IRSN contributions : *from TARs and S/U to V&UQ via DA*

Key Actions *and*

New proposals

IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE
Faire avancer la sûreté nucléaire

Layout

- Introduction (motivation)
  - general statements
- Data Assimilation (Bayesian-based inference)
  - Nuclear Data evaluation
  - ND libraries V&UQ
  - problem-oriented basic research
- V&UQ using Data Assimilation
  - basic statements and protocol
  - required inputs: IEs and CND
- TARs: complexities and opportunities
  - LWRs and safety assessment issues
  - MSFR concepts and an issue of controllability
- Potential deliverables

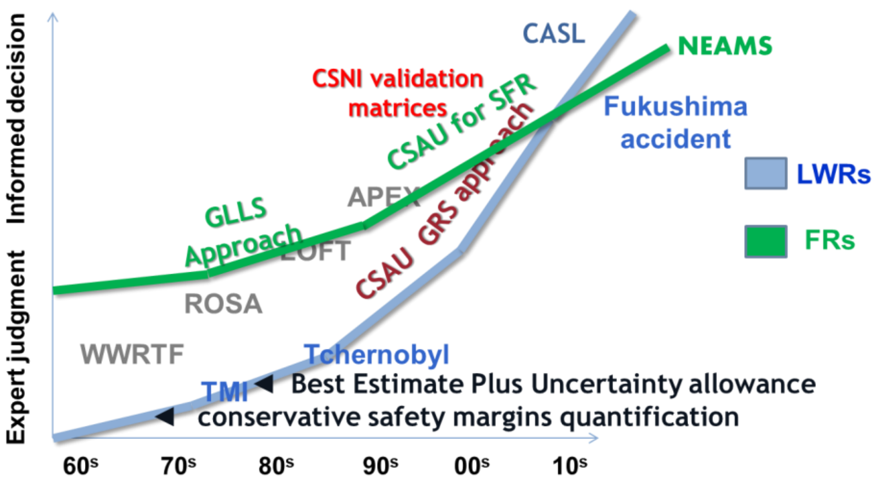
Phenomenological validation: objectives and trends

Commonly shared

- **progressive growth** => computational capacities & enhanced role of simulations
- imperative => all statements **to have a solid basis in reality**
- to be addressed => how far can we rely on modeling and do we have **a guidance for predictive capability maturity (PCM) characterization**
- In our understanding, PCM assessment = Validation => an entity made of => **Application Domain (applicability) characterization + Uncertainty Quantification**
- **Validation has become a specific scientific discipline with its own concept system**

Good practice and collaborations

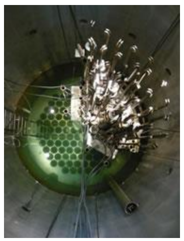
- **comparison with analogues**: Plant Measurements and Observations and experiments data (ex. CASL: *Consortium for Advanced Simulation of Light water reactorswww.casl.gov, 2014*)
- **an understanding of sources** of uncertainties: Uncertainty identification and propagation (ex. GRS-like approach: *E. Ivanov, B. Rearden, J. Baccou and K. Velkov, "Role of a phenomenological validation and integral experiments for maturing the predictive simulations", NED, V 362, 2020*)

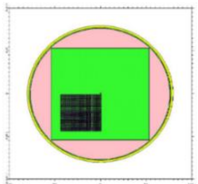


Phenomenological validation: practice and worldwide trends

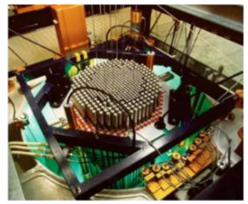
From comparison

- Legacy and newly designed IEs

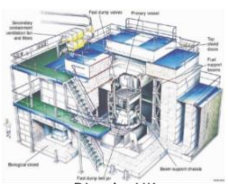




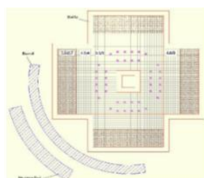
KRITZ, Sweden
(MOX, reactivity, reaction rates)



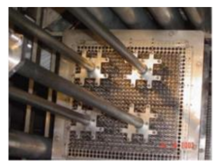
CROCUS, Switzerland
(transient processes)



Dimple, UK
(low power/ burnt fuel ~1% fima)



VENUS, Belgium
(zero power facility)



IPEN, Brazil
(UOX, reactivity, rates, kinetics)

Experiment	K-eff	Power/ Reaction rate	Temp. Effects	Spectral Indices	Kinetics	Borated/ Unborated	UO2/ MOX
CREOLE PWR (CREOLE-PWR-EXP-001)	Yes	Yes	Yes			Yes/ Yes	Yes/ Yes
CROCUS (CROCUS-LWR-RESR-001)	Yes				Yes	Yes/ No	Yes/ No
IPEN MB1 (IPEN(MB01)-LWR-RESR-001)	Yes			Yes	Yes	No/ Yes	Yes/ No
KRITZ1 (KRITZ-LWR-RESR-001, -002, -003)*	Yes	Yes	Yes			Yes/ No	No/ Yes
TCA (TCA-LWR-EXP-001)	Yes		Yes			Yes/ Yes	Yes/ No
DIMPLE (DIMPLE-LWR-EXP-001, -002)*	Yes	Yes		Yes		No/ Yes	No /Yes
VENUS-1 (VENUS-PWR-EXP-001, -003, -005)*	Yes	Yes				No/ Yes	Yes/ No
VVER Reactor (LR0-VVER-EXP-001)**	Yes	Yes	Yes	Yes		Yes/ No	Yes/ No

Origin, basis and remarks

- References
  - Dinh, Nam. *CASL Validation Data: An Initial Review*. United States: N. p., 2011. Web. doi:10.2172/1017862
  - Hongbin Zhang, Review of Experiments for CASL Neutronics Validation (CASL-U-2012-0039-000)
  - Joel A. Kulesza, Fausto Franceschini, Thomas M. Evans and Jess C. Gehin, **Overview of the Consortium for the Advanced Simulation of Light Water Reactors (CASL)**, EPJ Web of Conferences, 106 (2016) 03002
- Notes:
- An intuitive – an expert-based judgement
- Cases selected to be similar to design, phenomena and processes one plan to deals with (<= in particular, LWRs core behavior)
- No one could be considered as fully representative (<= gaps existence)
- Once gaps being identified to be filled by newly evaluated or designed IEs data

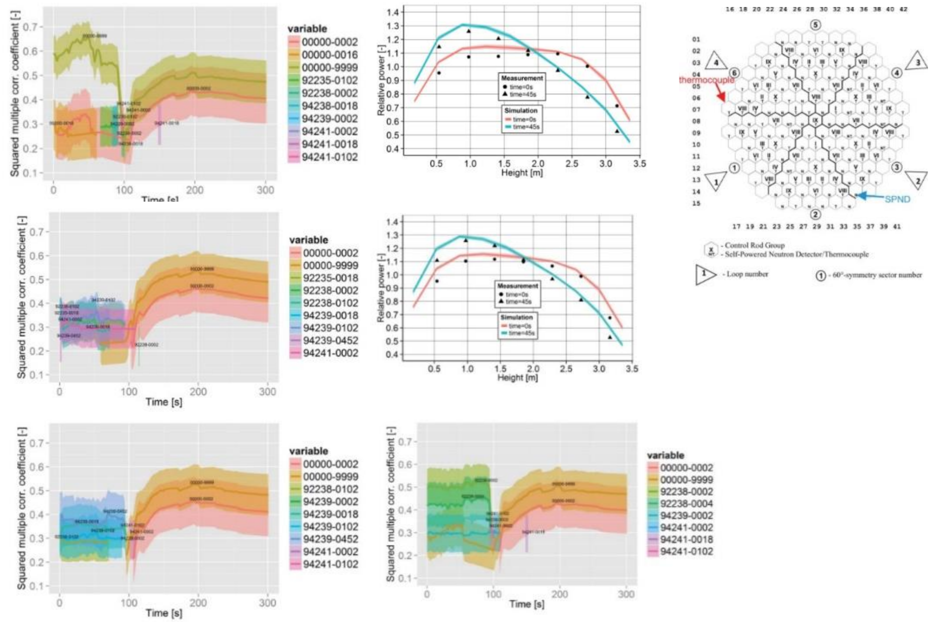
Phenomenological validation: practice and worldwide trends

Basis and remarks

- References
  - E. Ivanov, B. Rearden, J. Baccou and K. Velkov, “Role of a phenomenological validation and integral experiments for maturing the predictive simulations”, NED, V 362, 2020
  - A. Aures, N. Berner, W. Zwermann, (2020). Closing the Gap Between Sensitivity Analyses Based on Perturbation Theory and Random Sampling.
  - W. Zwermann et al, Nuclear data U/S analysis with XSUSA for fuel assembly depletion calculations, Nuclear Engineering And Technology, Volume 46, Issue 3, 2014
  - J.S. Martinez, W. Zwermann, O. Cabellos et al, Propagation of Neutron Cross Section, Fission Yield, and Decay Data Uncertainties in Depletion Calculations, Nuclear Data Sheets, Volume 118, 2014
- Conditioned
- **(IF)** fully credible Covariance matrices of Nuclear Data (CND) and other uncertainties
- Continuous dependence on parameters and no methodological errors

From understanding of uncertainties

- GRS safety assessment approach (since 90s) => SUSA, XSUSA, etc.

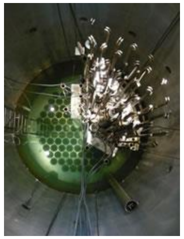


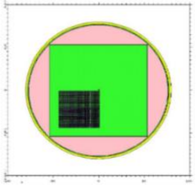
- Advantage => PMOs => known “macroscopic” output
- non-intrusive simple sampling frameworks
- Inferred contributions by XS uncertainties (CND) =>
- No links between available IEs and CNDs

Phenomenological validation: practice and worldwide trends

From comparison

- Legacy and newly designed Ies





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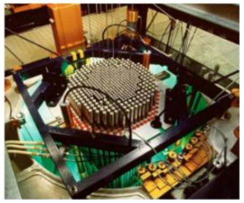

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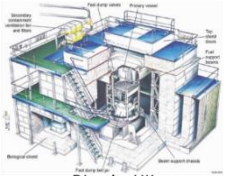

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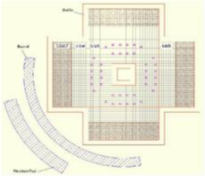

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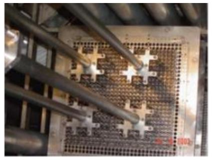


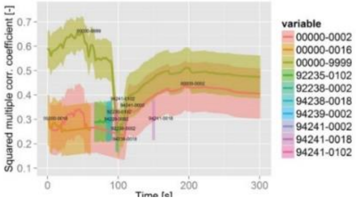
IPEN, Brazil
(UOX, reactivity, rates, kinetics)

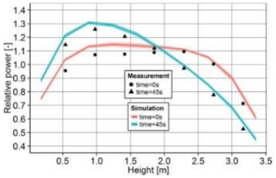
Questions to be addressed

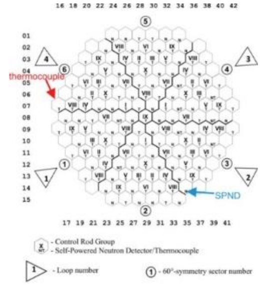
- What is beyond an Experimental Domain => could any plausible set of IEs entirely "encompass" demanded Application Domains

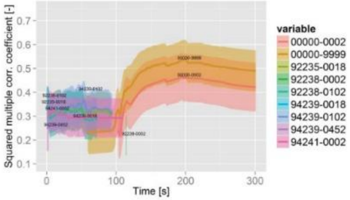
From understanding of uncertainties

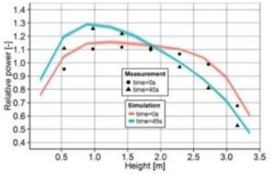
- GRS safety assessment approach (since 80s) => SUSA, XSUSA, etc.











