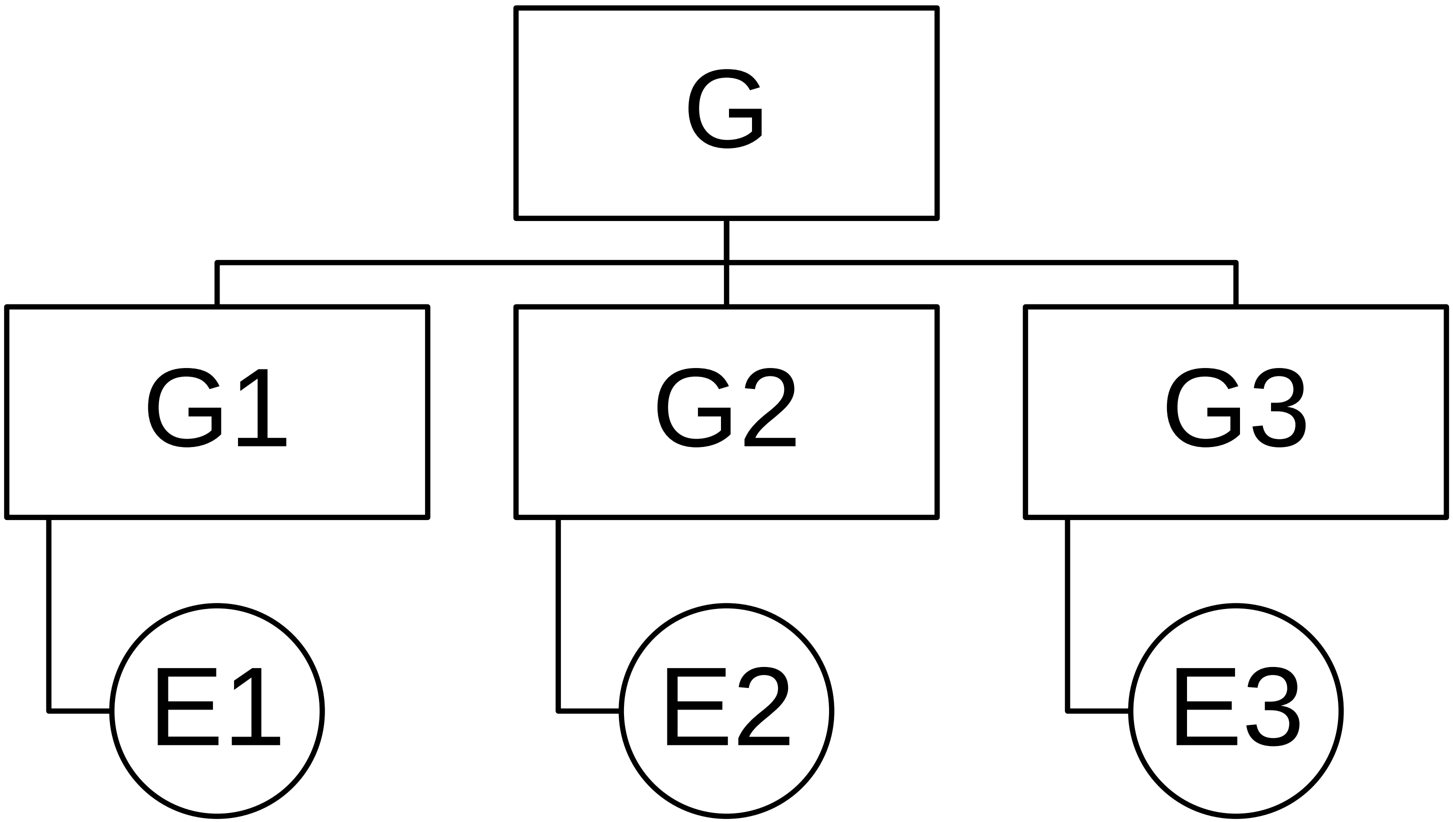
2011

1900 1940 1980 2000 2020

History of Simulation Regulation



Performing a simulation review



Critical Heat Flux

GOAL		The critical heat flux model can be trusted in reactor safety analyses.
G1		The experimental data supporting the CHF model is appropriate.
	G1.1	The experimental data has been collected at a credible test facility.
	G1.2	The experimental data has been be accurately measured.
	G1.3	The test bundle reproduced the local conditions in the reactor fuel bundle.
G2		The model was generated in a logical fashion.
	G2.1	The mathematical form of the model is appropriate.
	G2.2	The process for determining the model's coefficients was appropriate.
G3		The model has sufficient validation as demonstrated through appropriate quantification of its error.
	G3.1	The correct validation error has been calculated.
