Generation of Integral Experiment Lo-Fi Covariance Matrices for the Database for ICSBEP (DICE)

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Overview

- ICSBEP Handbook + DICE
- Experimental Covariance Does it Matter?
- NEA Expert Group: UACSA
- Historical Development of Covariance Data, in the Field of Nuclear Data
- Procedure to Generate Low Fidelity Covariance Data

ICSBEP Handbook and DICE

Handbook (est 1992/1995)

4874 Critical and Subcritical Benchmarks, Organized by Fissile Material, Form and Fission Spectrum

International Handbook of Evaluated Criticality Safety Benchmark Experiments

DATABASE for ICSBEP (DICE)

Answers How Efficiently Search the Handbook

- Distributed with Handbook since 2001
- Relational database
- User Friendly Way to Search

https://www.oecd-nea.org/science/wpncs/icsbep/dice.html

Evaluation Process: Section 2 Uncertainties

i. Each experimental Benchmark Model has a best estimate uncertainty

ii. The uncertainties are broken down into components

Uncertainties(pcm)	Case1	Case2	Case3	Case4	Case5	Case6
Clad Thickness	400	400	400	72	72	72
Boron Concentration	384	384	384	130	130	130
Enrichment	338	338	338	363	363	363
Experimental Uncertainty	300	300	300	300	300	300
Pitch	5	5	5	270	270	270

Total Uncertainty

	LCT021-1	LCT021-2	LCT021-3	LCT021-4	LCT021-5	LCT021-6
LCT021-1	720	0	0	0	0	0
LCT021-2	0	720	0	0	0	0
LCT021-3	0	0	720	0	0	0
LCT021-4	0	0	0	500	0	0
LCT021-5	0	0	0	0	500	0
LCT021-6	0	0	0	0	0	500

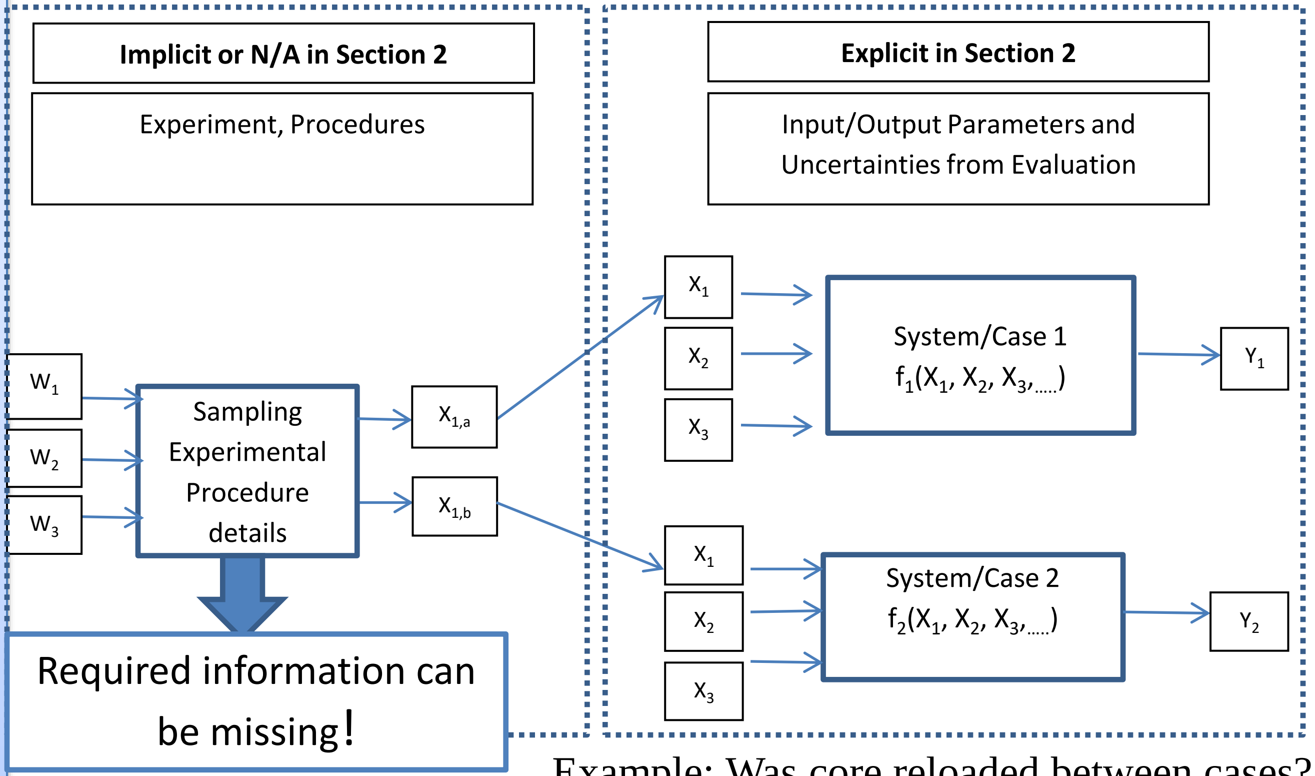
Shared uncertainty in benchmark models

Why Do Experimental Benchmark Models Have Covariance?

Uncertainty can be shared between experimental benchmark model cases

Example Sources of Shared Uncertainty:

a) Fuel Impurities
b) Pitch
c) Cladding Dimensions
d) Calibration
e) Measurement Device/Method



Implicit or N/A in Section 2

Experiment, Procedures

Explicit in Section 2

Input/Output Parameters and Uncertainties from Evaluation

Required information can be missing!

Example: Was core reloaded between cases?

	LCT021-1	LCT021-2	LCT021-3	LCT021-4	LCT021-5	LCT021-6
LCT021-1	720	0	0	0	0	0
LCT021-2	0	720	0	0	0	0
LCT021-3	0	0	720	0	0	0
LCT021-4	0	0	0	500	0	0
LCT021-5	0	0	0	0	500	0
LCT021-6	0	0	0	0	0	500

Experimental Correlations Matter!

Required for cross section adjustment methodology

Impacts subcriticality limits

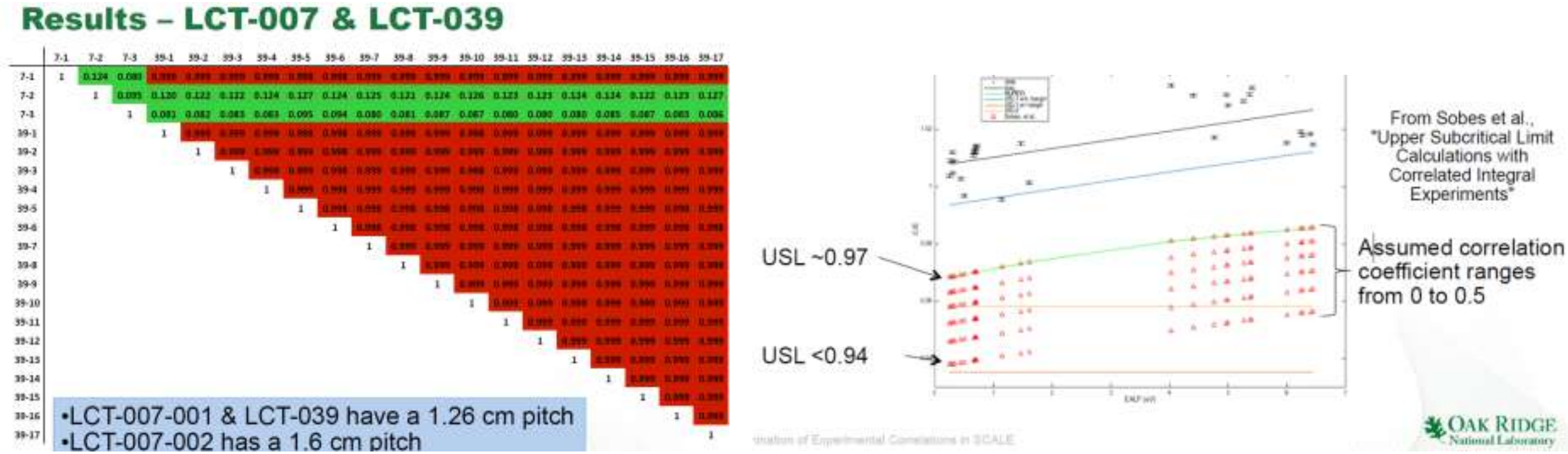
Required for rigorous uncertainty analysis

From State of the art Report: ***Overview of Approaches Used to Determine Calculational Bias in Criticality Safety Assessment***

“Of particular importance is that experimental uncertainties (and correlations between the uncertainties) have been properly evaluated, so that the weighting procedure used in the fitting process is applied correctly.”

T. Ivanova *et al*. (2003), Influence of the Correlations of Experimental Uncertainties on Criticality Prediction, Nucl. Sci. Eng., 145, p. 97.

