New Faculty Introduction
NUEN Advisory Council Presentation

Ryan G. McClarren

Bio (briefly)

- I received my PhD. in 2007 from the University of Michigan.
    - 2004 MSE and 2003 BSE in Nuclear Engineering from U of M.
- In graduate school I worked on numerical methods for radiation transport simulations
- I then was a postdoc and later a staff member at Los Alamos National Laboratory
    - In the computational physics group (CCS-2)
    - Here I also worked on radiation transport as well as high-performance computing
- I came to A&M as a Visiting Assistant Professor in Dec. 2008.
    - Besides being in NUEN I was also a fellow in the Institute for Applied Mathematics and Computational Science.

The most interesting piece of my biography

- In 2004, while I was in graduate school, I appeared on the TV game show *Jeopardy!*
- Unfortunately, at this time Ken Jennings, the most successful contestant in *Jeopardy!* history was on his streak
  - I end the show in 3rd place with $1.
  - I did get a Daily Double correct though.

What I do - Research

- I am active in two areas of research both in computation
- Radiation transport:
  - Neutronics
    - 4 papers *(Nuc. Sci. & Eng, Transport Theory and Stat. Phys., Annals of Nuc. Energy)*
  - X-ray transport methods
    - 12 papers (*J. Comp. Phys, TTSP, J. Quant. Spec. Rad. Transf., Physics Letters A, SIAM J. Scientific Computing*)
  - High-Energy Density Physics/inertial confinement fusion
    - 6 papers *(JQSRT, Phys. Plasmas, Fusion Sci. and Tech., High-Energy Density Physics)*
- Uncertainty Quantification
  - Predictive science
    - 4 papers (*Reliability Engineering and System Safety, Annals of Nuc. Energy)*
  - Propagation of uncertainties
    - 1 ongoing project regarding uncertainties in LOCA's

What I do - Teaching

- Undergraduate
  - NUEN 301 – Reactor Theory (Fall 2011)
    - 2 of 3 sections this term (56 out of 84 students)
  - NUEN 304 – Reactor Analysis (Spring 2010/2011)
    - ~50 students each term
- Graduate
  - I've developed an uncertainty quantification course.
  - Originally taught in Fall 2009 in the Statistics dept.
  - Scheduled to be taught this Spring in NUEN.

UQ Course Topics

- Verification/Review of numerical approximations (3 lectures)
- Validation Data (2 lectures)
- Uncertainty Quantification
    - Prob/Stats preliminaries (1 lecture)
    - Perturbation / first-order sensitivity
    - Sampling methods (2 lectures)
    - Reliability methods (1 lecture)
    - Polynomial Chaos/Collocation methods (2 lectures)
- Surrogate-based Methods
    - Linear regression (1.5 lectures)
    - Bayesian statistics (1 lectures)
    - Markov Chain Monte Carlo sampling (1 lecture)
    - Gaussian Process Regression (1.5 lectures)
    - MARS (1.5 lectures)
    - Applications of surrogates (1.5 lectures)
- Calibration and Prediction
    - Calibration methods (2 lectures)
    - Predictive models (2 lectures)

What is Predictive Simulation?

Computation is here to stay.

- Whether you call it simulation, scientific computing, computational science and engineering
  - It will be an important part of the scientific process in the future.
- We can't measure everything and theory can only go so far
  - In a vary narrow view, computational science tries to connect these dots.
    - This has been known for years in neutronics analysis: one can only measure the scalar flux at so many points in the reactor and analytic diffusion theory is severely limited.
- The uses of computation have evolved as computational horsepower has increased.
- Initially, computation was just a way to get solutions to analytically intractable equations.
- Later, discoveries were (and still are being) made using computation.
- Eventually, computers were used to guide the design of systems
  - Relying on prototypes and experiments to tune the codes.
- Today, we seek to use computation to predict the behavior of a system that
  - Can't tested by a full-scale experiment (due to safety, cost, or politics)