	G3.2	The validation data was appropriately distributed throughout the application domain.
	G3.3	Any inconsistencies in the error have been accounted for appropriately.
	G3.4	The model uncertainty has been appropriately quantified.
	G3.5	The model has been correctly implemented.

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Evaluation Framework

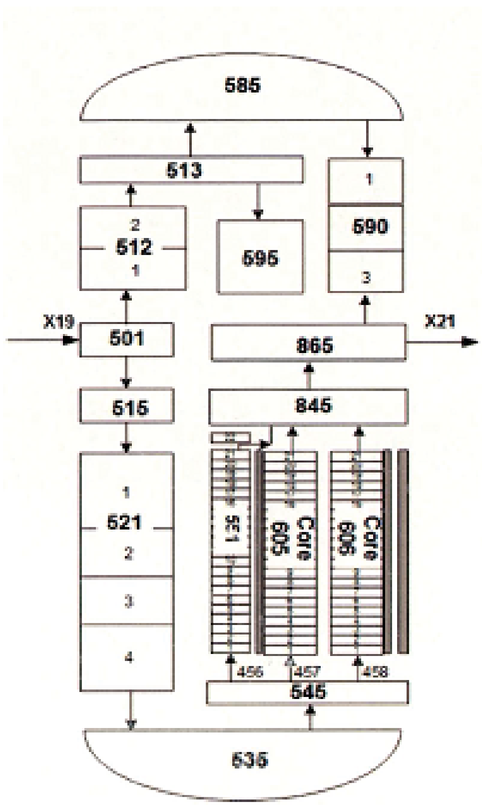
The calculational framework for evaluating behavior of a system during a scenario. It includes:

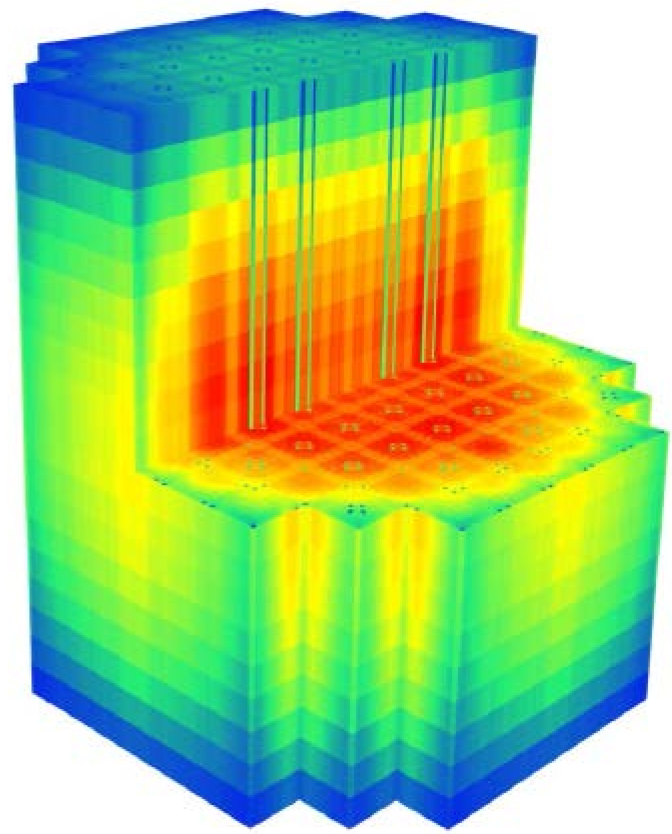
- computer programs
- mathematical models
- assumptions included in the programs
- procedure for treating the program input and output information
- specification of those portions of analysis not included in computer programs
- values of parameters
- other information necessary to specify the calculational procedure.

