The 11th European Review Meeting on Severe Accident Research (ERMSAR-2024), KTH, Stockholm, Sweden. May 12-16, 2024

UNCERTAINTY AND SENSITIVITY ANALYSIS OF THE ASTEC SOURCE TERM RESULTS OF A MBLOCA SCENARIO WITH THE ACTIVATION OF SEVERE ACCIDENT MANAGEMENT ACTIONS IN A GENERIC KONVOI PLANT

Stakhanova A, Gabrielli F, Sanchez-Espinoza V. H - Karlsruhe Institute of Technology (KIT)
Pauli E.-M., Hoefer A - Framatome GmbH

Table of content

- Introduction
- KArlsruhe Tool for Uncertainty and Sensitivity Analysis (KATUSA)
- ASTEC model of a generic KONVOI NPP
- MBLOCA SA scenario
- Uncertain input parameters
- Results of U&S analysis
- Conclusions and outlook

Introduction

Karlsruhe Institute of Technology

- Joint contribution KIT/Framatome GmbH to the H2020 Management and Uncertainties Of Severe Accidents (MUSA) project (2019-2023) coordinated by CIEMAT

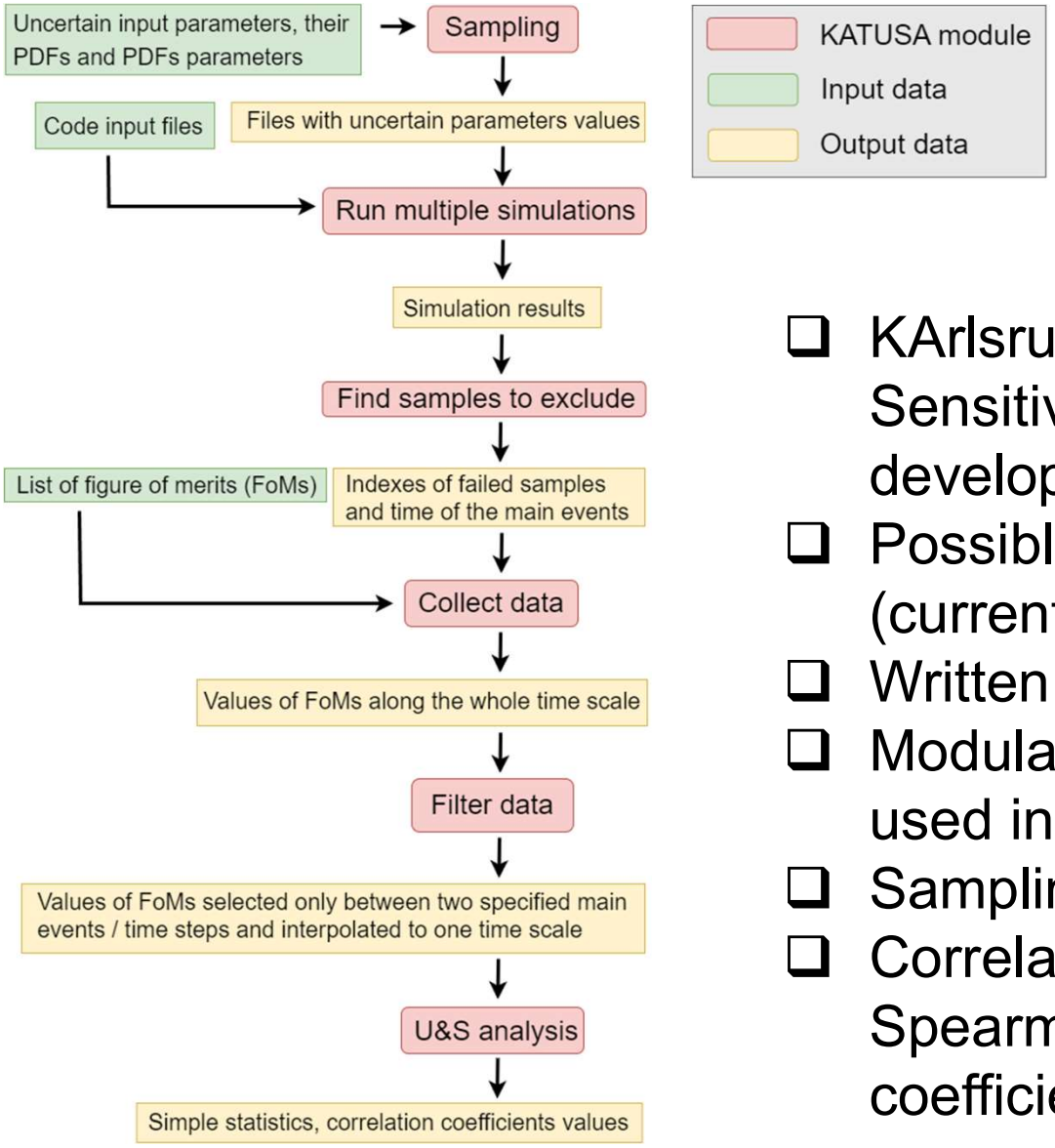
- ✓ SA code: ASTEC (version - 2.2.0.1)
- ✓ Generic KONVOI NPP
- ✓ MBLOCA scenario up to the basemat rupture with activation of SAM (Filtered Containment Venting System and Annulus air extraction system); MBLOCA without SAM, MBLOCA+SBO - not presented here
- ✓ Tool for U&S analysis – in-house KArlsruhe Tool for Uncertainty and Sensitivity Analysis (KATUSA)