V. Sobes, B. T. Rearden, D. E. Mueller, W. J. Marshall, J. M. Scaglione, and M. E. Dunn, “Upper Subcritical Limit Calculations with Correlated Integral Experiments.” **ANS Annual Meeting, San Antonio, TX, June 7–11, 2015**



Results – LCT-007 & LCT-039

	7-1	7-2	7-3	39-1	39-2	39-3	39-4	39-5	39-6	39-7	39-8	39-9	39-10	39-11	39-12	39-13	39-14	39-15	39-16	39-17
7-1	1	0.124	0.083	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7-2		1	0.095	0.120	0.122	0.122	0.124	0.127	0.124	0.125	0.121	0.124	0.126	0.123	0.123	0.124	0.124	0.122	0.123	0.127
7-3			1	0.081	0.082	0.083	0.083	0.095	0.094	0.080	0.081	0.087	0.087	0.080	0.080	0.080	0.085	0.087	0.083	0.086
39-1				1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
39-2					1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
39-3						1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
39-4							1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
39-5								1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
39-6									1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
39-7										1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
39-8											1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
39-9												1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
39-10													1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
39-11														1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
39-12															1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
39-13																1	[illegible]	[illegible]	[illegible]	[illegible]
39-14																	1	[illegible]	[illegible]	[illegible]
39-15																		1	[illegible]	[illegible]
39-16																			1	[illegible]
39-17																				1

- LCT-007-001 & LCT-039 have a 1.26 cm pitch
- LCT-007-002 has a 1.6 cm pitch

USL ~0.97

USL <0.94

From Sobes et al., "Upper Subcritical Limit Calculations with Correlated Integral Experiments"

Assumed correlation coefficient ranges from 0 to 0.5

Working on Methods: UACSA

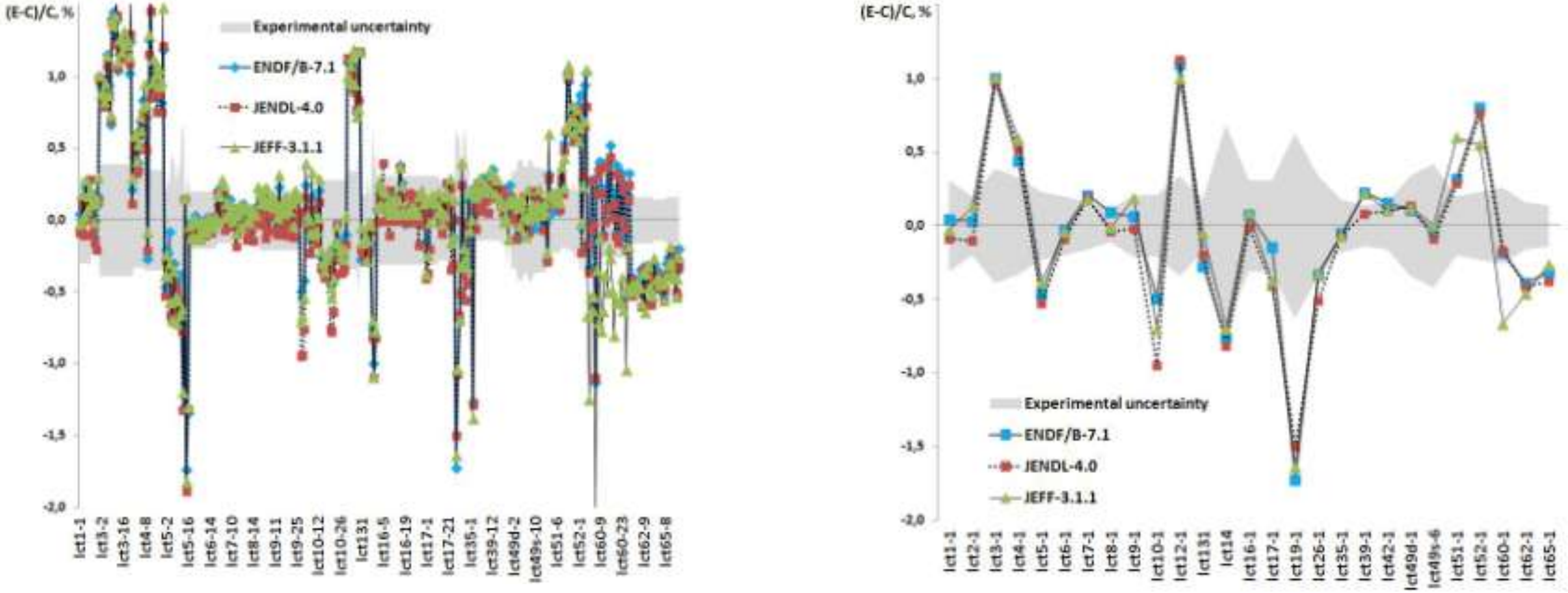
- International Expert Group on Uncertainty Analysis for Criticality Safety Assessment (~30 participants in July 2016)

Objectives:

1. Survey of the techniques for establishment of best-estimate results (as opposed to nominal or design-basis results) together with biases and uncertainties due to technological parameters.
2. Survey of the techniques and software tools for computation of keff sensitivities to nuclear data and draft recommendations to practitioners for using those techniques.
3. **Draft recommendations to the ICSBEP on methods to identify, estimate and document parameter correlations between different experiments and to identify, estimate and document keff correlations between benchmark experiments due to those parameters.**

Significant amount of work being done to develop tools to assist in using monte carlo sampling to generate covariance information. Comparisons of methods, assumptions etc.

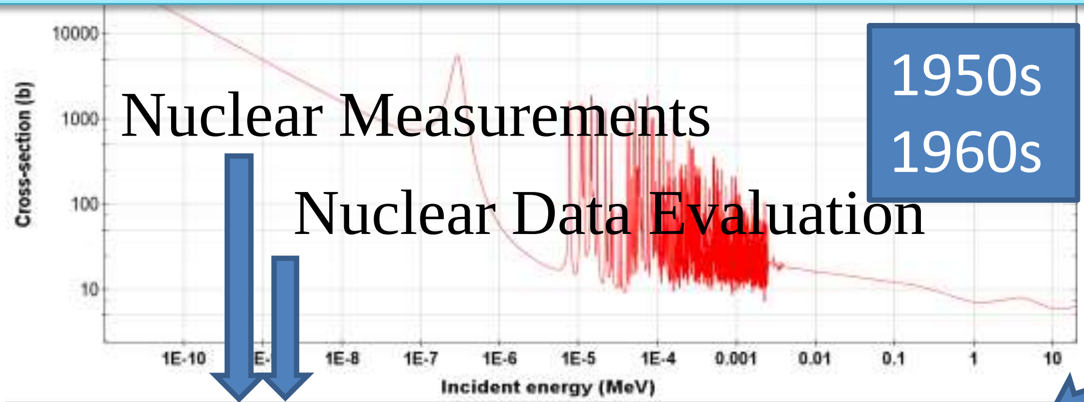
Example: Impact of Integral Experiments Correlations



Number of LEU-COMP-THERM configurations	Weighted k_{eff} bias, pcm		
	ENDF/B-VII.1	JENDL-4.0	JEFF-3.1.1
388 configurations	-63.3	-14.9	180.0
27 configurations	53.8	113.9	183.3

Tatiana Ivanova, Evgeny Ivanov, Giulio Emilio Bianchi "Establishment of Correlations for Some Critical and Reactor Physics Experiments", Nuclear Science and Engineering, Volume 178, Number 3, November 2014