- Consistency of CND ? in terms of an assessment <= uncertainties, as such, are not physical => non-measurable values

Not academic but practical interest to V&UQ => reliance to a Decision making support
Step toward "science-driven" validation => merging approaches within a Data Assimilation

G. Palmiotti, M. Salvatores, "The Role of Experiments and of Sensitivity Analysis in Simulation Validation Strategies with Emphasis on Reactor Physics," *Ann. Nucl. Energy*, 52, 10-21 (2013)

Data Assimilation ⇔ best fit within uncertainty bounds 1#3

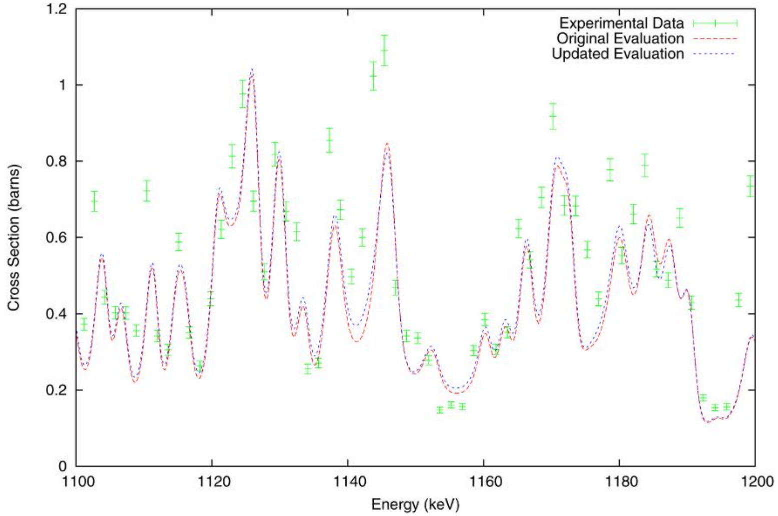
Simple lack of knowledge – *we don't know what we know* – theoretical model ⇔ almost fully consistent

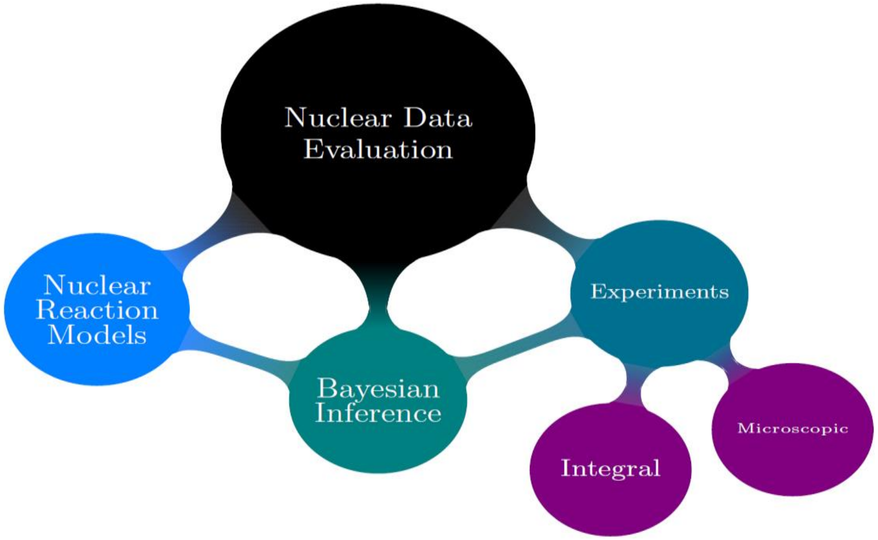
Given => new IEs data => of higher resolution than existing one [**selected representative IEs**]

Task => to adjust libraries (parameters inherent to nuclear reaction modeling) => data adjustment

=> to generate design-oriented library => ERALIB1, ABBN-78 (SFRs), ENDF/B-V (LWRs), etc.

=> to adapt general-purpose library to a given problem (Application object)





Vladimir Sobes, Luiz Leal, Goran Arbanas, Benoit Forget, Resonance Parameter Adjustment Based on Integral Experiments, Nuclear Science and Engineering | Volume 183 | Number 3 | July 2016 | Pages 347-355 (^{56}Fe inelastic XS)
C. De Saint Jean, P. Archier, E. Privas, G. Noguère, B. Habert, P. Tamagno, Evaluation of Neutron-induced Cross Sections and their Related Covariances with Physical Constraints, Nuclear Data Sheets, Volume 148

Given => PMO (boron concentrations, burn-up, reactivity effects, transfer function)

Task => *to "tune" a design-oriented (or exploitation support) tool => limited predictive capabilities*

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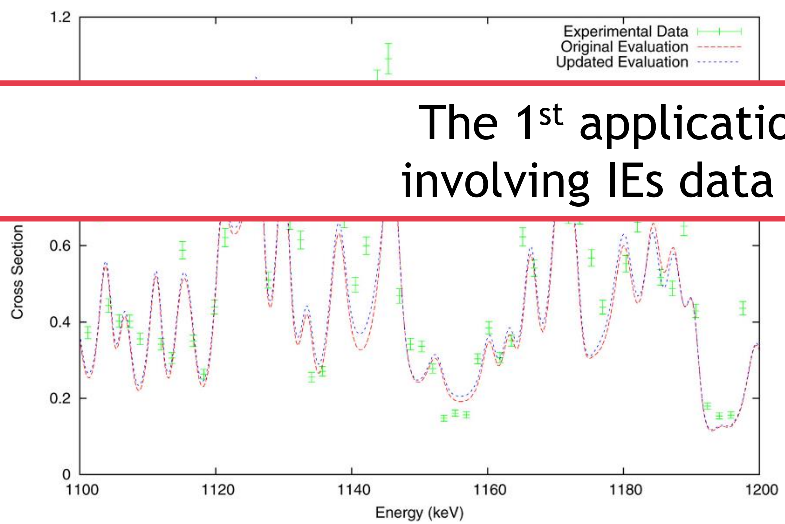

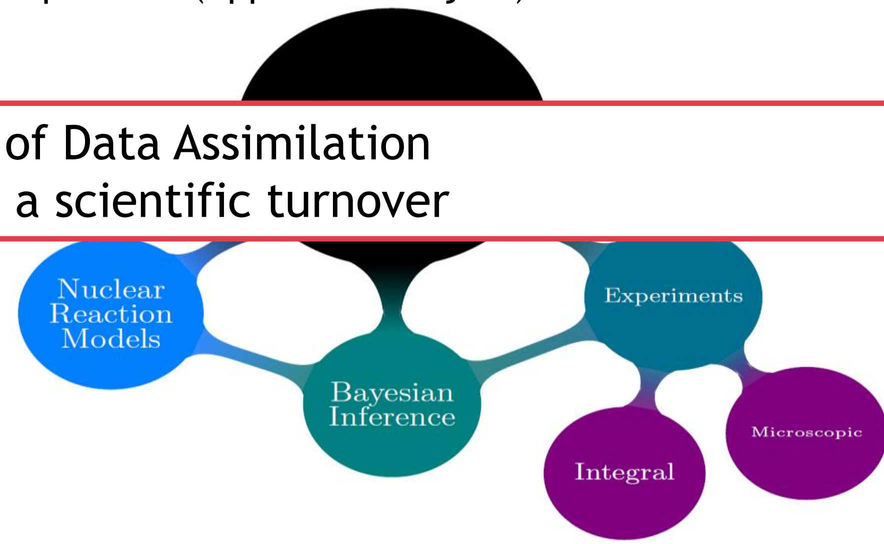

The 1st application of Data Assimilation
involving IEs data in a scientific turnover

Vladimir Sobes, Luiz Leal, Goran Arbanas, Benoit Forget, Resonance Parameter Adjustment Based on Integral Experiments, Nuclear Science and Engineering | Volume 183 | Number 3 | July 2016 | Pages 347-355 (^{56}Fe inelastic XS)
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IRSN MEMBRE DE ETSON

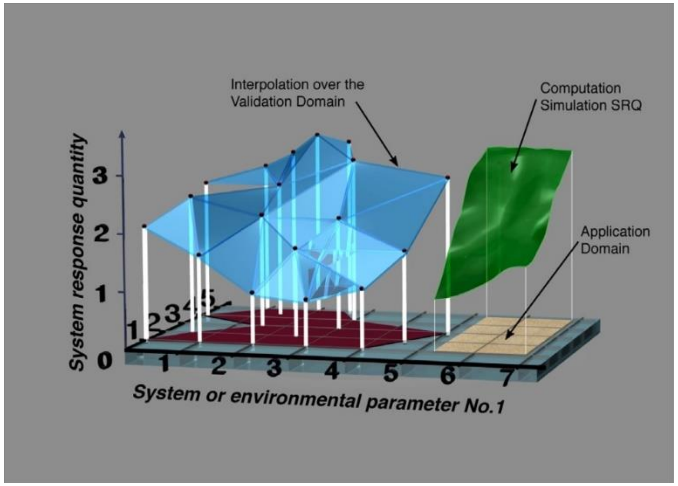
Data Assimilation ⇔ best fit within uncertainty bounds 2#3

Epistemic uncertainties - *we know that we don't know* – gaps in knowledge ⇔ theoretical model of limited consistency

Given => Objective Observations (C/E and relevant CIEs) against new IEs data (experiment-based benchmarks) => [**no one to be ignored** unless explained or of too low-fidelity]

Task => to characterize bias and uncertainty within an Application Domain (ill-posed inverse problem)

Notes => 1) Validation => Application-dependent; 2) Science-driven validation => Validation and Uncertainty Quantification; 3) extrapolation (transposition) => by parametrized model



In our case DA => to confirm a **usefulness of general-purpose library** within a given Application Domain

Oberkampf, W.L. and C. J. Roy (2010), Verification and Validation in Scientific Computing, Cambridge University Press, Cambridge, UK
G. Palmiotti, M. Salvatores, "The Role of Experiments and of Sensitivity Analysis in Simulation Validation Strategies with Emphasis on Reactor Physics," *Ann. Nucl. Energy*, **52**, 10-21 (2013)
T. Ivanova, I. Hill, Methodology and issues of integral experiments selection for nuclear data validation, *EPJ Web Conf.*, **146,** 2017

