# RELAP5-3D Statistics Based Uncertainty Analysis

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# Outline

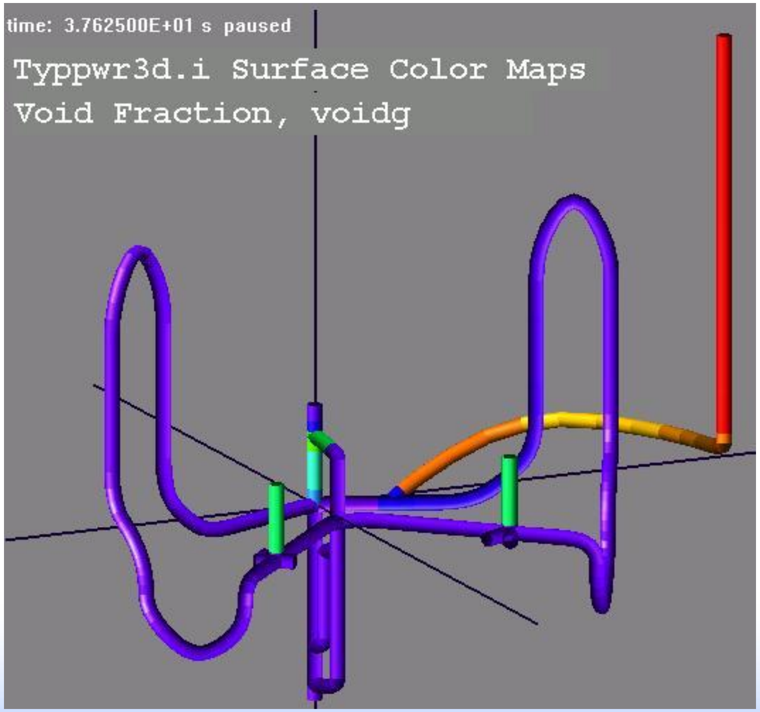
- Project Purpose and Key Phenomena
- Uncertainty Analysis and Ranking Methods
- Methodology
- AP600 and LOFT Studies
- Conclusions

# Project Purpose

- The purpose of this project was to improve the modeling capabilities of the RELAP5-3D nuclear power plant safety-analysis program by developing uncertainty estimates for its calculations.

# Key Phenomena

- We considered SB-LOCA and LB-LOCA scenarios modeled with RELAP5-3D.
  - Need to quantify calculation uncertainty in the key phenomenon (key output parameter).
- Find input parameters that most strongly affect the key output parameter
- Eg. Typical PWR LB-LOCA, find what most strongly affects PCT
- Considered Two Ranking Methods:
  - Phenomena Identification and Ranking Table (PIRT)
  - Statistical Methods



# *Phenomena Identification and Ranking Table*

- PIRT process is a structured and facilitated expert elicitation process wherein experts rank various phenomena pertaining to a particular scenario
  - PIRTs are typically combined with some simulation/ modeling in addition to expert elicitation.
- The phenomena are usually classified as follows:
  - 3 for High
  - 2 for Medium
  - 1 for Low

# Statistical Methods of Ranking

- Methods considered utilize statistical correlation coefficients.
  - Correlation coefficients measure the strength of the relationship between variables.
- Correlation coefficients provide a ranking of phenomena that most strongly effect a scenario.
  - SAS was utilized to generate them
- We utilized three different correlation coefficients:
  1. **Pearson** Product Moment Correlation Coefficient for two variables (assumes the 2 variables have approximately Normal distributions)
  2. **Spearman**'s Ranking Correlation Coefficient for two variables (non-parametric)
  3. **Kendall**'s Tau for two variables (non-parametric)

# Correlation Coefficients

- Significance of a correlation coefficient relates to its absolute value if the p-value < 0.05
  - If p-value > 0.05, correlation is in doubt
- Comparison of absolute value of correlation coefficient and PIRT level

| LEVEL | Correlation Coefficient | PIRT |
|---|---|---|
| High | 0.70 to 1.00 | 3 |
| Medium | 0.30 to 0.69 | 2 |
| Low | 0.01 to 0.29 | 1 |

