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Uncertainty & sensitivity analysis of SA simulations for KONVOI-1300 with ASTEC code. Prediction of source term values during SA

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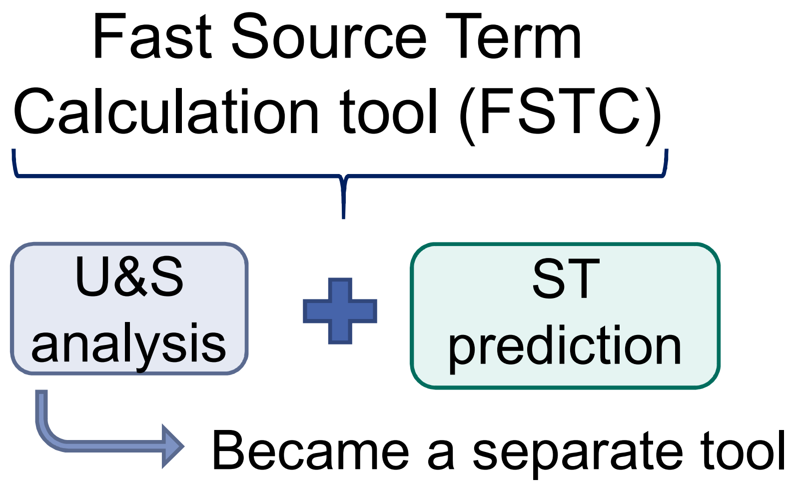
Introduction

- Presented results were obtained in the frame of the *WAME* project. And used in the frame of the *MUSA* project.
- *Goal of the project* – develop the approach for fast source term (ST) prediction and implement it in the software
- Delivering the accurate value of ST practically in real-time could *help the emergency team* to plan the actions and evaluate the accident consequences

Simulated with ASTEC code:

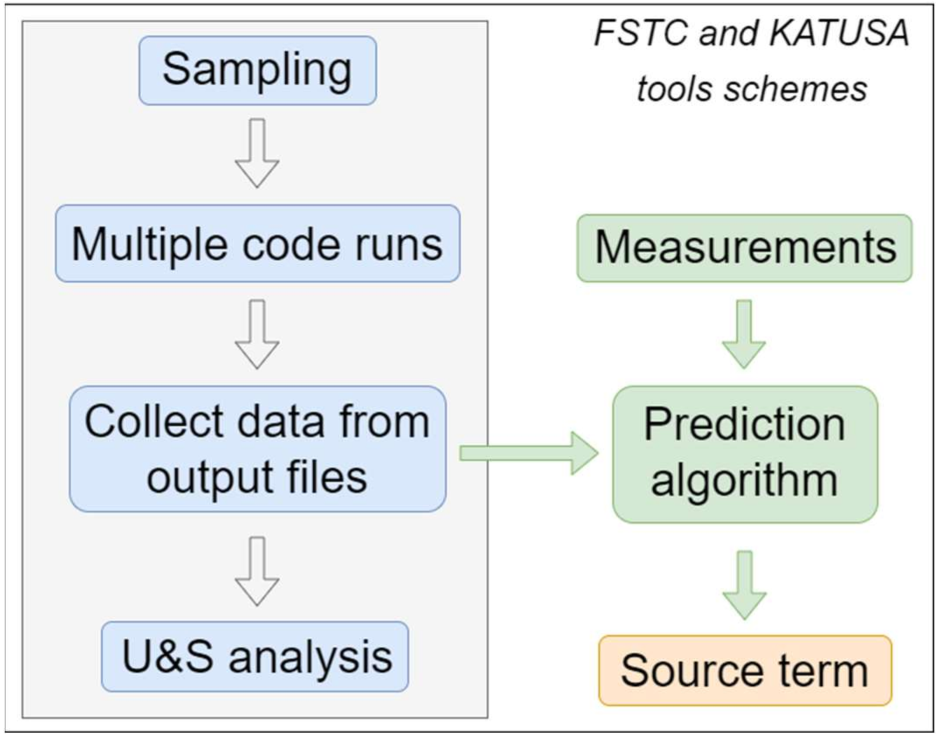
- KONVOI-1300 NPP
- MBLOCA, MBLOCA+SBO scenarios
- MBLOCA up to the basemat rupture



