NARSIS Workshop

Training on Probabilistic Safety Assessment for Nuclear Facilities

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Severe accident assessment with uncertainty and sensitivity analysis

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Severe Accident Assessment

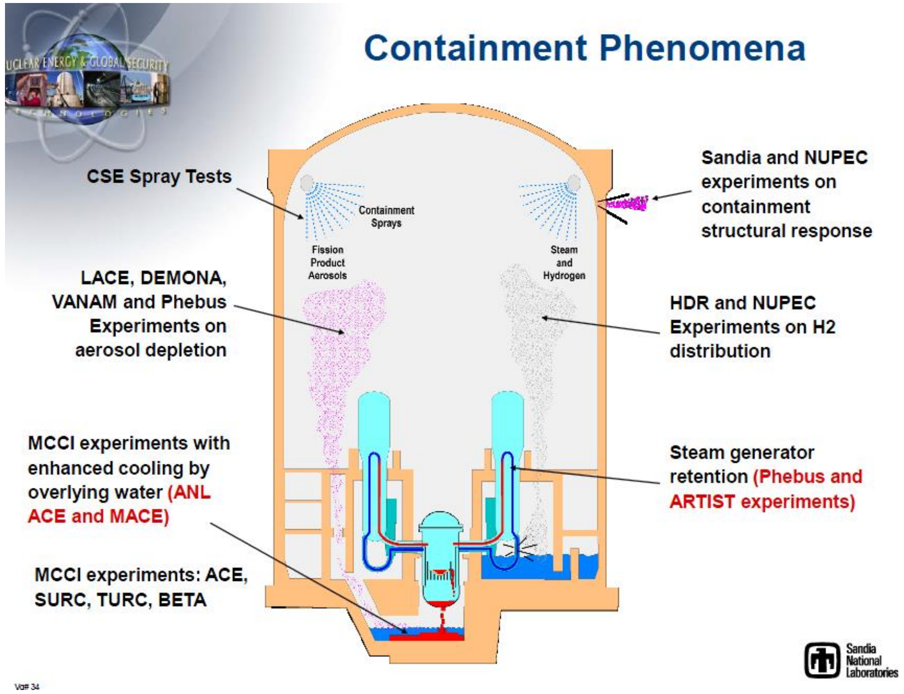
- Prediction of NPP response to severe accident (SA)
- Types of the severe accident tools:
  - Integral codes: MELCOR, MAAP, ASTEC.
  - Specific phenomena codes: ICARE/CATHARE, ATHLET_CD, RELAP/SCDAP, CONTAIN, COCOSYS
  - Specific integral codes sets: SAMPSON, RELAP/SCDAP – CONTAIN – VICTORIA, ATHLET-CD – COCOSYS.
  - CFD are used for some detailed phenomena.
- Level of details
  - Engineering Codes (i.e. MAAP)
  - Semi-Mechanistic Codes (MELCOR, ASTEC)
  - Mechanistic Codes (i.e. RELAP/SCDAPSIM)
  - CFD (i.e. OpenFoam)

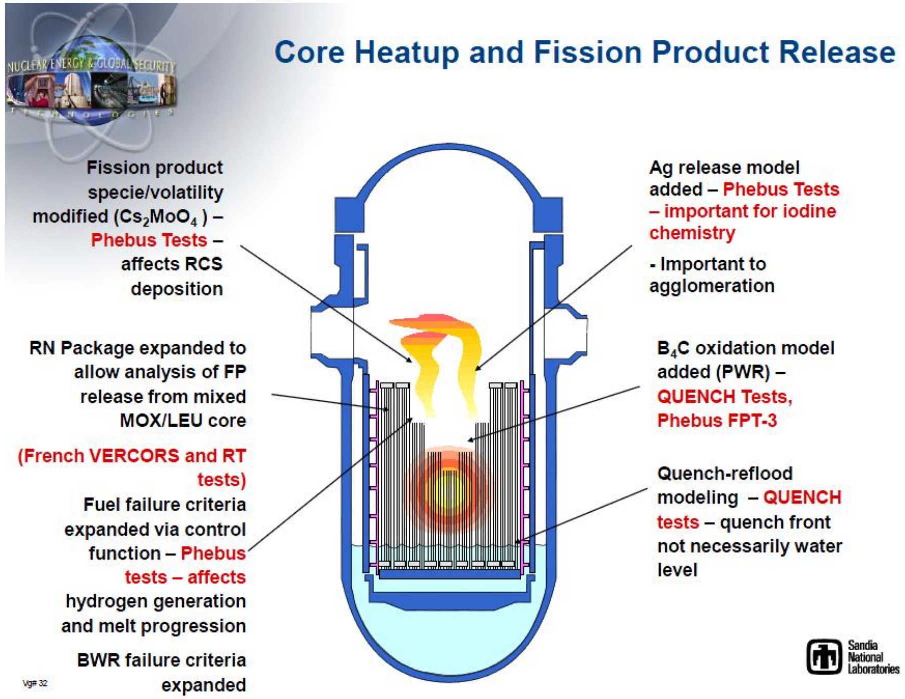
SA Assessment with Integral Codes

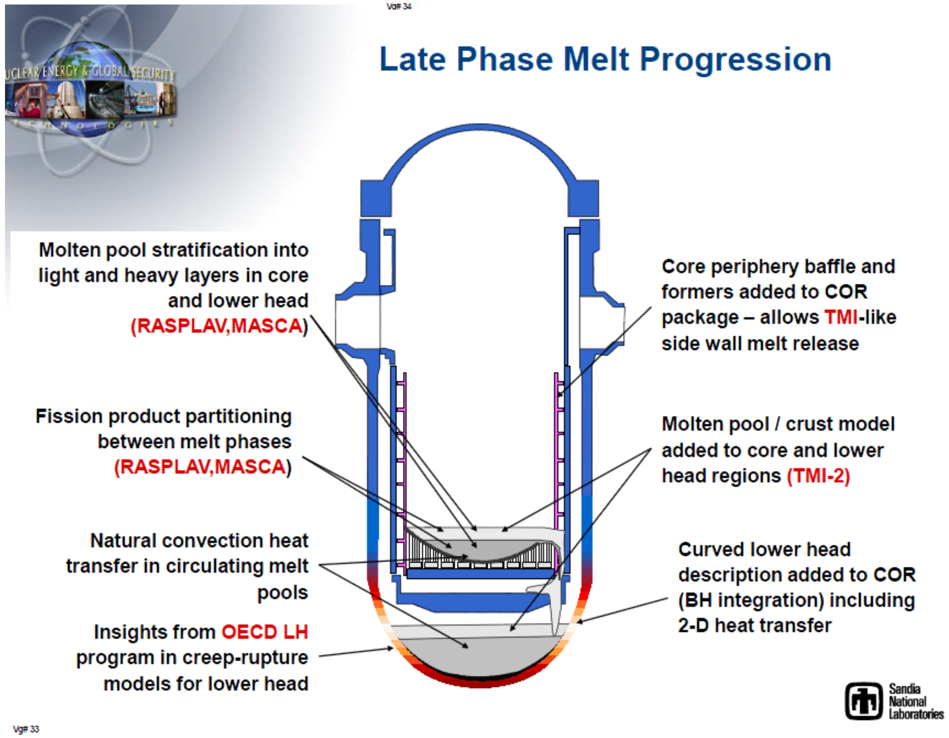
- **Integral codes allow to simulate whole plant**
- **Typical goals:**
  - Accident progression
  - Containment performance
  - Source term estimation
- **Part of PSA Level 2**
- **Input for PSA Level 3**
- **Support of SA management, staff training etc.**
- **The most popular codes:**
  - ASTEC
  - MAAP
  - MELCOR

SA Integral Codes

- Integral codes simulate almost all relevant phenomena
- Large experimental data portfolio
- Codes validated and verified (V&V)
  - MAAP, MELCOR >30 years
  - ASTEC >20 years