Mind of a reviewer

- What is the scenario being modeled?
  - What boundaries can I place on the scenario?
  - What phenomena are of greatest concern? (i.e., most important to the scenario or *most complex*?)
- Where is the documentation and is it complete?
- How are they modeling the scenario?
  - How have they defined their Evaluation Framework?
- Can I trust their Evaluation Framework?
  - How much should I trust/doubt different parts of it?
  - How much data do I have to support the different closure models and the evaluation framework as a whole?
- What is the uncertainty of the framework?
  - In the models, in the inputs
- How does the Quality Assurance Program work?
  - Appendix B program

Advanced Simulations





Advanced Simulations

Conventional Simulations

1. Contain a mathematical limit on the mesh size ($\Delta x > h$).
2. Start with closure equations and fill in with conservation equations as needed.
3. N computations per simulation.

Advanced Simulations

1. Approaches the exact solution as mesh size goes to zero ($\Delta x \to 0$).
2. Start conservation equations and fill in with closure equations as needed
3. Much greater than N computations per simulation.

Conditional Maturity

- **Conditional Probability** - P(A) vs. P(A|C)
- **Conditional Maturity** - M(A) vs. M(A|C)
  - A is an advanced simulation
  - C is a conventional simulation

Example

1. M(A) – My two phase CFD analysis resulted in a PCT of 1654 ºF.
2. M(A|C) – My two phase CFD analysis resulted in a PCT of 1654 ºF and my mature conventional analysis resulted in a PCT of 1783 ºF.

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Continuous Simulation

- **Single simulation** – perform a single bounding simulation
  - Any unknown inputs would be treated as some wide distribution
  - What happens when you actually know the input at a later time?
- **Continuous simulation** – perform a single *bounding* simulation
  - Any unknown inputs would be treated as some wide distribution
  - Additional simulations are performed as inputs become known

Example

1. I don't know what power level. I'll assume a uniform distribution between 0% and 100%. If I am operating at 73% power, is this still bounding?
2. I don't know what power level. I'll assume a uniform distribution between 0% and 100%. If I am operating at 73% power, I re-run the simulation at 73% power.

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Continuous Validation

- **Pre-Validation** – all validation must be performed before the simulation is trusted
- **Continuous Validation** – most validation must be performed before the simulation is trusted
  - I commit some amount of resources for validation each year

Example

1. All experimental testing is performed upfront.
2. Experimental testing is performed upfront, but it is recognized (expected) that additional information gained during through the simulation and during the simulation review process will reveal new experiments which should be performed.

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Continuous Review

- **Review** – Are the results of the simulation trustworthy? Yes or no.
  - Provides greater regulatory certainty but has a very high bar for approval...
- **Continuous Review** – Are the results of the simulation *currently* trustworthy?
  - Less certainty that the simulation will not have to be re-ran, but the review scope is much less
  - Does not need to consider what may happen in the future.

Example

1. Please approve this simulation, ignoring what we will learn in the future.
2. Please approve this simulation given what we know today, and feel free to look at it again in the future when we learn more.