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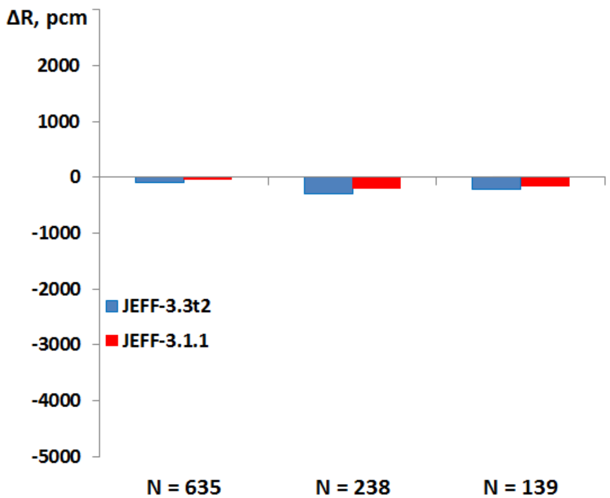
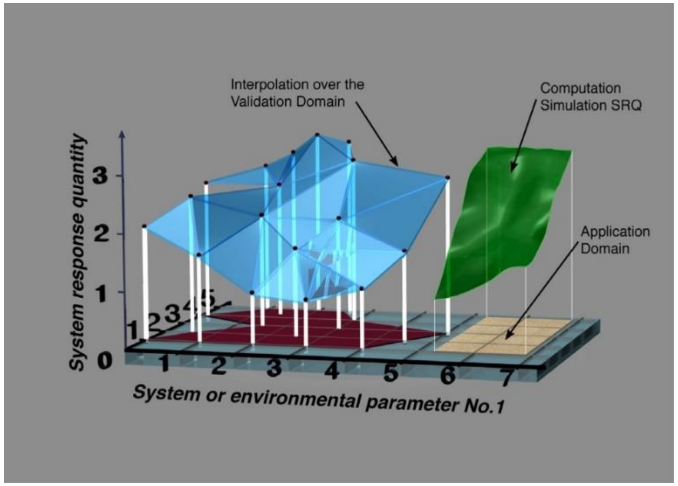


Intuitive (shorten χ^2)



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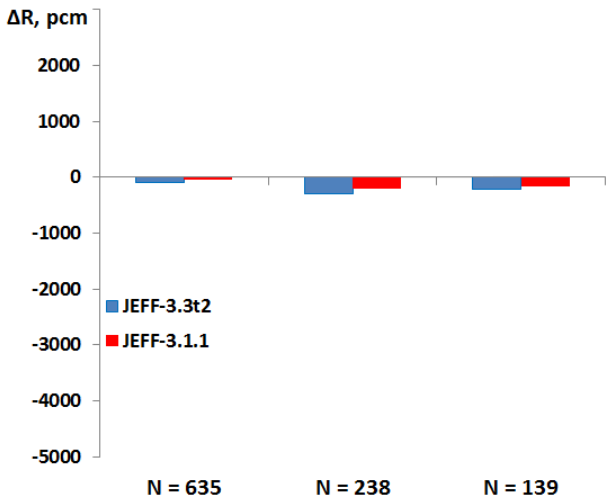

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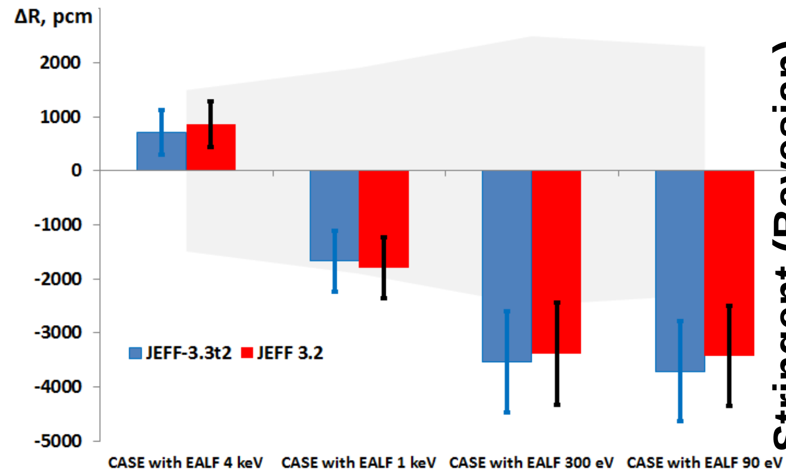

Stringent (Bayesian)

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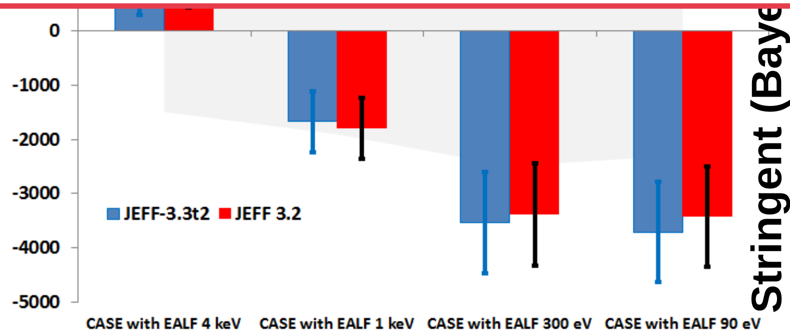
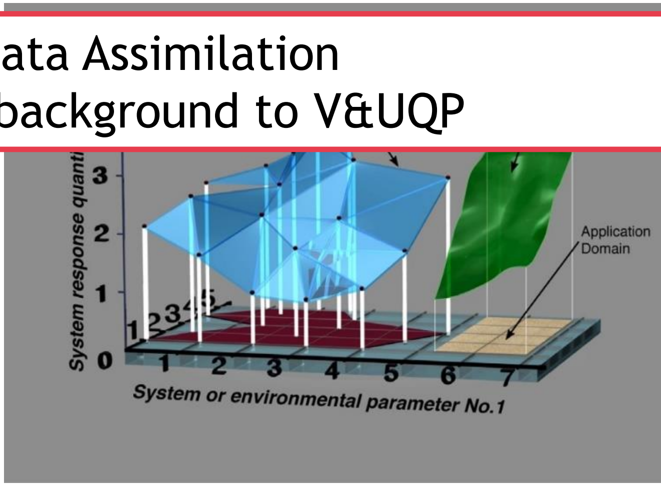
The 2nd application of Data Assimilation
providing an evidence-based background to V&UQP





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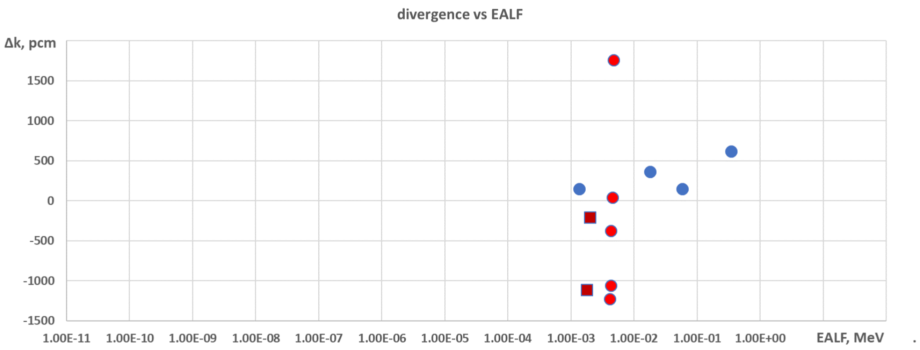
Data Assimilation ⇔ best fit within uncertainty bounds 3#3

<u>**Ontological uncertainties**</u> (Ont) - <u>*we don't know that we don't know*</u> – deficiency in theoretical model

Given => Observations to be explained => [<u>**seeking credible IEs data**</u>]

Task => to clarify possibility to arise an ontological issue [**contribution to HPRL**]



C/E for dedicated experimental cases

Unexpectedly large divergences have been found if EALFs were one through tens of keV

T. Ivanova, I. Hill, Methodology and issues of integral experiments selection for nuclear data validation, *EPJ Web Conf.*, **146,** 2017
E. Ivanov, C. De Saint Jean, V. Sobes et al, Nuclear Data Assimilation => basis and status, EPJ-N, 2020, to be published

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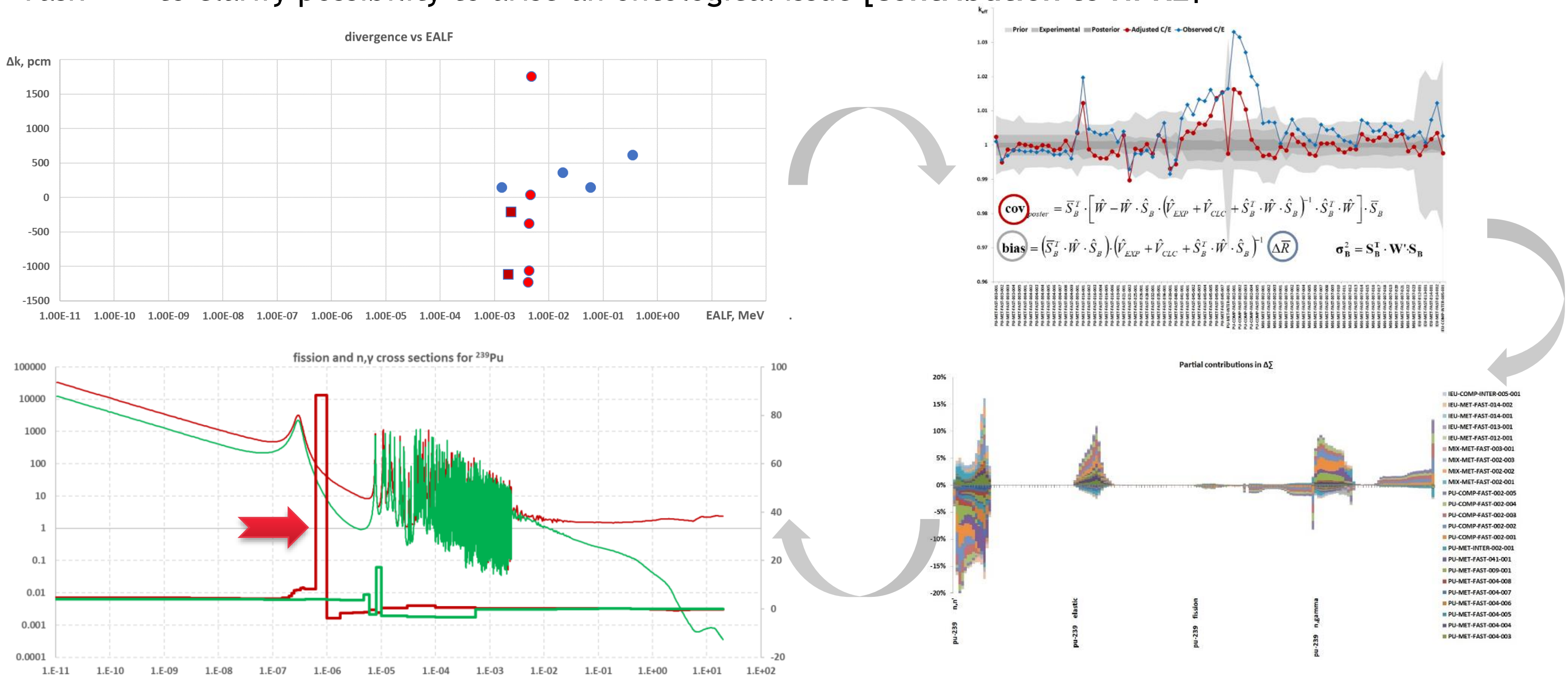