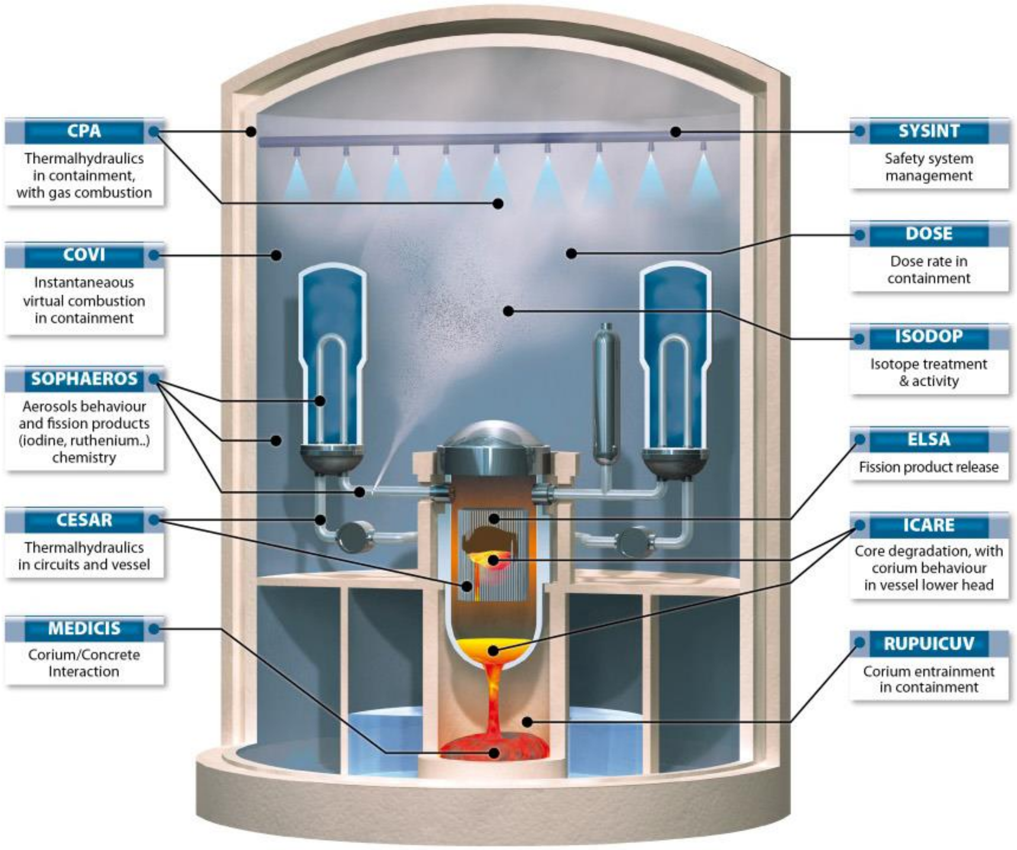




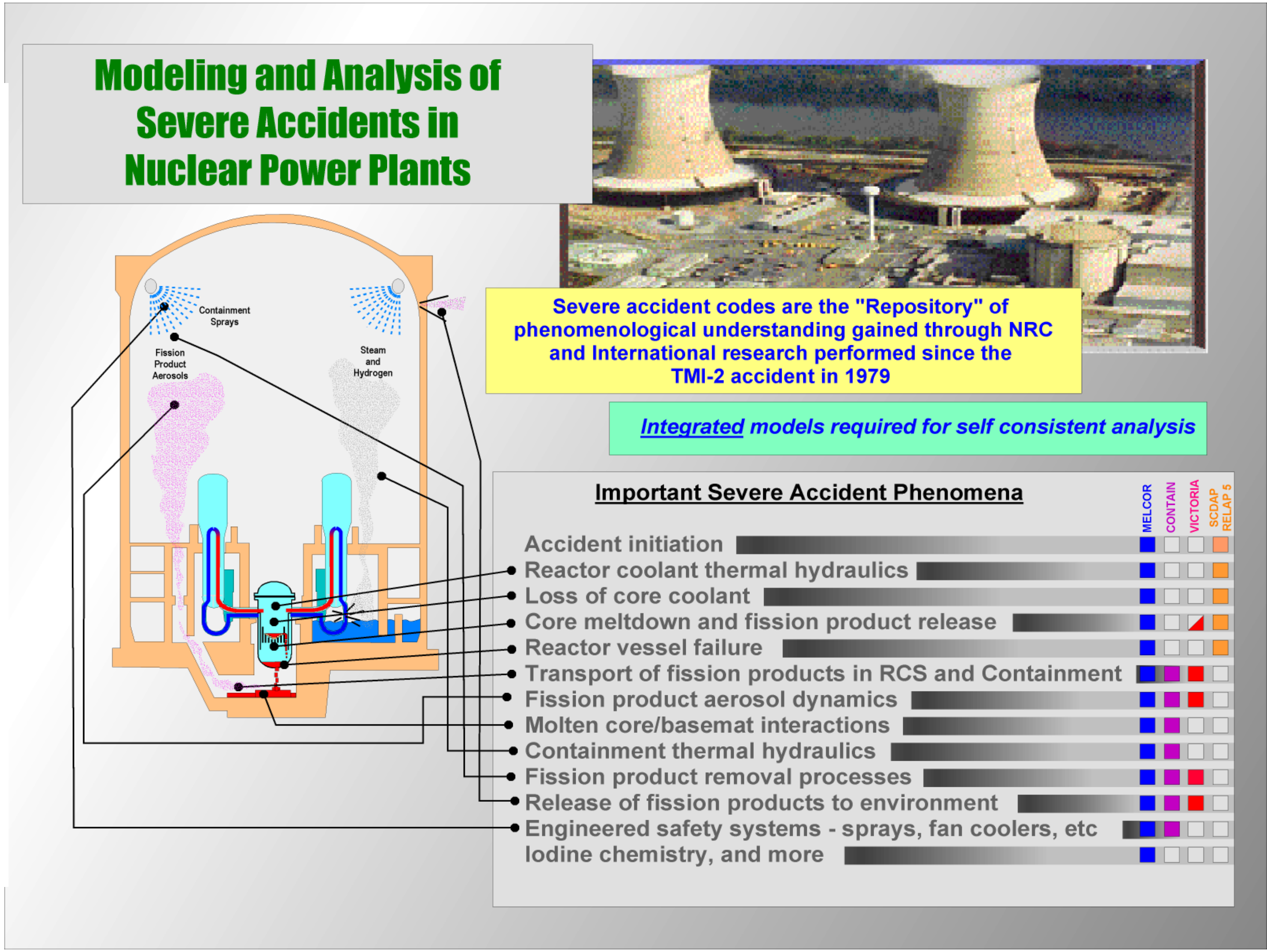


SA Integral Codes

ASTEC

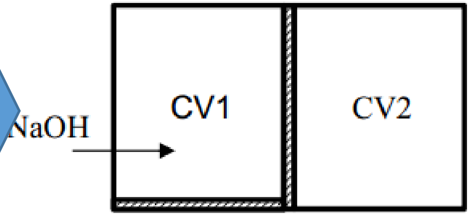


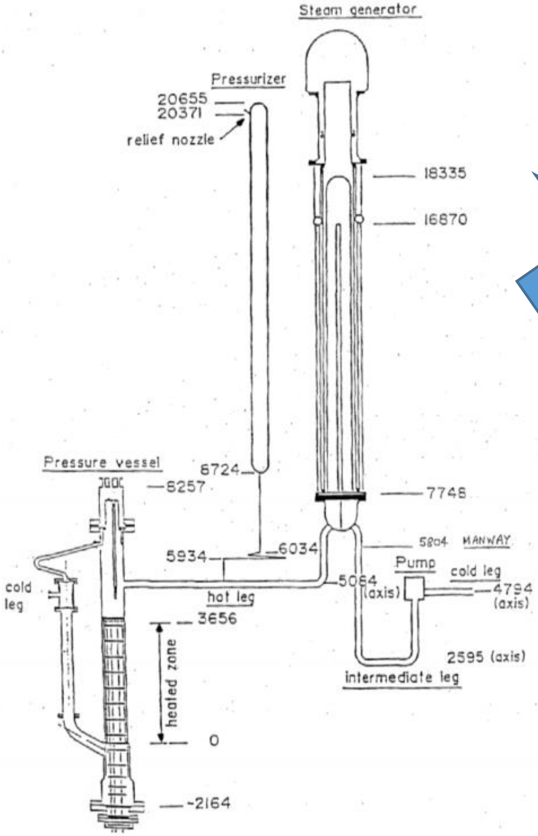
MELCOR

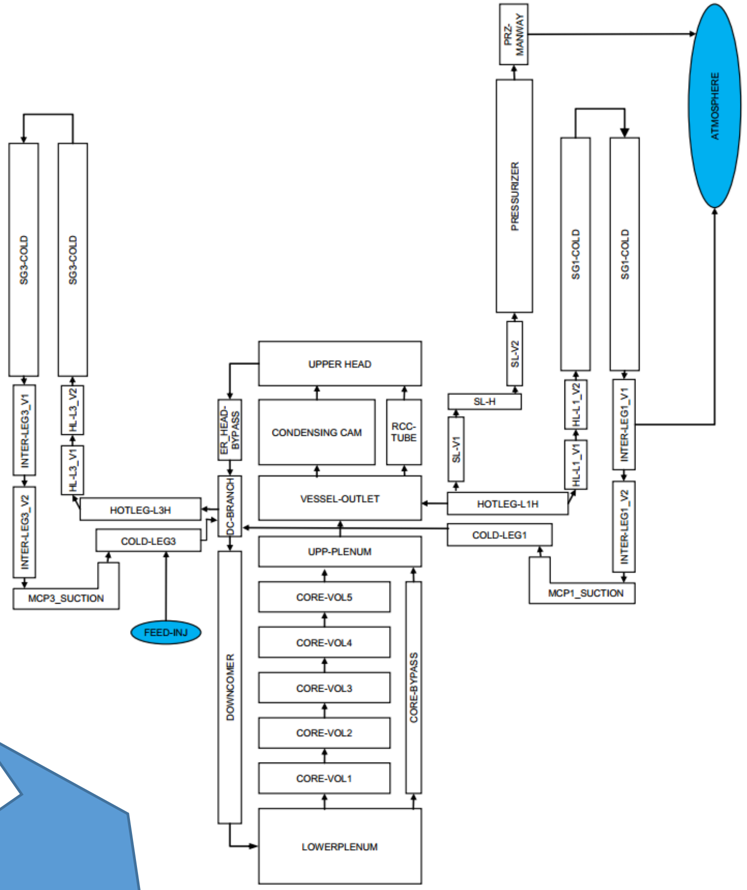


Modelling Experiments

- **Experimental facilities**
  - Separate Effect Test
  - Integral Experiments
- **Usually we start with experiments**
- **Apply gained experience to simulate NPP**

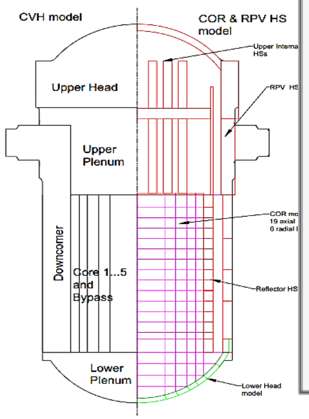


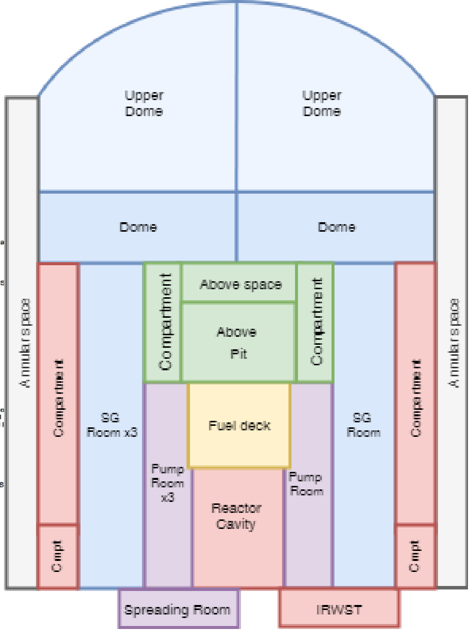


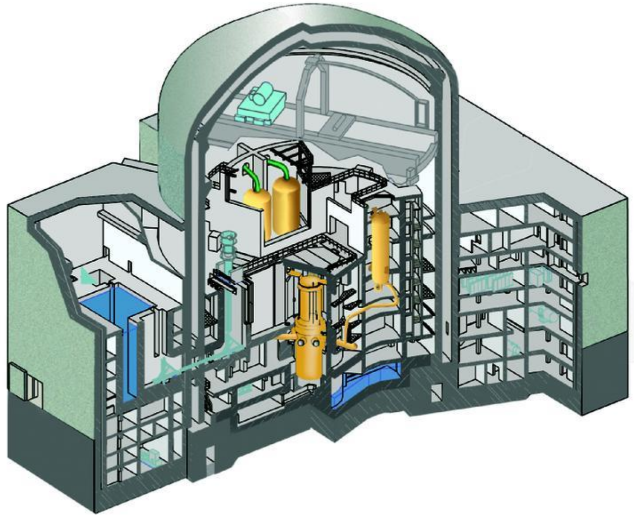


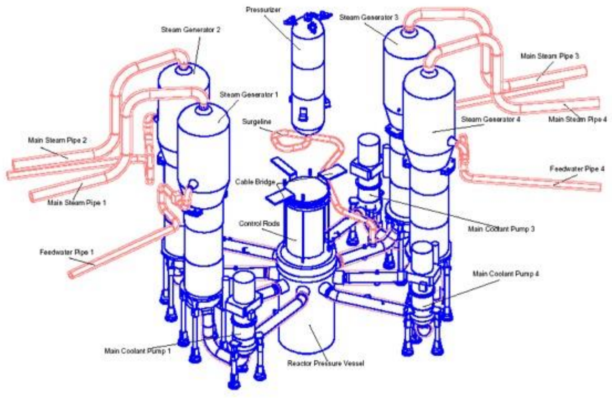
Modelling NPP

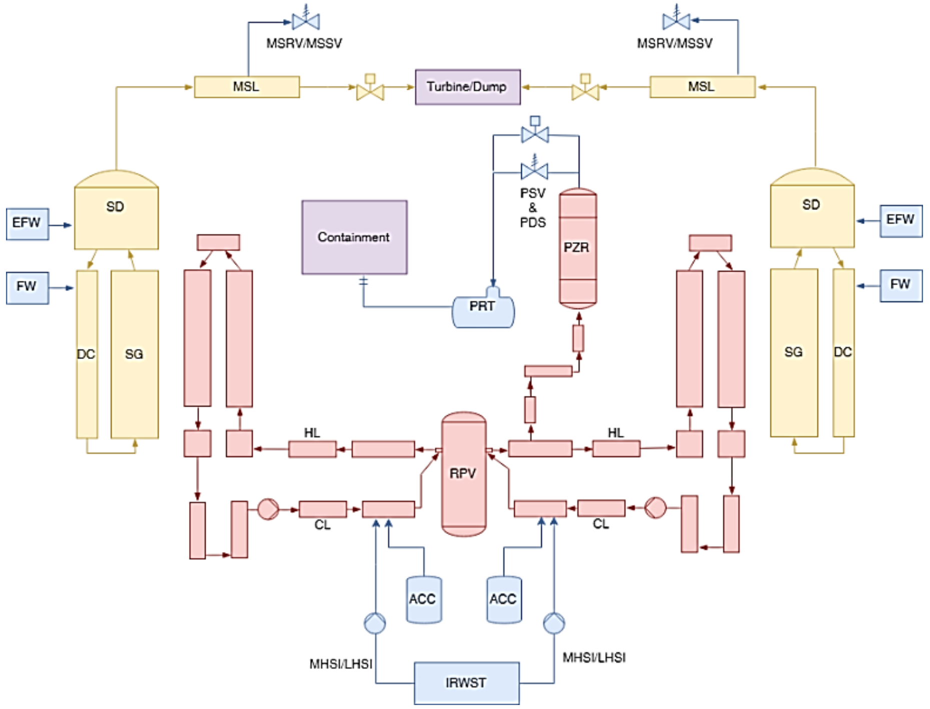
- Plant models
- Successful, experiment simulations does not guarantee successful plant simulations
- Large knowledge and experience is necesarry





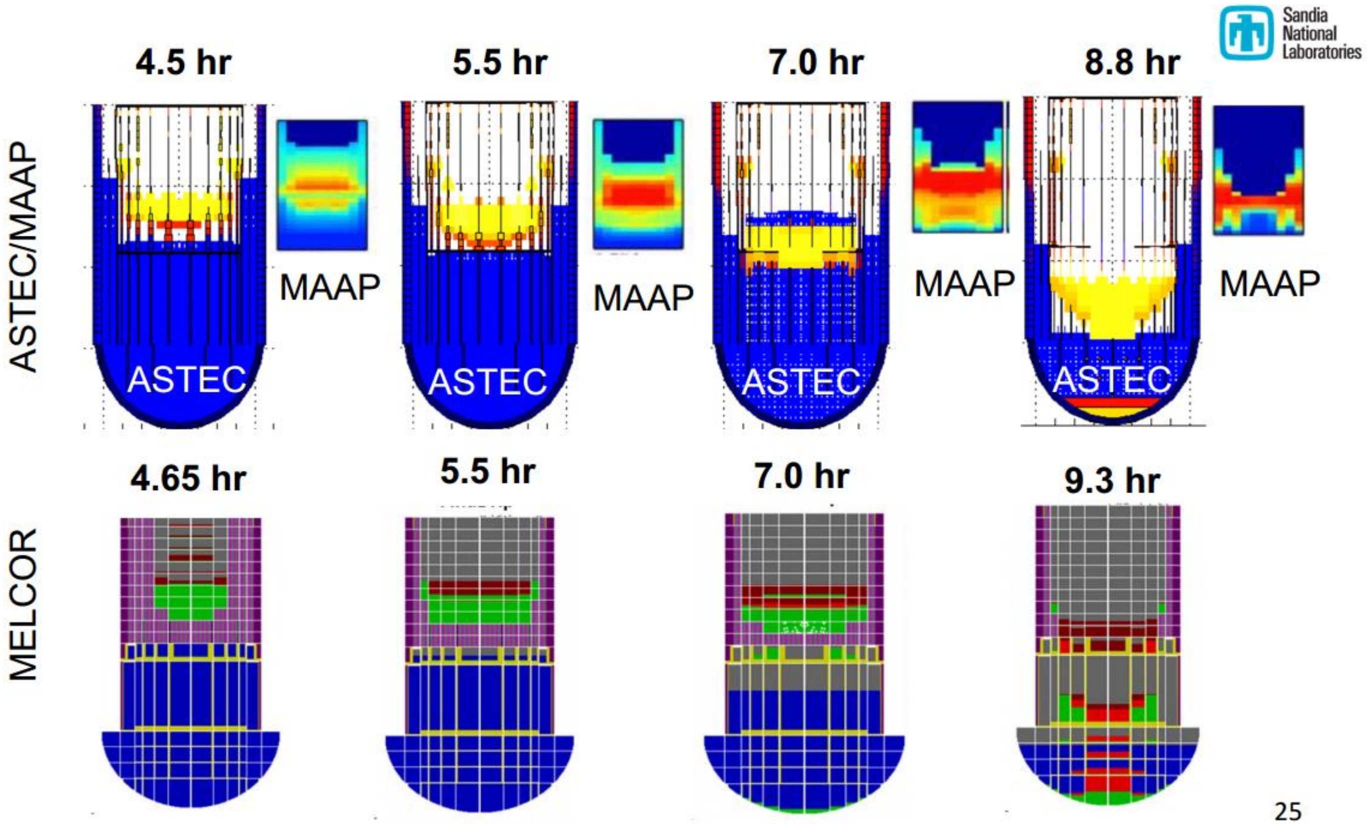


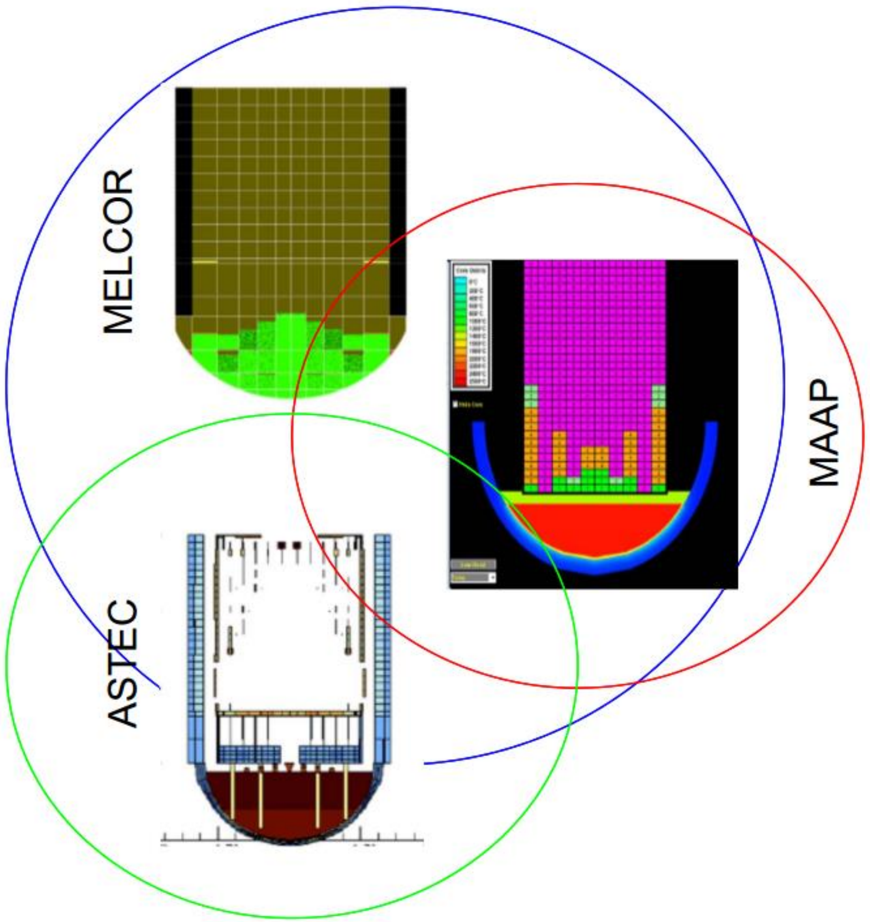




SA Integral Simulations

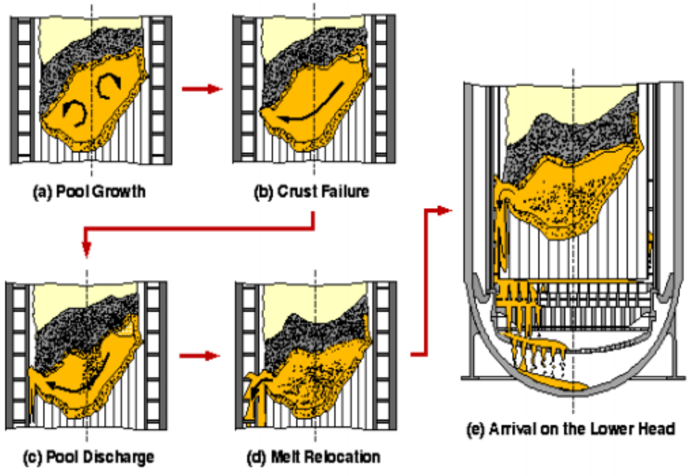
- Different codes can provide different results.
- Different users can obtain different results with the same code (user effect).
- Code cross comparison and benchmarks are improtant.