Example: Impact of Integral Experiments on Choosing Best Nuclear Data

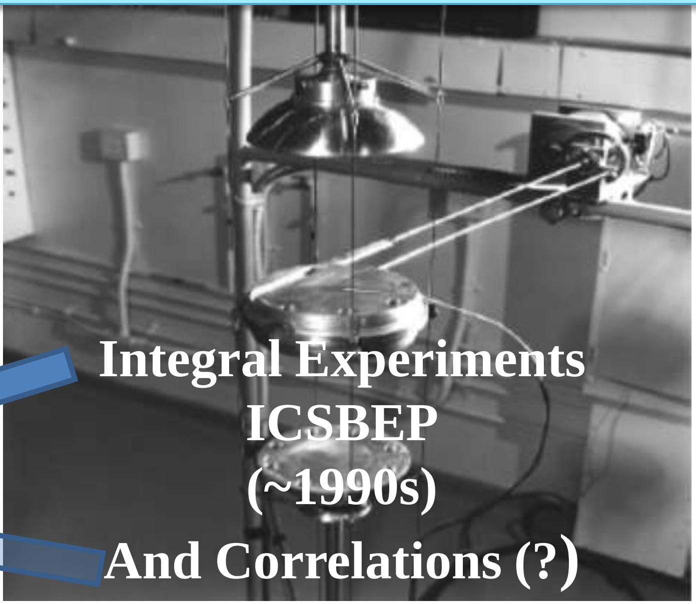


Nuclear Measurements

1950s
1960s

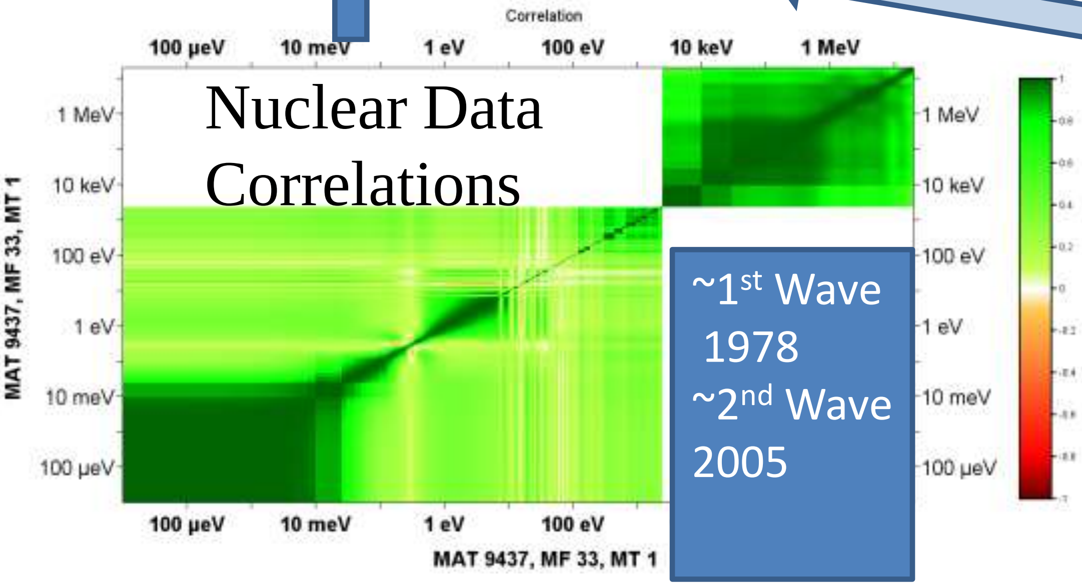
Nuclear Data Evaluation

$$J(T) = (T-T_o)^t M^{-1}(T-T_o) + [R_e - R_c(T)]^t [V_e + V_m]^{-1} [R_e - R_c(T)]$$



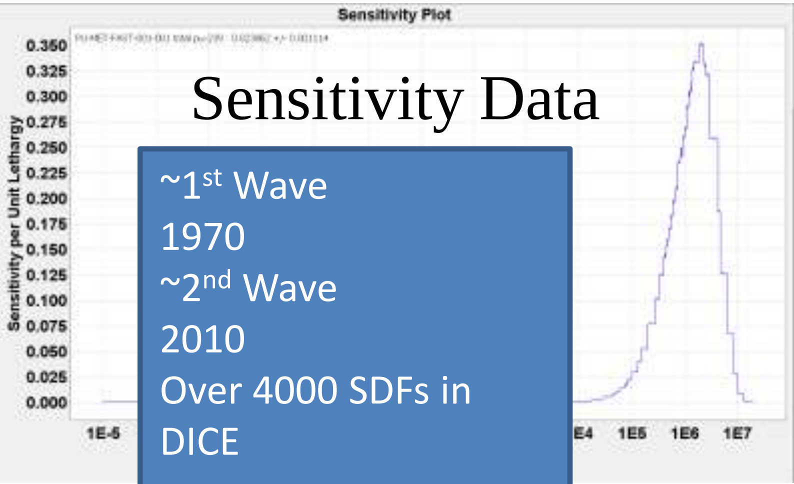
Integral Experiments
ICSBEP
(~1990s)

And Correlations (?)



Nuclear Data Correlations

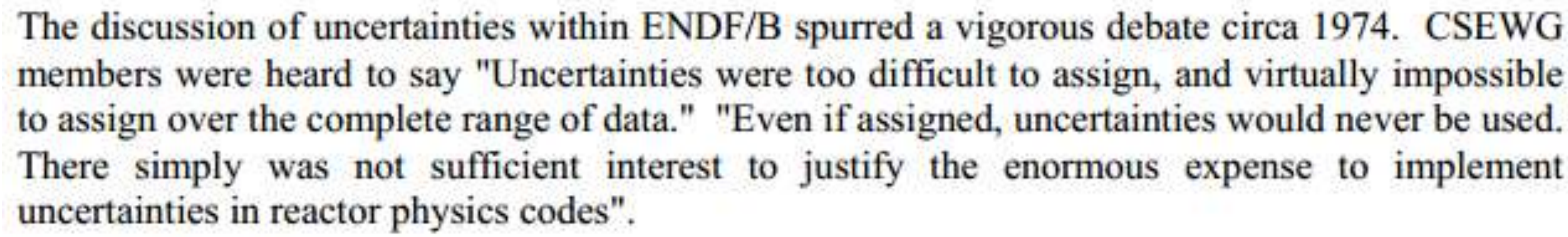
~1st Wave
1978
~2nd Wave
2005



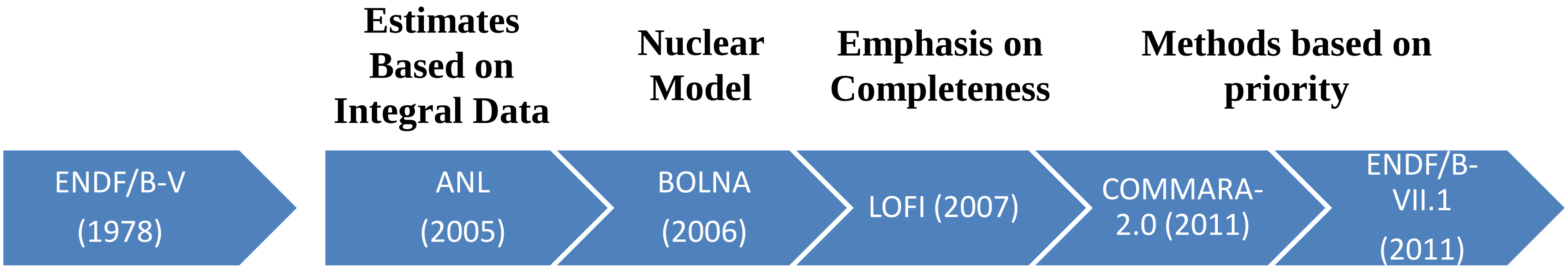
Sensitivity Data

~1st Wave
1970
~2nd Wave
2010
Over 4000 SDFs in DICE

Historical Perspective: ND Covariance Data



The discussion of uncertainties within ENDF/B spurred a vigorous debate circa 1974. CSEWG members were heard to say "Uncertainties were too difficult to assign, and virtually impossible to assign over the complete range of data." "Even if assigned, uncertainties would never be used. There simply was not sufficient interest to justify the enormous expense to implement uncertainties in reactor physics codes".



Estimates Based on Integral Data

Nuclear Model

Emphasis on Completeness

Methods based on priority

ENDF/B-V (1978)

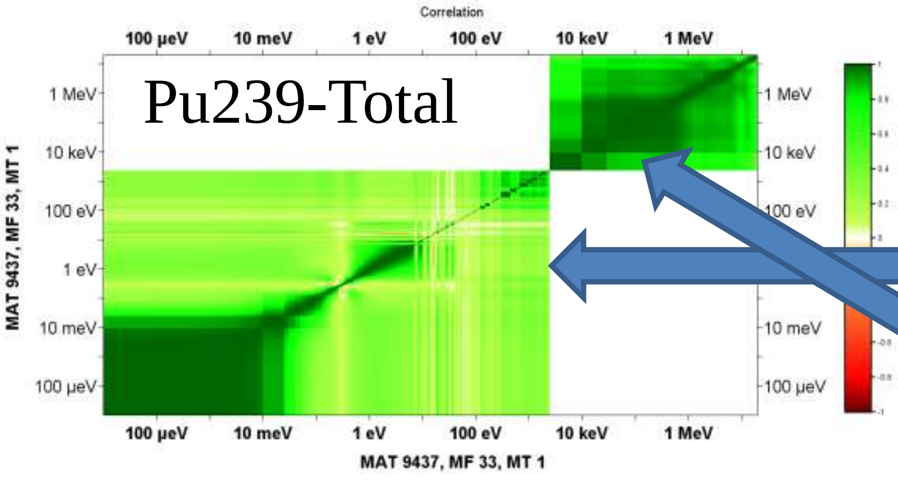
ANL (2005)

BOLNA (2006)

LOFI (2007)

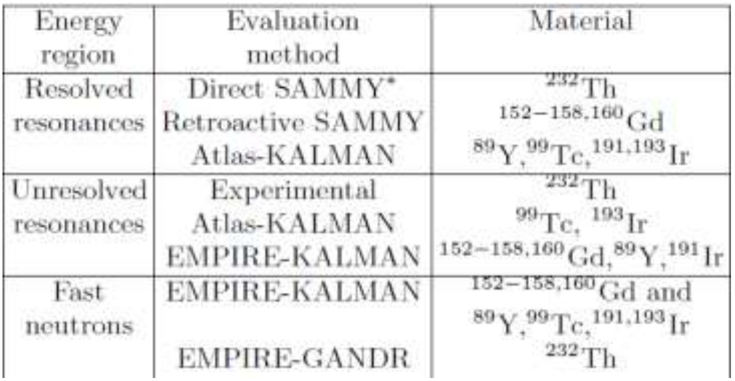
COMMARA-2.0 (2011)

ENDF/B-VII.1 (2011)



http://www.bnl.gov/isd/documents/41668.pdf

ENDF/B-VII.0(2006) contained only 26 (13 retained from VI.8)



Energy region	Evaluation method	Material
Resolved resonances	Direct SAMMY* Retroactive SAMMY Atlas-KALMAN	^{232}Th $^{152-158,160}$Gd ^{89}Y, ^{99}Tc, ^{191,193}Ir
Unresolved resonances	Experimental Atlas-KALMAN EMPIRE-KALMAN	^{232}Th ^{99}Tc, ^{193}Ir $^{152-158,160}$Gd, ^{89}Y, ^{191}Ir
Fast neutrons	EMPIRE-KALMAN EMPIRE-GANDR	$^{152-158,160}$Gd and ^{89}Y, ^{99}Tc, ^{191,193}Ir ^{232}Th

Integral Experiment Correlations

Is the best that can be done is to assign ‘0’ or ‘1’?