The Rise of Computer Simulation

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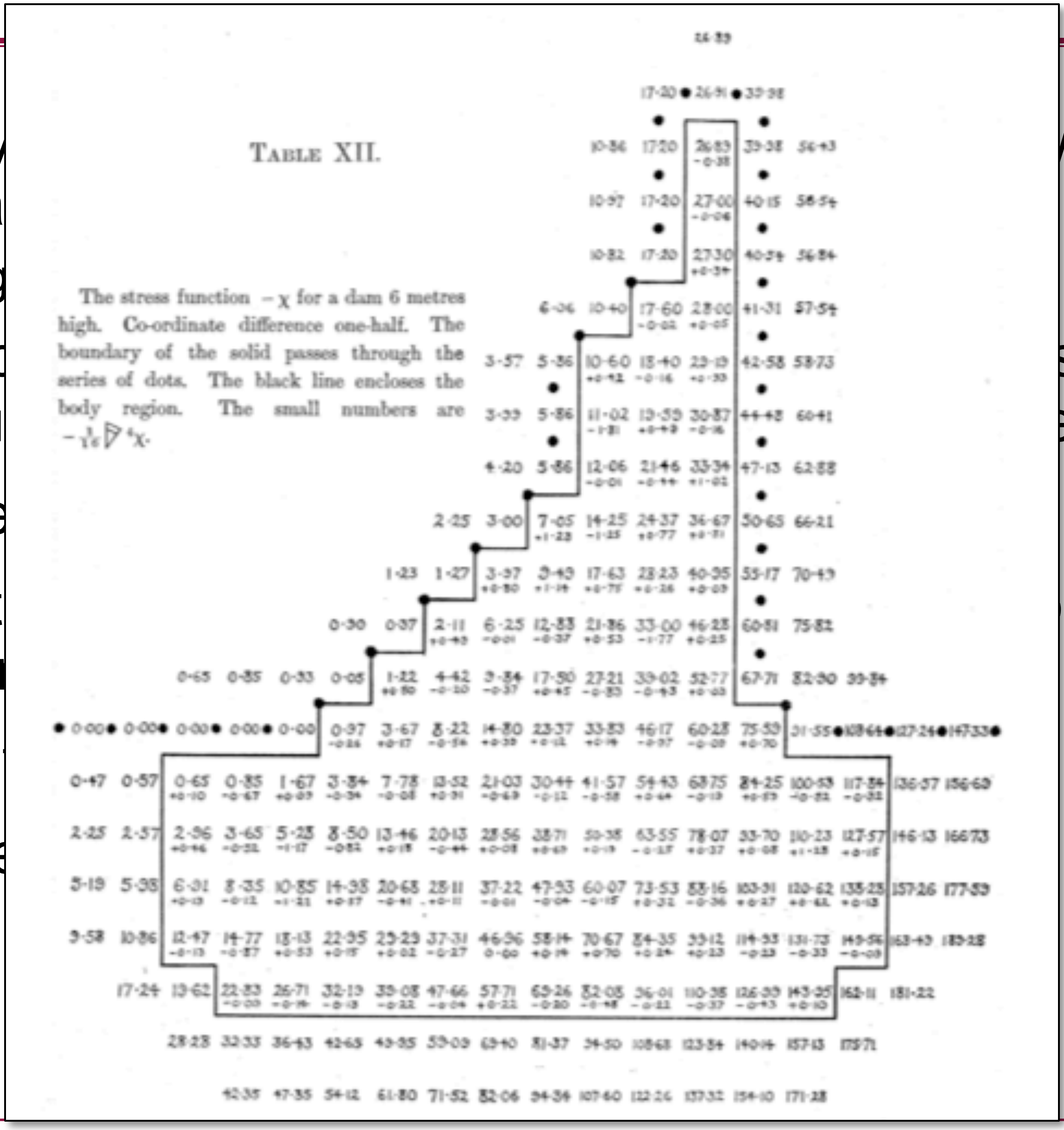
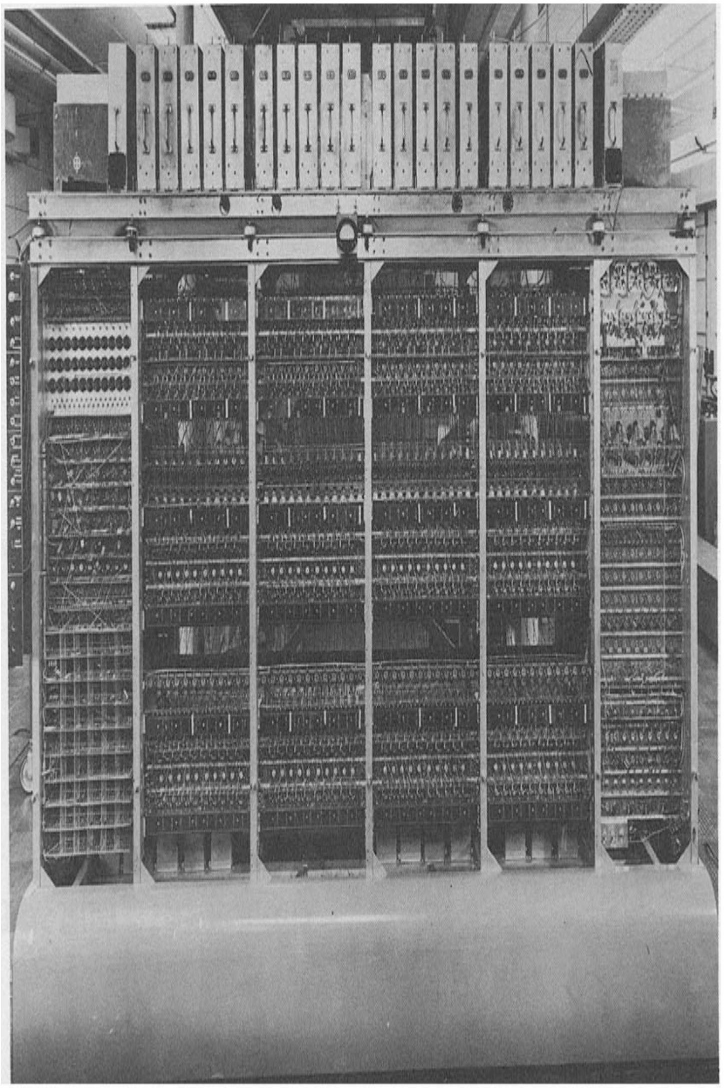