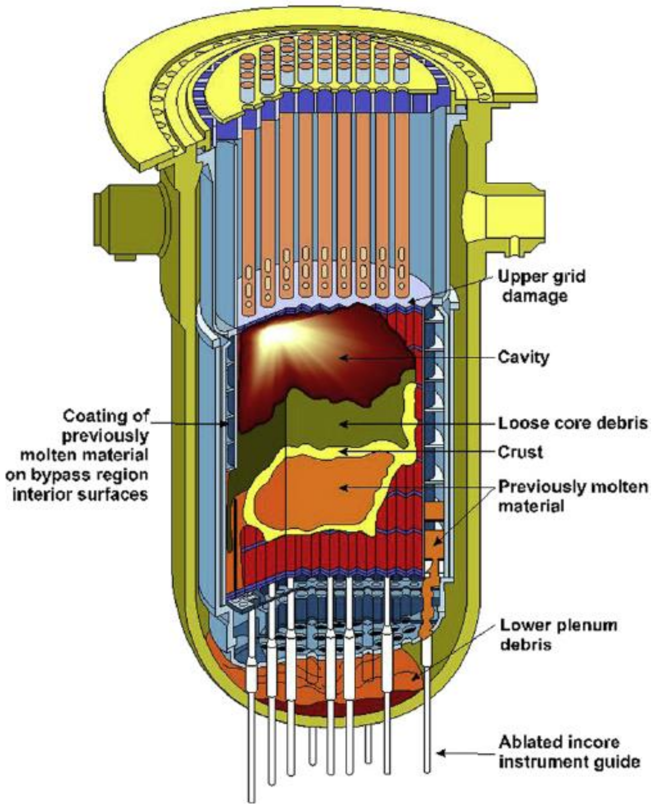




Uncertanities in SA

- NPP is a complex system
- Severe accident phenomenology is also complex
- Uncertanities are unavoidable
- Experimental data uncertanities
- Models uncertanities
- Various factors influence SA assessment
  - Variability; systems, human factors, other
  - Lack of knowledge about details of the phemomena
  - In principle relevant phenomena are recgnized
  - Modelling precission, discretization (nodalziation)
  - Codes, user effects, modeling approach
- Uncertainty qualification is unavoidable





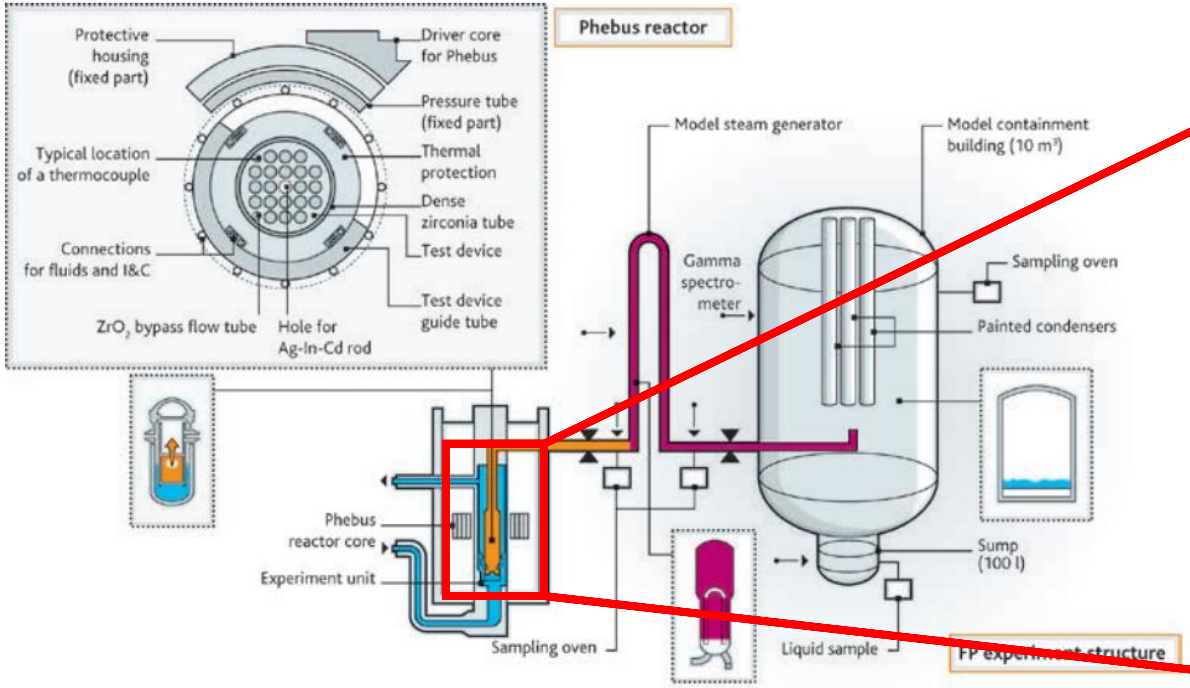
Sensitivity and Uncertanity Analysis (S&UA)

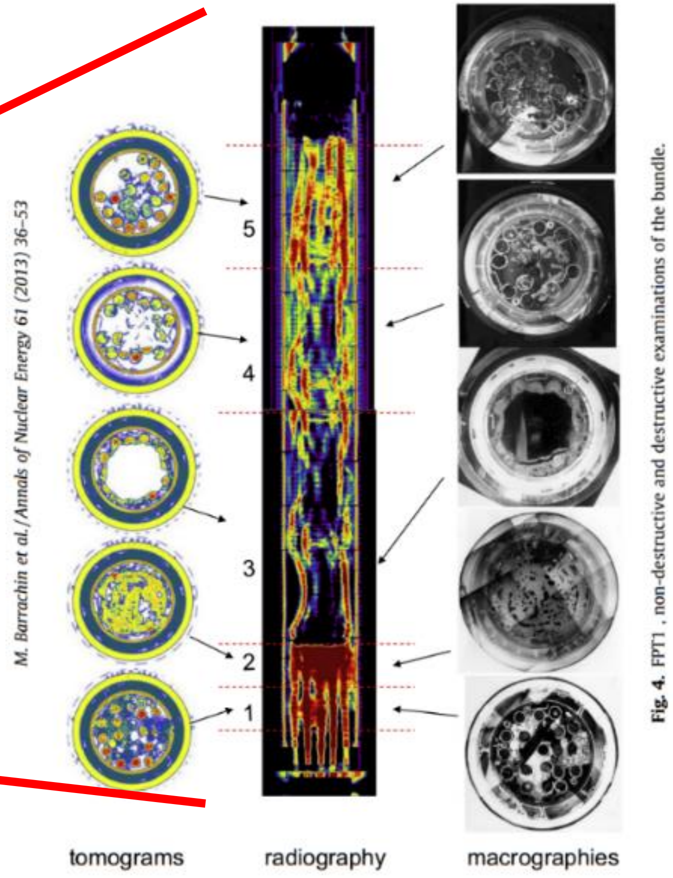
➢ Typical S&UA in NPP

1. Identification of uncertain input variables/models
2. Assigment of uncertanity information (distributions)
3. Determination of the sample size for the statistical significance of the uncertanity measures for the output variables.
4. Sampling.
5. Code execution
6. Post-processing of results.
7. Statistical analysis. Uncertanity and Senstivity quantification.
8. Study of individual cases/outliers.

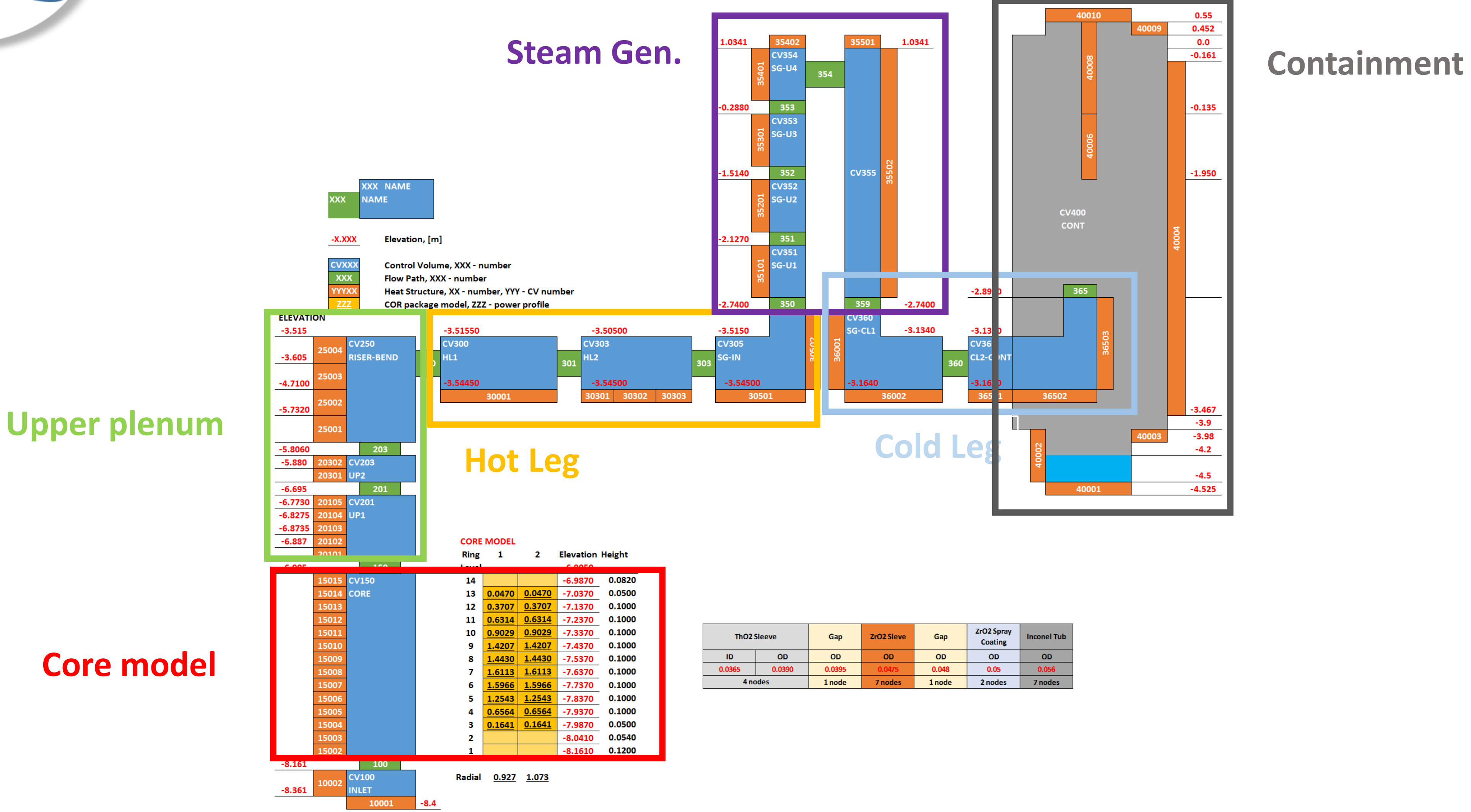
Example – Hydrogen source term in FPT-1

- Example MELCOR application - FPT-1 integral experiment.
- H2 source term in Phebus FPT-1 test.
- Bascially: How much hydrogen was generated during the core degradatinon ?
- Uncertanity and sensitivity analysis.





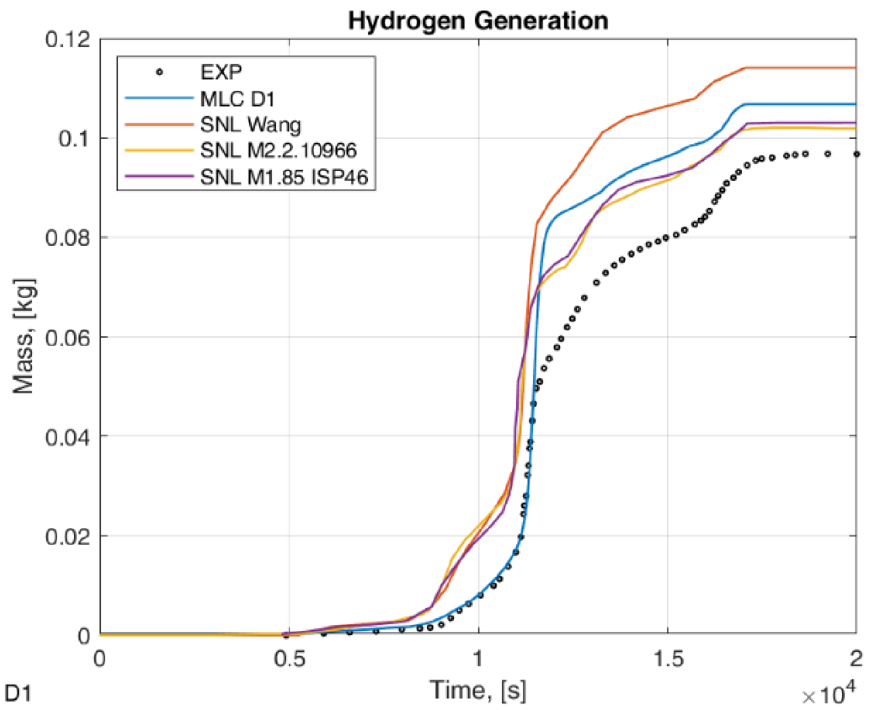
Example - Model Development



ThO2 Sleeve		Gap	ZrO2 Sleve	Gap	ZrO2 Spray Coating	Inconel Tub
ID	OD	OD	OD	OD	OD	OD
0.0365	0.0390	0.0395	0.0475	0.048	0.05	0.056
4 nodes		1 node	7 nodes	1 node	2 nodes	7 nodes

Example – Tests and Simulations

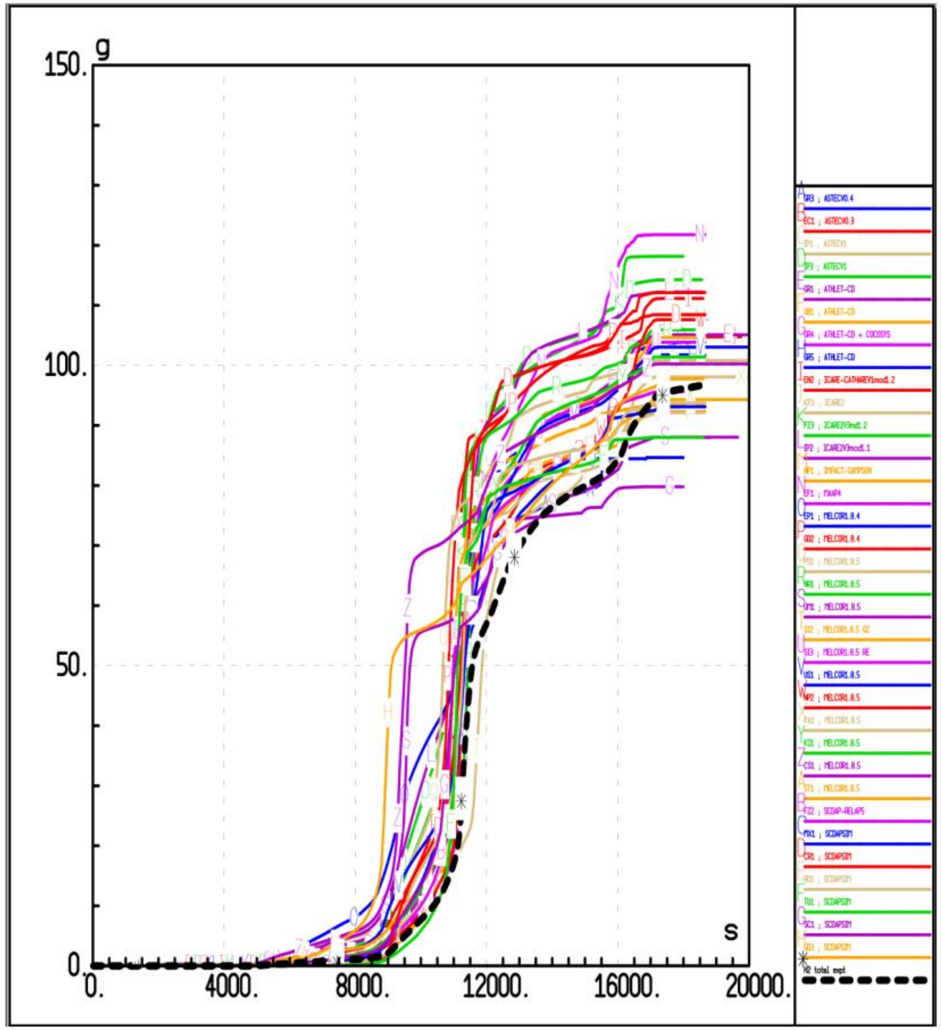
- Use state-of-the art modeling – best estimate calculation
- Comparison with experimental data (if available).
- Comparison with the literature (if possible).
- Comparison with other codes (if possible).