The peaks on lower-left corner are NOT corrections but ratio between corrections with and w/o new IEs

- no more continuous dependence on a parameter – the only assumption in a Bayesian inference

T. Ivanova, I. Hill, Methodology and issues of integral experiments selection for nuclear data validation, *EPJ Web Conf.*, **146,** 2017

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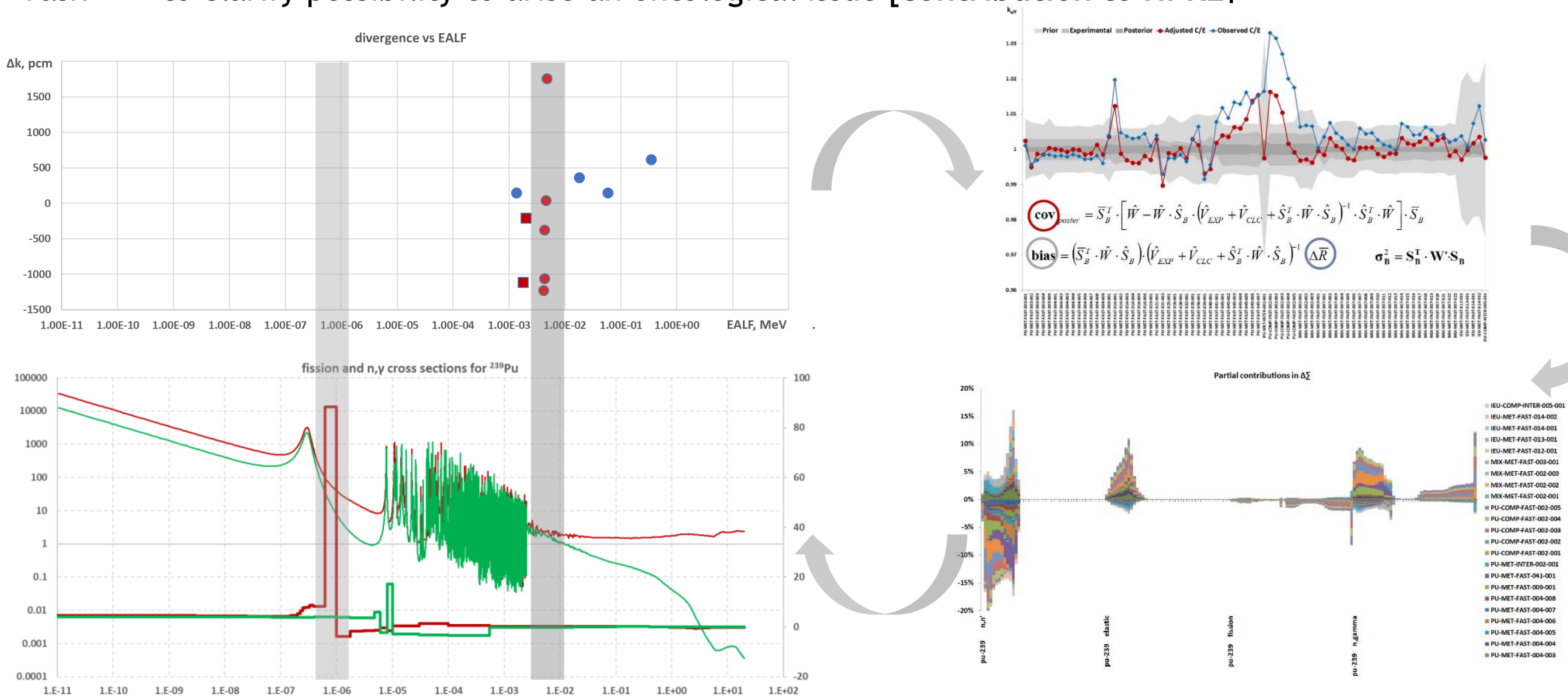

Note => **Ont** surprisingly contradicts to the first guess: ^{240}Pu, EALF~100 keV => ^{239}Pu fission 0.3-0.8 eV

T. Ivanova, I. Hill, Methodology and issues of integral experiments selection for nuclear data validation, *EPJ Web Conf.*, **146,** 2017

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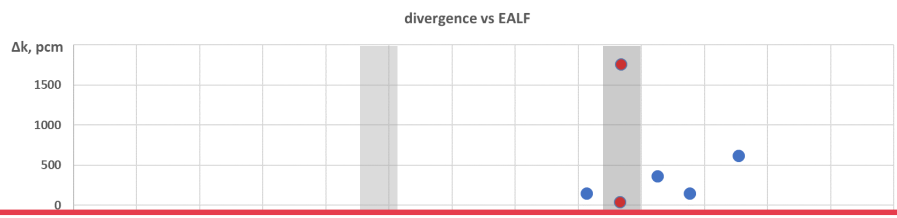
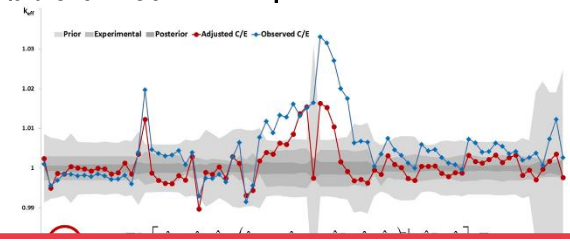
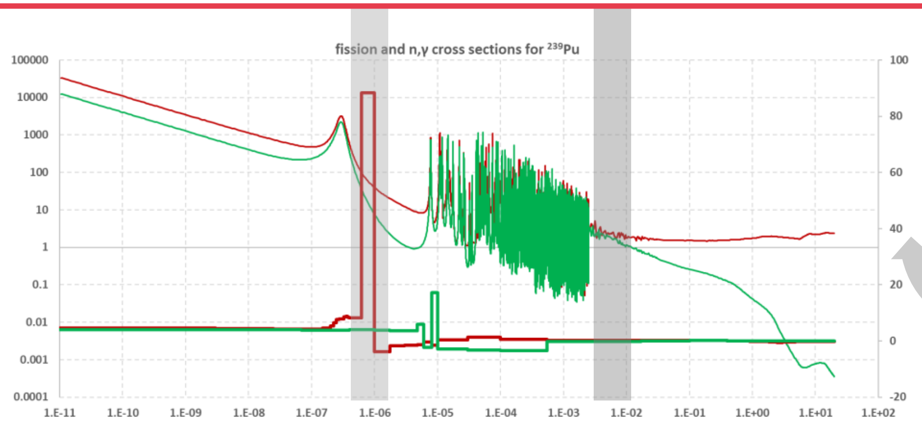
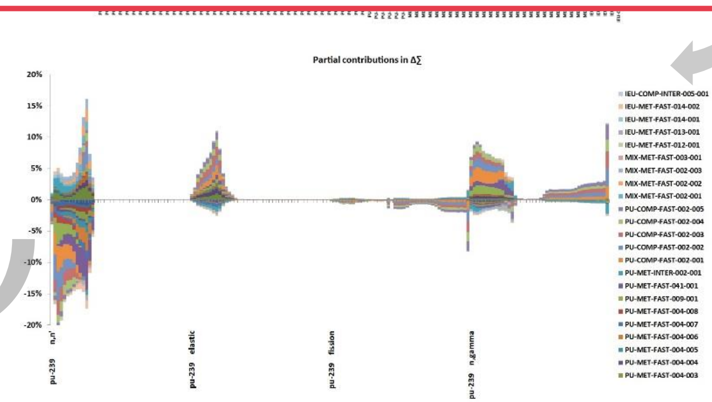




The 3rd application of Data Assimilation
prioritizing problem-oriented fundamental research programs





Note => **Ont** surprisingly contradicts to the first guess: ^{240}Pu, EALF~100 keV => ^{239}Pu fission 0.3-0.8 eV

T. Ivanova, I. Hill, Methodology and issues of integral experiments selection for nuclear data validation, *EPJ Web Conf.*, **146,** 2017
E. Ivanov, C. De Saint Jean, V. Sobes et al, Nuclear Data Assimilation => basis and status, EPJ-N, 2020, to be published

DA ingredients in terms of science-driven Validation process

V&UQ protocol => major phases	DA contributions and other actions
To collect all needed data	Testing IEs consistency (reversing Bayesian inferences)
To characterize IEs data and prior uncertainties (CND)	Given: "tuned" libraries =>
To withdraw used IEs from V&UQ **1st application**	Identifying used IEs data **Reference to simple adjustment**
To parametrize model and AO	Perturbation Theory or other ROMs
To quantify C/E + uncertainties	Examining CND, Establishing CovEX
To apply/establish Bayesian framework quantifying bias and uncertainties => given parameters	Optimizing deterministic (GLLSM-like), stochastic (BMC, HMC, etc.) and hybrid algorithms
To ensure an absence of Ontological issues **3rd application**	Prioritizing problem-oriented basic research programs **an ontological uncertainty treatment**
To transpose knowledge (bias + uncertainty) comparing with TARs	Performing additional statistical testing, and using given parametrization

Topics to be discussed within the sub-group

Subject	Content
TARs related to conceptual design, exploitation and safety assessment	Reasoned discussion on very basic matters of an establishment of TARs Meaningful analysis ⇔ linking nuclear technologies and TARs
Requirements to IEs and Handbooks	an elimination of double use of ▪ IEs (inherent to a ND evaluation), and ▪ libraries (inherent to a benchmarks' evaluation) current status of IEs covariances (CovEX)
Requirements and status of ND covariances (CND)	compatibilities and linear-algebra issues cross-covariances => analysis and assessment (IEs impacts, eliminations)