In any moment of decision, the best thing you can do is the right thing, the next best thing is the wrong thing, and the worst thing you can do is nothing.

Theodore Roosevelt

The idea is to try to give all the information to help others to judge the value of your contribution; not just the information that leads to judgment in one particular direction or another.

Richard P. Feynman

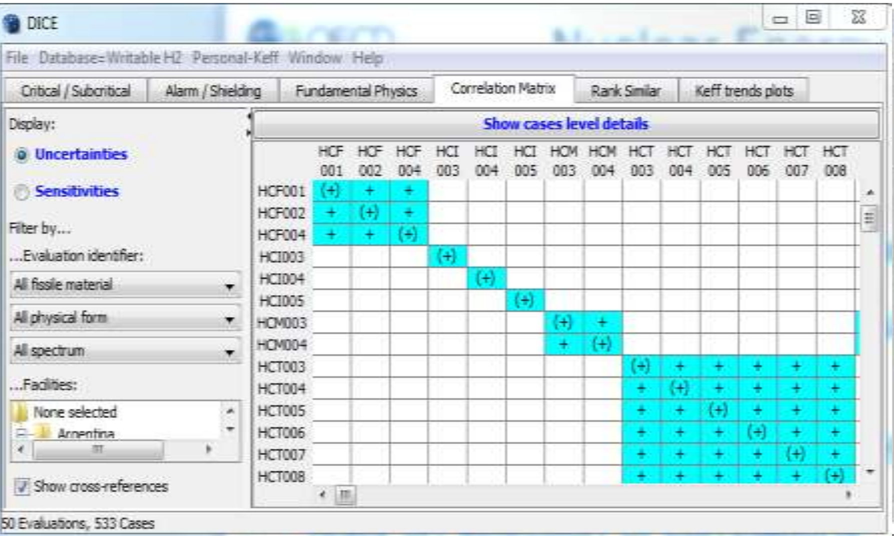
Status of Existing Correlations (DICE Correlation Matrix Tab)

Correspond to the correlations of benchmark model uncertainties

- **Level 1 correlations show that evaluations are correlated**
- **Level 2 correlations give the quantitative information about the correlations between cases**
- **Currently 94 cases have correlation data [level2] in DICE**

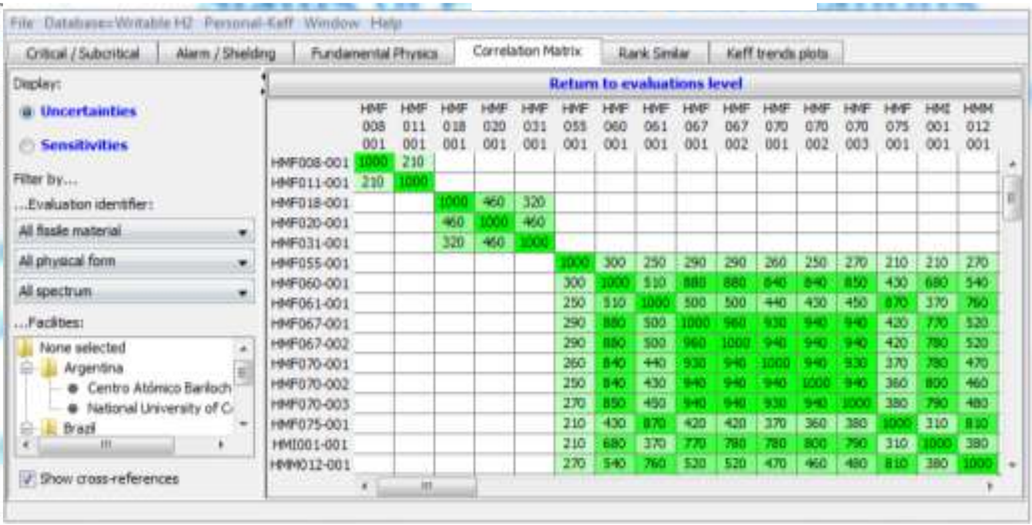
(or ~2%). Level 2 required for analysis.

$$\rho_{12} = \frac{\sum \sigma_1{}^X \rho \sigma_2{}^X}{\sigma_1{}^T \sigma_2{}^T}$$



	HCF 001	HCF 002	HCF 004	HCI 003	HCI 004	HCI 005	HCM 003	HCM 004	HCT 003	HCT 004	HCT 005	HCT 006	HCT 007	HCT 008
HCF001	(+)	+	+											
HCF002	+	(+)	+											
HCF004	+	+	(+)											
HCI003				(+)										
HCI004					(+)									
HCI005						(+)								
HCM003							(+)	+						
HCM004							+	(+)						
HCT003									(+)	+	+	+	+	+
HCT004									+	(+)	+	+	+	+
HCT005									+	+	(+)	+	+	+
HCT006									+	+	+	(+)	+	+
HCT007									+	+	+	+	(+)	+
HCT008									+	+	+	+	+	(+)

50 Evaluations, 533 Cases



	HMF 008 001	HMF 011 001	HMF 018 001	HMF 020 001	HMF 031 001	HMF 055 001	HMF 060 001	HMF 061 001	HMF 067 001	HMF 067 002	HMF 070 001	HMF 070 002	HMF 070 003	HMF 075 001	HMI 001 001	HMM 012 001
HMF008-001	1000	210														
HMF011-001	210	1000														
HMF018-001			1000	460	320											
HMF020-001			460	1000	460											
HMF031-001			320	460	1000											
HMF055-001						1000	300	250	290	290	260	250	270	210	210	270
HMF060-001						300	1000	510	880	880	840	840	850	430	680	540
HMF061-001						250	510	1000	500	500	440	430	450	870	370	760
HMF067-001						290	880	500	1000	960	930	940	940	420	770	520
HMF067-002						290	880	500	960	1000	940	940	940	420	780	520
HMF070-001						260	840	440	930	940	1000	940	930	370	780	470
HMF070-002						250	840	430	940	940	940	1000	940	360	800	460
HMF070-003						270	850	450	940	940	930	940	1000	380	790	480
HMF075-001						210	430	870	420	420	370	360	380	1000	310	810
HMI001-001						210	680	370	770	780	780	800	790	310	1000	380
HMM012-001						270	540	760	520	520	470	460	480	810	380	1000

2015 May: ICSBEP Technical Review Group Meeting

Proposal For Developing Correlations Within an Evaluation For Legacy Experiments

1) Extract uncertainties in the evaluation in a form suitable for future inclusion in a database. **[NEA Intern]** →Hiroshi Kikusato
2) Compute the percentage contribute of different uncertainties **[NEA Intern]**
3) Identify top contributors (Usually a few contributors make 90% of the uncertainty) **[NEA Intern]**
4) With the help of section 2, consider if these components change between cases **[NEA Intern First cut + Experts]**
5) Assign correlation between top components **[Experts]**
6) Excel sheet computes the amount of shared uncertainty between two cases in one evaluation **[Spreadsheet developed at NEA—prototype developed by I.Hill, J. Dyrda]**

Other contributors are treated as uncorrelated (thus total is likely underestimated)

Aim: Use above procedure to generate 1000 decent correlation coefficients in 2 years.

Incorporate feedback + support from UACSA group?