Previous work - MBLOCA without SAM - described in:

Stakhanova, A., Gabrielli, F., Sanchez-Espinoza, V.H., Pauli, E., Hoefer, A., Uncertainty and sensitivity analysis of the ASTEC simulations results of a MBLOCA scenario in a generic KONVOI plant using the FSTC tool. In Proceedings of 10th European Review Meeting on Severe Accident Research (ERMSAR-2022), 2022, pp.861-872.

Stakhanova, A., Gabrielli, F., Sanchez-Espinoza, V.H., Pauli, E., Hoefer, A., Uncertainty and sensitivity analysis of the ASTEC simulations results of a MBLOCA scenario in a generic KONVOI plant using the FSTC tool. Annals of Nuclear Energy, 192, (2023), p.109964. DOI: https://doi.org/10.1016/j.anucene.2023.109964

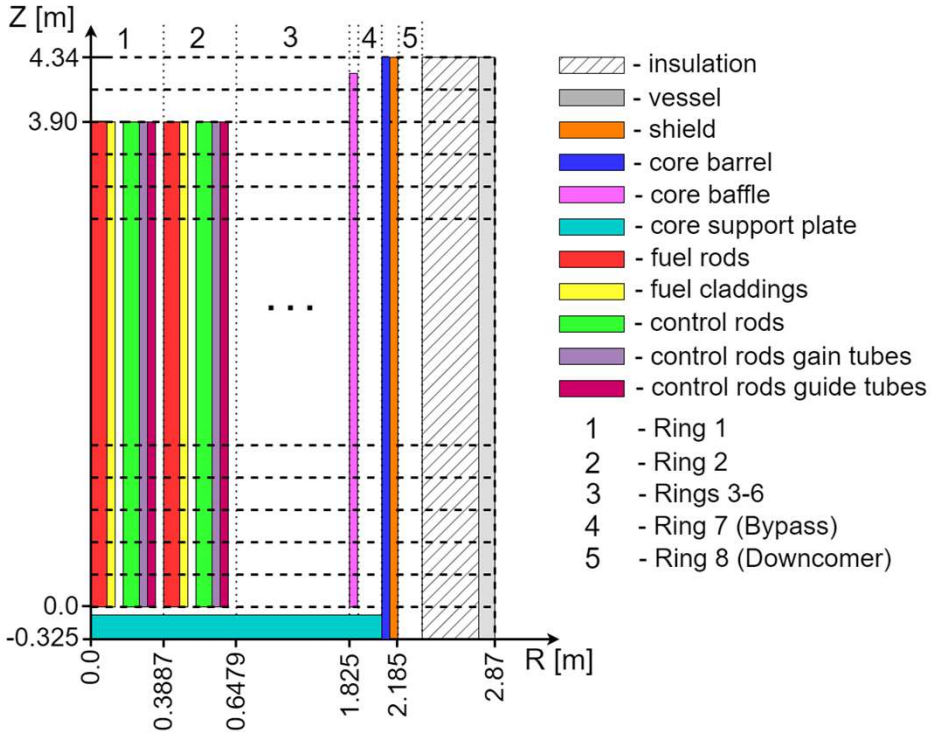
KATUSA tool for U&S analysis



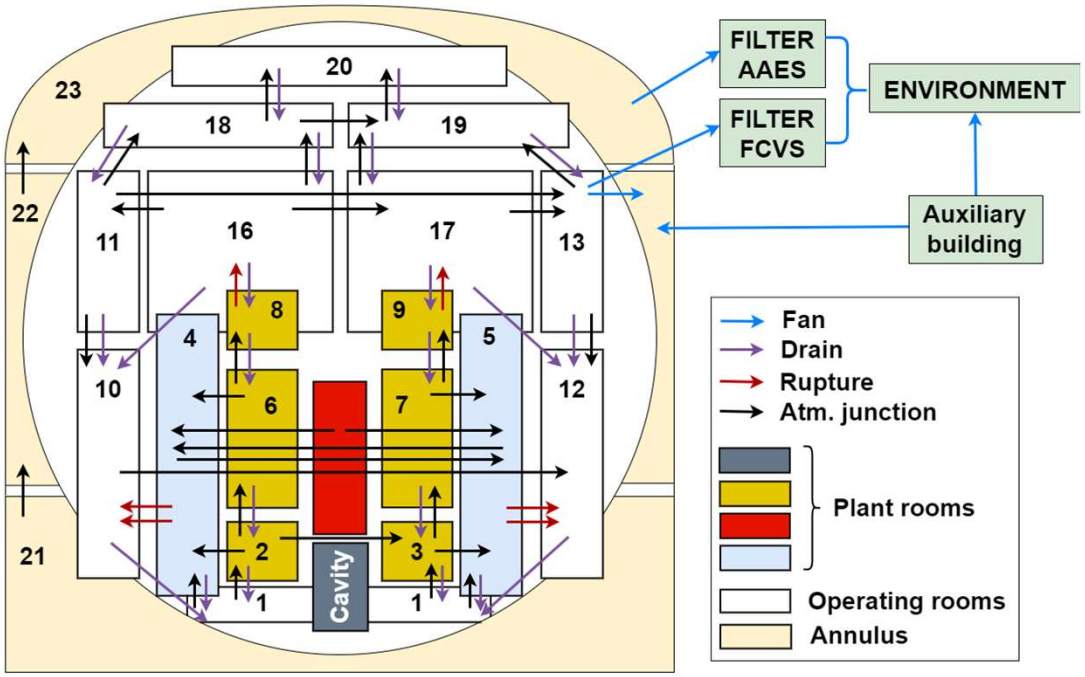
KATUSA tool scheme

- KArlsruhe Tool for Uncertainty and Sensitivity Analysis (KATUSA) tool developed at KIT
- Possible to couple with different codes (currently: ASTEC, TwoPorFlow)
- Written in Python language
- Modular structure. Each module could be used independently
- Sampling algorithms: SRS, LHS
- Correlation coefficients: Pearson, Spearman, distance, Maximal Information coefficient

KONVOI NPP ASTEC model



Core nodalization



Containment nodalization

- Core: six cylindrical rings plus two channels for the downcomer and the bypass
- Containment: 26 rooms plus an auxiliary building.