Preparatory actions (1#2) covariance of IEs uncertainties

	HST 019 001	HST 025 001	HST 025 002	HST 025 004	HST 025 005	HST 027 001	HST 028 001	HST 028 003	HST 028 005	HST 028 007	HST 028 009	HST 028 011	HST 028 013	HST 028 015	HST 028 017	HST 029 001	HST 030 001	HST 030 004	HST 032 001	HST 035 001	HST 035 005	HST 035 007
HST019-001	1	0,45	0,45	0,43	0,41	0,13	0,26	0,23	0,2	0,16	0,36	0,35	0,33	0,31	0,32	0,32	0,15	0,29		0,34	0,17	0,18
HST025-001	0,45	1	0,73	0,72	0,62	0,09	0,2	0,19	0,16	0,12	0,26	0,24	0,24	0,22	0,22	0,22	0,12	0,21		0,32	0,14	0,12
HST025-002	0,45	0,73	1	0,72	0,62	0,09	0,2	0,19	0,16	0,12	0,26	0,24	0,24	0,22	0,22	0,22	0,12	0,21		0,32	0,14	0,12
HST025-004	0,43	0,72	0,72	1	0,62	0,09	0,19	0,17	0,14	0,11	0,23	0,23	0,21	0,2	0,2	0,2	0,1	0,19		0,3	0,12	0,11
HST025-005	0,41	0,62	0,62	0,62	1	0,08	0,15	0,14	0,12	0,09	0,19	0,18	0,18	0,17	0,17	0,16	0,09	0,16		0,22	0,11	0,1
HST027-001	0,13	0,09	0,09	0,09	0,08	1	0,29	0,27	0,3	0,81	0,33	0,34	0,33	0,3	0,77	0,76	0,82	0,78		0,22	0,15	0,2
HST028-001	0,26	0,2	0,2	0,19	0,15	0,29	1	0,4	0,43	0,31	0,46	0,47	0,65	0,42	0,36	0,37	0,28	0,37		0,36	0,21	0,27
HST028-003	0,23	0,19	0,19	0,17	0,14	0,27	0,4	1	0,41	0,29	0,43	0,45	0,43	0,39	0,34	0,34	0,26	0,34		0,33	0,2	0,25
HST028-005	0,2	0,16	0,16	0,14	0,12	0,3	0,43	0,41	1	0,32	0,47	0,49	0,48	0,74	0,36	0,37	0,28	0,37		0,34	0,21	0,28
HST028-007	0,16	0,12	0,12	0,11	0,09	0,81	0,31	0,29	0,32	1	0,33	0,35	0,34	0,3	0,81	0,81	0,87	0,83		0,24	0,16	0,2
HST028-009	0,36	0,26	0,26	0,23	0,19	0,33	0,46	0,43	0,47	0,33	1	0,63	0,61	0,56	0,5	0,51	0,3	0,47		0,43	0,25	0,31
HST028-011	0,35	0,24	0,24	0,23	0,18	0,34	0,47	0,45	0,49	0,35	0,63	1	0,62	0,57	0,5	0,51	0,31	0,48		0,42	0,25	0,32
HST028-013	0,33	0,24	0,24	0,21	0,18	0,33	0,65	0,43	0,48	0,34	0,61	0,62	1	0,56	0,49	0,5	0,29	0,47		0,41	0,24	0,32
HST028-015	0,31	0,22	0,22	0,2	0,17	0,3	0,42	0,39	0,74	0,3	0,56	0,57	0,56	1	0,45	0,46	0,27	0,42		0,37	0,22	0,28
HST028-017	0,32	0,22	0,22	0,2	0,17	0,77	0,36	0,34	0,36	0,81	0,5	0,5	0,49	0,45	1	0,89	0,82	0,87		0,34	0,2	0,25
HST029-001	0,32	0,22	0,22	0,2	0,16	0,76	0,37	0,34	0,37	0,81	0,51	0,51	0,5	0,46	0,89	1	0,81	0,87		0,34	0,21	0,25
HST030-001	0,15	0,12	0,12	0,1	0,09	0,82	0,28	0,26	0,28	0,87	0,3	0,31	0,29	0,27	0,82	0,81	1	0,83		0,22	0,14	0,17
HST030-004	0,29	0,21	0,21	0,19	0,16	0,78	0,37	0,34	0,37	0,83	0,47	0,48	0,47	0,42	0,87	0,87	0,83	1		0,34	0,2	0,24
HST032-001																			1			
HST035-001	0,34	0,32	0,32	0,3	0,22	0,22	0,36	0,33	0,34	0,24	0,43	0,42	0,41	0,37	0,34	0,34	0,22	0,34		1	0,76	0,75
HST035-005	0,17	0,14	0,14	0,12	0,11	0,15	0,21	0,2	0,21	0,16	0,25	0,25	0,24	0,22	0,2	0,21	0,14	0,2		0,76	1	0,84
HST035-007	0,18	0,12	0,12	0,11	0,1	0,2	0,27	0,25	0,28	0,2	0,31	0,32	0,32	0,28	0,25	0,25	0,17	0,24		0,75	0,84	1

Correlated IEs uncertainties, where CovEX come from ?

- Shared materials (the same cast) and components (the same fabricant/supplier)

  Shared experimental equipment (the same facility, or detector, and so on) or measurement standards

  …others…

  Similar tools and libraries used in benchmarks' evaluations/simplification (levelized densities and shapes, lattices regularization, etc.)

an example

	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	B_9	B_{10}	B_{11}
B_1	1000	515	399	446	299	300	302	356	374	393	397
B_2	515	1000	408	463	320	321	331	403	411	434	436
B_3	399	408	1000	470	365	368	361	394	441	473	393
B_4	446	463	470	1000	407	411	410	453	495	533	447
B_5	299	320	365	407	1000	438	442	449	477	508	442
B_6	300	321	368	411	438	1000	444	453	482	512	442
B_7	302	331	361	410	442	444	1000	584	584	569	544
B_8	356	403	394	453	449	453	584	1000	741	702	702
B_9	374	411	441	495	477	482	584	741	1000	736	724
B_{10}	393	434	473	533	508	512	569	702	736	1000	687
B_{11}	397	436	393	447	442	442	544	702	724	687	1000

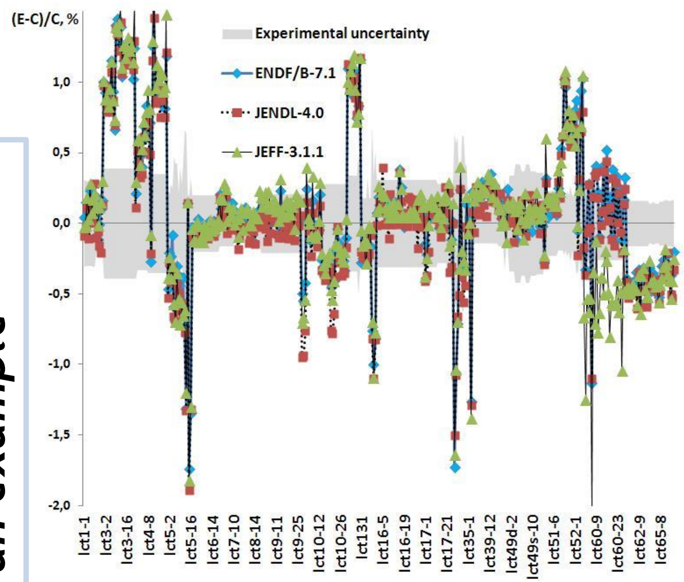
$$r_{IE,QoI} = \frac{\left(\bar{S}_{QoI}^{T} \cdot \widehat{W} \cdot \bar{S}_{IE}\right)}{\sqrt{\left(\bar{S}_{QoI}^{T} \cdot \widehat{W} \cdot \bar{S}_{QoI}\right) \cdot \left(\bar{S}_{IE}^{T} \cdot \widehat{W} \cdot \bar{S}_{IE}\right)}}$$

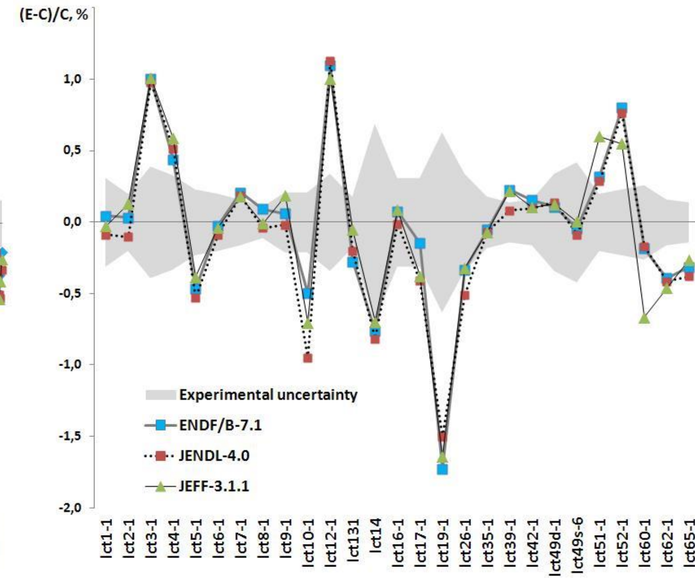
Simple representativity factor (C_K criteria) to be replaced

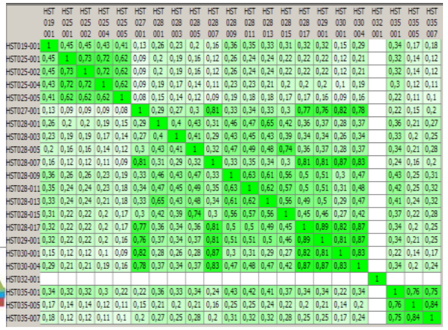
T. Ivanova, G. E. Bianchi "Establishment of Correlations for Some Critical and Reactor Physics Experiments", NSE, **178**, Number 3, November 2014

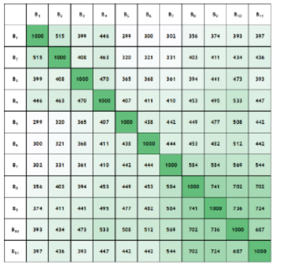
Preparatory actions (1#2) covariance of IEs uncertainties

an example









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

$$r_{IE,QoI} = \frac{\left(\bar{S}^T_{QoI} \cdot \widehat{W} \cdot \bar{S}_{IE}\right)}{\sqrt{\left(\bar{S}^T_{QoI} \cdot \widehat{W} \cdot \bar{S}_{QoI}\right) \cdot \left(\bar{S}^T_{IE} \cdot \widehat{W} \cdot \bar{S}_{IE}\right)}}$$

Simple representativity factor (C_K criteria) to be replaced

IEs data correlate due to facilities, equipment, materials and techniques

Ignorance of correlations => under-estimation of uncertainties

Use of only non-correlated cases => over-estimation of uncertainties

Suggestion => establishing "physically*" consistent Covariance matrices of Experimental Data uncertainties (CovEX)

T. Ivanova, G. E. Bianchi "Establishment of Correlations for Some Critical and Reactor Physics Experiments", NSE, **178**, Number 3, November 2014

Preparatory actions (2#2) prior uncertainties

$$\frac{\Delta\bar{\sigma}}{\bar{\sigma}} = \widehat{W}\cdot\bar{S}_{IE}\cdot\left(\hat{V}_{IE}+\hat{V}_{CLC}+\bar{S}_{IE}^{T}\cdot\widehat{W}\cdot\bar{S}_{IE}\right)^{-1}\cdot\frac{\Delta\bar{R}_{IE}}{\bar{R}_{IE}}$$