Could provide tools to test the performance in applications

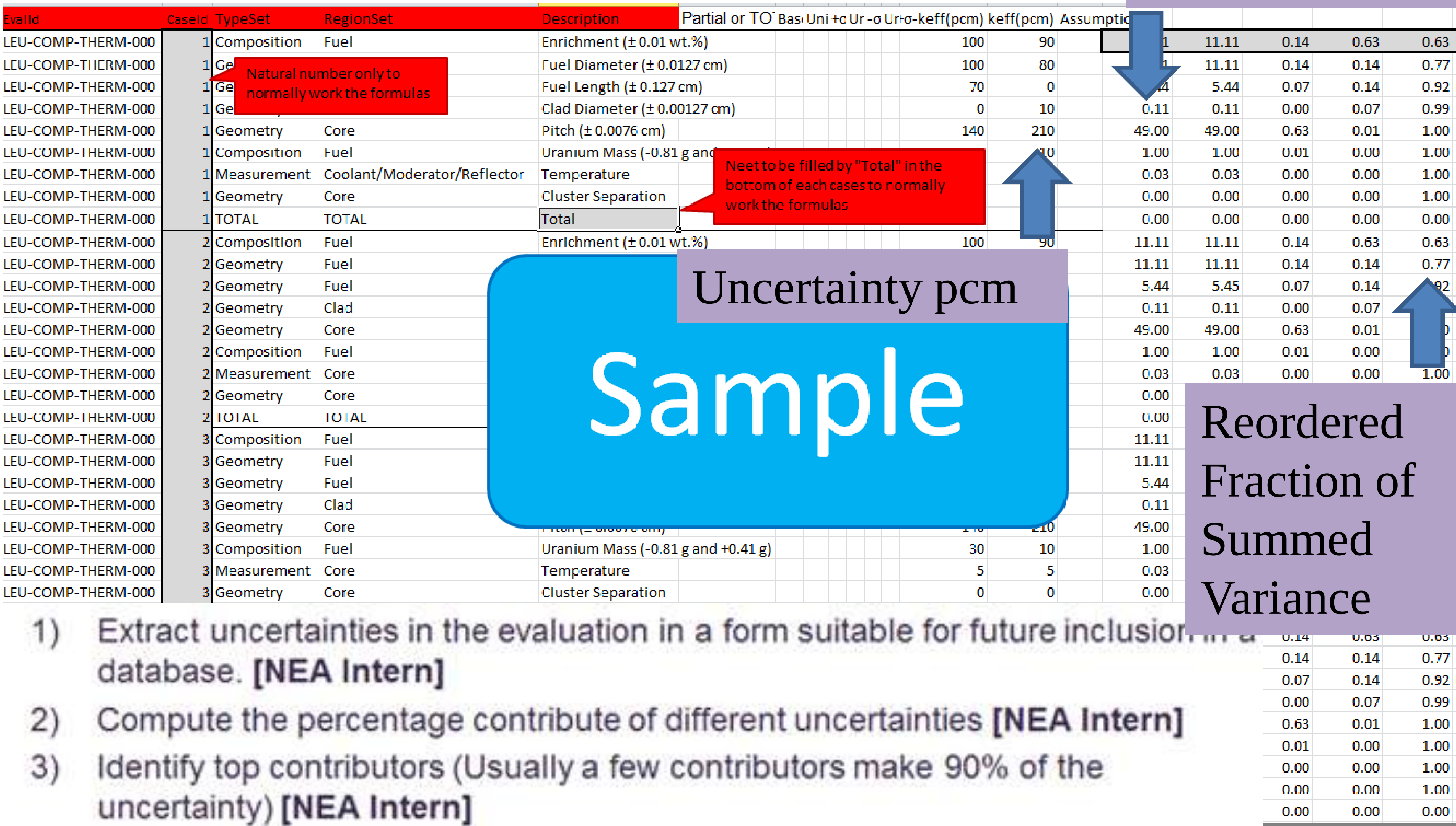
1. **Something is better than nothing.**
2. **Try to get 80% of the way with 20% effort**

Goal to provide as many, hopefully 1000’s of correlations. Synergy with the provided sensitivity files.

The next step is for DICE to combine the correlation data with the sensitivity data to help identify experiments for testing nuclear data, and for crit saftey applications.

<u>Subgroup formed with ICSBEP TRG</u>

Example of Data Extraction Sheet



Percentage of Total Variance

Natural number only to normally work the formulas

Neet to be filled by "Total" in the bottom of each cases to normally work the formulas

Uncertainty pcm

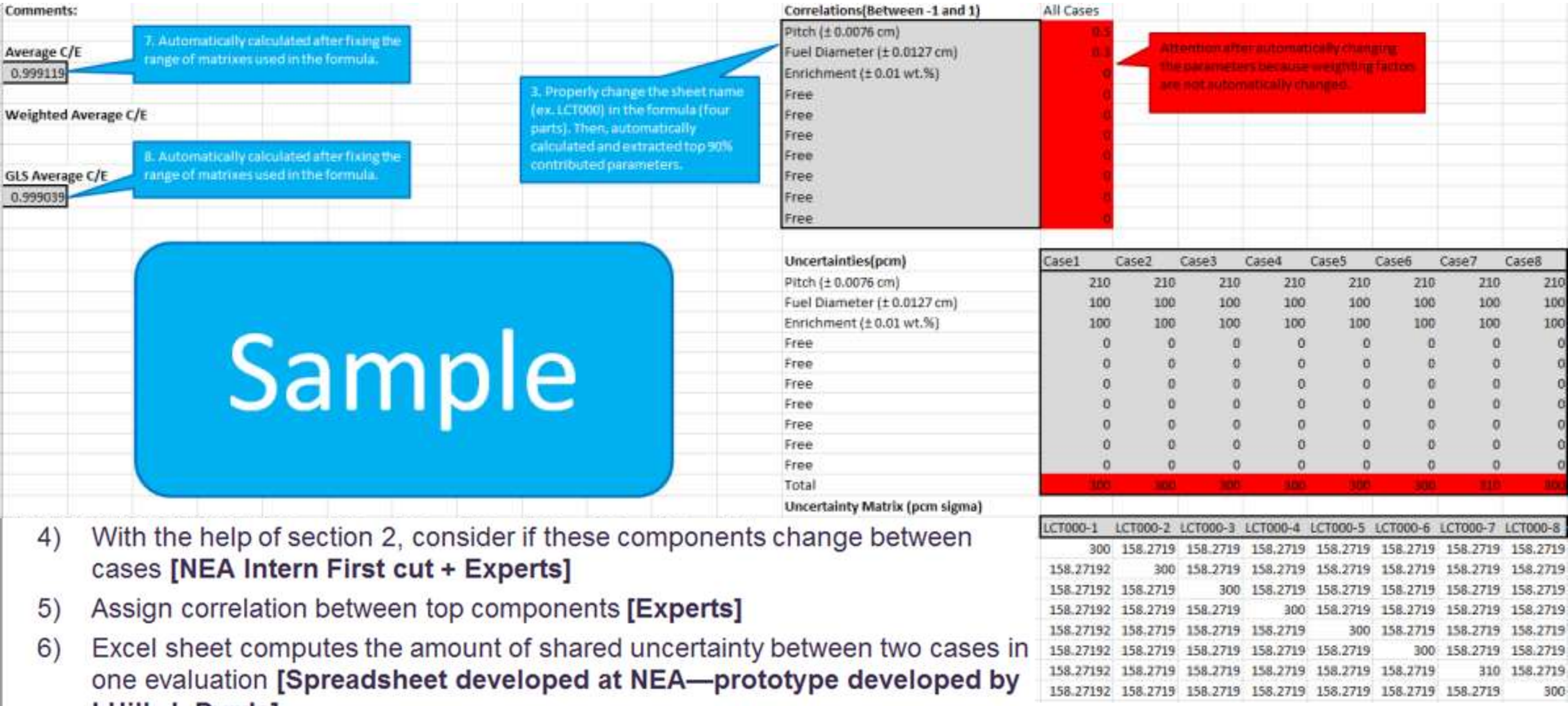
Sample

Reordered Fraction of Summed Variance

EvalId	CaseId	TypeSet	RegionSet	Description	Partial or TO	Bas	Uni +σ	Ur -σ	Ur+σ-keff(pcm)	keff(pcm)	Assumptio					
LEU-COMP-THERM-000	1	Composition	Fuel	Enrichment (± 0.01 wt.%)					100	90		[illegible]	11.11	0.14	0.63	0.63
LEU-COMP-THERM-000	1	Ge		Fuel Diameter (± 0.0127 cm)					100	80		[illegible]	11.11	0.14	0.14	0.77
LEU-COMP-THERM-000	1	Ge		Fuel Length (± 0.127 cm)					70	0		[illegible]	5.44	0.07	0.14	0.92
LEU-COMP-THERM-000	1	Ge		Clad Diameter (± 0.00127 cm)					0	10		0.11	0.11	0.00	0.07	0.99
LEU-COMP-THERM-000	1	Geometry	Core	Pitch (± 0.0076 cm)					140	210		49.00	49.00	0.63	0.01	1.00
LEU-COMP-THERM-000	1	Composition	Fuel	Uranium Mass (-0.81 g and					[illegible]	[illegible]		1.00	1.00	0.01	0.00	1.00
LEU-COMP-THERM-000	1	Measurement	Coolant/Moderator/Reflector	Temperature								0.03	0.03	0.00	0.00	1.00
LEU-COMP-THERM-000	1	Geometry	Core	Cluster Separation								0.00	0.00	0.00	0.00	1.00
LEU-COMP-THERM-000	1	TOTAL	TOTAL	Total								0.00	0.00	0.00	0.00	0.00
LEU-COMP-THERM-000	2	Composition	Fuel	Enrichment (± 0.01 wt.%)					100	90		11.11	11.11	0.14	0.63	0.63
LEU-COMP-THERM-000	2	Geometry	Fuel									11.11	11.11	0.14	0.14	0.77
LEU-COMP-THERM-000	2	Geometry	Fuel									5.44	5.45	0.07	0.14	[illegible]
LEU-COMP-THERM-000	2	Geometry	Clad									0.11	0.11	0.00	0.07	
LEU-COMP-THERM-000	2	Geometry	Core									49.00	49.00	0.63	0.01	[illegible]
LEU-COMP-THERM-000	2	Composition	Fuel									1.00	1.00	0.01	0.00	[illegible]
LEU-COMP-THERM-000	2	Measurement	Core									0.03	0.03	0.00	0.00	1.00
LEU-COMP-THERM-000	2	Geometry	Core									0.00				
LEU-COMP-THERM-000	2	TOTAL	TOTAL									0.00				
LEU-COMP-THERM-000	3	Composition	Fuel									11.11				
LEU-COMP-THERM-000	3	Geometry	Fuel									11.11				
LEU-COMP-THERM-000	3	Geometry	Fuel									5.44				
LEU-COMP-THERM-000	3	Geometry	Clad									0.11				
LEU-COMP-THERM-000	3	Geometry	Core	Pitch (± 0.0076 cm)					140	210		49.00				
LEU-COMP-THERM-000	3	Composition	Fuel	Uranium Mass (-0.81 g and +0.41 g)					30	10		1.00				
LEU-COMP-THERM-000	3	Measurement	Core	Temperature					5	5		0.03				
LEU-COMP-THERM-000	3	Geometry	Core	Cluster Separation					0	0		0.00				
														0.14	0.63	0.63
														0.14	0.14	0.77
														0.07	0.14	0.92
														0.00	0.07	0.99
														0.63	0.01	1.00
														0.01	0.00	1.00
														0.00	0.00	1.00
														0.00	0.00	1.00
														0.00	0.00	0.00