TABLE XII.

The stress function $-\chi$ for a dam 6 metres high. Co-ordinate difference one-half. The boundary of the solid passes through the series of dots. The black line encloses the body region. The small numbers are $-\frac{1}{16}\nabla^4\chi$.

Fermi-Pasta-Ulam Experiment

- Discovery through computation.
- Simulated a series of masses connected by linear and nonlinear springs.
- The masses slide w/o friction along a table.
- Showed intuition was wrong – nonlinear dynamics is tricky.
- Used MANIAC computer at Los Alamos National Lab.
- I couldn't find how long the simulations took.
- MANIAC: ~5000 FLOPS
- PlayStation 3: 218 GFLOPS

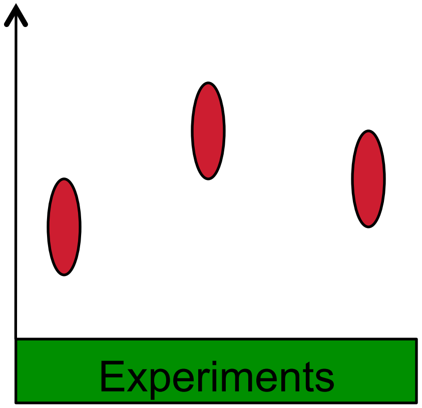


Moving From Discovery to Prediction

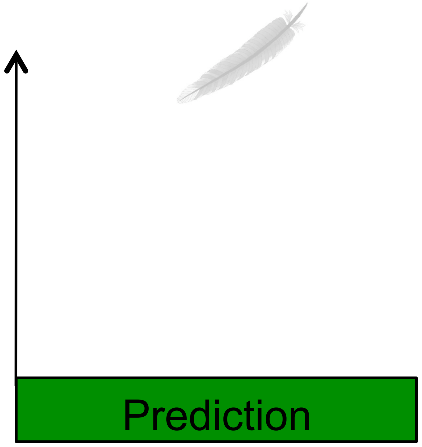
- The emergence of computation as a field has lead to engineers and scientists to ask the question: If we can…
    - Minimize and understand numerical error in our computations, (verify that our codes work)
    - Build confidence in our models using, for example, small-scale experiments (validate our models for particular situations)
    - Understand and measure the effects of uncertain parameters in our simulation (quantify the uncertainty (UQ) in our calculations)…
- We can predict, with quantified and qualified uncertainties, the behavior of a system under conditions inaccessible to experiment.
- We can attempt to answer this question today because of the maturation of the fields of
    - Numerical analysis and computer science
    - Computational physics
    - Statistics

Predictive Simulation needs humans.