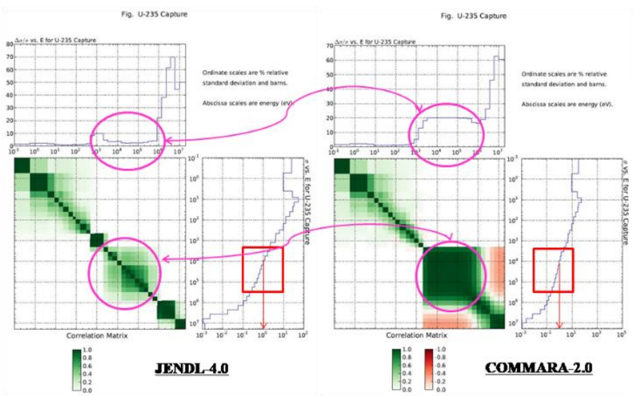
$\hat{V}_{IE}$ as CovEX for all involved IEs data (see above)

$$\frac{\Delta\bar{\sigma}}{\bar{\sigma}} = \widehat{W}\cdot\bar{S}_{IE}\cdot\left(\hat{V}_{IE}+\hat{V}_{CLC}+\bar{S}_{IE}^{T}\cdot\widehat{W}\cdot\bar{S}_{IE}\right)^{-1}\cdot\frac{\Delta\bar{R}_{IE}}{\bar{R}_{IE}}$$

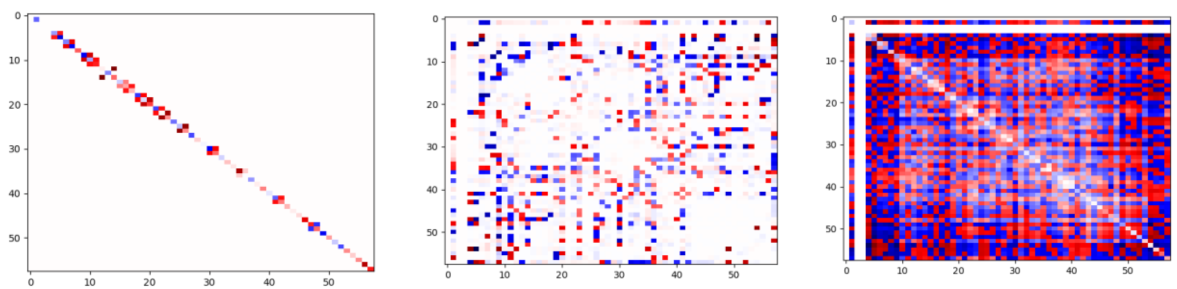
$\hat{V}_{CLC}$ a numerical tool error => minimizing => precise solvers (Monte-Carlo)

$$\frac{\Delta\bar{\sigma}}{\bar{\sigma}} = \widehat{W}\cdot\bar{S}_{IE}\cdot\left(\hat{V}_{IE}+\hat{V}_{CLC}+\bar{S}_{IE}^{T}\cdot\widehat{W}\cdot\bar{S}_{IE}\right)^{-1}\cdot\frac{\Delta\bar{R}_{IE}}{\bar{R}_{IE}}$$

$\widehat{W}$ prior Covariance matrix of Nuclear Data (CND) => independent on ND



$$\widehat{W}' = \widehat{W} - \left(\bar{S}_{IE}^{T}\cdot\widehat{W}\cdot\bar{S}_{IE}\right)\cdot\left(\hat{V}_{IE}+\hat{V}_{CLC}+\bar{S}_{IE}^{T}\cdot\widehat{W}\cdot\bar{S}_{IE}\right)^{-1}\cdot\left(\bar{S}_{IE}^{T}\cdot\widehat{W}\cdot\bar{S}_{IE}\right)$$



Prior CND => inconsistent but useful

Posterior CND => consistent yet in a local domain (covered by IEs)

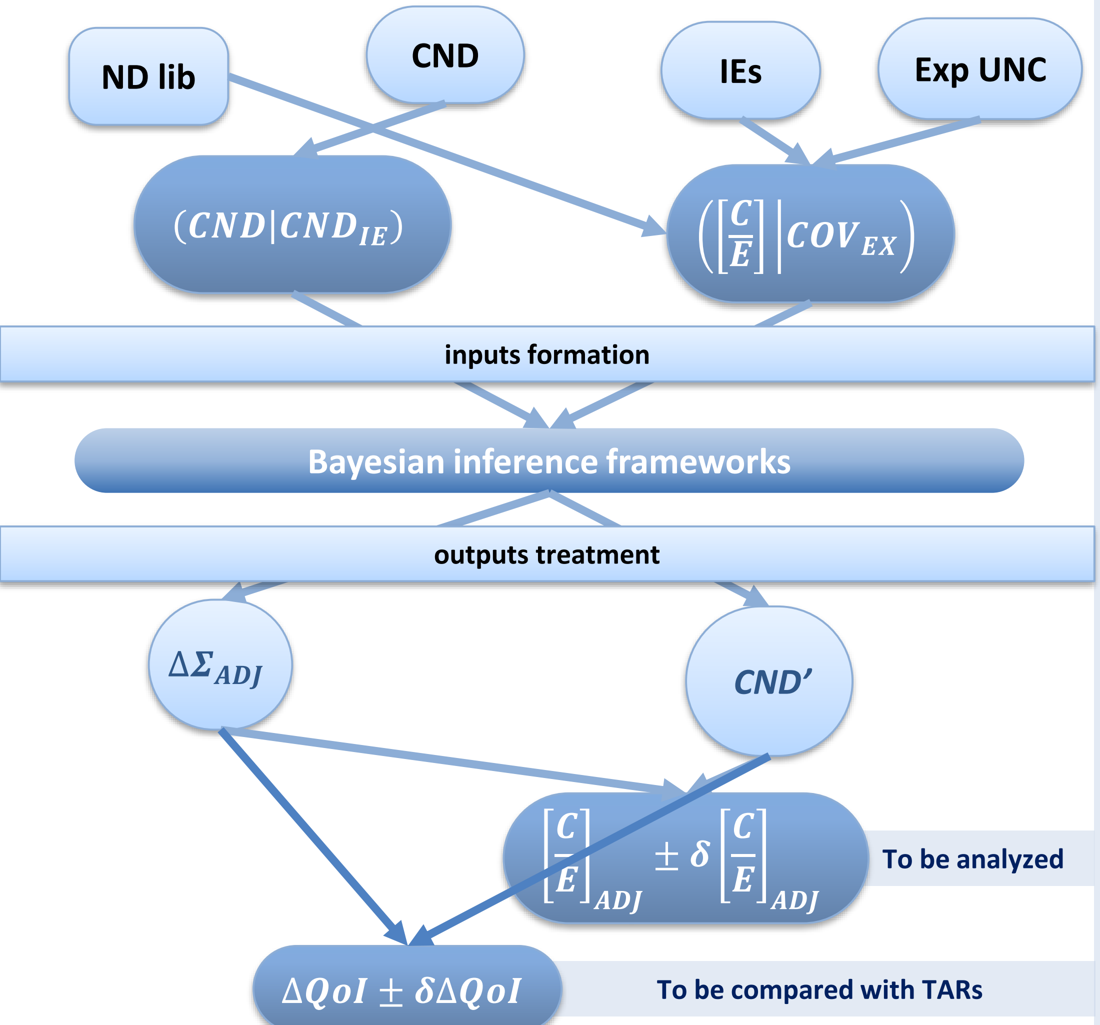
Metrics of information => ratio between functionals given by Prior and Posterior CND

Posterior CND meaning as a pocket of knowledge (information extracted from IEs)

Suggestions: to validate a library => to provide prior CND and

to withdraw IEs have been yet used in data “tuning”

Step towards shared protocol of science-driven V&UQ



Data Assimilation contributions

- Suite of *IEs* collection with *CovEX* (***withdrawing cases used in lib_s tuning***)
- Observations (*C*/*E*) calculations
- *CND* in a suitable format

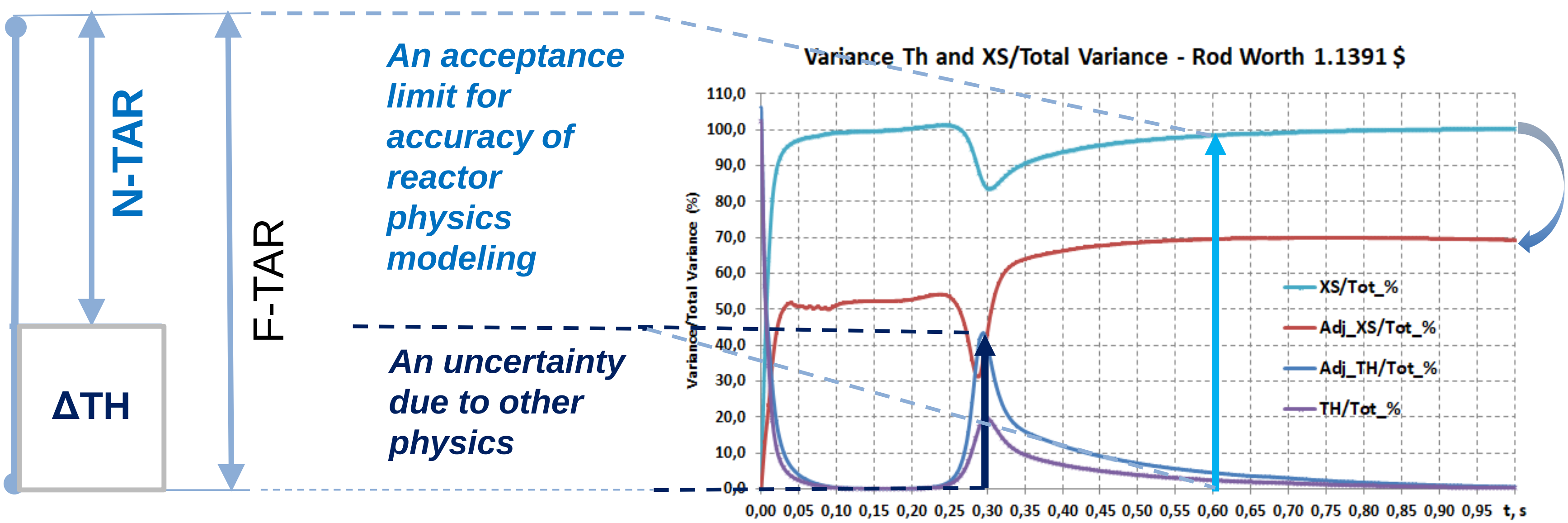
any => *deterministic* or *stochastic*

Data Assimilation *outputs*

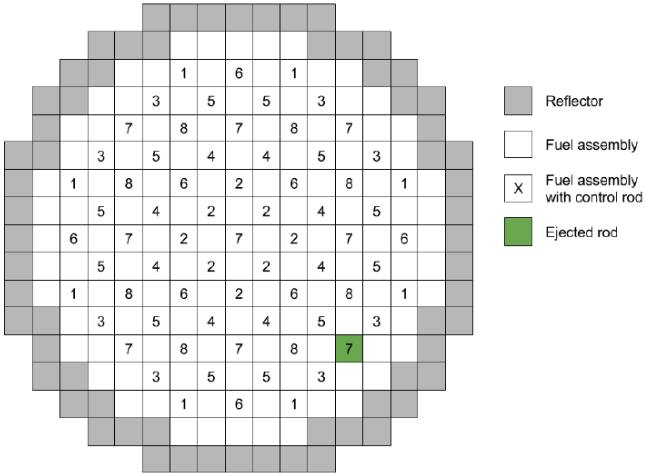
- **Ontological issues testing**
- **Informed Decision Making support**