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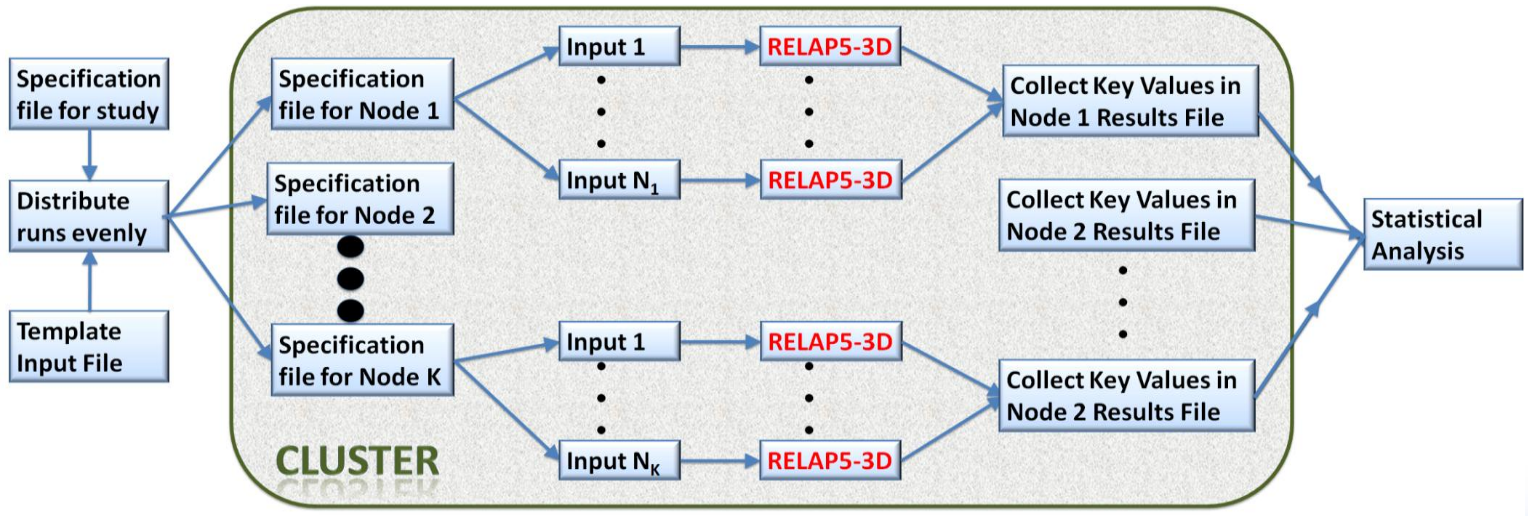
# Goals

1. Utilize SAS to generate Pearson, Spearman, and Kendall rankings for RELAP5-3D calculations
2. Compare to PIRT rankings.
   - Only if P-value < 0.05.
3. Possibly improve PIRT rankings.

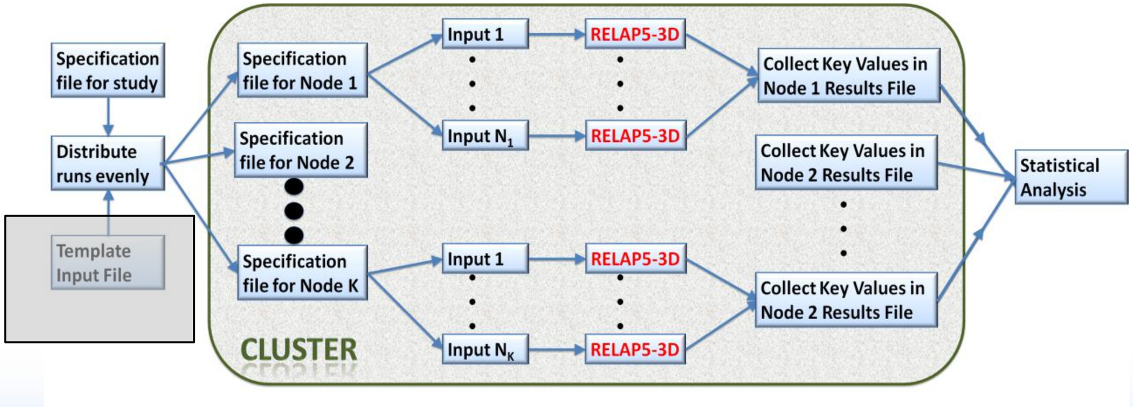
# The Process

1. Identify key input and output
2. Generate input files
3. Run the input files
4. Analyze the results
5. Draw conclusions