NARSI

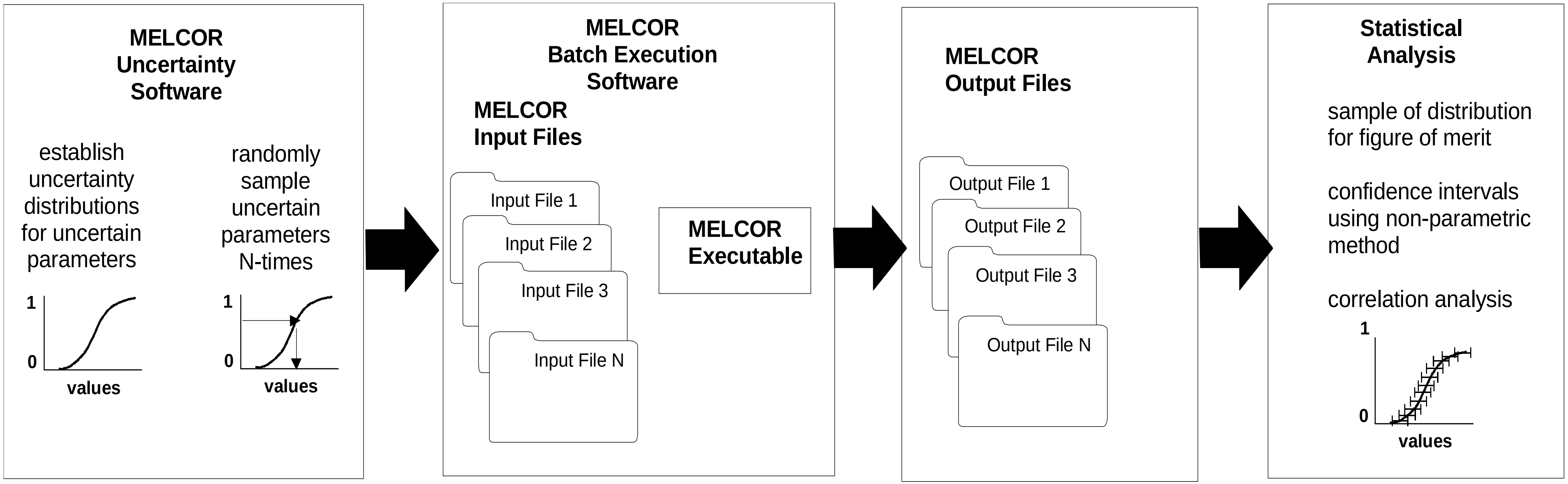
International Standard Problem 46

Report results



Example – S&UA Methodology

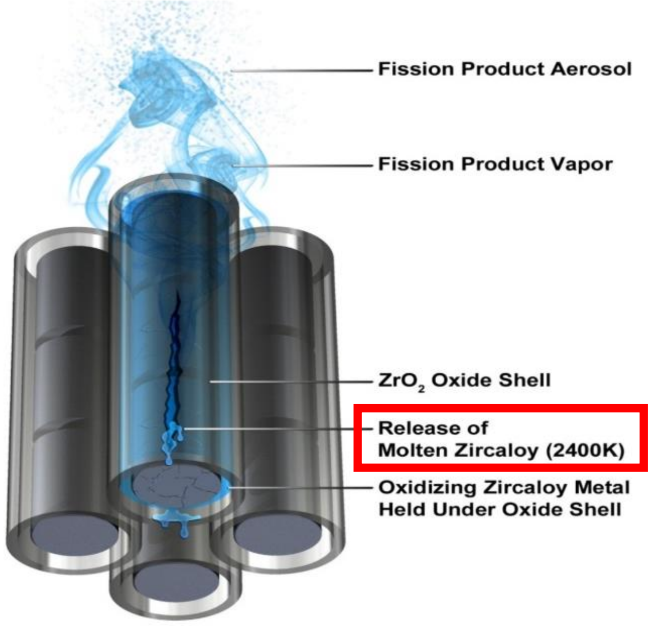
➢ **Senstivity and Uncertanity Methodology (with MELCOR)**

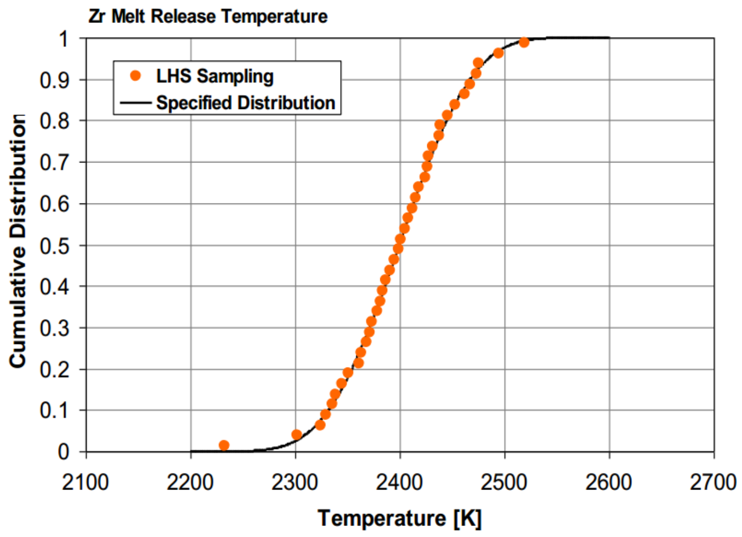


Example - Identification of uncertanities

- Identifty uncertain input variables or models
- Identify probablity distributions
- Example - simple as there is Gantt report Ref. [3].
  - Parameter #1 Zr melt breakout temperaute

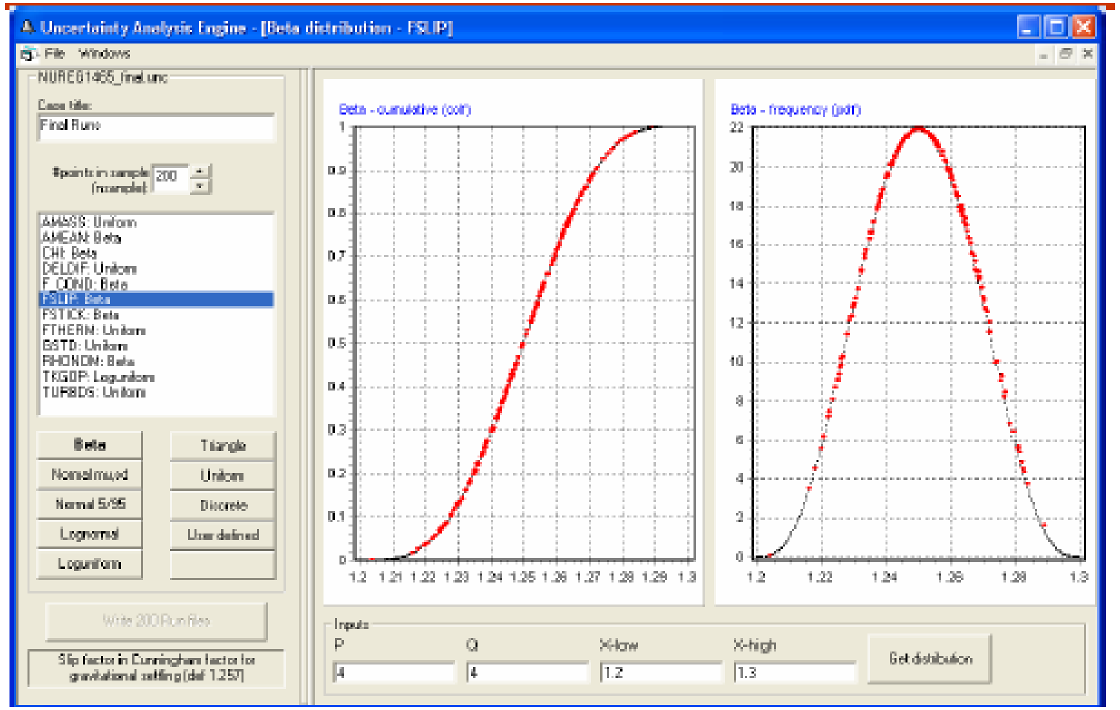
No	Parameter	Probability distribution
0	Oxidation Rate Coefficients	Discrete, Uniform
1	Molten Material Holdup Parameters - Zr Melt Breakout Temperature	Normal
2	Core (Fuel) Component Failure Parameters - Fuel Rod Failure Temperature	Normal
3	Secondary Material Transport Parameters - Secondary UO2 Content	Normal
4	Candling Heat Transfer Coefficient - Zr Freezing	Log-Normal
5	Core-Region Particulate Debris Diameter	Log-Normal
6	Debris porosity	Triangular
7	Radiation Exchange Factor Radial	Normal
8	Radiation Exchange Factor Axial	Normal
9	Molten clad drainage rate	Log-Normal

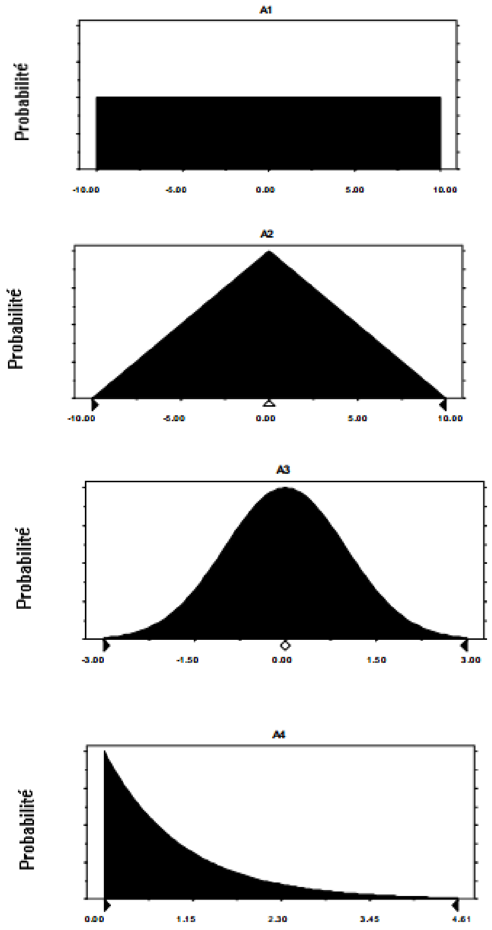




Identification of uncertanities and distributions

- **Codes have dedicated tools to sample and pre-process and post-process**
  - MELCOR Uncertanity Engine
  - ASTEC SUNSET Package
- **Typical distributions (i.e. for MELCOR)**
  - Uniform
  - Triangular
  - Normal
  - Expontential
  - Log-normal
  - Log-triangular
  - Log-uniform
  - Beta
  - Discrete





Sample Size - Samuel Wilks

- **Samuel Wilks**
- **S. S. Wilks, "Determination of Sample Sizes for Setting Tolerance Limits," *Ann. Math. Stat.*, vol. 12, no. 1, pp. 91–96, 1941.**

DETERMINATION OF SAMPLE SIZES FOR SETTING TOLERANCE LIMITS

BY S. S. WILKS

Princeton University, Princeton, N. J.

1. Introduction. In the mass production of a given product or apparatus piece-part, Shewhart[1] has discussed a practical procedure for detecting the existence of assignable causes of variation in a given quality characteristic of the product as measured by a variable x. For example, x may be the thickness in inches of a washer or the tensile strength in pounds of a small aluminum casting made according to a given set of specifications; x varies in value from washer

Example – Sample Size

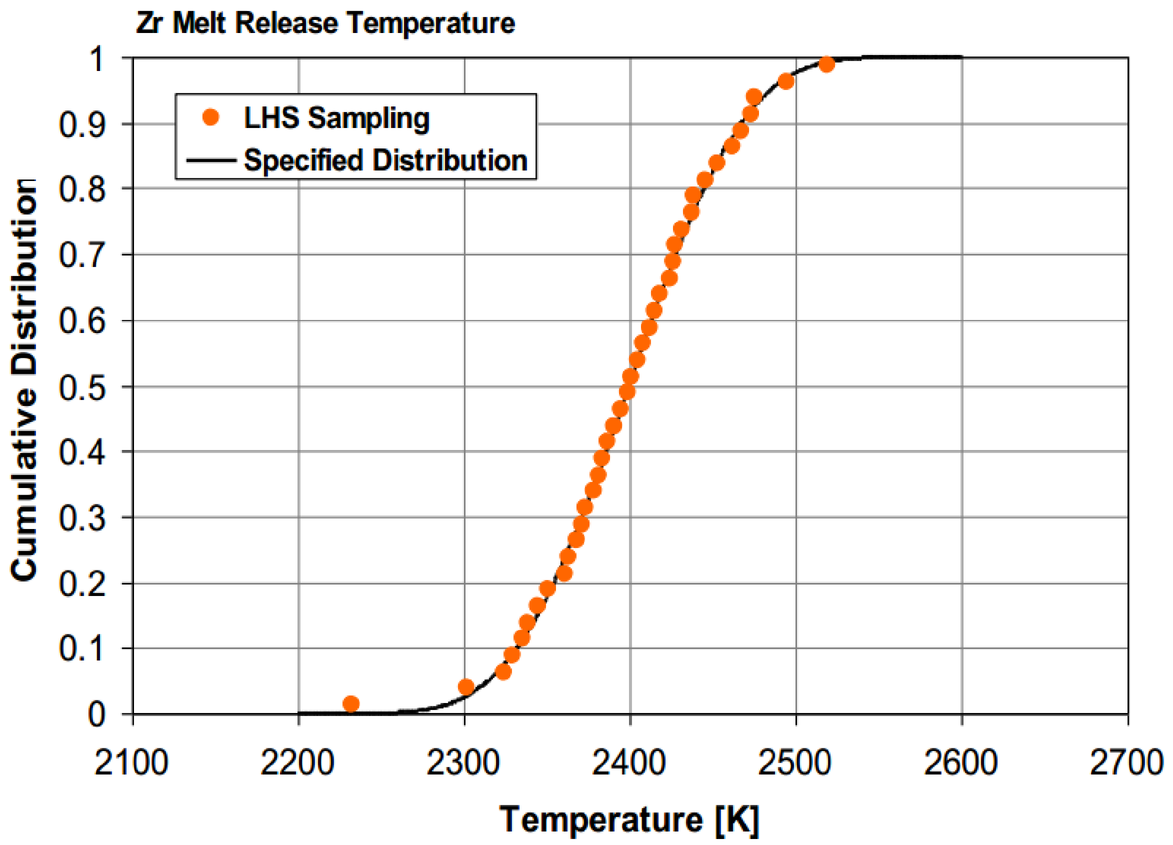
- **Select size of the sample.**
  - It takes ~3h per one run
  - Limited computational resource and more simulation can be too expensive
  - Popular approach – Wilks formula
  - Example - 93 samples 95%/95%
- **More samples – greater % of distribution to be sample with higher confidence**

$$C = 1 - n \cdot p^{n-1} + (n+1) \cdot p^{n}$$

Confidence Level	Sample Size to span p =			
(%)	0.9	0.95	0.99	0.999
90	37	76	388	3888
95	46	93	473	4742
99	64	130	661	6635
99.9	88	180	919	9228