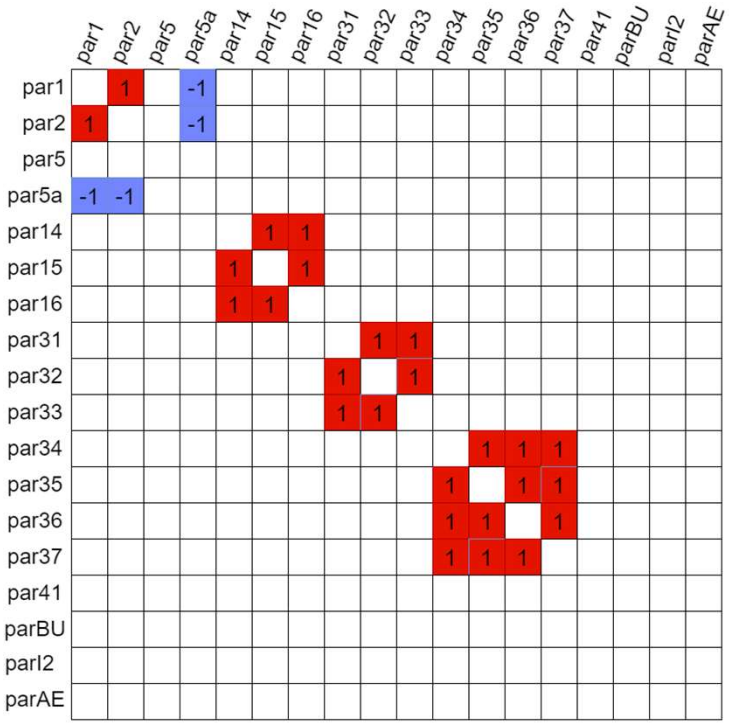
- Annulus air extraction system (AAES): always available. Efficiency of the filters: 99.995% for aerosols; 99% for gaseous iodine
- Filtered Containment Venting System (FCVS): activated as SAM action, efficiency of the filters is 99.9% for aerosols and 99% for gaseous iodine

MBLOCA SA scenario

Karlsruhe Institute of Technology

- Plant works at full power before the start of the transient.
- Scenario is initiated by a 12” break on the cold leg (t=0 s).
- SCRAM signal (t=1 s). The admission to turbine and the main feed water pumps into the steam generator are closed (t=1.5 s).
- The Emergency Core Cooling System (ECCS) signal (t=6 s)
- The Main Coolant Pumps (MCPs) are coasted down (t=7 s) and the pressure regulation in the pressurizer is switched off.
- The Emergency Feed Water System (EFWS) is activated when the liquid level of one steam generator falls below 4.50 m.
- The gas temperature in the primary circuit exceeds 650 °C, the High- and Low-Pressure Injection Systems (HPIS/LPIS) are activated.
- The water injections stop when the tanks are empty leading to the start of core degradation (start of fission products release at t=564 s in base case scenario).
- The reactor pressure vessel fails (t=12054 s in base case scenario)
- Corium is relocated into the cavity (end of corium slump t=12071 s in base case scenario)
- Cavity is flooded by water when the horizontal erosion reaches 0.5 m.
- The simulation ends when basemat rupture occurs.

Uncertain input parameters



Uncertain input parameters correlation matrix

Two new parameters added comparing to the previous simulations:

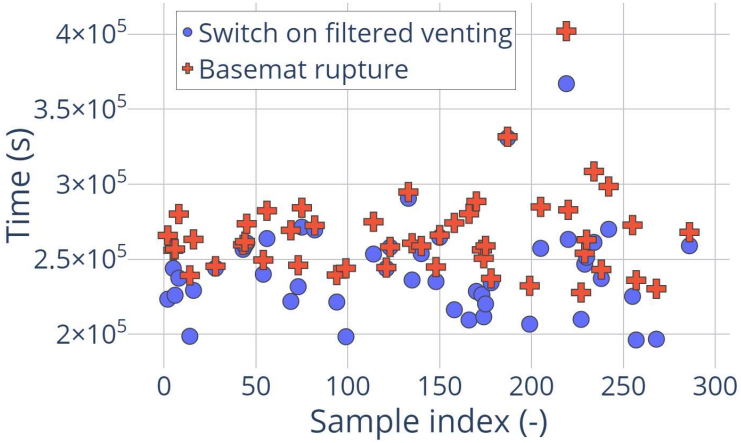
parI2 – Filter efficiency for Gases (I2) – Not analyzed yet in the presented results

