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Karlsruhe Institute of Technology

WAME project. Development of a real-time system to improve decision making in severe accident event in nuclear power plants.

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(Work is made in cooperation with Framatome GmbH, Erlangen)

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<u>Goal of the project:</u> improvement in real-time source term prediction to help technical support center in case of accident at NPP.

- SA codes cannot be used in that case, because they are time-consuming
- Probably the most common strategy in that case is prepare database with source term values and use Bayesian Belief Networks (BBN) to choose appropriate source term
- Idea of WAME project is to modify prepared source terms base on real measurements
- For that MOCABA algorithm (developed in Framatome) was suggested

<u>Connection to IAEA CRP I31033:</u> Database for MOCABA algorithm should cover as much as possible outcomes of simulated process depending on changes in input data.

- Identify most important parameters for given accident scenario
- Set the Probability Density Function (PDF) for each parameters
- Sample uncertain input parameters inside given range
- Run multiple SA code simulations
- Collect simulation results and calculate simple statistics and correlation coefficients

<u>FSTC tool:</u>

- Scheme below is briefly showing work-flow without details
- Python language; Windows & Linux
- Currently coupled with ASTEC code

Sampling → Multiple simulations → Collect and filter results → U&S analysis

U&S Analysis of ASTEC KONVOI simulations

- Forming the final list of uncertain input parameters is iterative process. Initial list, for example, consists of 40 parameters all with uniform distribution and all from ASTEC models. Then it was reduced and available information about PDFs was extracted from literature. Two parameters governing leakage rate and burn-up were added also. Results with these 16 parameters shown further.