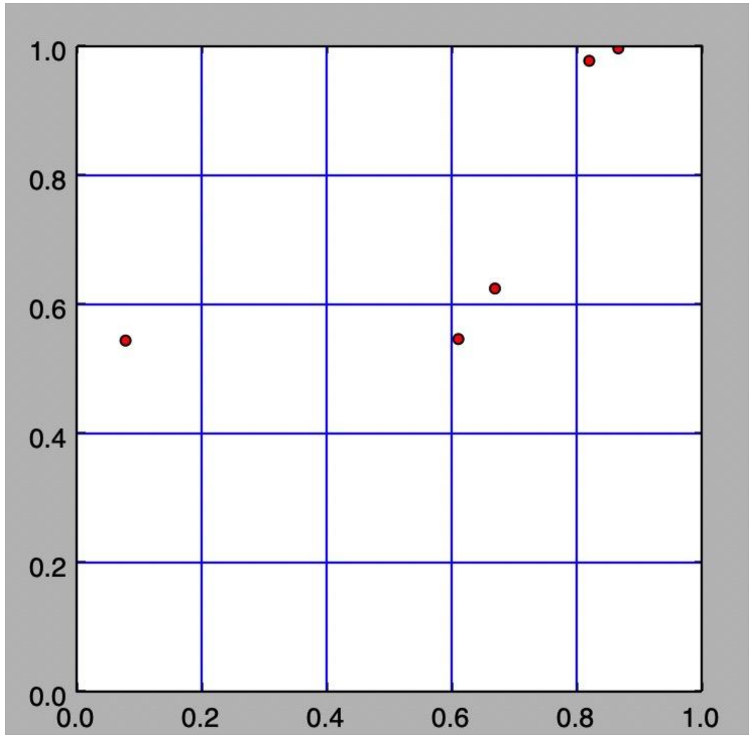
Example – Sampling

- **Sampling.**
  - SRS – Simple Random Sampling
  - LHS – Latin Hypercube Sampling