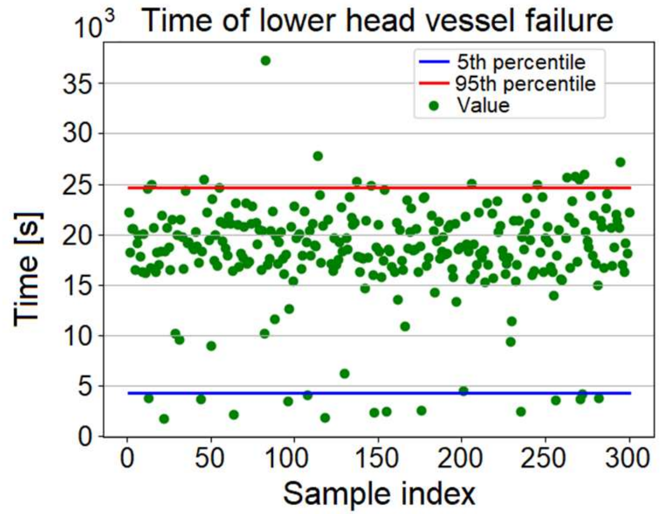
FSTC and KATUSA tools

- *Fast Source Term Calculation (FSTC)* tool [1] combines functionality for U&S analysis and ST prediction
- Bayesian *MOCABA approach* (developed in Framatome [2, 3]) is implemented in our tool
- U&S analysis part used to *prepare the input database* for the prediction algorithm
- U&S part is *now a separate tool* – KArlsruhe Tool for Uncertainty and Sensitivity Analysis (KATUSA)
- FSTC is *coupled* with *ASTEC* code. In KATUSA coupling to *TwoPorFlow* code added (and potentially to other codes)

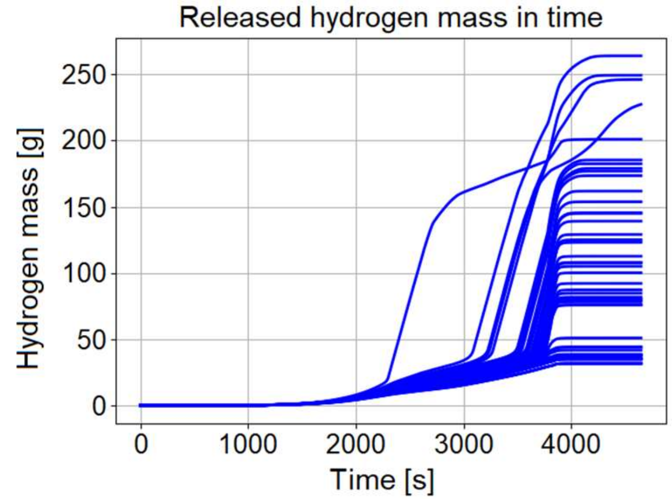
New software



Example of the output for MBLOCA simulations



Example of the output for QUENCH-08 simulations



Additional info about the tools:

- Written in Python language (therefore is automatically cross-platform)
- Sampling – SRS, LHS
- Correlation coefficients – Pearson, Spearman, distance, MIC
- GUI for U&S analysis part would be added