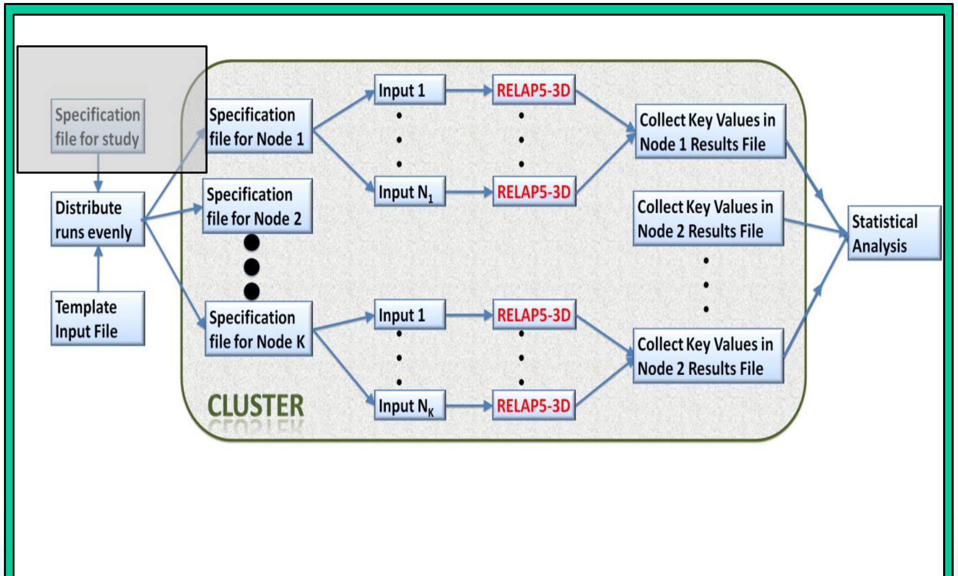
# Marking the Input Deck

1. Identify the key output parameter
   a) E.G. collapsed core level, PCT, etc.
2. Select key input parameters
3. Locate RELAP5-3D input values that correspond to the key input parameters within deck
4. Replace their values with **$VARx**, x = 1, 2, 3, …



# Build Generator Specification (Spec) File

- Generator *SPEC file* specifies all controlling information for the study
  - For each variable: max, min, std deviation, # values, statistical distribution, and group
    - A group of variables varies together. E.G. discharge coef