- For KONVOI simulations number of samples was usually set to 200 or 300
- 300 samples run took ~3.5 days on 32 cores
- For all simulations Latin Hypercube sampling method was used
- Further results only for MBLOCA scenario will be shown (in project simulations for MBLOCA+SBO, SBLOCA and SBLOCA+SBO are planned)
- ASTEC2.2b severe accident code is used for simulations
- Set of main events happening during accident progression is chosen. For example, “start of fission product release”, “lower head vessel failure”, “first material slump in lower plenum”, etc.
- In general results between any pair of main event could be extracted and analyzed.

Uncertain input parameters

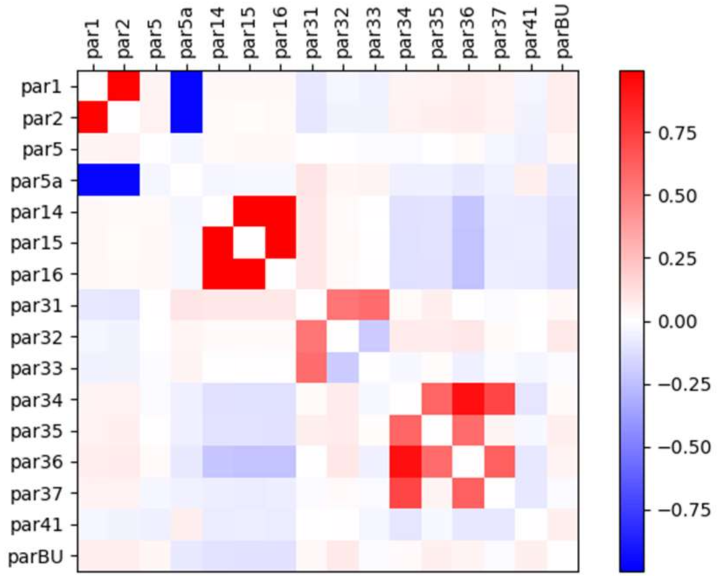
Parameter	Best estimated value	Probability density function	Meaning
par1	5.0	Normal	STRU ELSA Correction factor for the ratio S/V of the fuel pellets due to roughness
par2	0.03	Normal	STRU ELSA Correction factor for the ratio S/V of the fuel pellets for the limited steam access
par5	1.2E-5	Normal	STRU ELSA Geometrical diameter of the grain
par5a	2.0E-6	Triangular	Standard deviation of geometrical diameter of the grain
par14	2500.0	Normal	VESSEL:INTE Threshold Temperature of the cladding Dislocation [K]
par15	2300.0	Normal	VESSEL:INTE Threshold Temperature of the oxide layer Dislocation [K]
par16	250.0E-4	Normal	VESSEL:INTE Threshold thickness of the oxide layer [mm]
par31	3.5	Uniform	SOPHAEROS:AEROSOLS Particle mean thermal conductivity (J/m/K)
par32	840.0	Uniform	SOPHAEROS:AEROSOLS Average specific heat (J/kg K) of the aerosol
par33	3000.0	Triangular	SOPHAEROS:AEROSOLS particle mean density (kg/m3)
par34	1.0E-08	Triangular	SOPHAEROS:AEROSOLS:SIZE particle minimum geometrical radius (m)
par35	2.0E-05	Triangular	SOPHAEROS:AEROSOLS:SIZE particle maximum geometrical radius (m)
par36	1.0	Triangular	SOPHAEROS:AEROSOLS:SHAPE Shape factor relative to particle coagulation
par37	1.0	Beta	SOPHAEROS:AEROSOLS:SHAPE Shape factor relative to Stokes velocity
par41	1.0	Uniform	Coefficient for the leakage rate
parBU	164.0	Uniform	Effective full power days