ASTEC model of a generic KONVOI NPP

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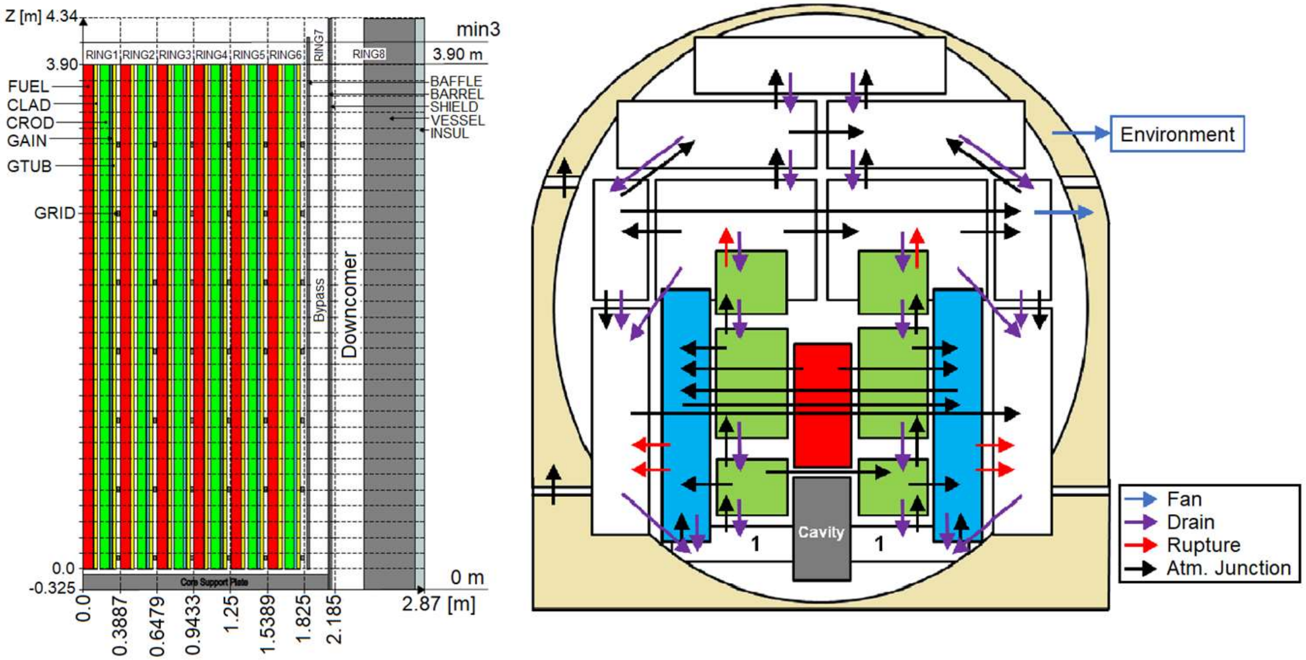
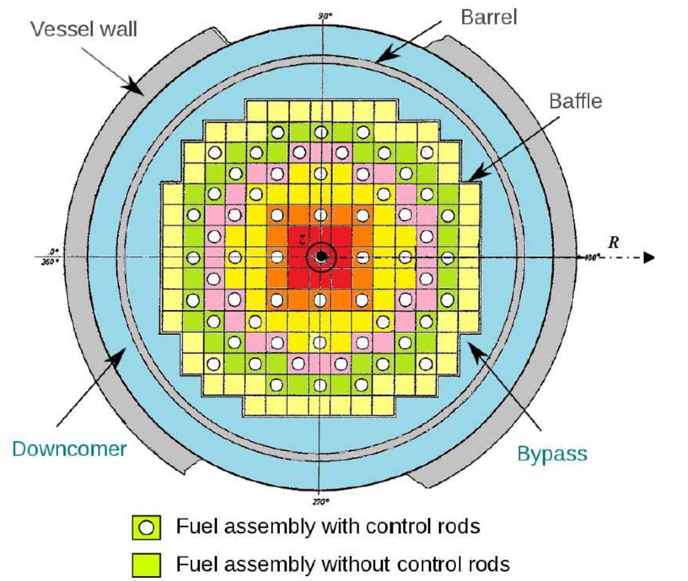


Core and containment nodalization (From [4,5])



Cross-section of the core model (From [4])

- On the upper figure the following presented: the plant rooms (green, red, grey, and light blue boxes); the operating rooms (white boxes); the annulus (light yellow boxes)
- Fan connects the containment and the annulus, as well as the annulus and the environment (marked with light blue arrows)
- Active zone divided into slices 300 mm thick
- Lower head region represented with one cell
- Radially core and vessel together are divided into eight rings

- ASTEC 2.2b is used
- All ASTEC modules are activated
- Based on the generic input deck from EU CESAM project [6]
- Fuel inventories calculated with ORIGEN-ARP code
- No filtering