1) Extract uncertainties in the evaluation in a form suitable for future inclusion in a database. **[NEA Intern]**
2) Compute the percentage contribute of different uncertainties **[NEA Intern]**
3) Identify top contributors (Usually a few contributors make 90% of the uncertainty) **[NEA Intern]**

Example of Covariance Sheet



Comments:

Average C/E
0.999119

7. Automatically calculated after fixing the range of matrixes used in the formula.

Weighted Average C/E

GLS Average C/E
0.999039

8. Automatically calculated after fixing the range of matrixes used in the formula.

3. Properly change the sheet name (ex. LCT000) in the formula (four parts). Then, automatically calculated and extracted top 90% contributed parameters.

Sample

Correlations(Between -1 and 1)	All Cases
Pitch (± 0.0076 cm)	0.5
Fuel Diameter (± 0.0127 cm)	0.1
Enrichment (± 0.01 wt.%)	0
Free	0
Free	0
Free	0
Free	0
Free	0
Free	0
Free	0

Attention after automatically changing the parameters because weighting factors are not automatically changed.

Uncertainties(pcm)	Case1	Case2	Case3	Case4	Case5	Case6	Case7	Case8
Pitch (± 0.0076 cm)	210	210	210	210	210	210	210	210
Fuel Diameter (± 0.0127 cm)	100	100	100	100	100	100	100	100
Enrichment (± 0.01 wt.%)	100	100	100	100	100	100	100	100
Free	0	0	0	0	0	0	0	0
Free	0	0	0	0	0	0	0	0
Free	0	0	0	0	0	0	0	0
Free	0	0	0	0	0	0	0	0
Free	0	0	0	0	0	0	0	0
Free	0	0	0	0	0	0	0	0
Free	0	0	0	0	0	0	0	0
Total	300	300	300	300	300	300	310	300

Uncertainty Matrix (pcm sigma)

LCT000-1	LCT000-2	LCT000-3	LCT000-4	LCT000-5	LCT000-6	LCT000-7	LCT000-8
300	158.2719	158.2719	158.2719	158.2719	158.2719	158.2719	158.2719
158.27192	300	158.2719	158.2719	158.2719	158.2719	158.2719	158.2719
158.27192	158.2719	300	158.2719	158.2719	158.2719	158.2719	158.2719
158.27192	158.2719	158.2719	300	158.2719	158.2719	158.2719	158.2719
158.27192	158.2719	158.2719	158.2719	300	158.2719	158.2719	158.2719
158.27192	158.2719	158.2719	158.2719	158.2719	300	158.2719	158.2719
158.27192	158.2719	158.2719	158.2719	158.2719	158.2719	310	158.2719
158.27192	158.2719	158.2719	158.2719	158.2719	158.2719	158.2719	300

4) With the help of section 2, consider if these components change between cases **[NEA Intern First cut + Experts]**
5) Assign correlation between top components **[Experts]**
6) Excel sheet computes the amount of shared uncertainty between two cases in one evaluation **[Spreadsheet developed at NEA—prototype developed by I.Hill, J. Dyrda]**

Status of Groundwork

Good Progress! (~100 evaluations ~1000 cases)
✓Well structured, reusable, transparent
✓Allows looking across many evaluations
✓Quick feedback of important terms
✓Quick Correlation Matrix Generation (within approx)

Posted the excel sheet to the protected area of ICSBEP Technical Review Group Area. Have shared with some interested parties. No restrictions per se.

Features:

✓ Uncertainties LCT and HMF cases have been extracted to excel;

✓ Extraction compatible with incorporation into DICE (leverage experience with schema for keff unc in IDAT);

✓ Assigned ‘types’ and ‘regions’ and ‘descriptions’;

✓ All uncertainties in pcm;

✓ Sheets automatically calculate the fraction of variance and flag the top 90%;

✓ Allows correlation value to be assigned to top components and automatically propagates computes the correlation matrix;

✓ Computes ‘Average’ and ‘GLS average’

Why Say LoFi?

Issue	Lo-Fi	Hi-Fi	Consequence of Lo-Fi
Are Section 2 Uncertainties Correct?	Yes	No	No re-evaluation is done.
Uncertainties Considered	Top 90% Variance	All (often reduced also)	Significantly limits # of terms. Assumption needed for component not considered.
Sampling Method	None	Monte Carlo	Very quick ☺
Cross term dependence	No (avoid!)	Yes	Need to avoid
Ambiguous sign of sensitivity coefficient	Avoid	Non issue	Can have sign dependence rho (to fudge)
Judgement required	Yes	Yes	Always need pesky human judgement
Across Different Evaluations	No	Yes	Could do, but not low hanging fruit
Matching Total vs. Quad Total	Tricky	Consistent	Subjective (can be large impact)

99% of time is spent reading the evaluation….judgement part

Examples: LCT-021 and LCT-022

Uncertainties(pcm)	Case1	Case2	Case3	Case4	Case5	Case6
Clad Thickness	400	400	400	72	72	72
Boron Concentration	384	384	384	130	130	130
Enrichment	338	338	338	363	363	363
Experimental Uncertalnty	300	300	300	300	300	300
Pitch	5	5	5	270	270	270

Sum shared (ρ=1) and unshared (ρ=0)

	LCT021-1	LCT021-2	LCT021-3	LCT021-4	LCT021-5	LCT021-6
LCT021-1	1.000	0.784	0.784	0.408	0.408	0.408
LCT021-2	0.784	1.000	0.784	0.408	0.408	0.408
LCT021-3	0.784	0.784	1.000	0.408	0.408	0.408
LCT021-4	0.408	0.408	0.408	1.000	0.694	0.694
LCT021-5	0.408	0.408	0.408	0.694	1.000	0.694
LCT021-6	0.408	0.408	0.408	0.694	0.694	1.000

Case1 and Case2

$$\rho_{12} = \frac{\sum \sigma_1{}^X \rho \sigma_2{}^X}{\sigma_1{}^T \sigma_2{}^T}$$

Uncertainties(pcm)	Case1	Case2	Case3	Case4	Case5	Case6	Case7
External Diameter of Fuel Rod Clad	280	280	110	80	50	20	20
234U and 236U	180	180	80	65	50	30	30
Clad Mass and Composition	180	180	220	230	240	240	240
Enrichment	150	150	180	205	230	290	290
Pitch of Fuel	140	140	70	40	10	50	50
Fuel Pellet Diameter	50	50	40	65	90	200	200

	LCT022-1	LCT022-2	LCT022-3	LCT022-4	LCT022-5	LCT022-6	LCT022-7
LCT022-1	1.000	0.962	0.845	0.771	0.682	0.596	0.596
LCT022-2	0.962	1.000	0.845	0.771	0.682	0.596	0.596
LCT022-3	0.845	0.845	1.000	0.955	0.919	0.840	0.840
LCT022-4	0.771	0.771	0.955	1.000	0.961	0.903	0.903
LCT022-5	0.682	0.682	0.919	0.961	1.000	0.936	0.936
LCT022-6	0.596	0.596	0.840	0.903	0.936	1.000	0.977
LCT022-7	0.596	0.596	0.840	0.903	0.936	0.977	1.000

Clearly more difficult when ρ is somewhere between 0 and 1. Best to decompose if possible…..

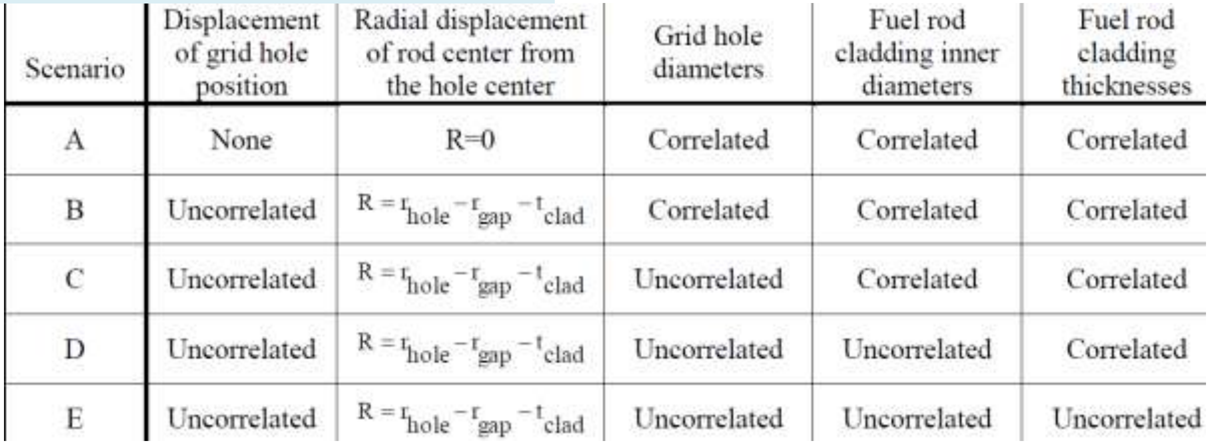
ρ between 0 and 1

The judgement part…..