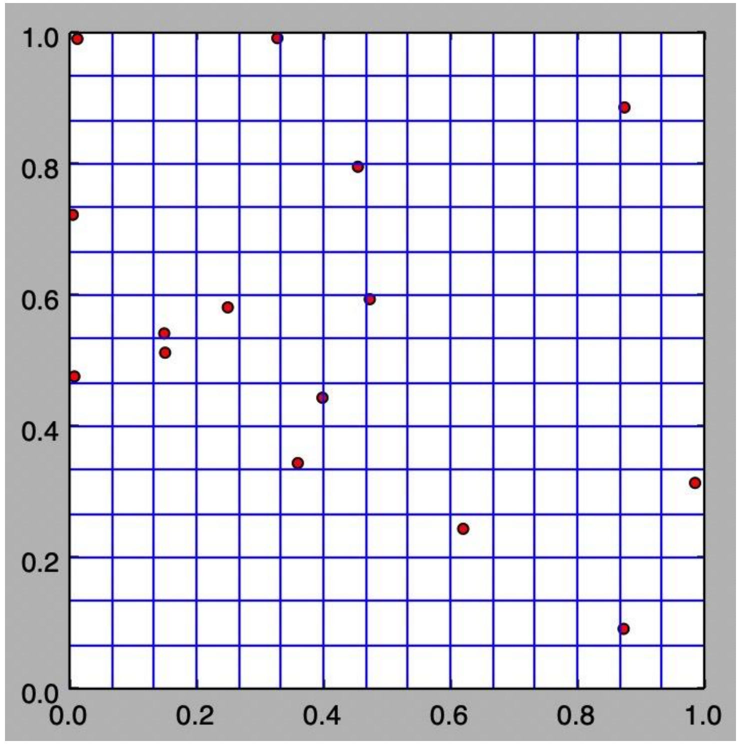


Sampling: Standard Random Sampling

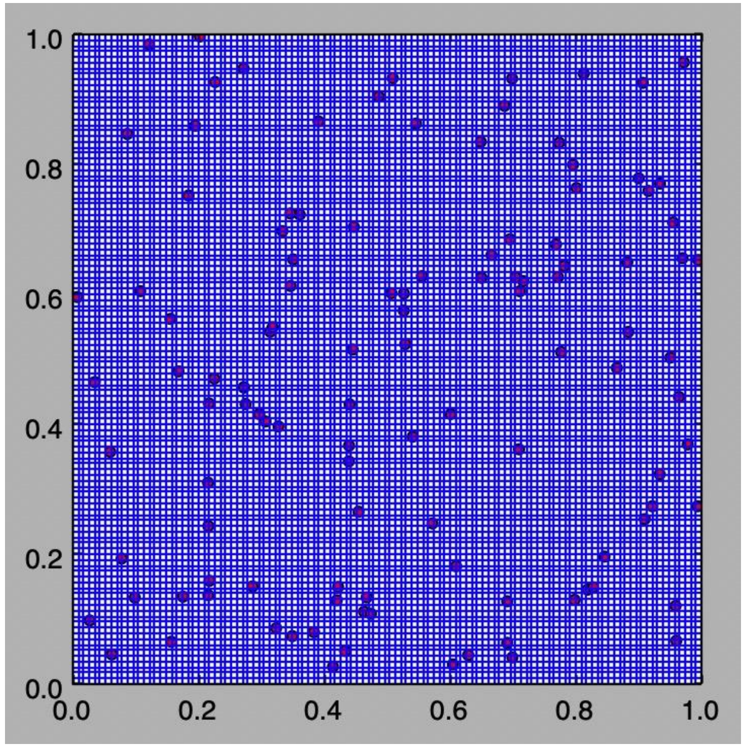
N=5



N=15

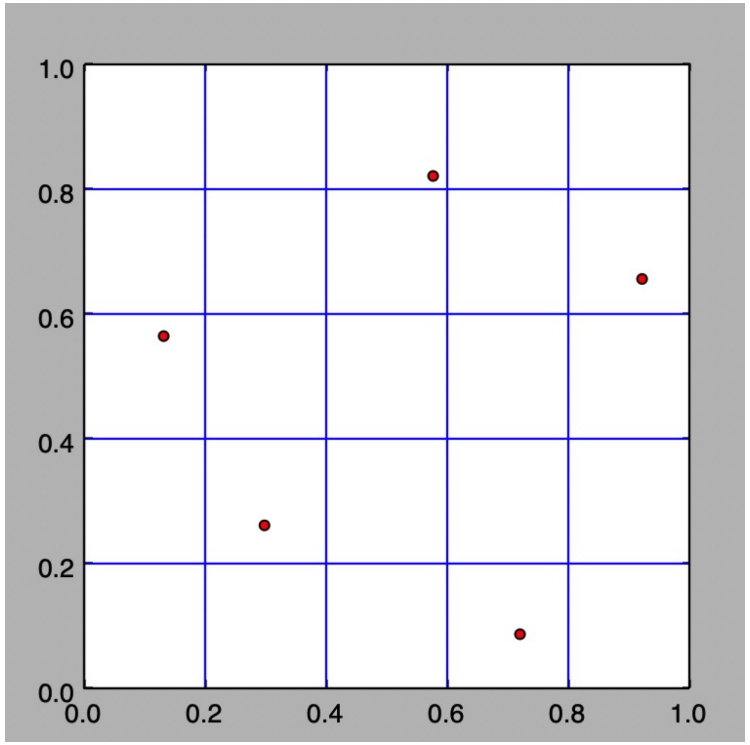


N=115

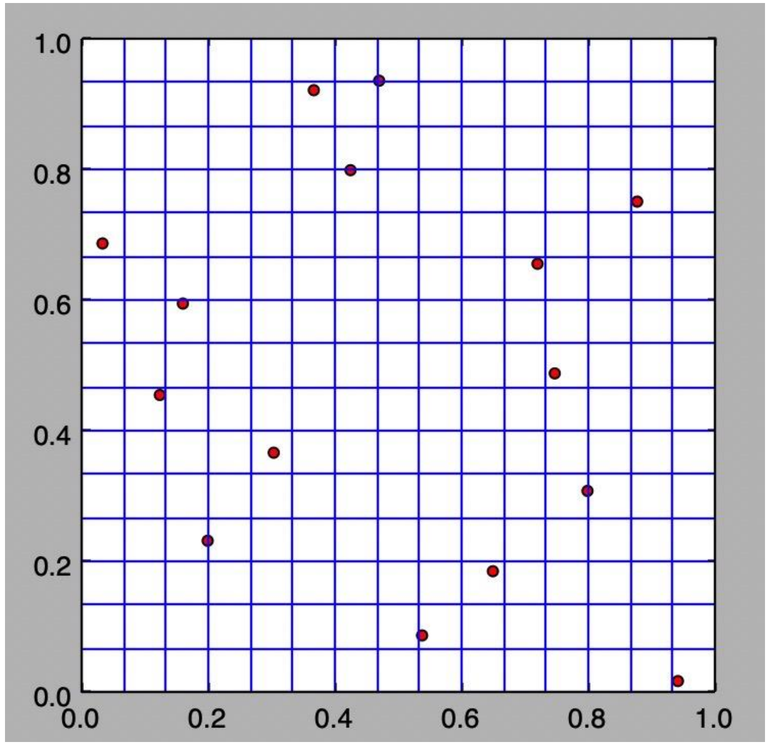


Sampling: Latin Hypercube Sampling

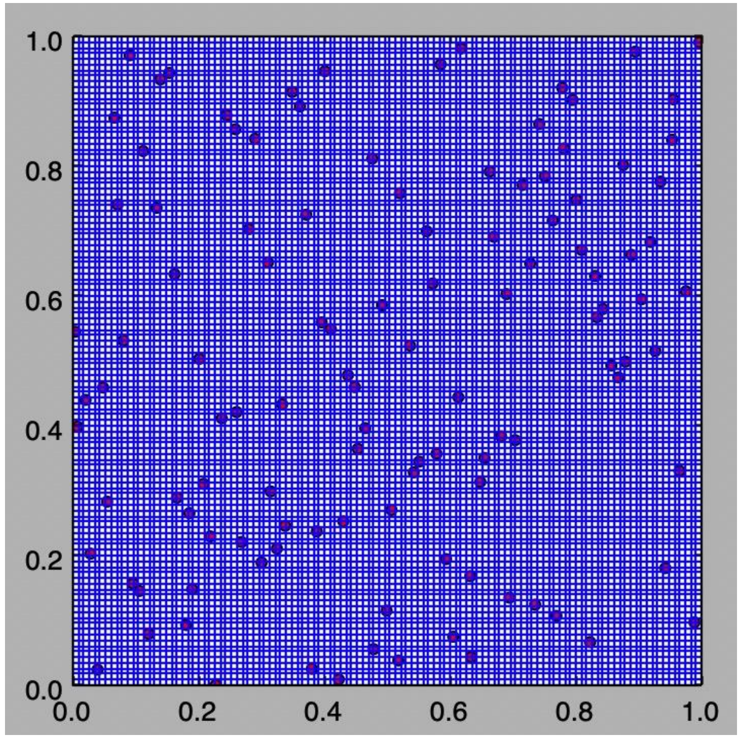
N=5



N=15



N=115



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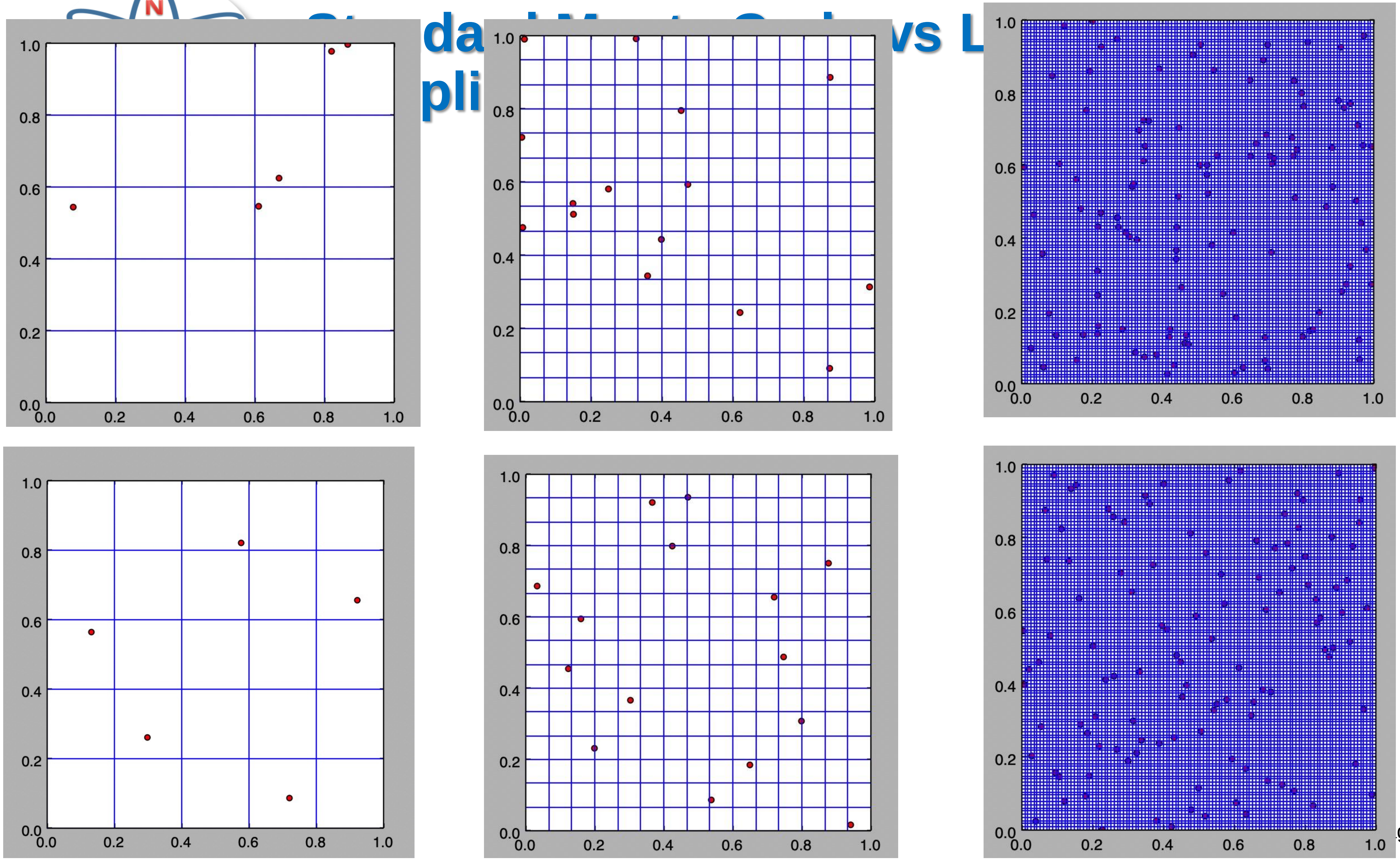
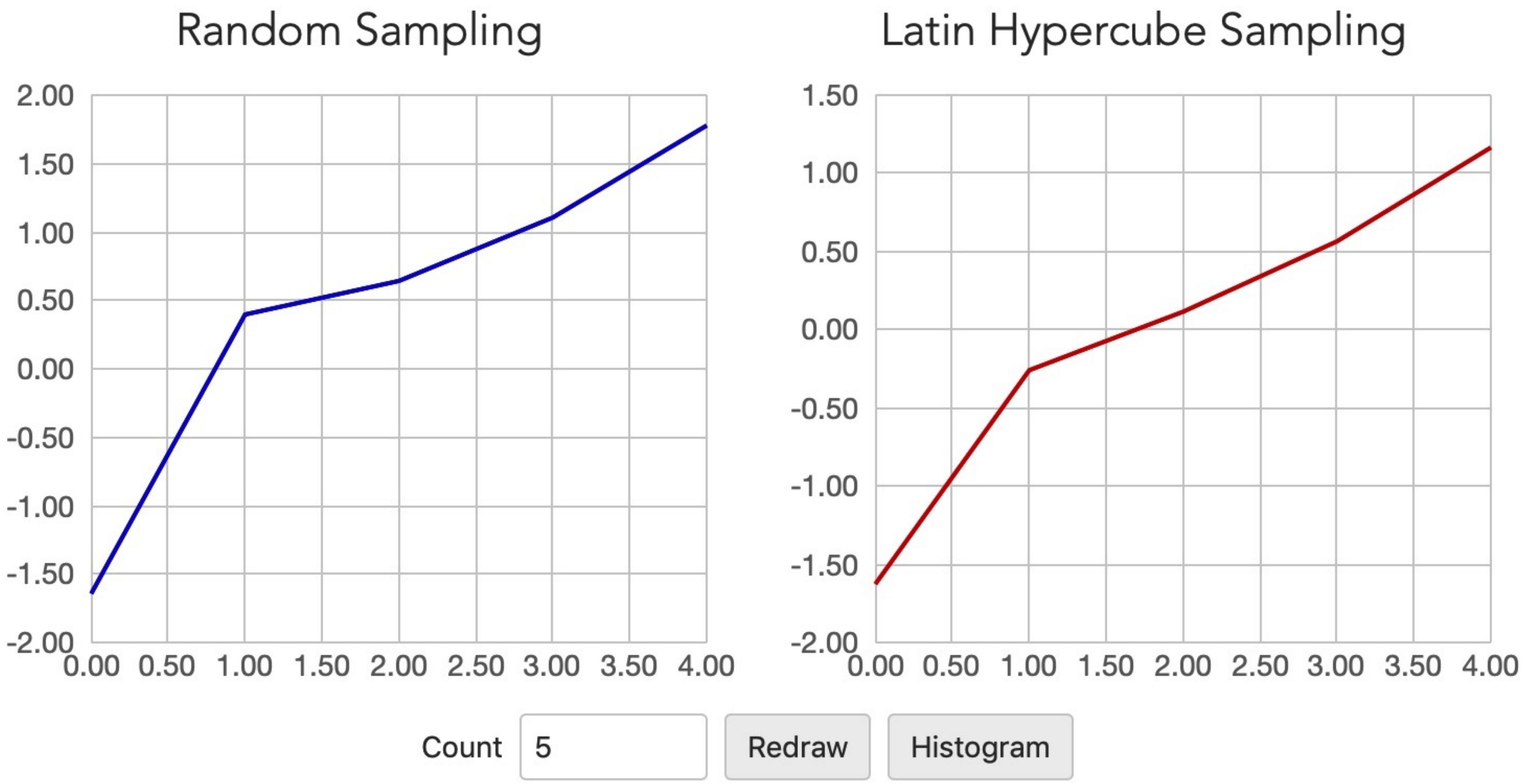
pli



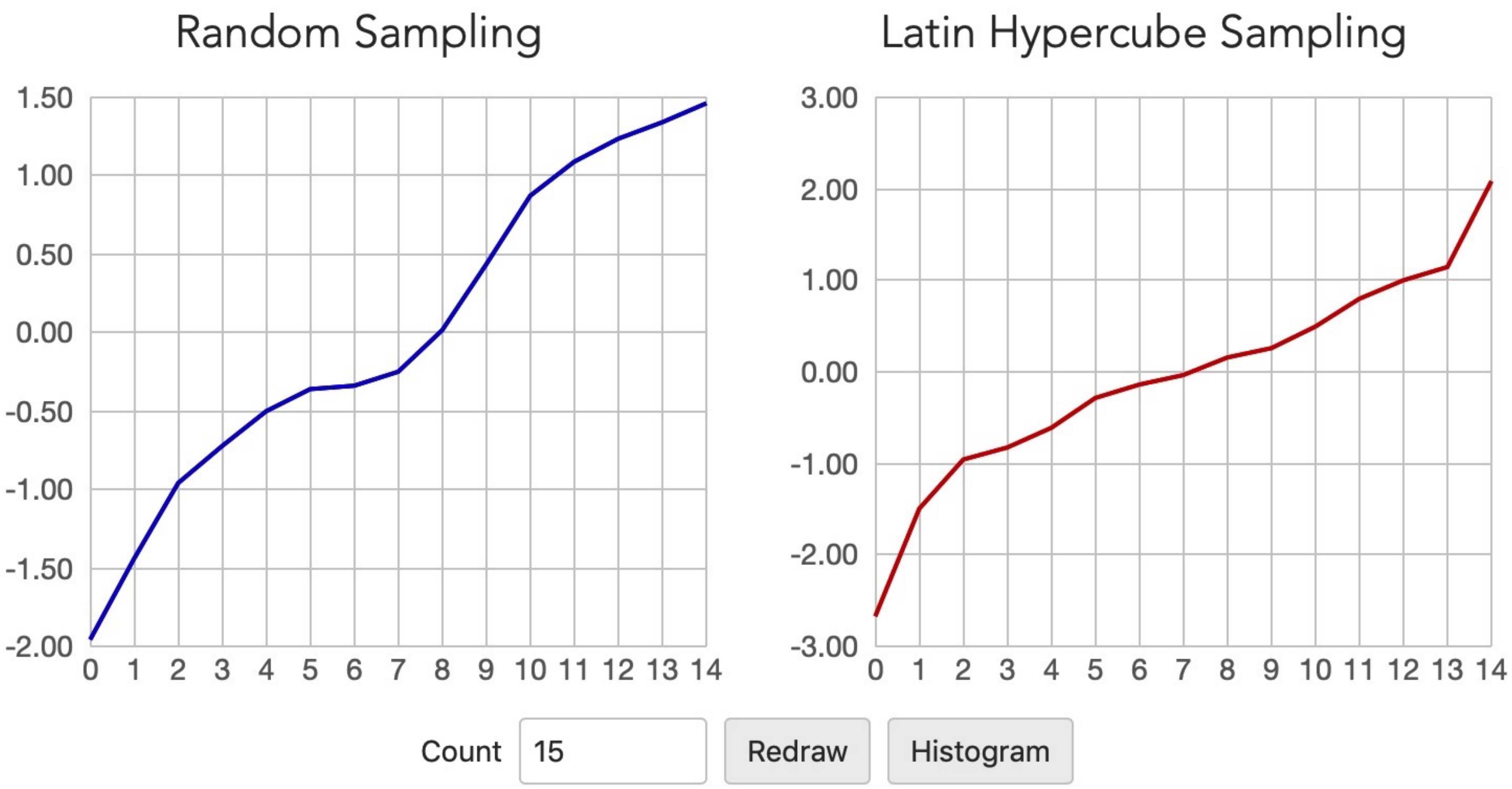
standard

LHS

SRS vs LHS

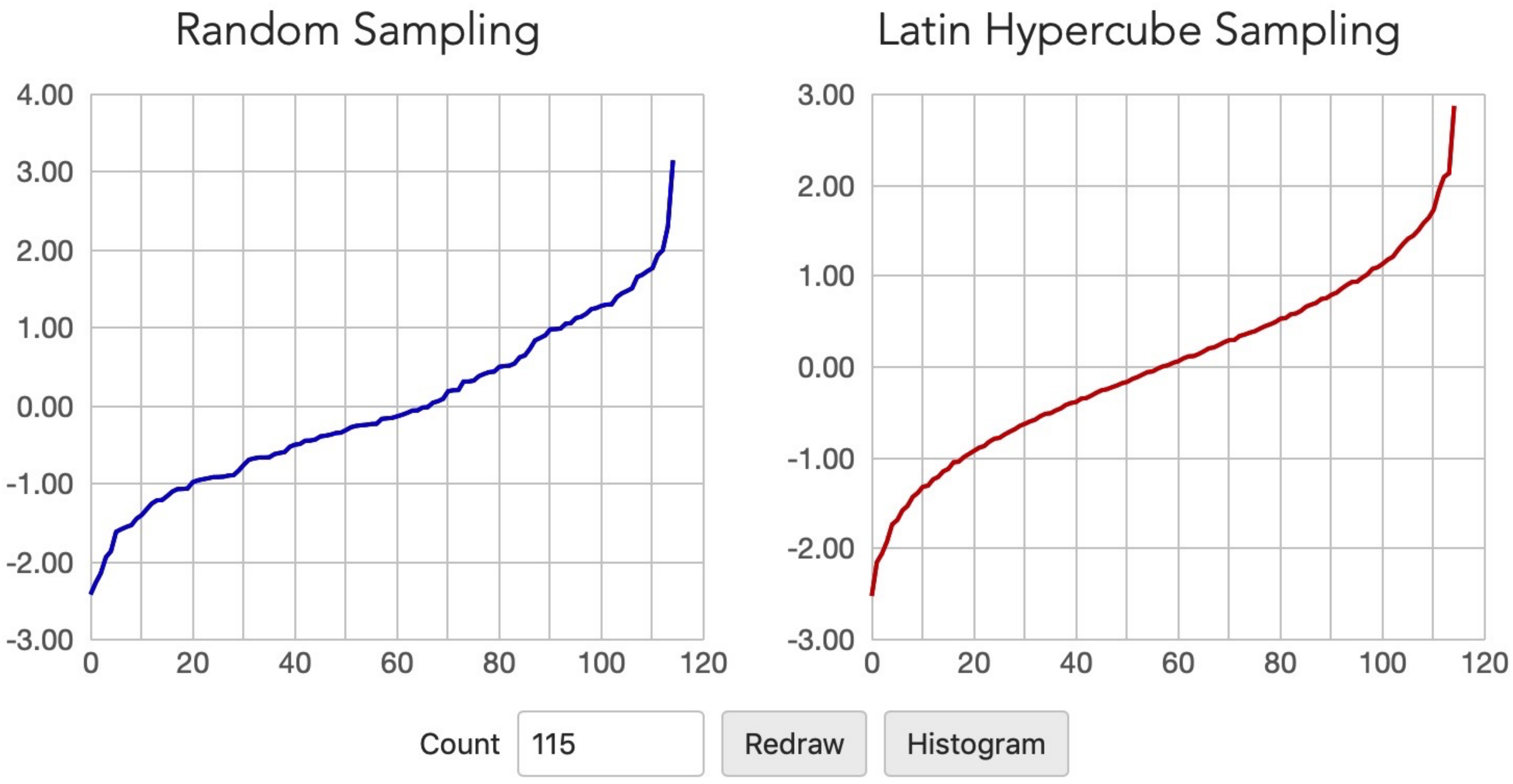

Random Sampling
Latin Hypercube Sampling
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
0.00 0.50 1.00 1.50 2.00 2.50 3.00 3.50 4.00
Count
5
Redraw
Histogram

SRS vs LHS



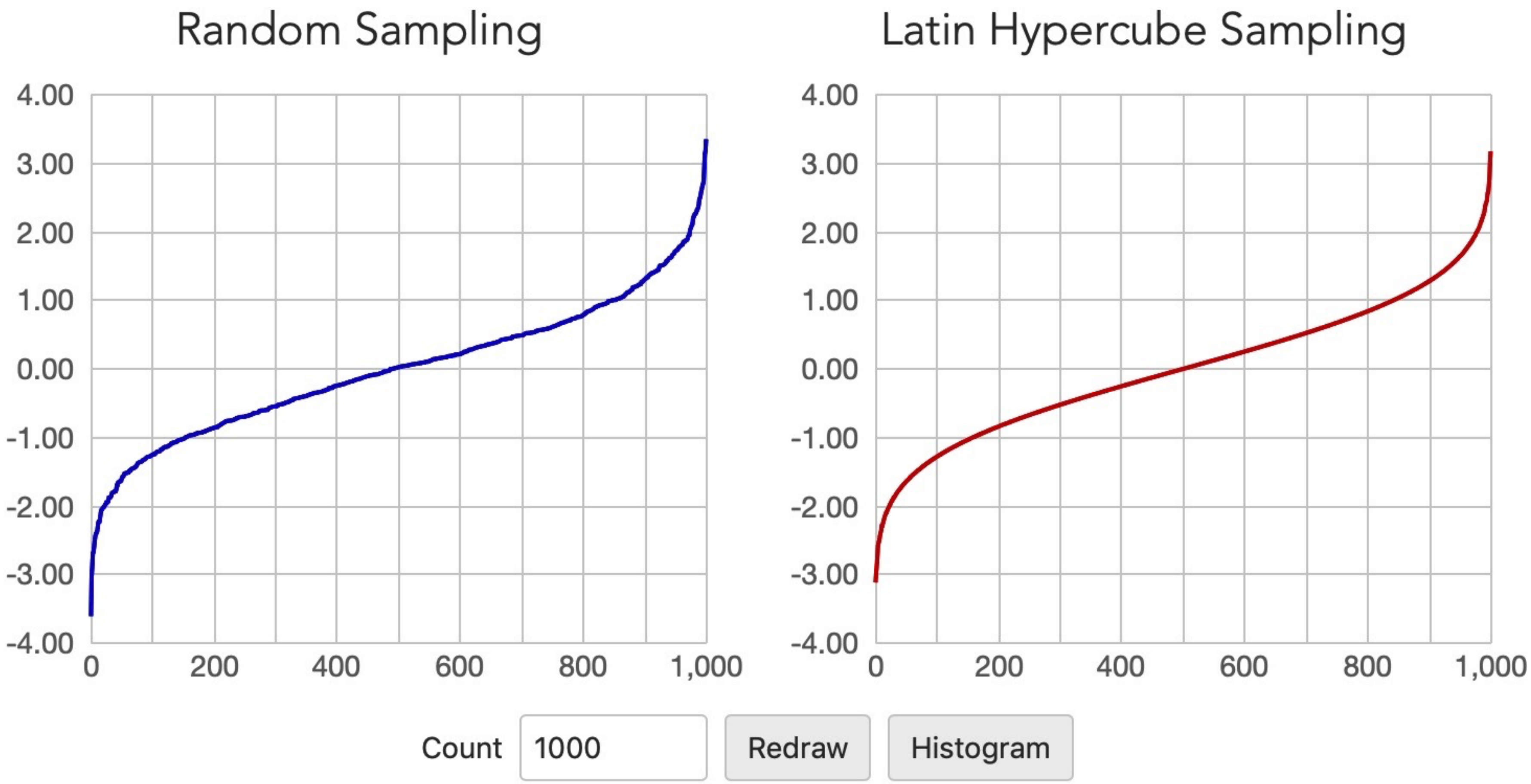
Random Sampling
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Latin Hypercube Sampling
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Count
15
Redraw
Histogram