U&S analysis KONVOI-1300

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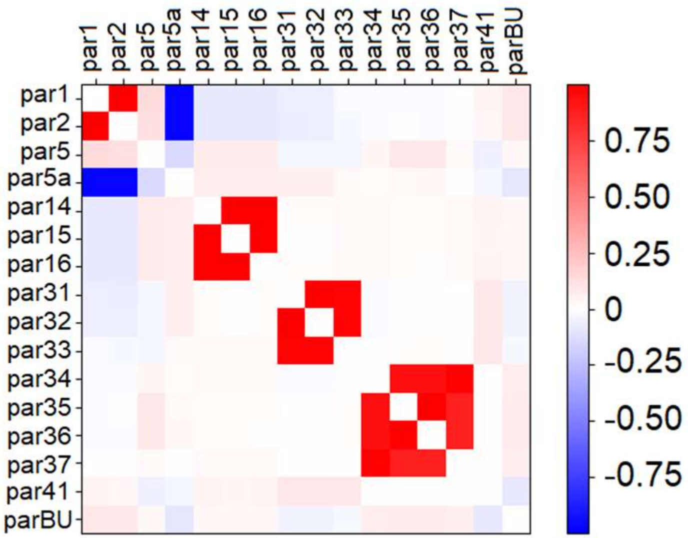
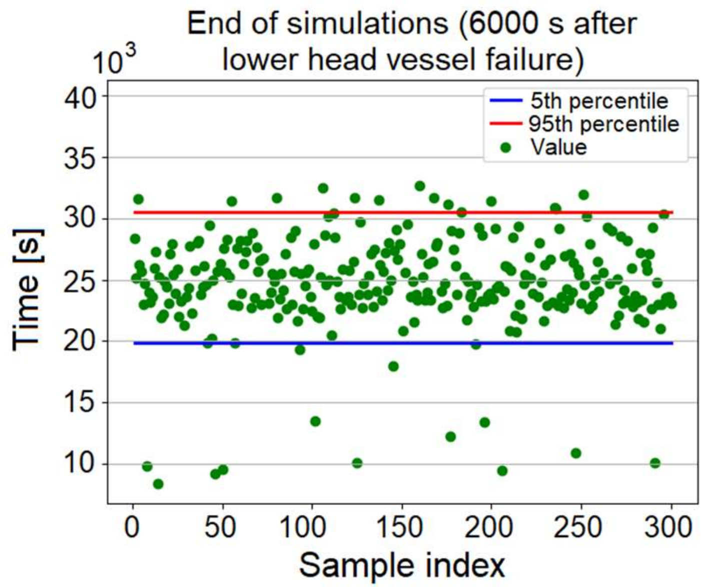
- MBLOCA and MBLOCA+SBO scenarios
- For MBLOCA scenario – “short” (simulations stop at 6000 s after lower head vessel failure) and “full” (up to the basemat rupture) versions
- 16 uncertain input parameters – 14 of them related to the ASTEC models + parameter for number of effective full power days + parameter governing leakage rate between containment and annulus



Correlations between uncertain input parameters. 300 samples, MBLOCA scenario.



Time, when ASTEC calculation stopped. 300 samples, MBLOCA scenario.

- Failed runs are excluded from further analysis
- User can manually exclude runs (for example, with shortest SA progression time)

Uncertain input parameters

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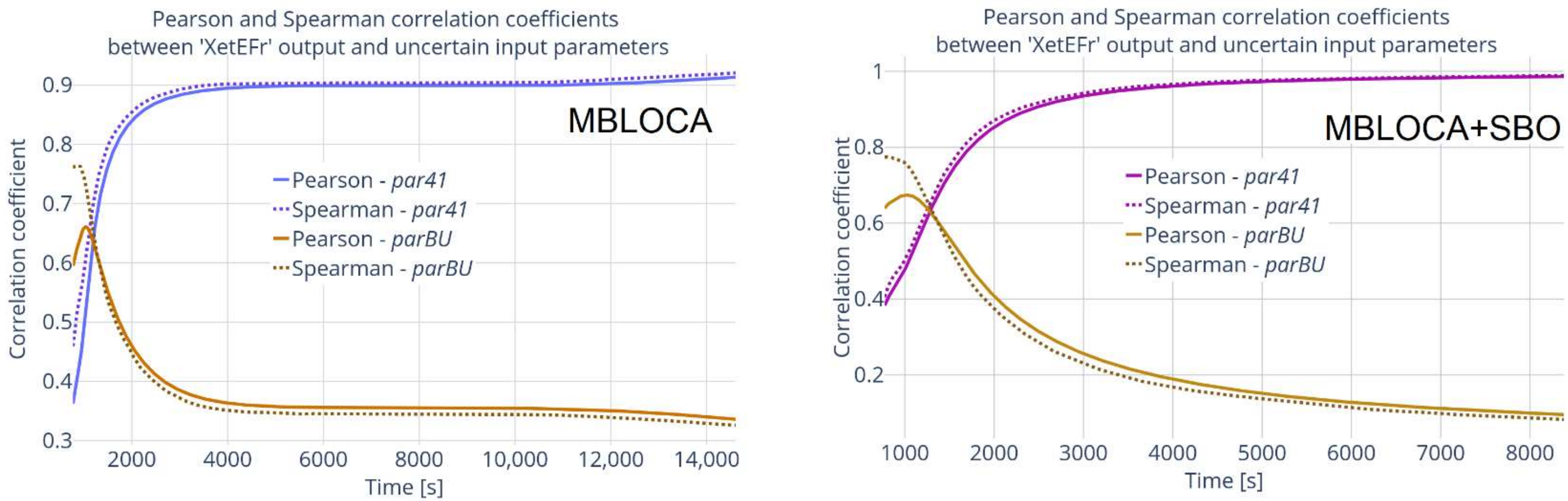
Par-r	Best estimated value	Probability density function	Meaning
par1	5.0	Normal	STRU ELSA Correction factor for the ratio S/V of the fuel pellets due to roughness
par2	0.03	Normal	STRU ELSA Correction factor for the ratio S/V of the fuel pellets for the limited steam access
par5	1.2E-5	Normal	STRU ELSA 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