- Even if I develop the greatest UQ methods and software,
  - I cannot use them on any problem and get results that are predictive or useful.
- We need domain scientists (experts) to answer questions such as
  - Is the system I am predicting “nearby” systems that I have experimental data?
  - Are we near a physics cliff?
    - A different regime where we need new “physics” to describe the system
  - What are reasonable ranges for the uncertain parameters?
- What if a I drop my pen from shoulder height?
  - Use that data to “validate” the model



$$Time = \sqrt{\frac{2h}{g}}$$



Predictive Science is a Growing Research Area

- All aspects of computational science need further research, for example in
  - Verification: How can we demonstrate that large, multiphysics codes are giving the “right” answers
  - Validation and Data Assimilation: How can we draw conclusions for small-scale or single physics simulations to understand model error
  - Uncertainty Quantification: Given all the uncertainties in system how can we identify the important uncertainties and assess their impact
- Other important of open questions (“Science Based Nuclear Energy Systems Enabled by Advanced Modeling and Simulation at the Extreme Scale,” DOE workshop)
  - Coupling predictive simulations: dynamic PRA
  - Quantify probabilities of rare outcomes
  - Quantify uncertainties after extrapolations
- Many large projects
  - Predictive Science Academic Alliance Program– 5 x $17M centers (DOE/NNSA)
  - Consortium for Advanced Simulation of Light Water Reactors (CASL) - $25M year collaboration for simulation of nuclear systems
- Important in all projects with a computational aspect

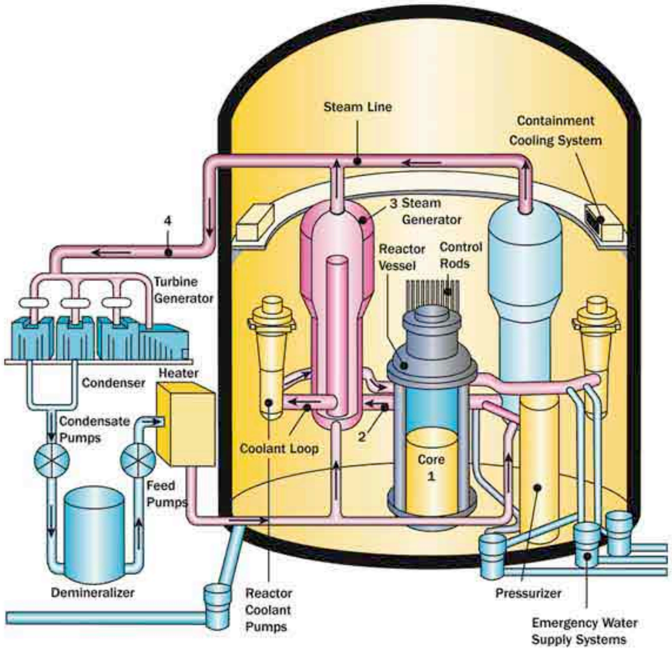
Sensitivity Analysis and Uncertainty Quantification for

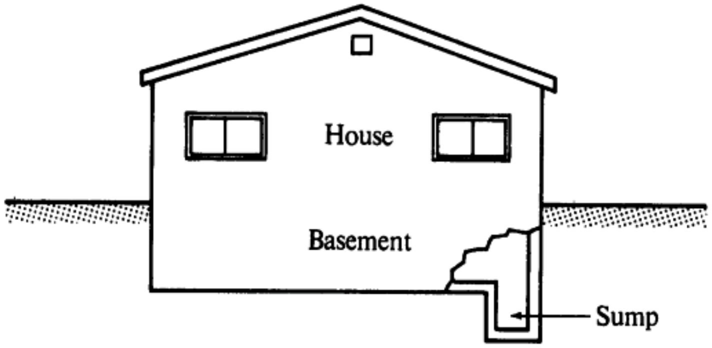
Loss of Coolant Accidents (LOCA)

Emergency Core Cooling in a LOCA

- Consider the situation in reactor where a pipe in the primary loop breaks and leaks coolant.
- In order to keep the reactor core from melting (bad), the water that leaked will need to be re-circulated through the core
  - After backup sources of water are depleted.
- This is accomplished through sumps in at the bottom of containment
  - Water is pumped from the sump back into the core

Typical Pressurized-Water Reactor





How might the pumps fail?