- **Hypothesis 1:** Answers to certain questions about experimental procedure will change the probability that uncertainty is shared.

You Never Have Complete Info on This

You Have Something Less Precise



Scenario	Displacement of grid hole position	Radial displacement of rod center from the hole center	Grid hole diameters	Fuel rod cladding inner diameters	Fuel rod cladding thicknesses
A	None	R=0	Correlated	Correlated	Correlated
B	Uncorrelated	$R = r_{hole} - r_{gap} - t_{clad}$	Correlated	Correlated	Correlated
C	Uncorrelated	$R = r_{hole} - r_{gap} - t_{clad}$	Uncorrelated	Correlated	Correlated
D	Uncorrelated	$R = r_{hole} - r_{gap} - t_{clad}$	Uncorrelated	Uncorrelated	Correlated
E	Uncorrelated	$R = r_{hole} - r_{gap} - t_{clad}$	Uncorrelated	Uncorrelated	Uncorrelated

<u>Example Questions Influencing ρ, for Shared Pitch Uncertainty:</u>

a) Was the core rebuilt between measurements?

b) Was the same grid plate used?

c) Were new fuel elements used?

d) Were fuel elements taken from the same batch?

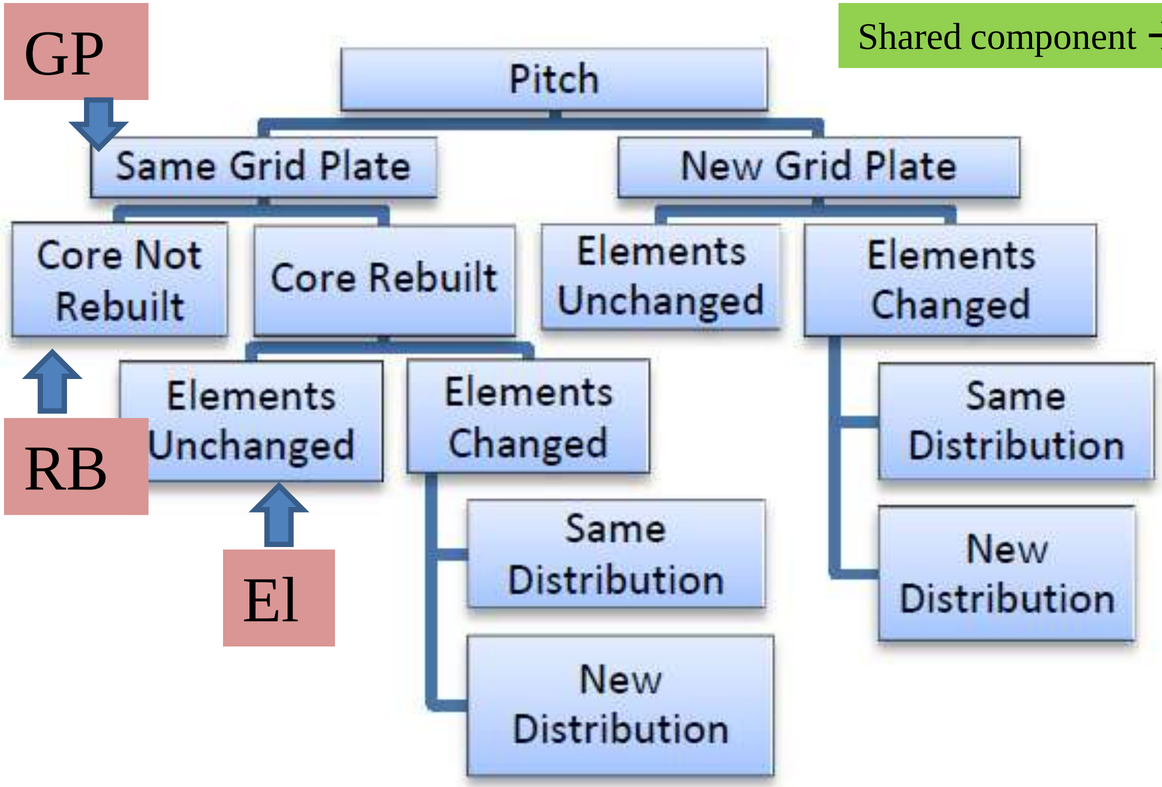
e)When were the measurements done?

Working with information within existing evaluation. UACSA can help recommend how to improve existing information!

Decision Trees (1)

- Number of questions are an infinite set/intractable, so are naturally limited to the most significant.
- Questions posed are ones that can often be answered or inferred by reading the evaluation

More branches can be added! (limited here to questions that often have answers)



- Pitch
  - Same Grid Plate
    - Core Not Rebuilt
    - Core Rebuilt
      - Elements Unchanged
      - Elements Changed
        - Same Distribution
        - New Distribution
  - New Grid Plate
    - Elements Unchanged
    - Elements Changed
      - Same Distribution
      - New Distribution

GP

RB

El

Shared component →

$$\sigma_P{}^2 = \sigma_{GP}{}^2+\sigma_{El}{}^2+\sigma_{RB}{}^2$$

GP	EL	RB	ρ
0	0	0	→0
0	0	1	?
			?
			?
1	0	0	?
1	0	1	?
1	1	0	?
1	1	1	→1

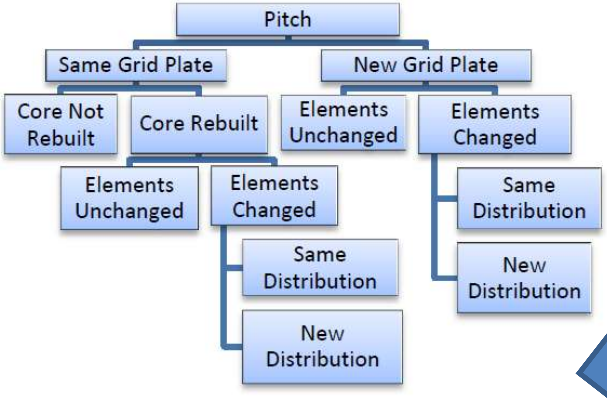
Depicted as discrete but can be fuzzy

Decision Trees (2)

Hypothesis 2: In the absence of other relevant information it is reasonable to use the same judgement for fraction of shared uncertainty. So trees can be reused.

Jaynes calls this principle a Desideratum of Consistency, and it is to be used in the assignment of a priori pro babilities. This Desideratum of Consistency is: "In two problems where we have the same a priori information we should assign the same a priori probability."

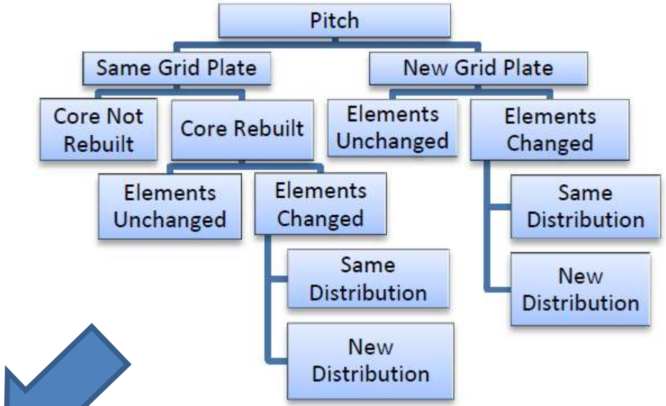
Evaluation LCT-AAA
Cases Y



- Pitch
  - Same Grid Plate
    - Core Not Rebuilt
    - Core Rebuilt
      - Elements Unchanged
      - Elements Changed
        - Same Distribution
        - New Distribution
  - New Grid Plate
    - Elements Unchanged
    - Elements Changed
      - Same Distribution
      - New Distribution