U&S analysis KONVOI-1300

- Main FoMs are release of different FPs in vessel, primary circuit, containment, and environment
- For all FoMs simple statistics and correlation coefficients are calculated
- For considered FPs (Xe, Kr, Cs, I, Ba, La, Mo) release in environment, the most important uncertain input parameters are – par41 (governing leakage), parBU (governing burnup)



Correlation between Xe release in environment and uncertain input parameters (par41 and parBU). MBLOCA (left), MBLOCA+SBO (right)

U&S analysis KONVOI-1300

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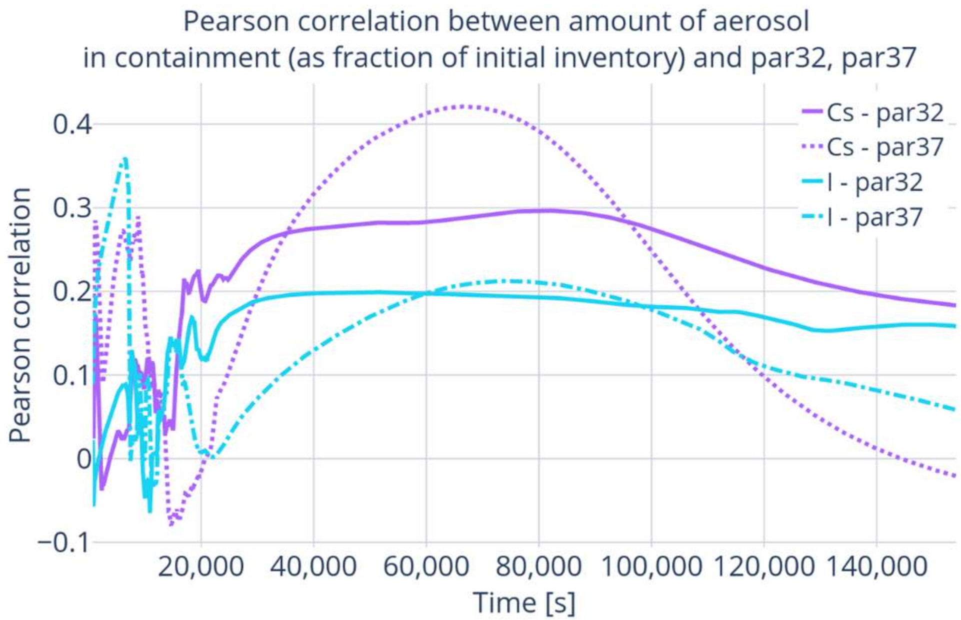
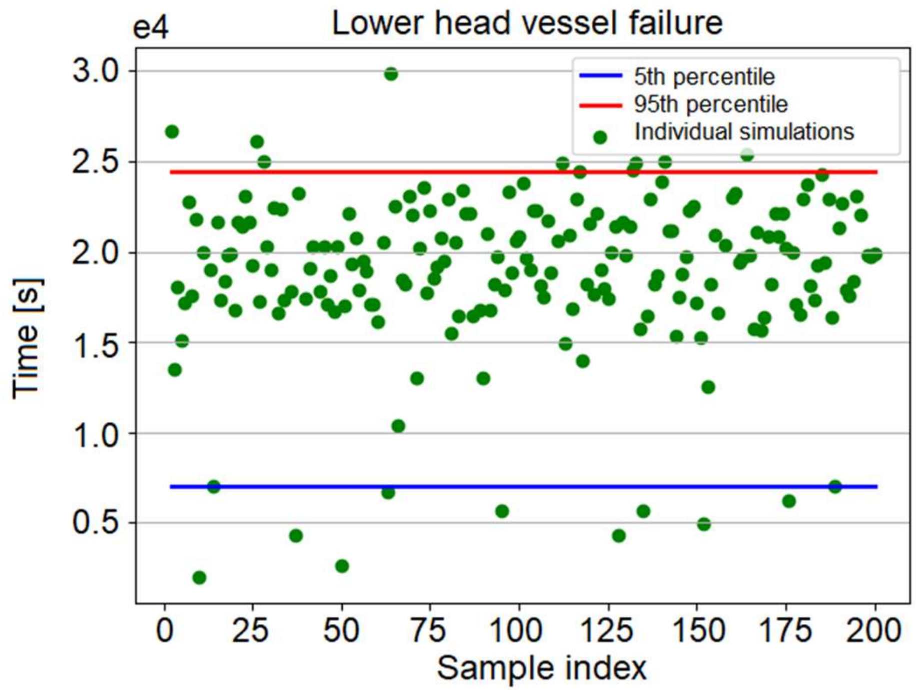
- Additional findings for 'full' MBLOCA scenario [7] are the influence of **par32** (Average specific heat of the aerosol) and **par37** (Shape factor relative to Stokes velocity) on release of Cs and I aerosols in containment during the later phase of the accident.