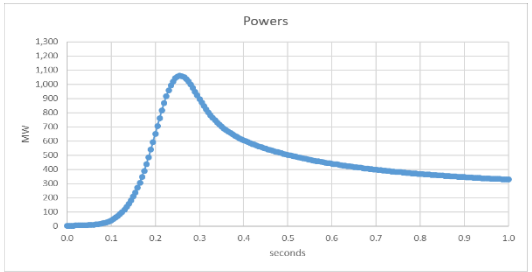
Target accuracy establishment for multi-physics processes

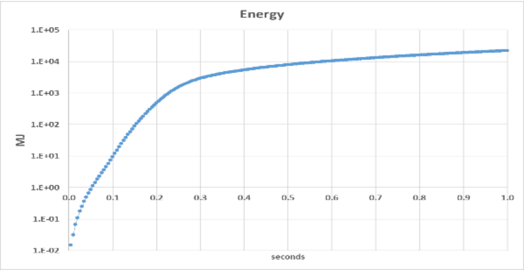
- Target Accuracy Requirements (TARs) represent wishes and acceptance limits established by designers and/or assessors
- Sg46 task => to establish TARs for Nuclear Data libraries
- One should separate (approximately) impacts due to reactor physics and due to other physics => combining sampling and linearized response (sensitivity) studies
- Sampling-based back-propagation with reduced (adjusted) ND uncertainties
- Note: practically used simulations (no exemptions) based on a hierarchic structure; we are following a kind of a gradient descent approach to quantify uncertainties of different nature

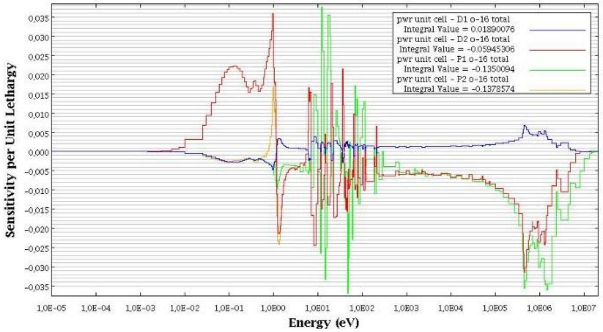


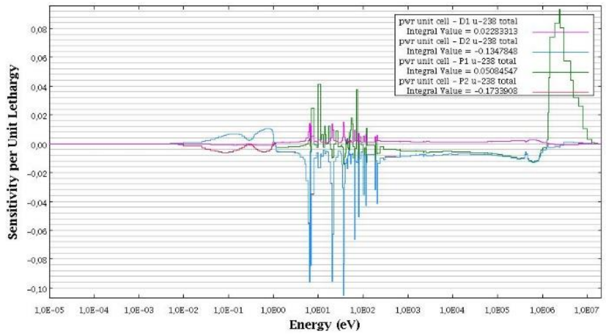
UQP for LWR RIA => links to WPRS/EGMUP 1#2











Given:

- the case to be assessed => Reactivity Insertion Accident on PWR
- tools available => fully validated TH tools and robust coupled calculational chain

Task:

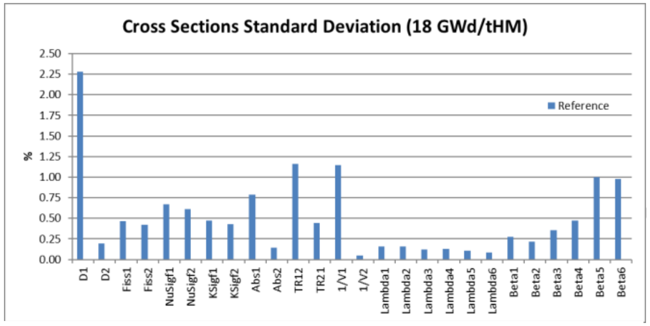
- to estimate uncertainties of power peak and deposit energy
- to perform UQ basing on an evidence-based background

Methodology =>
separated different physics uncertainties, XS and CND calibration, and sampling to an Errors' Propagation

Hierarchic algorithm => cell => lattice => few groups core / coupled modeling
Uncertainties' calibration => ND + CND => GPT => Posterior few-groups CND

IRSN MEMBRE DE ETSON

UQP for LWR RIA => links to WPRS/EGMUP 2#2

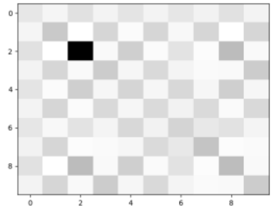


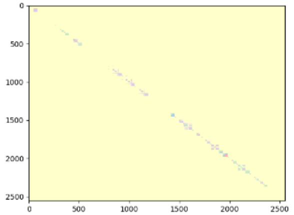
Homogenization of ND into few groups XS

Uncertainties Quantification and Propagation (UQP) using Generalized Perturbation Theory (GPT)

Prior Uncertainties Propagation

ND contributors in D_1 uncertainties





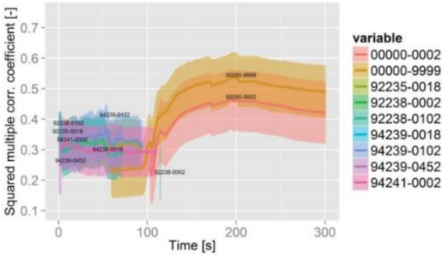
V&UQ differs for different physics (Propagation-based in TH and full DA-based in PhR)

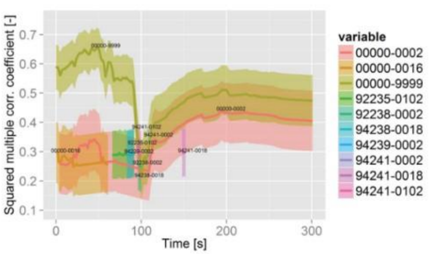
Available => principle contributors in F-TARs and N-TARs <= to commensurate with conservatisms

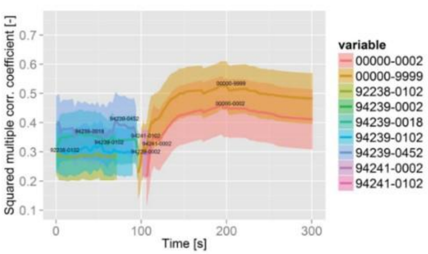
[A.Sargeni, G.Bruna et al, "Evidence-based background for constrained uncertainty quantification in a core transient analysis", ANE, 2021 (to be published)]

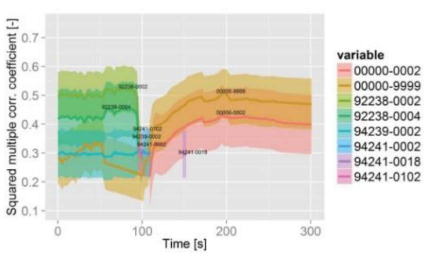
ND TARs might be fundamentally different for static and transient AOs [GRS example]

[E. Ivanov et al, "Role of a phenomenological validation and integral experiments for maturing the predictive simulations", NED, V 362, 2020]



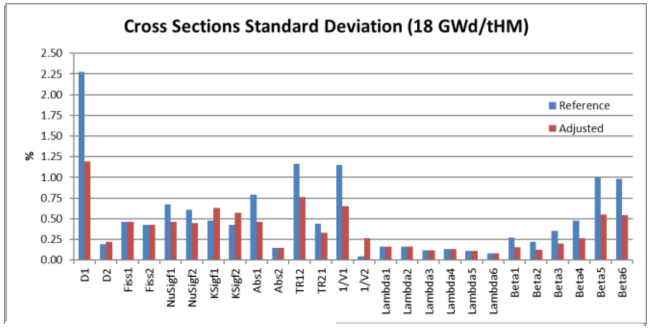


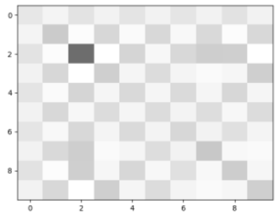


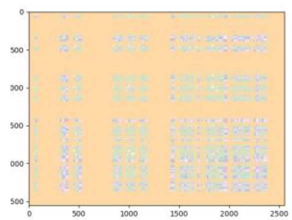


IRSN MEMBRE DE ETSON

UQP for LWR RIA => links to WPRS/EGMUP 2#2







Homogenization of ND into few groups XS

Uncertainties Quantification and Propagation (UQP) using Generalized Perturbation Theory (GPT)

Posterior Uncertainties Quantification & Propagation

ND contributors in D_1 uncertainties

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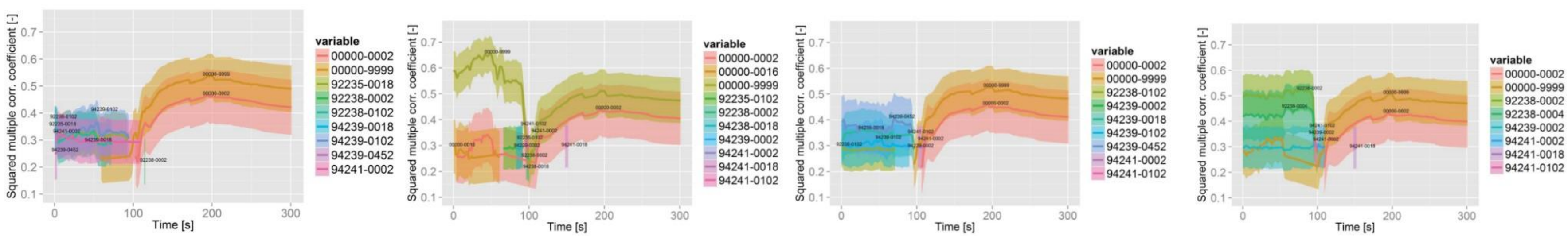
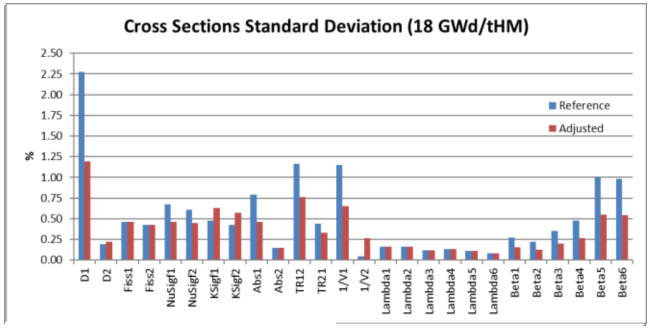
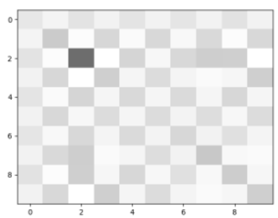
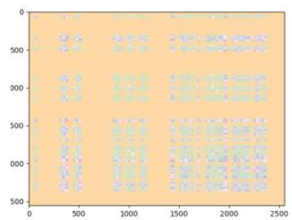