Indicates that this is a Generator Spec File

# of Node Spec Files to be Generated

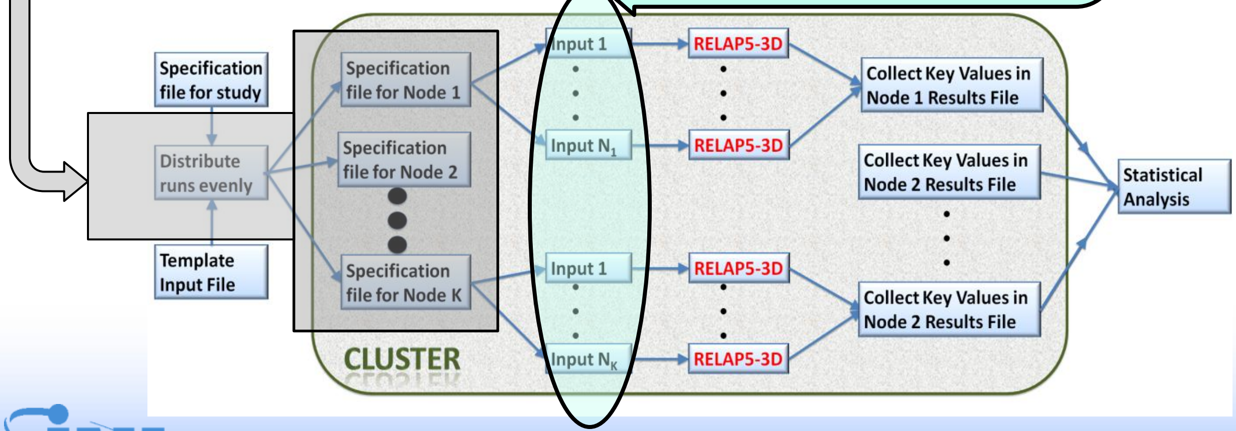
generate

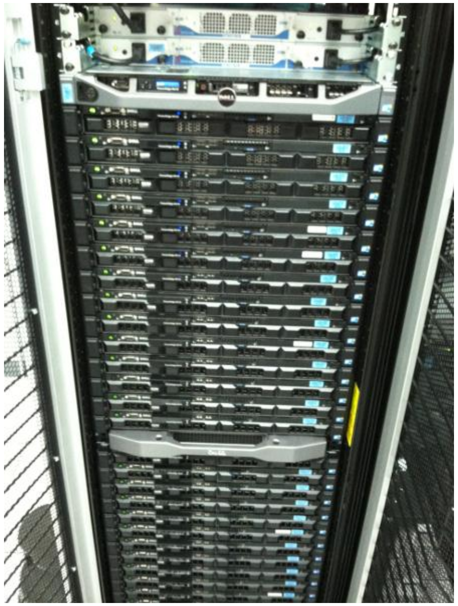
apnv4 14 9 6 14

| | | | | | | |
|---|---|---|---|---|---|---|
| VAR1 | 0.95 | 1.05 | 0.1 | 3 | uniform | 1 |
| VAR2 | 0.000005 | 0.0005 | 0.000015 | 3 | uniform | 2 |
| VAR3 | 1.08 | 3.24 | 1.18143 | 3 | uniform | 3 |
| VAR4 | 1.091 | 3.273 | 0.004028 | 3 | uniform | 4 |
| VAR5 | 0.23056 | 0.34584 | 0.01632 | 3 | uniform | 5 |
| VAR6 | 0.08726 | 0.104712 | 0.02616 | 1 | uniform | 6 |
| VAR7 | 0.22788 | 0.27852 | 0.000015 | 3 | uniform | 7 |
| VAR8 | 0.0 | 1.0 | 0.05609 | 3 | uniform | 8 |
| VAR9 | 0.772 | 0.9264 | 0.01632 | 1 | uniform | 9 |
| VAR10 | 0.641 | 0.7692 | 0.008726 | 1 | uniform | 10 |
| VAR11 | 1.0 | 1.3 | 0.000015 | 1 | uniform | 11 |
| VAR12 | 1.0 | 1.3 | 0.05609 | 1 | uniform | 12 |
| VAR13 | 0.00015 | 0.0005 | 0.01632 | 1 | uniform | 13 |
| VAR14 | 0.000005 | 0.00015 | 0.008726 | 1 | uniform | 14 |

# Using a Cluster Supercomputer

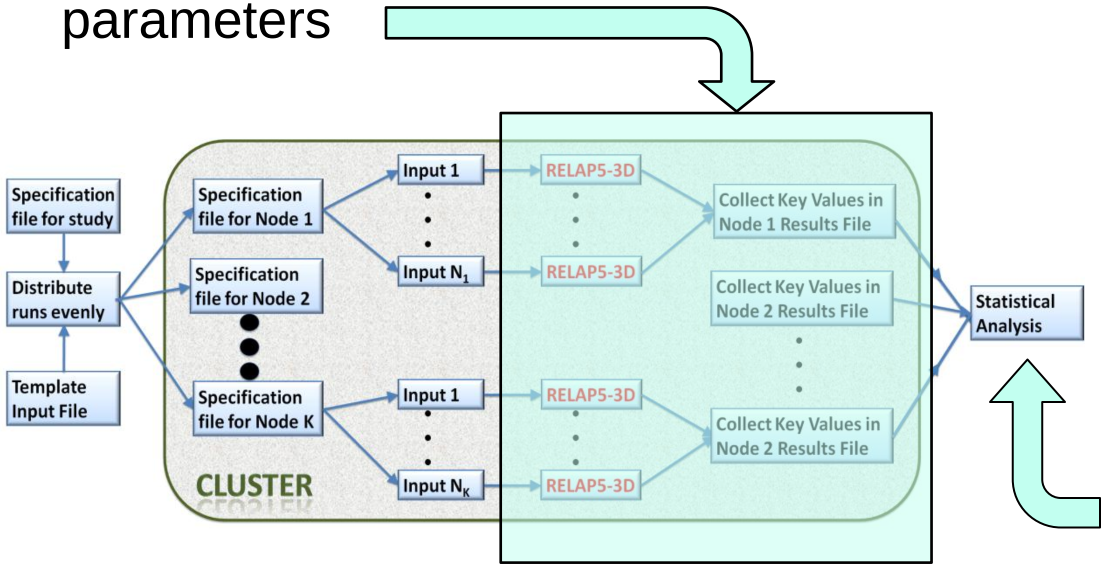
- Our AP600 Small Break Transient takes 5 minutes
  - 6561 runs of Study requires 547 hours = 23 days, on workstation
- Quark cluster has 12 cores per node
  - Same 6561 runs on 9 nodes took 17.5 hours
- Cluster throughput gets clogged transferring files to nodes.
- Distribute "partial" specification files, then build input files on the node to reduce runtime