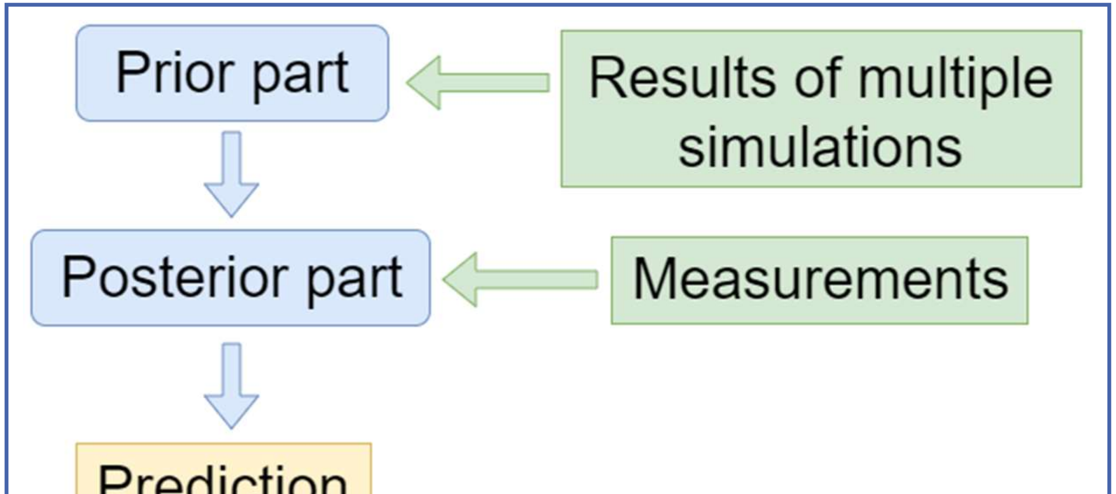
Correlation between Cs and I aerosols release in containment and uncertain input parameters (par32 and par37). 'Full' MBLOCA. From [7]



Time of the lower head vessel failure for all 200 simulations. 'Full' MBLOCA.