Correlations between input parameters

Initially suggested correlations

	par1	par2	par5	par5a	par14	par15	par16	par31	par32	par33	par34	par35	par36	par37	par41	parBU
par1		1		-1												
par2	1			-1												
par5																
par5a	-1	-1														
par14						1	1									
par15					1		1									
par16					1	1										
par31									1	1						
par32								1		-1						
par33								1	-1							
par34												1	1	1		
par35											1		1	-1		
par36											1	1		1		
par37											1	-1	1			
par41																
parBU																

Correlations after applying Iman-Conover method

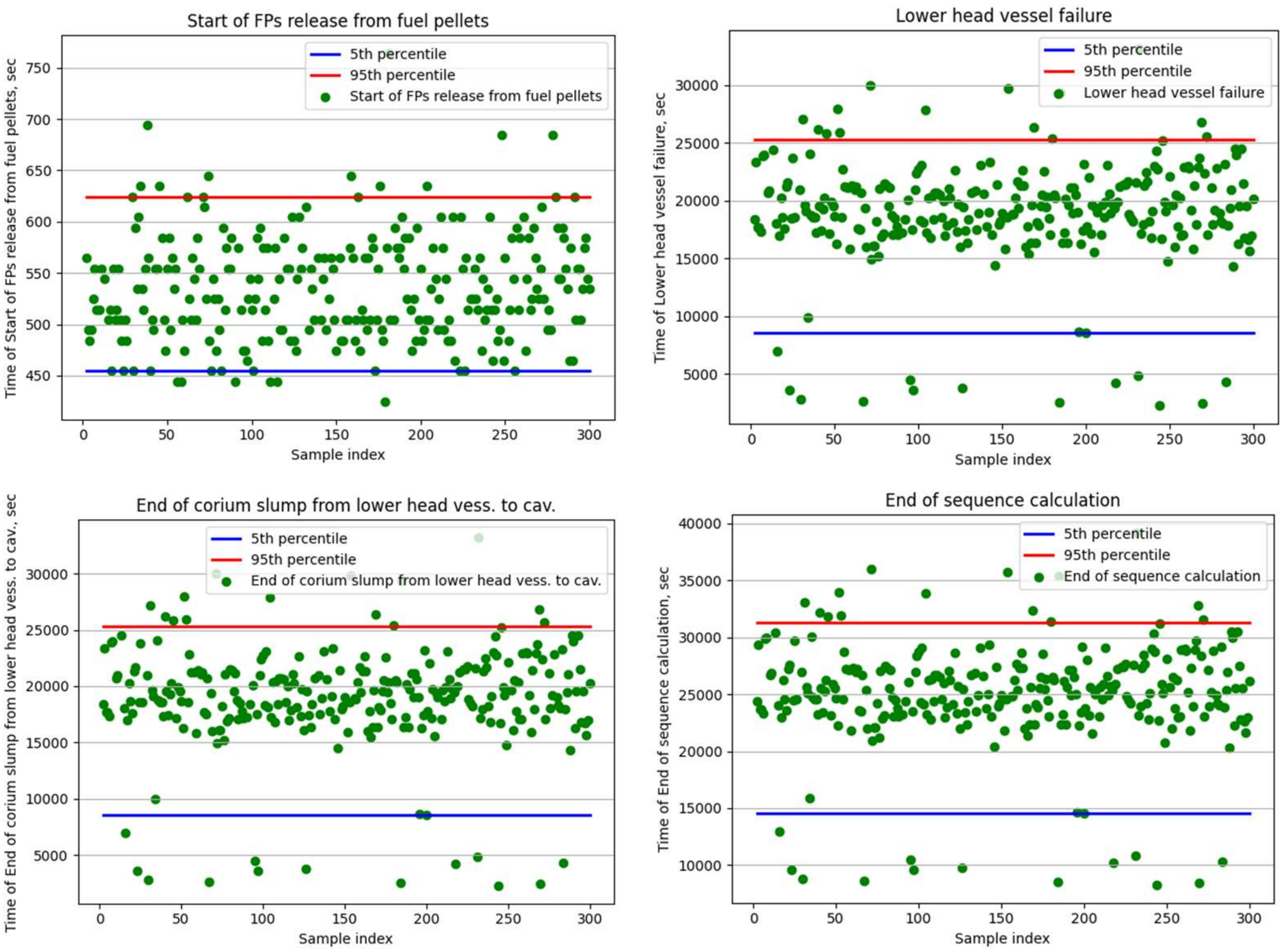


[Please note, that initial correlation matrix could be not suitable for Choletsky decomposition, which is one of the steps of Iman-Conover method, and some additional methods should be applied first to the correlation matrix to make it suitable for decomposition – for example, iterative spectral algorithm, alternating projections method or others]