GP	EL	RB	ρ
0	0	0	→0
0	0	1	?
0	1	0	?
0	1	1	?
1	0	0	?
1	0	1	?
1	1	0	?
1	1	1	→1

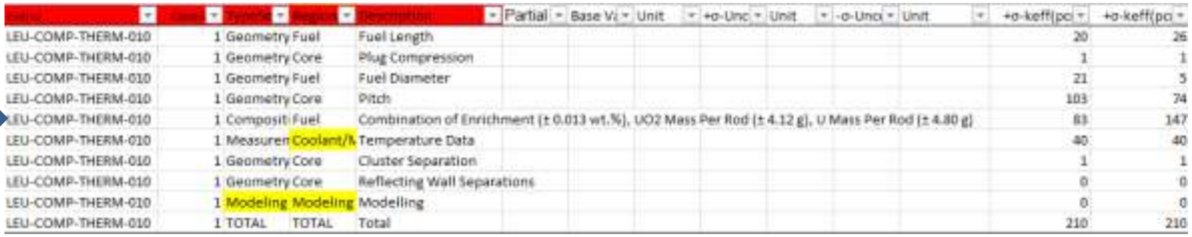
Evaluation LCT-BBB
Cases Z



- Pitch
  - Same Grid Plate
    - Core Not Rebuilt
    - Core Rebuilt
      - Elements Unchanged
      - Elements Changed
        - Same Distribution
        - New Distribution
  - New Grid Plate
    - Elements Unchanged
    - Elements Changed
      - Same Distribution
      - New Distribution

Overview of Procedure

Extract Uncertainties



[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Partial	Base V:	Unit	+σ-Unc	Unit	-σ-Unc	Unit	+σ-keff(pc	+σ-keff(pc
LEU-COMP-THERM-010	1	Geometry	Fuel	Fuel Length								20	26
LEU-COMP-THERM-010	1	Geometry	Core	Plug Compression								1	1
LEU-COMP-THERM-010	1	Geometry	Fuel	Fuel Diameter								21	5
LEU-COMP-THERM-010	1	Geometry	Core	Pitch								103	74
LEU-COMP-THERM-010	1	Composit	Fuel	Combination of Enrichment (± 0.013 wt.%), UO2 Mass Per Rod (± 4.12 g), U Mass Per Rod (± 4.80 g)								83	147
LEU-COMP-THERM-010	1	Measurem	Coolant/N	Temperature Data								40	40
LEU-COMP-THERM-010	1	Geometry	Core	Cluster Separation								1	1
LEU-COMP-THERM-010	1	Geometry	Core	Reflecting Wall Separations								0	0
LEU-COMP-THERM-010	1	Modeling	Modeling	Modelling								0	0
LEU-COMP-THERM-010	1	TOTAL	TOTAL	Total								210	210

Make ‘Trees/Rules’

Note: Rule = leaf on decision tree

Rule 1.1) Same fuel elements used [Assign c=0.99]

Currently have 34 rules + sub rules

Assign Uncertainty Component to a Tree Branch/Rule

Output Correlation Matrix

	C1	C2	C3	C4	C5	C6	C7
C1	1.000	0.861	0.728	0.663	0.602	0.530	0.530
C2	0.861	1.000	0.728	0.663	0.602	0.530	0.530
C3	0.728	0.728	1.000	0.791	0.781	0.720	0.720
C4	0.663	0.663	0.791	1.000	0.815	0.773	0.773
C5	0.602	0.602	0.781	0.815	1.000	0.822	0.822
C6	0.530	0.530	0.720	0.773	0.822	1.000	0.866
C7	0.530	0.530	0.720	0.773	0.822	0.866	1.000

Wrote a Document With the Trees and Assignment of Leaves

- These rules are decision tree for assigning how much of an uncertainty component is shared between cases.
- This helps to encode ‘expert’ judgement based on a given set of questions/information.
- Rules offer a repeatable, transparent, consistent, procedure that can reproduced.
- These rules were made in consultation with some evaluators, but are user dependent [some obvious some not].

Most rules are simple!

Avoiding Complicated Cases.

- Allows users to generate their own covariance data.
- Impact of different assumptions can be tested (combined with ND, chi squared etc)

Using the top 90% of variance, match the rules with the uncertainty terms.

If information was outside of the existing rules, then expand tree

Correlation assignment:

a) Water gap between core and screen c=0.2. **Rule 3.3**.

b) Critical water height c=0.2. **Rule 8**.

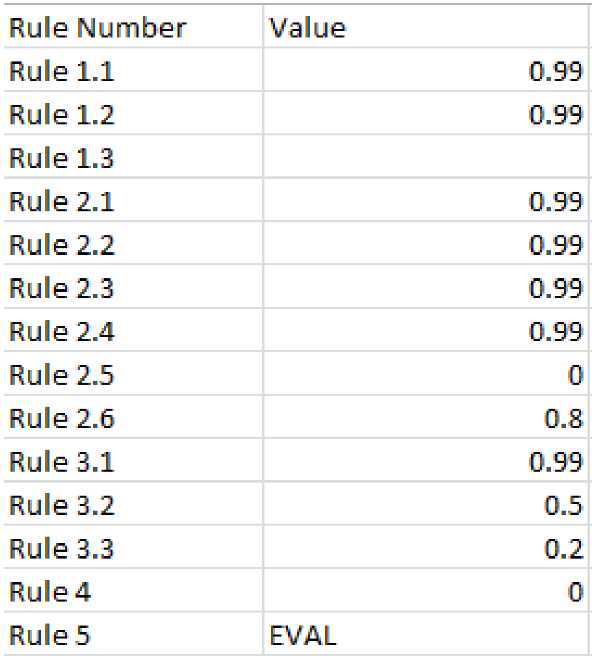
c) Fuel Diameter c=0.99. **Rule 1.1**.

d) Temperature c=0.2. **Rule 7**.

e) Cladding outer diameter c=0.99. **Rule 1.1**.

FYI: 20% is a commonly assumed systematic uncertainty in modern ICSBEP evaluations

- If you don't like a correlation, you chose a new value for the rule, and the correlation matrix updates automatically



Rule Number	Value
Rule 1.1	0.99
Rule 1.2	0.99
Rule 1.3	
Rule 2.1	0.99
Rule 2.2	0.99
Rule 2.3	0.99
Rule 2.4	0.99
Rule 2.5	0
Rule 2.6	0.8
Rule 3.1	0.99
Rule 3.2	0.5
Rule 3.3	0.2
Rule 4	0
Rule 5	EVAL

After making many trees and much reading…

Note: Largest Eigenvalue/Case similar to average correlation

Evaluation	#Cases	Largest Eigenvalue/#Cases
LCT001	8	0.95
LCT003	22	0.47
LCT004	20	0.54
LCT 006	18	0.80
LCT 009	27	0.83
LCT 010	30	0.80
LCT 016	32	0.92
LCT 017	29	0.81
LCT 021	6	0.62
LCT 022	7	0.84
LCT 025	4	0.98
LCT 026	6	0.88
LCT 027	4	0.64
LCT 028	20	0.91
LCT 029	12	0.67
LCT 032	9	0.78
LCT 033	52	0.35
LCT 034	26	0.53
LCT 035	3	0.80
LCT 037	11	0.61

Evaluation	#Cases	Largest Eigenvalue/#Cases
LCT 038	14	0.30
LCT 039	17	0.94
LCT 042	7	0.59
LCT 043	9	0.93
LCT 044	10	0.95
LCT 045	21	0.44
LCT 046	22	0.92
LCT 047	3	0.95
LCT 054	8	0.93
LCT 057	36	0.48
LCT 058	9	0.93
LCT 061	10	0.90
LCT 066	10	0.37
LCT 068	17	0.67
LCT 070	12	0.97
LCT 071	4	0.85
LCT 072	9	0.68
LCT 074	4	0.95
LCT 075	6	0.94

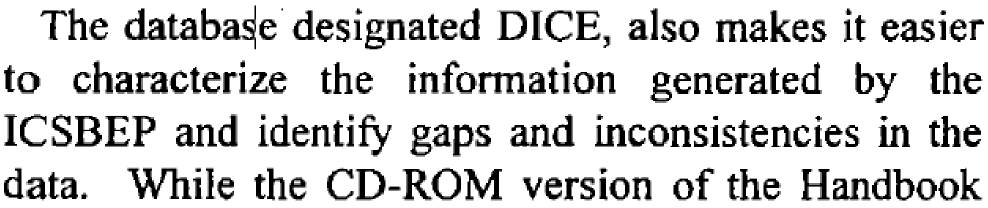
Next Phase: More Experiment Types, Impact on Fits and Adjustment

- Move to HMT experiments [Mostly a new set of trees]
- Check chi-squared values with different assumptions
- Check impact on nuclear data adjustment

<u>Long term:</u>

Incorporate all information in DICE. (Not so long ☺)

Form entire uncertainty matrix; allow better identification of outliers, and better identification for experiment sets that can be used to test nuclear data. Show which C/E variations not explain by nuclear data or experimental uncertainties)



The database designated DICE, also makes it easier to characterize the information generated by the ICSBEP and identify gaps and inconsistencies in the data. While the CD-ROM version of the Handbook

http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/39/077/39077391.pdf

Help ND evaluators, other practitioners find relevant experiments!

Conclusion

- Think about shared uncertainty when doing validation
- Currently in DICE Correlations of benchmark uncertainties are available for ~ 100 configurations….hopefully increased soon

Considering adding Lo-Fi correlations 2016? 2017?

- Work is going on to create low-fidelity correlations and decision trees for establishing correlations:
  - Rules based correlation used to increase the correlation data by a factor of five
  - Uncertainties extracted into excel
  - Trees developed
  - Major uncertainties assigned to a rule
  - Users can provide own values for rules and correlation coefficients are automatically updated
  - Documentation needs to be developed more…draft available for comment.