Prediction algorithm

- Prediction algorithm implemented in FSTC tool is based on MOCABA framework developed by Framatome [2, 3]



MOCABA approach scheme

- Algorithm could be used to predict any parameter of interest, not only ST values
- User specifies, which parameters values to predict and what measured data to use
- Algorithm itself is divided into two parts – prior and posterior
- Prior part output are mean values and correlations between parameters and between parameters values at different time steps
- Prior part as input gets the results of the multiple simulations (see output of 'collect data' step on slide 5)

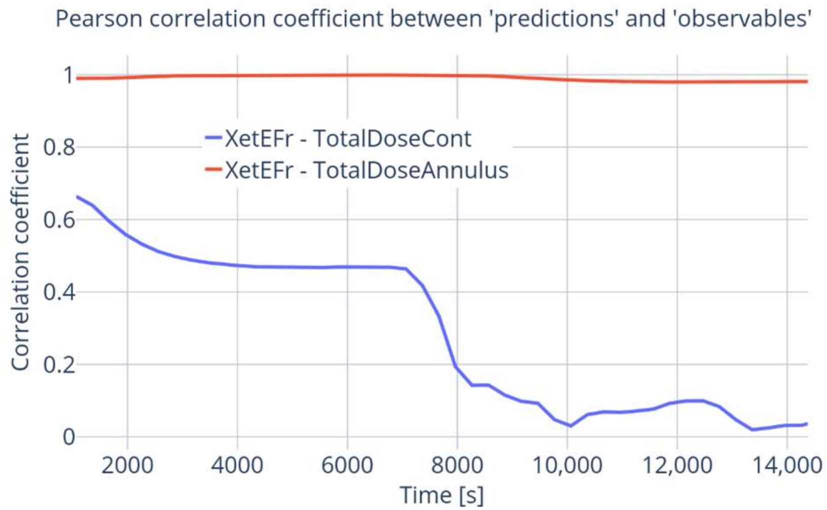
Prediction algorithm

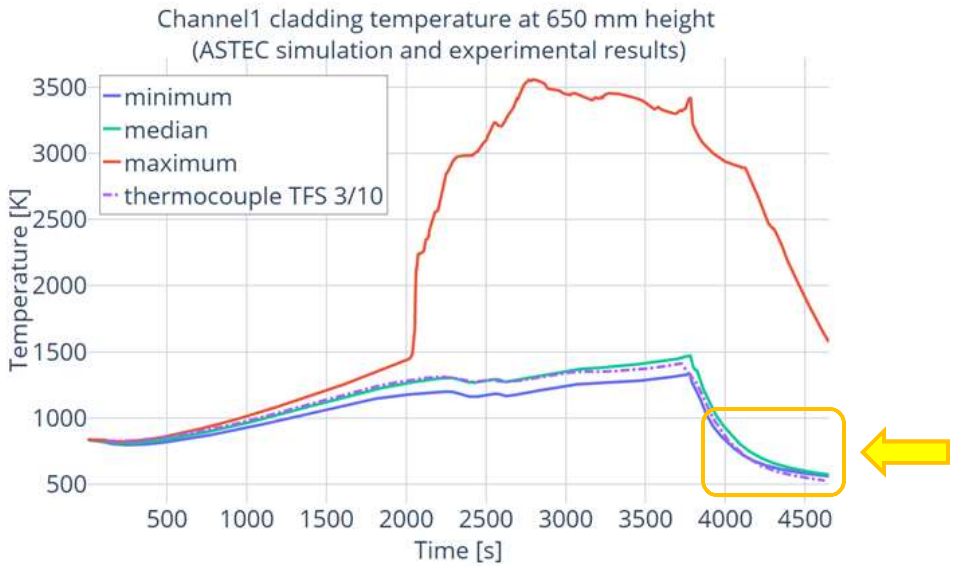
- Prior part output and measured data are used as input for posterior part
- Posterior part created the prediction itself

Important to check:

- ✓ Correlation between measured parameters and parameters to predict
- ✓ Diapason of the input data values for prior part. Measurements should not lie outside of this diapason

Example of correlation values between parameter to predict (XetEFr) and measured data (TotalDoseCont, TotalDoseAnnulus). Data from MBLOCA simulations