parAE - Filter efficiency for Aerosols

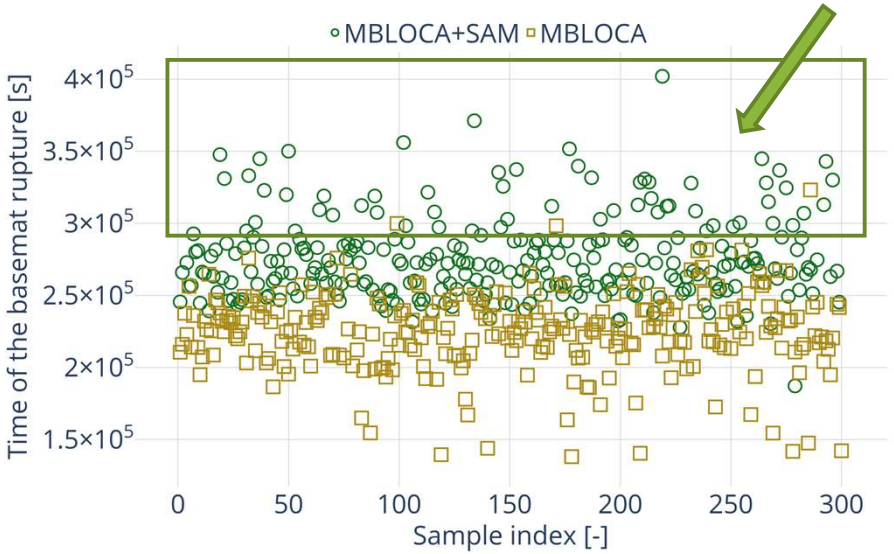
Par-r	Phenmenon	Meaning
par1	Fission product release from the fuel	Correction factor for the ratio S/V of the fuel pellets due to roughness
par2		Correction factor for the ratio S/V of the fuel pellets for the limited steam access
par5		Geometrical diameter of the grain
par5a		Standard deviation of geometrical diameter of the grain
par14	Cladding integrity criteria	Threshold Temperature of the cladding Dislocation [K]
par15		Threshold Temperature of the oxide layer Dislocation [K]
par16		Threshold thickness of the oxide layer [mm]
par31	Aerosols behavior in the RCS	Particle mean thermal conductivity (J/m/K)
par32		Average specific heat (J/kg K) of the aerosol
par33		Particle mean density (kg/m3)
par34		Particle minimum geometrical radius (m)
par35		Particle maximum geometrical radius (m)
par36		Shape factor relative to particle coagulation
par37		Shape factor relative to Stokes velocity
par41	Containment leakage	Flow rate (m3/s)
parBU	Fuel burn-up	Effective full power days

U&S analysis results

- 300 simulations
- 12 finished incorrectly
- In 48 simualtions FCVS is activated