- The pumps that recirculate water to the core need to be reliable
  - Redundant pumps are installed to deal with this.
- A real risk is the debris clogging the pumps, therefore screens are installed to keep debris out of the pump.
- Of course, if the screens get clogged then the pump will lose its suction ability
  - Coolant won't flow to the core, and core damage will result.
- The debris can come from several sources
  - Insulation on the pipes
  - Concrete dust
  - "Latent debris"
- The size of the break will influence the about of debris.

An event in Sweden demonstrated that clogging could be a problem

- The Barseback event in 1992 had sump screens clog in a BWR.
- While the reactor was coming back from a shutdown, a relief valve mistakenly opened.
- The containment vessel spray systems pumps clogged 1 hour into the event.
  - Clogging due to mineral wool debris (220 pounds)
  - The safety analysis for the plant said this wouldn’t happen for 10 hours
  - The operators were able to back flush the pumps and clear the debris.
- The upshot is that the amount of debris produced was grossly underestimated in the analysis.
- As a result of this incident the NRC investigated clogging at PWRs and BWRs
  - For PWRs they created Generic Safety Issue 191 (GSI-191)
  - GSI-191 has been open for almost 15 years.
- Interestingly, in 1975 there was a “War of the Worlds”-type radio broadcast in Sweden about a disaster at the Barseback plant.

Debris Generation and Screen Clogging

- When a pipe bursts a jet of water and steam, and perhaps a shock wave, can be generated
  - This will remove and disintegrate insulation around the break location.
- Certain types of insulation are very good at clogging the sump screens.
- The jet can hit other pipes or material and create other debris.
- All of this depends on the size of the break and the location.
- There has been much experiment and modeling regarding jet formation and debris generation/transport to the screens.

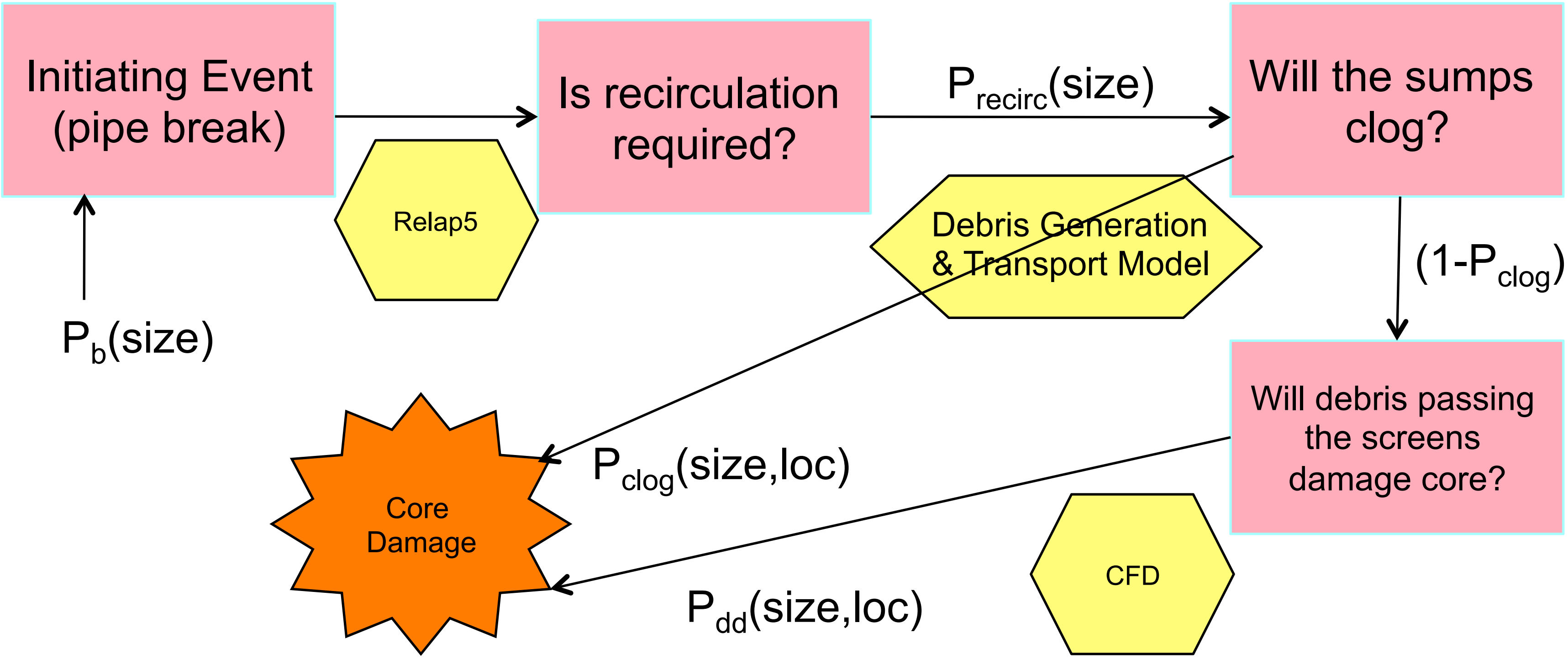
Pictures from insulation debris clogging experiments (NUREG/CR-6762, Vol. 1)