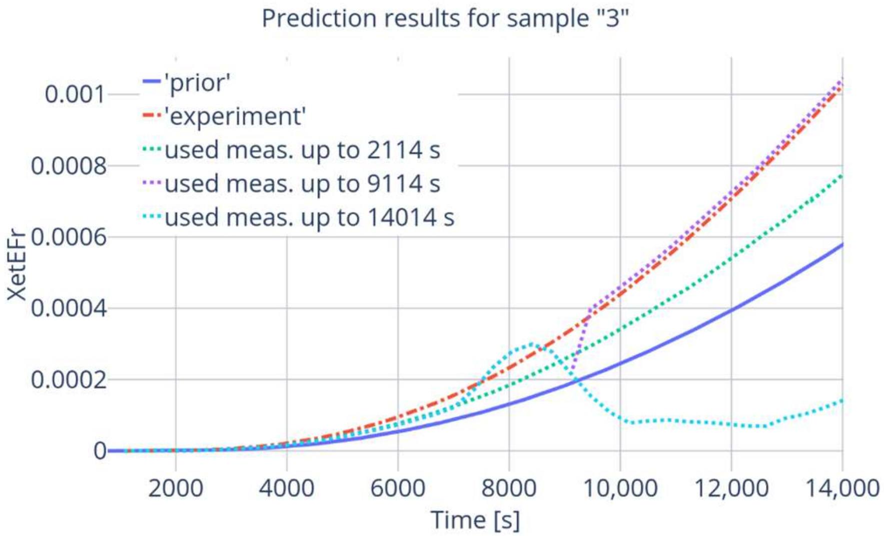




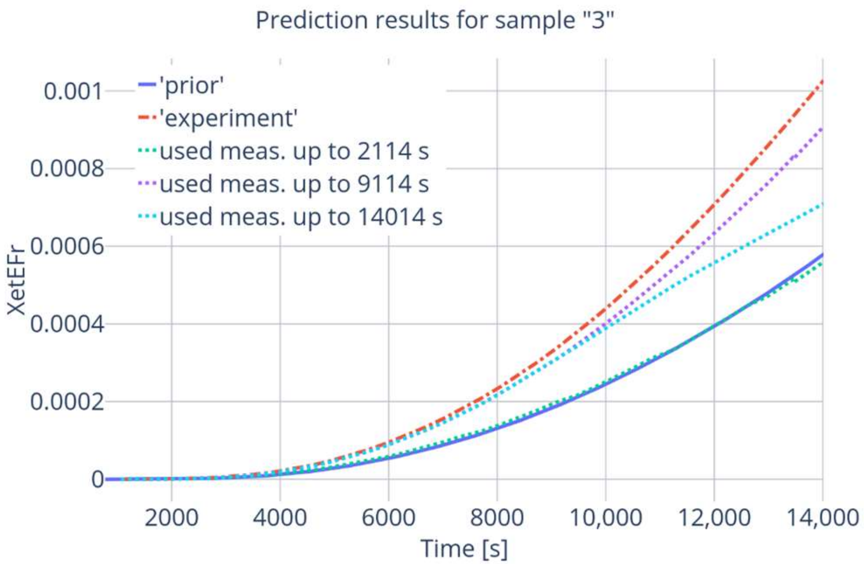
Example of outliers for testing MOCABA algorithm on real experimental data from QUENCH-08 and using for prior part ASTEC simulation results

ST prediction results

Dose rate in containment included in measurements



Only dose rate in annulus included in measurements



- To apply prediction algorithm to SA simulations [8], measurement were also simulated with the ASTEC code
- Input for prior part – results of 300 MBLOCA scenario simulations (uncertain parameters sampled with LHS)
- Run 100 additional MBLOCA simulations to imitate measurements (same uncertain parameters sampled with LHS)
- Each of 100 simulations treated as individual ‘experiment realization’

On the figures – example how low correlation value (see slide 11) between parameter to predict and measurements could affect results

Outlook

- ✓ New software (FSTC and KATUSA) developed at KIT for U&S analysis and fast source term prediction
- ✓ U&S analysis of MBLOCA and MBLOCA+SBO scenarios at KONVOI-1300 NPP performed with ASTEC code and FSTC tool
- ✓ Uncertainty parameters related to containment leakage and fuel burn-up are the most significant for fission product release to the environment and containment
- ✓ In simulations up to the basemat rupture effect from the uncertainty parameters governing the aerosol behavior observed on Cs and I release to the containment
- ✓ Source term predictions made with prediction algorithm based on MOCABA framework developed in Framatome
- ✓ Prediction results are better, if correlation between parameter to predict and measured parameter is high

Thank you for your attention!

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