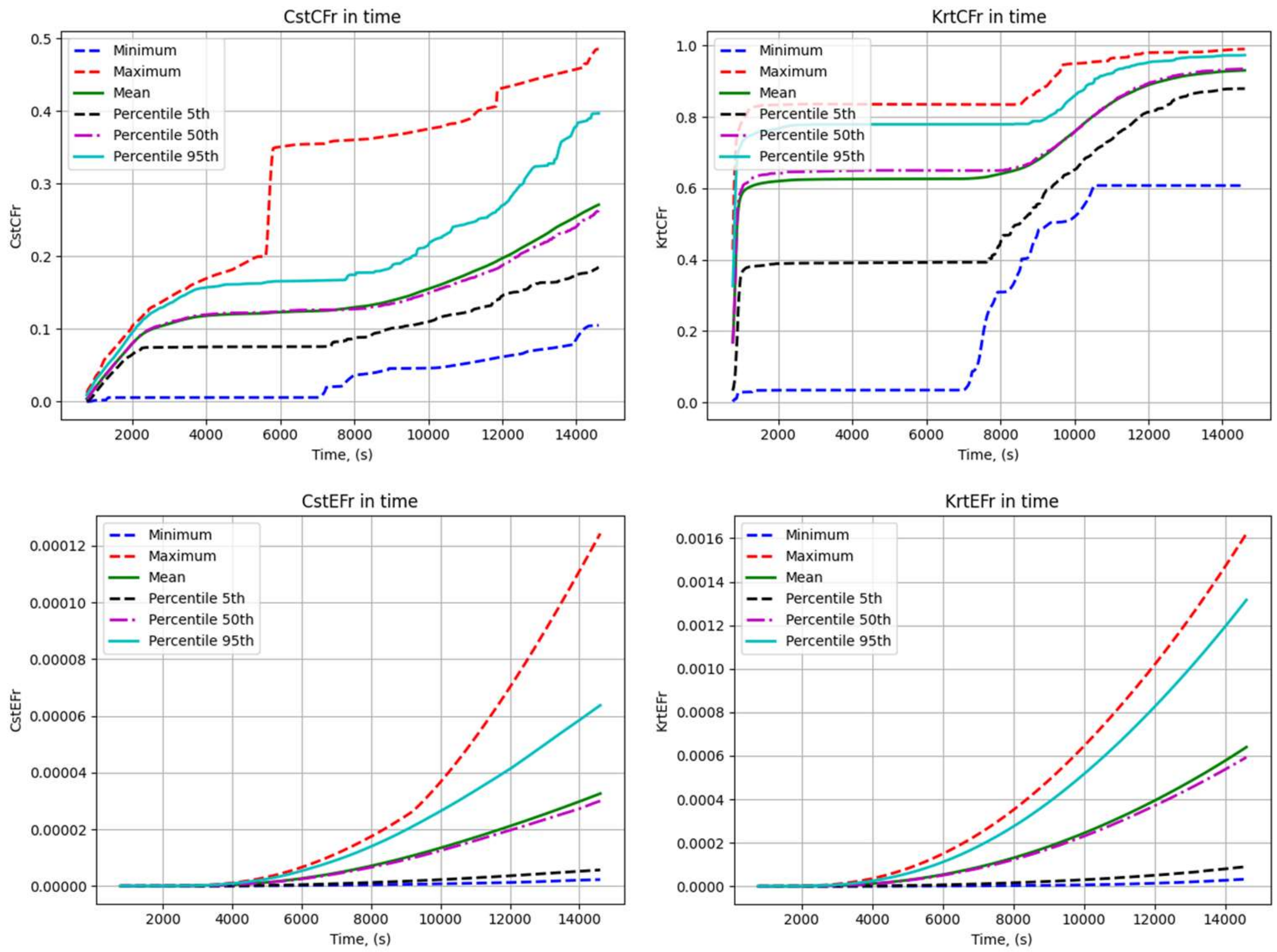
- Iman-Conover method: Ronald L. Iman & W. J. Conover (1982) A distribution-free approach to inducing rank correlation among input variables, Communications in Statistics - Simulation and Computation, 11:3, 311-334, DOI: 10.1080/03610918208812265
- Implementation of Iman-Conover method: https://stats.stackexchange.com/questions/271686/iman-conover-implementation-for-correlated-randoms-in-python-with-numpy-scipy; https://www.howardrudd.net/how-tos/vba-monte-carlo-risk-analysis-spreadsheet-with-correlation-part-3a/; https://www.howardrudd.net/how-tos/vba-monte-carlo-risk-analysis-spreadsheet-with-correlation-part-3b/; https://www.howardrudd.net/how-tos/vba-monte-carlo-risk-analysis-spreadsheet-with-correlation-part-4/
- Methods for correcting non-positive definite matrices: “Correcting Non Positive Definite Correlation Matrices”, Maree, S.C., 2012, Bachelor Thesis, TUDelft

Results of U&S analysis for MBLOCA scenario

Example of how different could be time of main events occurrence:



Results of U&S analysis for MBLOCA scenario



Simple statistics for Cs and Kr in containment and environment (as fraction of initial inventory)