# Collecting and Analyzing Run Info

- Runs RELAP5-3D on each input deck
- Collects key output parameter value from each output file
- Adds it to *__parameter value file__* on line with corresponding input parameters




- SAS imports the *__Parameter value file__*
- SAS calculates the __Correlation Coefficients__
- The coefficients create a "__ranking__" analysis of PIRT

# 1st Set of Studies: SB-LOCA

- Westinghouse AP600
  - Generation III NPP which utilizes *passive* safety
  - 2 loop 600 MWe **P**ressurized **W**ater **R**eactor
- Using AP600 PIRT, identified 13 variables of interest, 7 ‘highs’, 4 ‘mediums’, and 2 ‘lows’ as well as a key output parameter of collapsed core level.
- Conducted 4 studies (2 inch, 4 inch, 6 inch, & 8 inch Break)

# AP600 Studies: Original PIRT Ranks

| HIGH | MEDIUM | LOW |
|---|---|---|
| flow-resistance in In-containment Refueling Water Storage Tank | Passive Residual Heat Removal | |
| Automatic Depressurization System energy release | Steam Generators heat transfer | |
| flow in accumulator 1 | ADS 1 Flow resistance | PRHR flow-resistance |
| flow in accumulator 2 | ADS 2 Flow resistance | PRHR flow-resistance |
| injection line-Core Makeup Tank (CMT) | | |
| level in CMT | | |
| Core power | | |

# Corr. Rankings with p <0.05

Differences between PIRT & Corr. Rankings shown in color.

– The rest were inconclusive (p > 0.05)

| Study | High ρ | Medium ρ | Low ρ |
|---|---|---|---|
| 2 in | Core Power (PIRT High) | | PRHR-Flow Resistance (PIRT low) |
| 4 in | Core Power (PIRT High) | | |
| 6 in | | Core Power (PIRT High)<br>Level in CMT (PIRT High)<br>PRHR-Flow Resist. (PIRT **LOW**) | Steam Generators-heat transfer (PIRT Medium) |
| 8 in | | Core Power (PIRT High)<br>Level in CMT (PIRT High) | SG heat transfer (PIRT Medium) |

# $2^{nd}$ Set of Studies: LB-LOCA

- LB-LOCA: **L**oss-**O**f-**F**luid-**T**est
  - Experimental Facility at the INL with a 50 MW PWR designed to simulate the response of a commercial PWR during a LOCA.
  - Utilizing a previous study done at the INL, 6 variables of interest were identified in addition to a key output parameter of **P**eak **C**lad **T**emperature
  - Conducted 2 studies:
    1. Each of the 6 variables had 3 values (min, mean/ nominal, max)
    2. Each of the 6 variables had 5 values (min, lower-middle, mean/ nominal, upper-middle, max)

# LOFT Studies

- Our key output parameter was PCT
- Using Wilson & Davis' study:

| Group # | Variable(s) in Group | Phenomena |
|---|---|---|
| 1 | VAR1-VAR24 | Peaking Factor |
| 2 | VAR25 | Fuel Clad Gap Width |
| 3 | VAR26-VAR43 | Fuel Thermal Conductivity |
| 4 | VAR44 | Clad to Coolant Heat Transfer |
| 5 | VAR45-VAR46 | Break Discharge Coefficient |
| 6 | VAR47-VAR51 | Pump Degradation |

# LOFT Studies Created a Ranking

- Correlation coefficients varied slightly between the two studies
  - However, the rankings remained the same.
- Study results (for $p < 0.05$):

| Correlation | Phenomena |
|---|---|
| High | Fuel Clad Gap Width (Group2) |
| Medium | Clad to Coolant Heat Transfer (Group 4) & Peaking Factor (Group 1) |
| Low | Break Discharge Coefficient (Group 5) & Fuel Thermal Conductivity (Group 3) |

# Conclusion

- In AP600 Studies, the break size largely dictated which variables were most important to collapsed core level.
  - An input variable, ranked low in PIRT, had a medium correlation coefficient.
    - Further studies are indicated for that variable.
  - RELAP5-3D input does not perfectly match the key input phenomena, so the correlation results are similarly imperfect.
- In LOFT studies, fuel clad gap width was most strongly correlated with the PCT.
- Correlation methods can be used to identify PIRT rankings that may need further investigation
- Correlation methods can also be used to create initial rankings in the absence of a PIRT.