Can we replace the insulation with something that won't clog the sump screen?

- Yes, there are insulations that are less susceptible to this problem
- Changing insulation is not a slam dunk though.
- Cost is high: $40 million
  - That money could go to other safety projects
- Exposure to workers is in the several hundred rem range.
  - Trading a potential risk for a guaranteed hazard.
- These reasons have lead to a risk informed (PRA) approach to this problem
  - Is there quantifiable reduction in core damage frequency (CDF, aka meltdown risk) by changing the insulation?
  - This is the topic of collaboration between STP, TAMU, tu, LANL, and others.

Computation of Core Damage

- At the end of the day we want to know how the CDF is affected by changing the insulation.
  - If this effect is small, then replacing the insulation does not credibly affect safety.
- There are several questions we are trying to answer using computation that will inform the PRA.



Initiating Event (pipe break)

Relap5

Is recirculation required?

$P_{recirc}(size)$

Will the sumps clog?

Debris Generation & Transport Model

$(1-P_{clog})$

$P_b(size)$

Will debris passing the screens damage core?

Core Damage

$P_{clog}(size,loc)$

CFD

$P_{dd}(size,loc)$

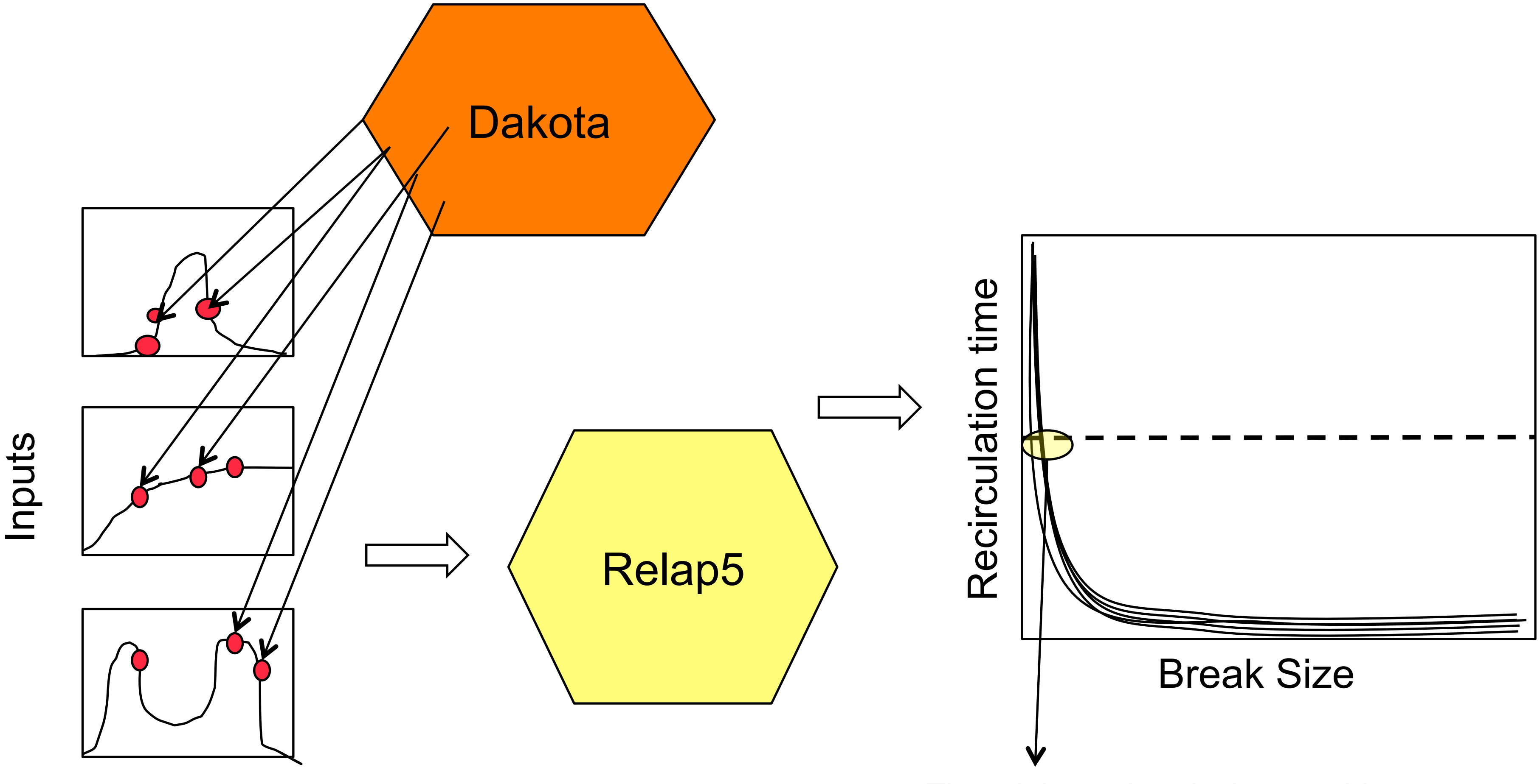
Uncertainties in the Problem

- There are two types of uncertainty in this problem.
- One types is inherent randomness (aleatory)
  - Physical variability in the accident initiation
    - Where is the break? How large is it?
  - Uncertainties about the state of the system
    - Exact operating power, water temperature, etc.
- The other type is due to the fact that we approximate the physics in our calculations (epistemic)
  - The thermal hydraulics models are approximate and they have tuning parameters to account for missing physics.
  - There are constants of nature that we don’t know precisely.