Results of U&S analysis for MBLOCA scenario

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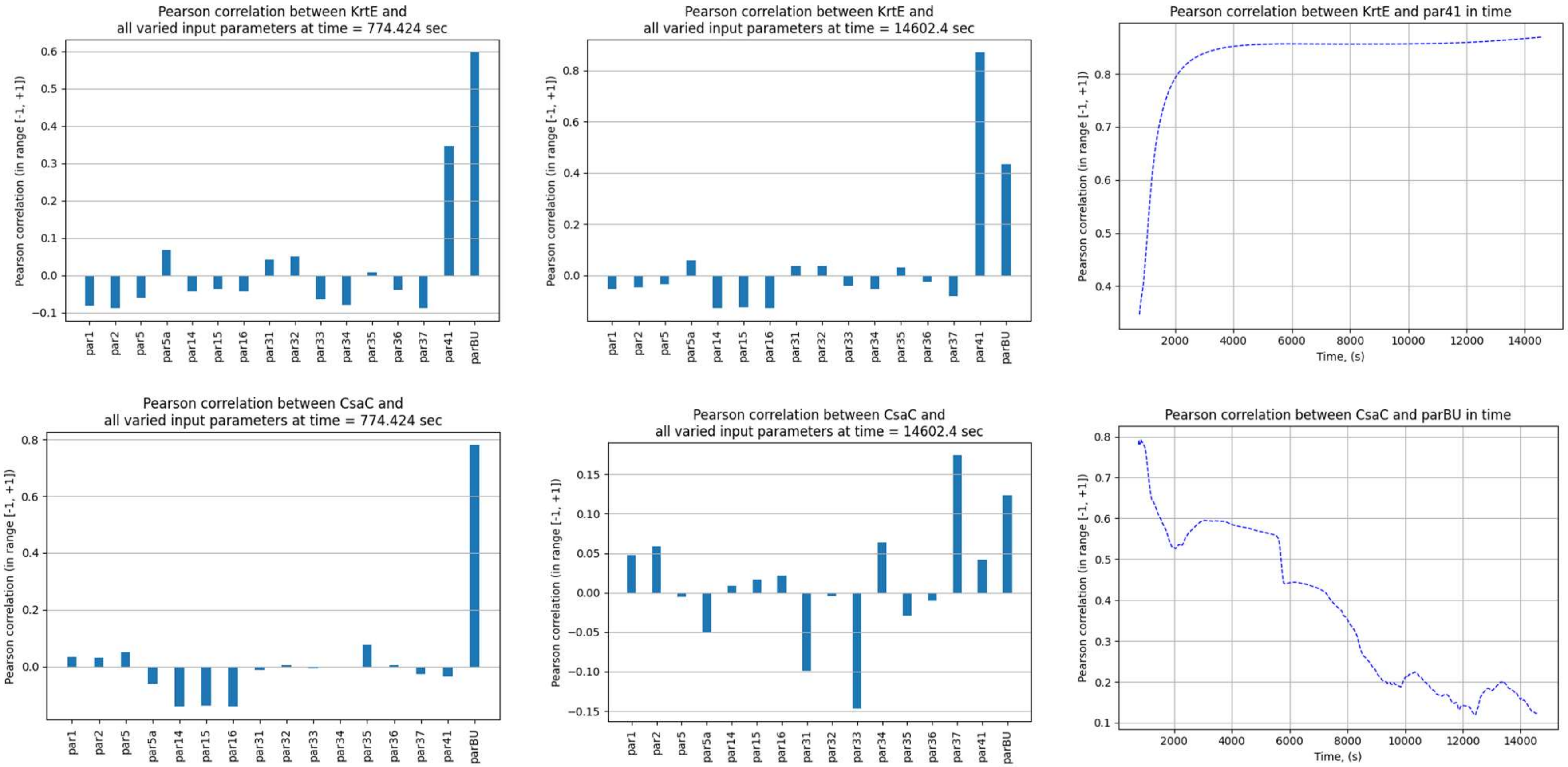

Examples of Pearson correlation coefficients for total amount of Kr in environment and Cs aerosols in containment for two different time points (start of fission product release, ~ end of the process)

Conclusions and next steps

- U&S analysis was performed for ASTEC simulation results of MBLOCA scenario at KONVOI NPP (using generic ASTEC input file for KONVOI + some modifications)
- Analyzing changes of Pearson correlation coefficients in time could provide the better understanding – which parameters are important at different stages of the process.
- Couple sets of simulations for MBLOCA + SBO were made with additional uncertain input parameters, regarding iodine chemistry. And some of these parameters will be added to current list of input parameters.
- Simulations for SBLOCA and SBLOCA+SBO will be performed.
- For QUENCH-08 simulations test with different number of samples and 'consistency' test were made. The same could be done for KONVOI simulations also.