SRS vs LHS



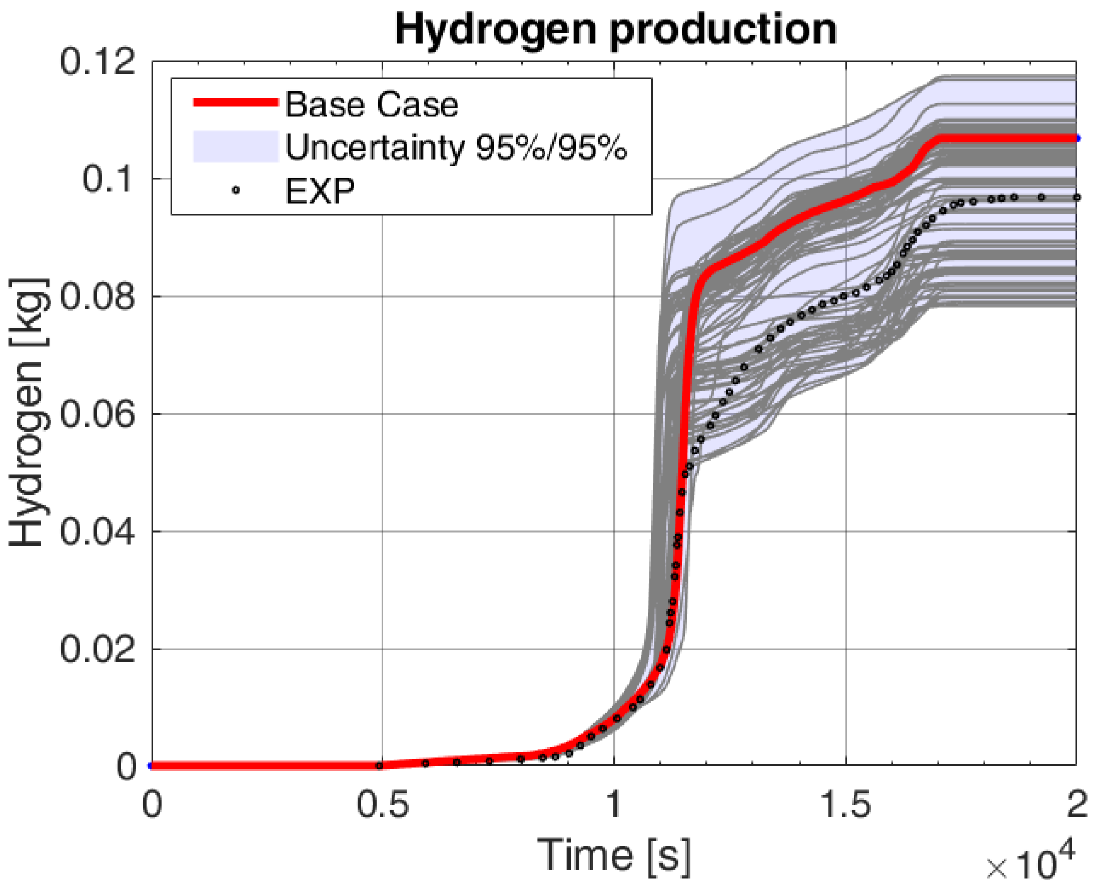
Random Sampling
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
0
20
40
60
80
100
120
Latin Hypercube Sampling
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
0
20
40
60
80
100
120
Count
115
Redraw
Histogram

SRS vs LHS


Random Sampling
Latin Hypercube Sampling
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
0
200
400
600
800
1,000
Count
1000
Redraw
Histogram

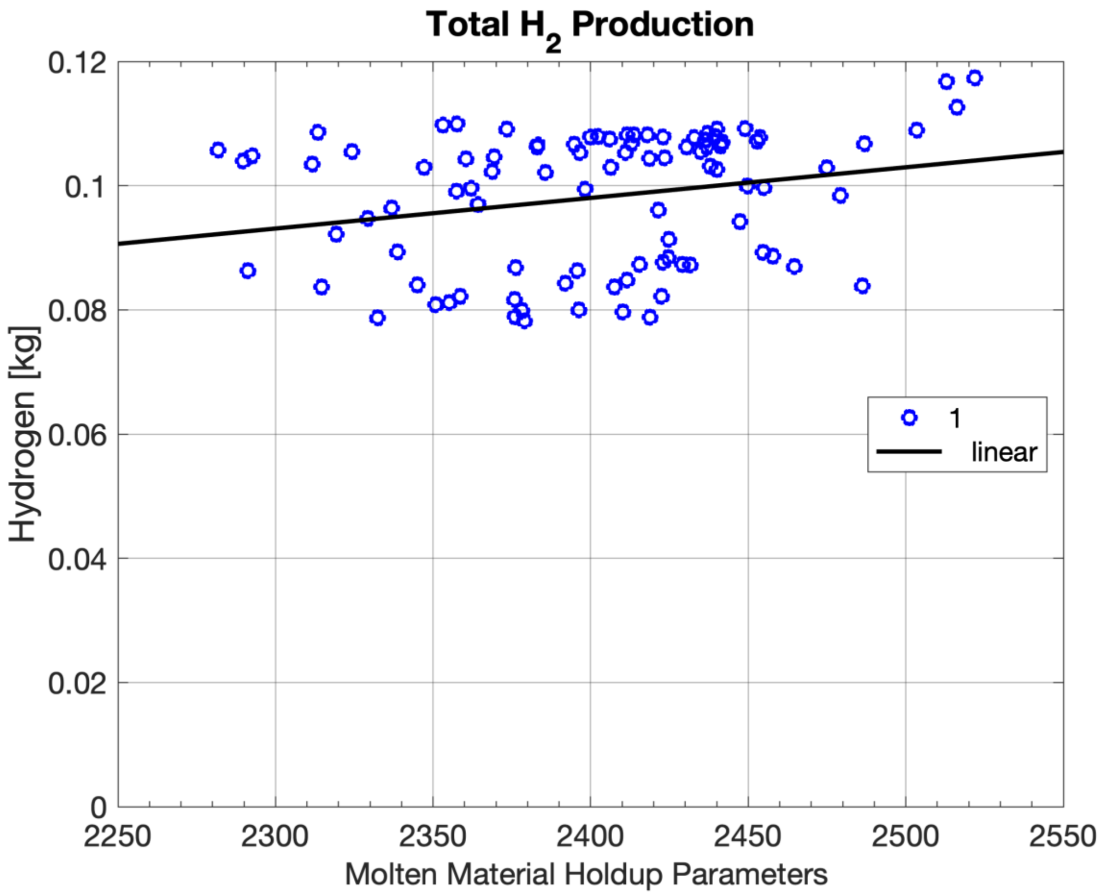
Example – Uncertanity

- Generate models with sampled values.
- Perform Simulations
- Post-process results.
- Uncertanity analysis
  - Confidence Intervals
  - Example: Limits from the sample represents the 95% confidence interval within which 95% of all the possible values lie.



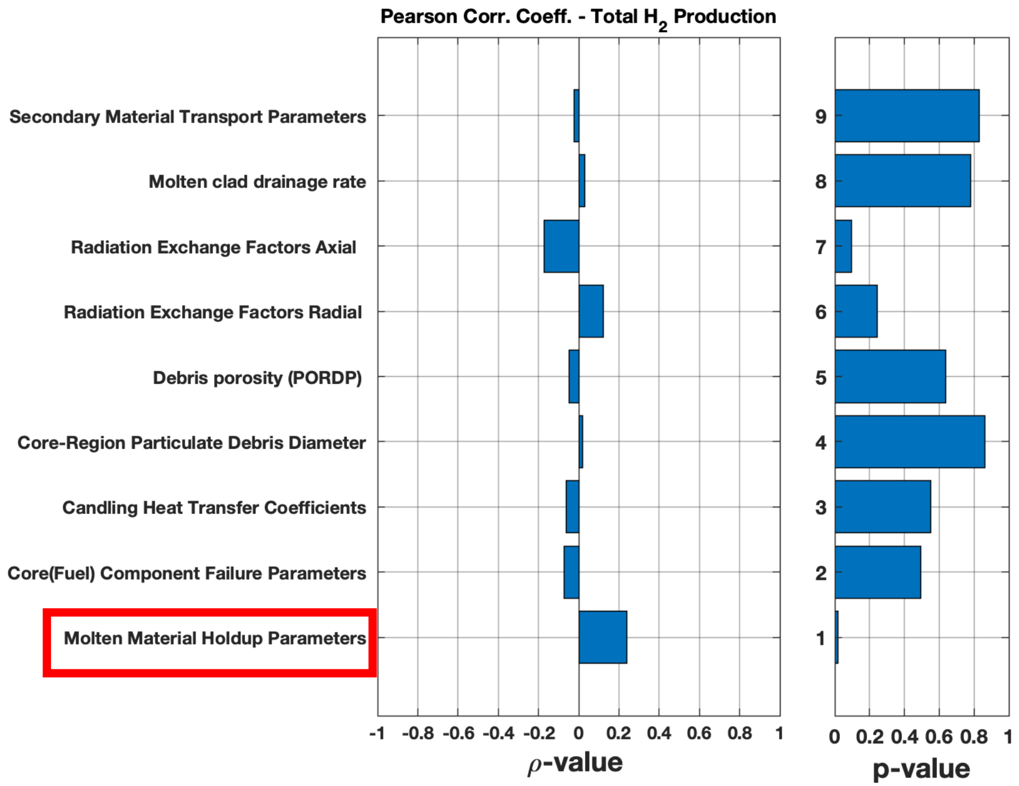
Example – Senstivity

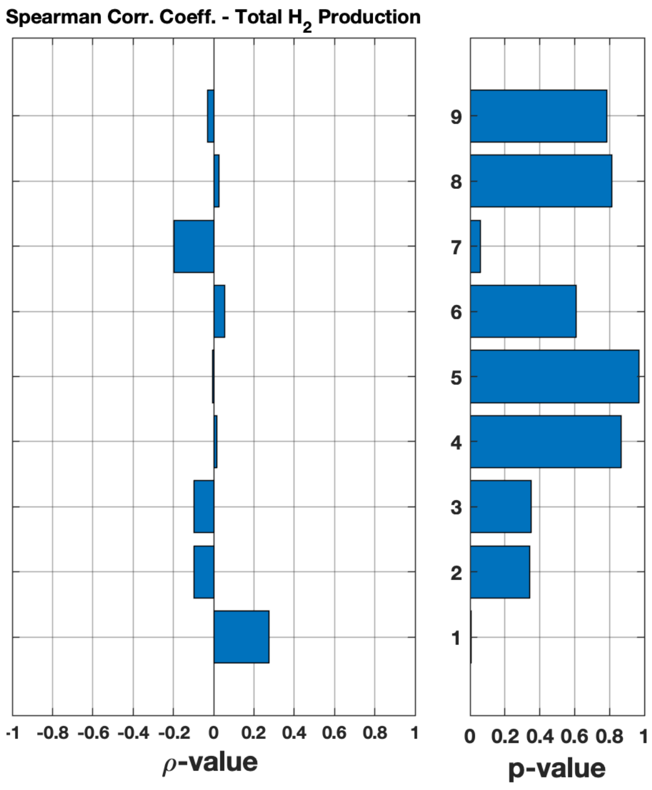
- Linear regression is simple & popular in the literature
- Other more sofisticated are possible

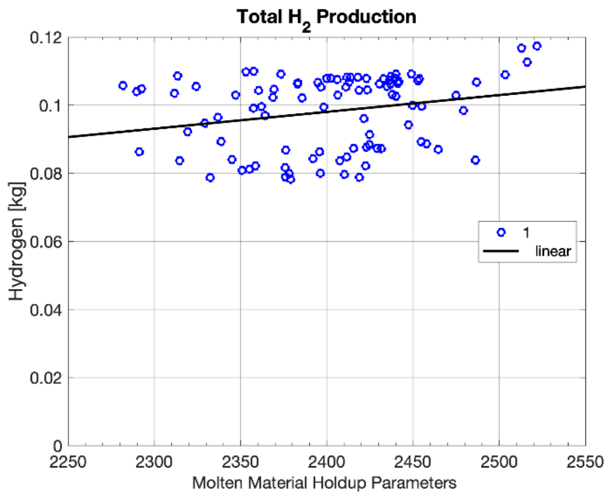


Example – Senstivity

- **Pearson (Linear) and Spearman (non-linear) are popular, other are also possible.**
- **For parameter #1, low p-value and „large” rho value indicates possible correlation (in Example it is weak).**