Summary

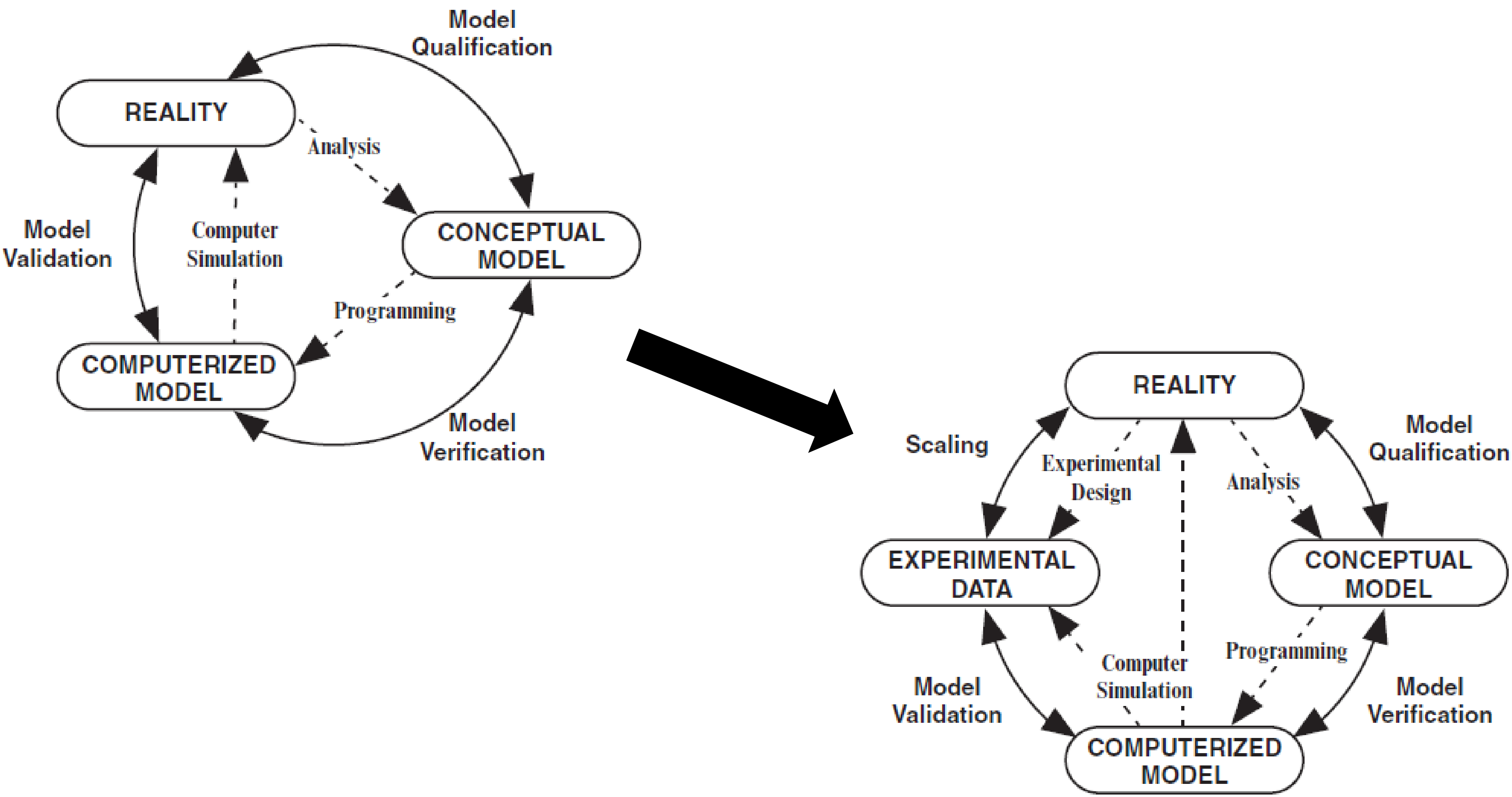
The Objective was to communicate **my**

- Understanding of the history of simulation review,
- Method for performing simulation reviews, and
- Questions / Ideas for the future.

Questions

Questions, comments, corrections ?

Scope of V&V (BU)



Current Regulations (BU)

- Stated as very prescriptive (Appendix K), and then became general (Best Estimate)
- There are a wide range of simulations reviewed, but most of the focus is on **Safety Analysis**
  - Anticipated Operational Occurrences (AOOs) / Transients
    - events which will or may occur once in the lifetime of a plant
    - fuel failure is not allowed
  - Postulated Accidents
    - events which are not expected, but are postulated
    - fuel failure is expected, but must be limited

NRC Guidance (BU)

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Evaluation Model Development and Assessment Process (EMDAP)

1. Establish Requirements for Capability
2. Develop Assessment Base
3. Develop Evaluation Model
4. Assess Evaluation Model Adequacy
5. Adequacy Decision

- “Transient and Accident Analysis Methods” – Regulatory Guide 1.203
- “Review of Transient and Accident Analysis Methods” – Standard Review Plan 15.0.2
- Origins in Code Scaling, Applicability, and Uncertainty (CSAU)

- Overall, these provide a high level approach, but do not provide specifics (i.e., what is adequate validation?)