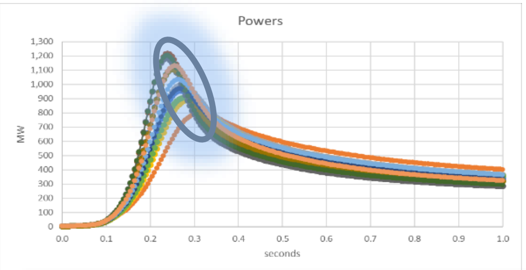
IRSN MEMBRE DE ETSON

UQP for LWR RIA => links to WPRS/EGMUP 2#2

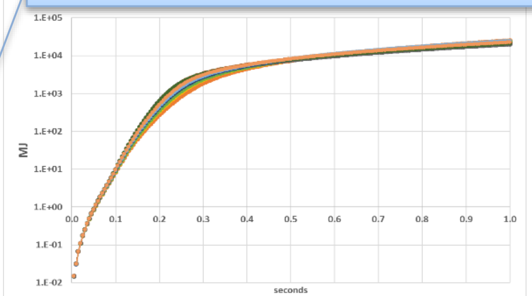


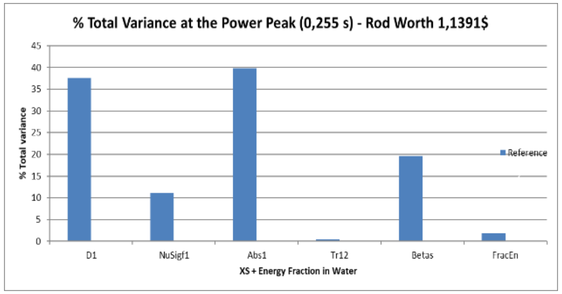


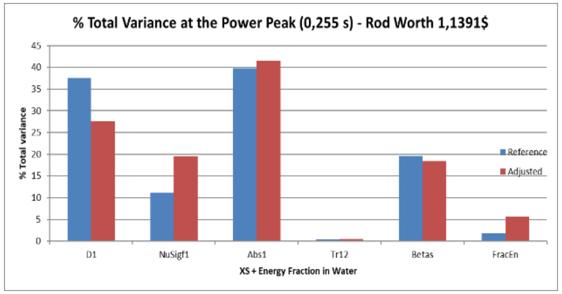




ND contributors in D_1 uncertainties







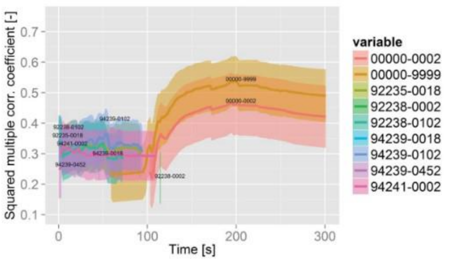
V&UQ differs for different physics (Propagation-based in TH and full DA-based in PhR)

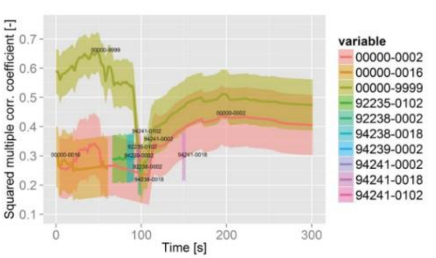
Available => principle contributors in F-TARs and N-TARs <= to commensurate with conservatisms

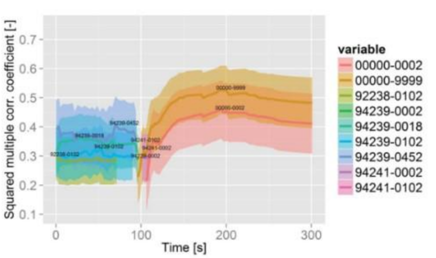
[A.Sargeni, G.Bruna et al, "Evidence-based background for constrained uncertainty quantification in a core transient analysis", ANE, 2021 (to be published)]

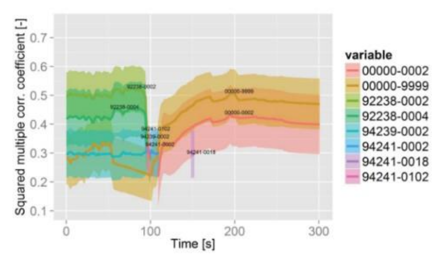
ND TARs might be fundamentally different for static and transient AOs [GRS example]

[E. Ivanov et al, "Role of a phenomenological validation and integral experiments for maturing the predictive simulations", NED, V 362, 2020]









IRSN MEMBRE DE ETSON

Molten Salt Fast Reactor functional TARs

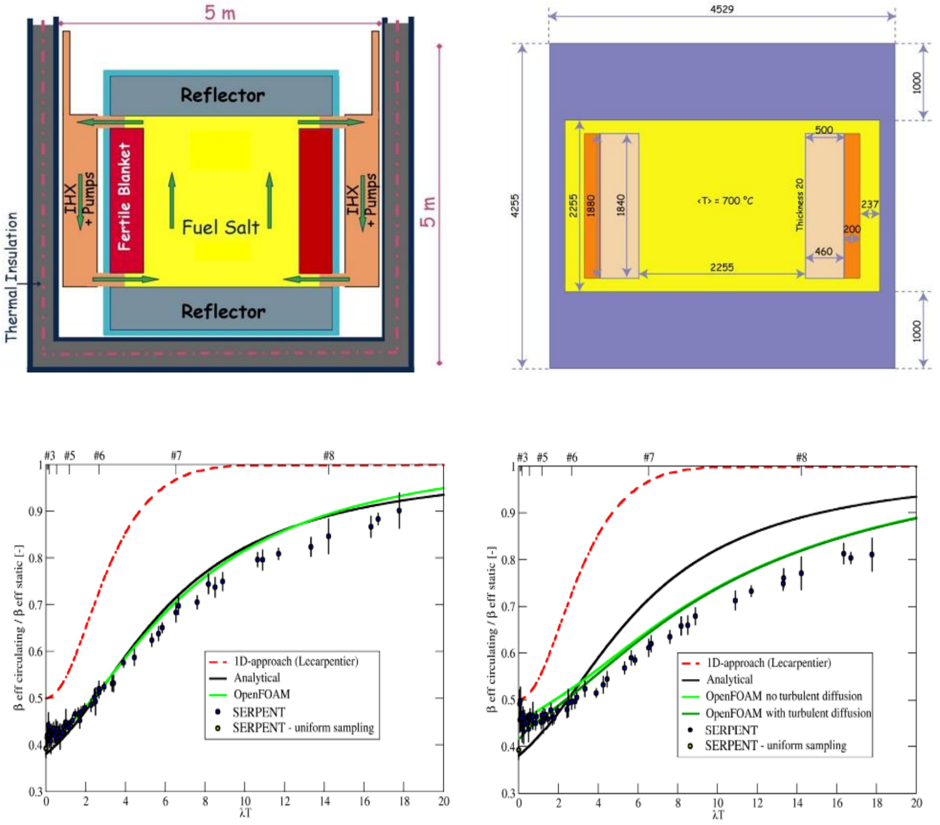
TARs: controllability

TARs have been established basing on the physics behind principles of the entire system control

Peculiarity of MSR => no dedicated power output

- Δk_{eff} ~ 1.0 % if $\omega = 0.0\ m/sec$ with f.p.
- Δk_{eff} ~ 0.2 % if ω: $\beta_{eff} \cong 0$ & circulating f.p.
- $\frac{c_{232}}{k_{eff}}\frac{\Delta k_{eff}}{\Delta c_{232}}$ ~ 2 % for static case
- $\frac{c_{233}}{k_{eff}}\frac{\Delta k_{eff}}{\Delta c_{233}}$ ~ 3 % for static case
- $\frac{c_{238}}{k_{eff}}\frac{\Delta k_{eff}}{\Delta c_{238}}$ ~ 2 % for static case
- $\frac{c_{239}}{k_{eff}}\frac{\Delta k_{eff}}{\Delta c_{239}}$ ~ 7 % for static case
- $\frac{c_{Zr.Mo.Ce}}{k_{eff}}\frac{\Delta k_{eff}}{\Delta c_{Zr.Mo.Ce}}$ ~ 12 % for static case

Calculational model



MODEL FOR SENSITIVITY STUDIES

Mariya Brovchenko, Jan-Leen Kloosterman, Lelio Luzzi, Elsa Merle, Daniel Heuer, Axel Laureau, Olga Feynberg, Victor Ignatiev, Manuele Aufiero, Antonio Cammi, Carlo Fiorina, Fabio Alcaro, Sandra Dulla, Piero Ravetto, Lodewijk Frima, Danny Lathouwers, Bruno Merk, Neutronic benchmark of the molten salt fast reactor in the frame of the EVOL and MARS collaborative projects, EPJ Nuclear Sci. Technol. 5 2 (2019)

Potential IRSN participation: collaboration and delivery

- **MSFR** [IRSN & CNRS] =>
  - Quantified TARs for major functionals
  - Commented article and inputs for sensitivity coefficients calculations
- **LWRs RIA** [IRSN] =>
  - Quantified TARs to power and energy yields in a power excursion accident
  - Commented articles explaining unconventional options in TARs establishment
- **V&UQP protocol** [IRSN and all ?] =>
  - Synopsis on major "ingredients" of science-driven (DA-based) V&UQ process
  - An example on IEs uncertainties quantification and CovEX establishment
  - Draft and consolidated comments to a science-driven V&UQ protocol

Suggestion: to see a meaningful discussion on validation criteria in a reliance (separately) to conceptual design, basic research and safety assessment

Note: [*differences in objectives…*]
in simple adjustment => uncertainties give a range for variations;
in V&UQ => DA forms [localized] models for evolving uncertainties [related to AO]

Potential IRSN participation: collaboration and delivery

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  - Commented article and inputs for sensitivity coefficients calculations
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- **V&UQP protocol** [IRSN and all ?] =>
  - Synopsis on major “ingredients” of science-driven (DA-based) V&UQ process
  - An example on IEs uncertainties quantification and CovEX establishment
  - Draft and consolidated comments to a science-driven V&UQ protocol
- **Crucial items** [all ?]=>
  - List of IEs have been used in ND evaluation
  - Current Status of CND for XSs, secondary particles yield and cross-correlations
- One **contribution to HPRL** [IRSN and all ?]

Thank you for your time

Questions?