- We must account for both types of uncertainty in predicting the behavior of the system.

Propagating Uncertainty

- In many respects, this is a vanilla UQ problem:
  - Propagate uncertainties through a computer code to find the distribution of outputs.
- For this particular project we are using DAKOTA, a code from Sandia National Labs.
- DAKOTA can be taught to edit input files for RELAP5 to vary uncertain parameters and then aggregate the output into a distribution.
- Also, because RELAP5 does not take a long time to run, we can propagate uncertainties using a Monte Carlo approach
  - Sample from the distributions of the input, and run the code to get a sample from the output.

Propagating Uncertainty



The minimum break size requiring recirculation is in this range.

We need more than the minimum break size

- We also need to give the LANL debris generation and transport model the conditions (flow rate, temperature, etc.) for the jet at the break.
  - Including uncertainties.
- Then the hard part will be downstream effects.
- The material passing the sump screens will be very uncertain
  - Particle sizes, composition etc.
  - As well as where it ends up.
- We will model some of the effects with computational fluid dynamics codes to see if, for example, a coolant channel gets blocked.
- The CFD codes won't be as fast as RELAP5, so Monte Carlo won't necessarily work well.
- The results from CFD will inform RELAP5 simulations of system response.

The end result

- At the end of the day all of these calculations will be rolled up into a PRA calculation
  - To see what the CDF due to sump failure is with both types of insulation.
- This will be the first such analysis to incorporate uncertainties in the thermal hydraulics modeling into a PRA calculation.
- The conclusions reached, positive or negative, will affect many PWRs in the US.