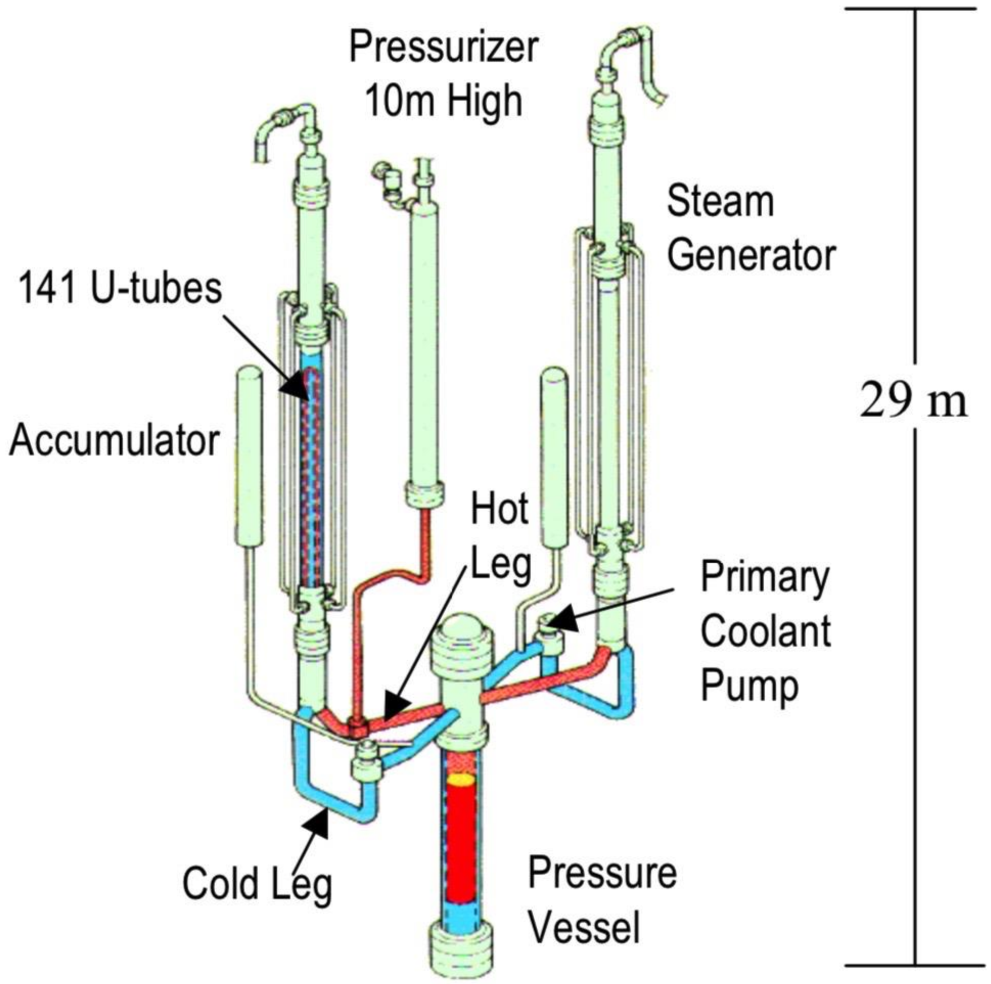






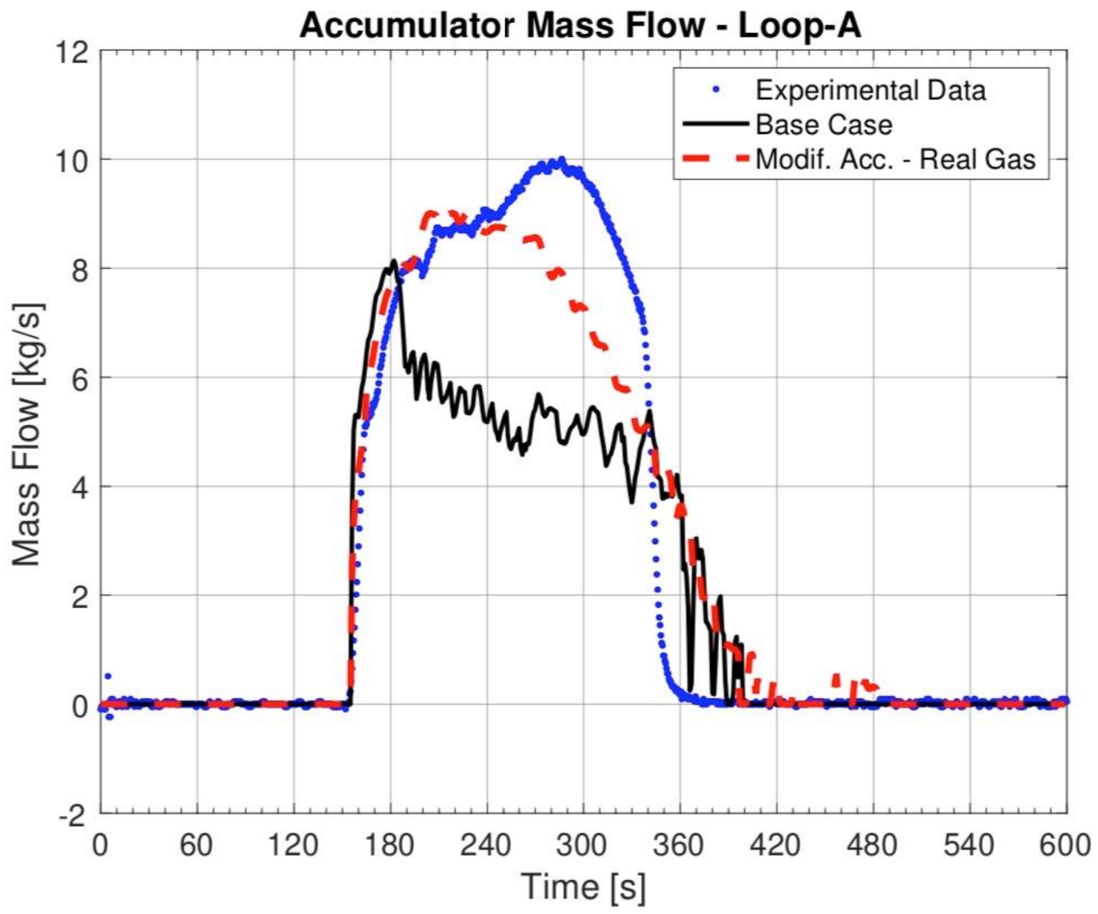
Intermediate Break LOCA

- ➢ **Other example**
- ➢ **Large Scale Test Facility in Japan**
- ➢ **13% break size of the cold leg**

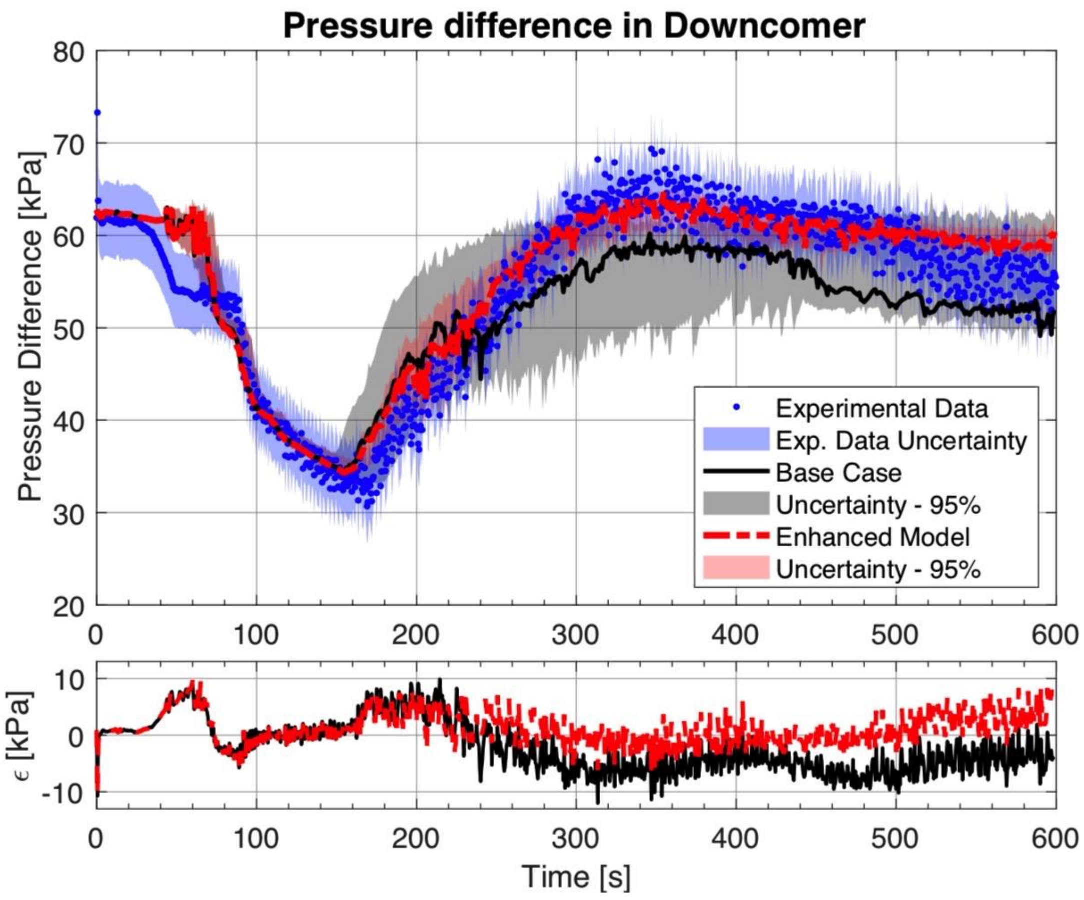


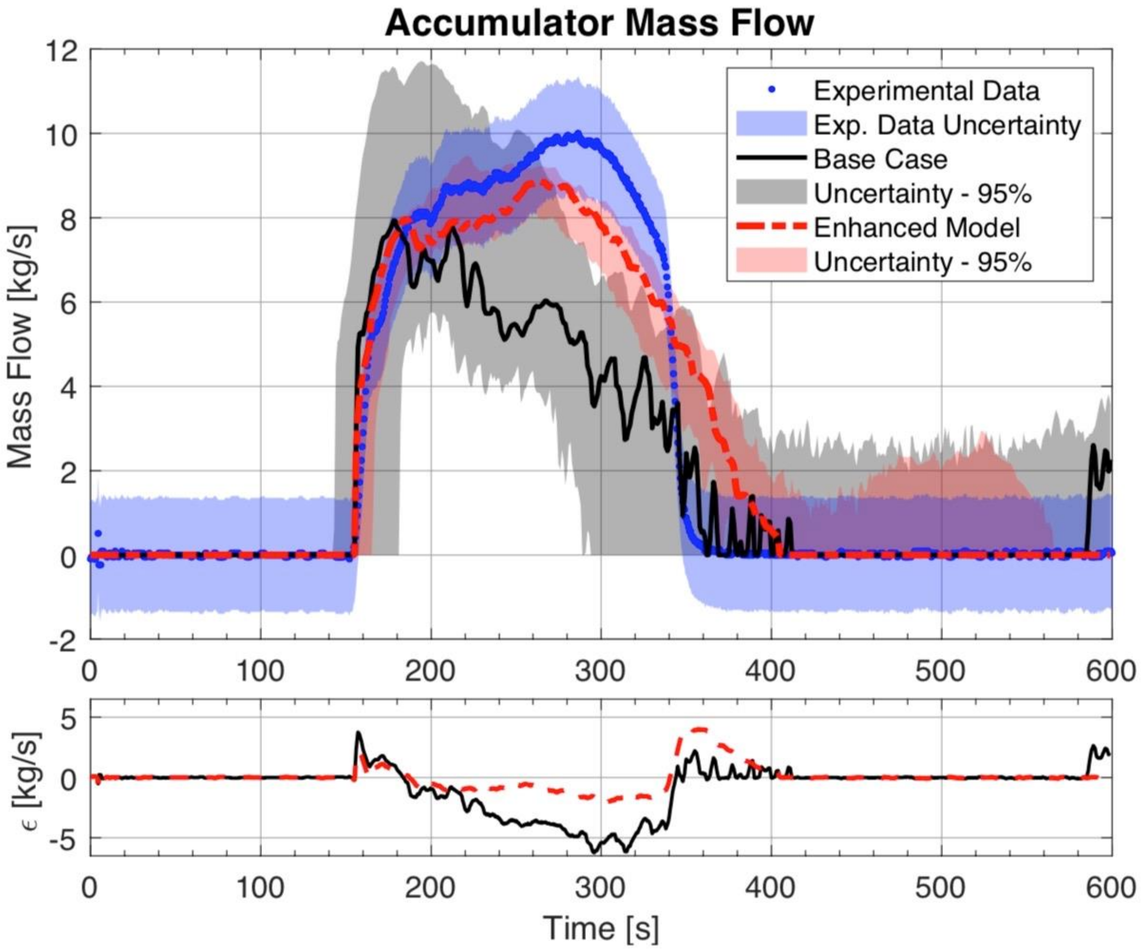
Enhancement model of accumulator

- **Standard model of accumulator (gas expansion) changed to more realistic, based on experimental data**



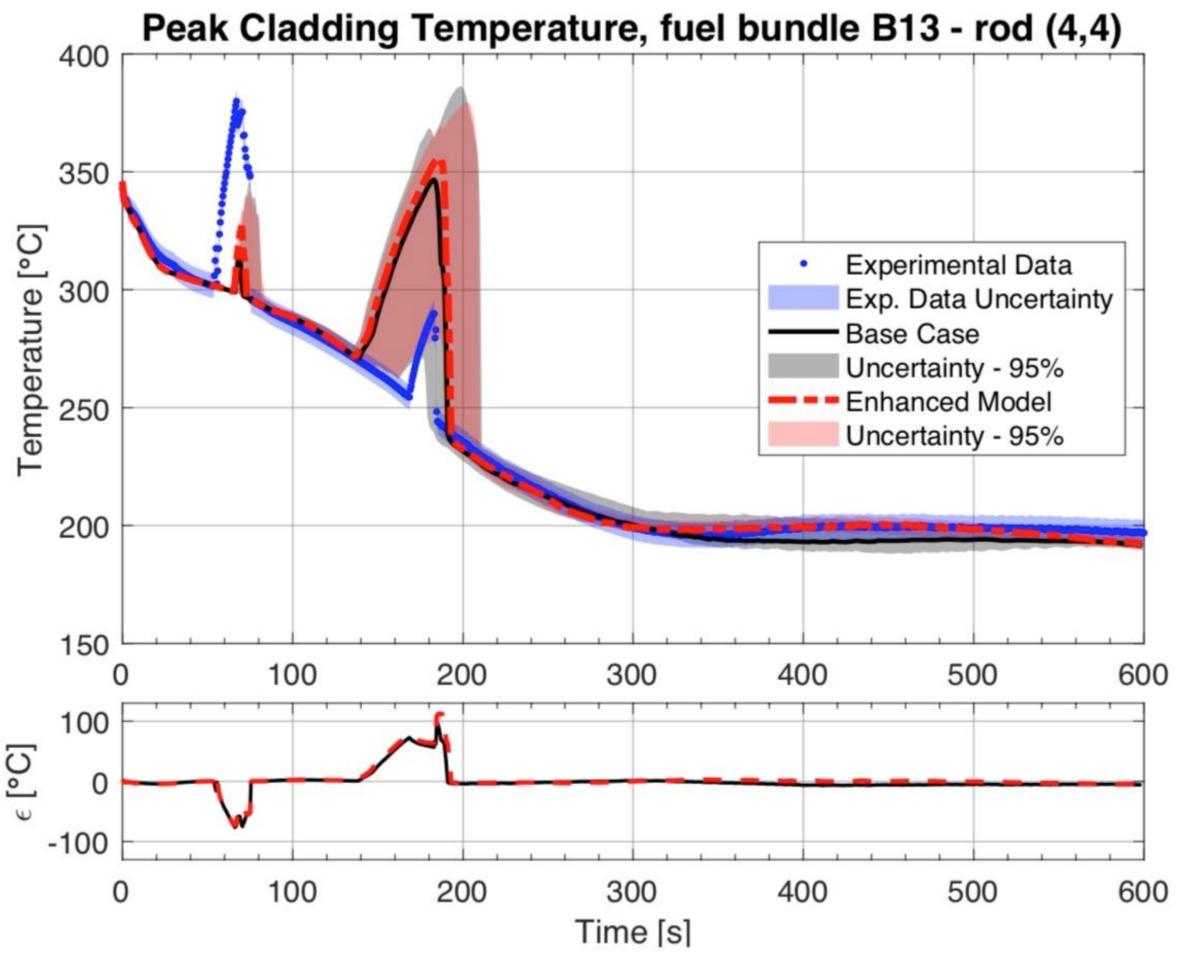
Enhancement model of accumulator – how the uncertainties propagation changes





How do we know that our model is correct ?

- **After uncertainty modeling we can learn that we could commit errors in nodalization or boundary conditions, local measurements**
- **And what if there is no emperimental data ? How can we be sure that even after uncertainties analysis we are on the safe side ?**



References

[1] Seghal, B. R., Nuclear Safety in Light Water Reactors – Severe Accident Phenomoneology, Pergamon Press, 2012.

[2] Jacquemain, D., Nuclear Power Reactor Core Melt Accidents – Current State of Knowledge, IRSN, EDP Sciences, 2015.

[3] Gauntt, R. O., An Uncertanity Analysis of the Hydrogen Source Term for a Station Blackout accident in Sequoyah Using MELCOR 1.8.5. SAND2014-2210, 2014.

[4] Modarres, M. Risk Analysis in EngineeringL Techniques, Tools and Trends, Taylor & Francis, 2006.

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Thank you for your attention

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