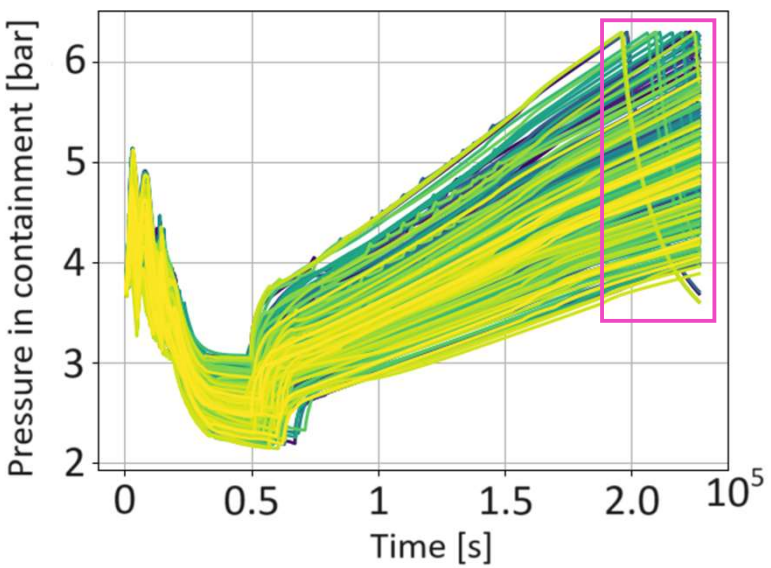


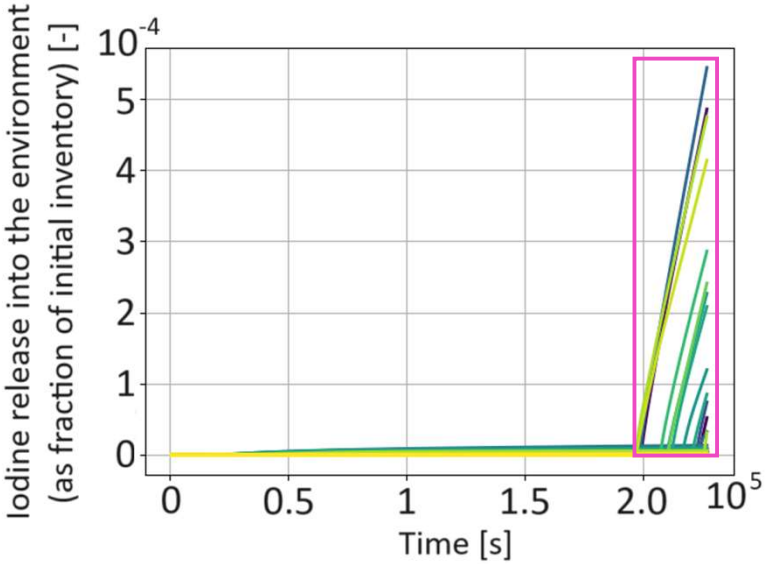
Longer time till basemat rupture due to depressurization

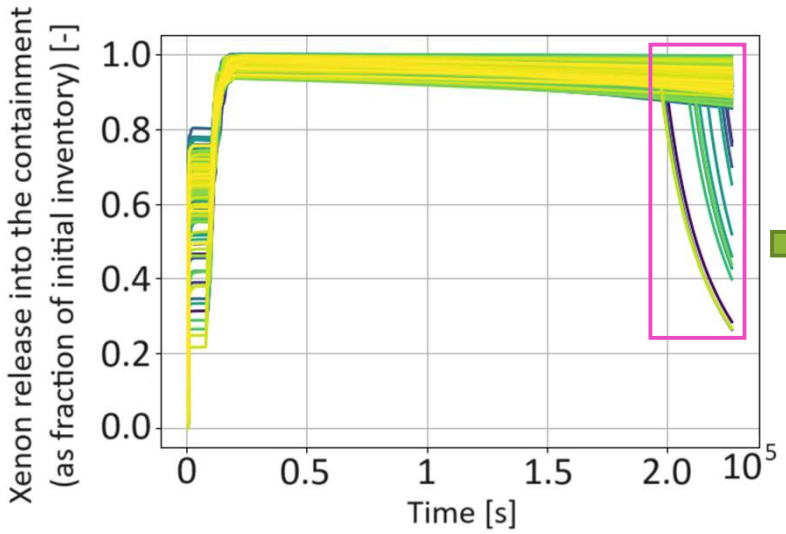


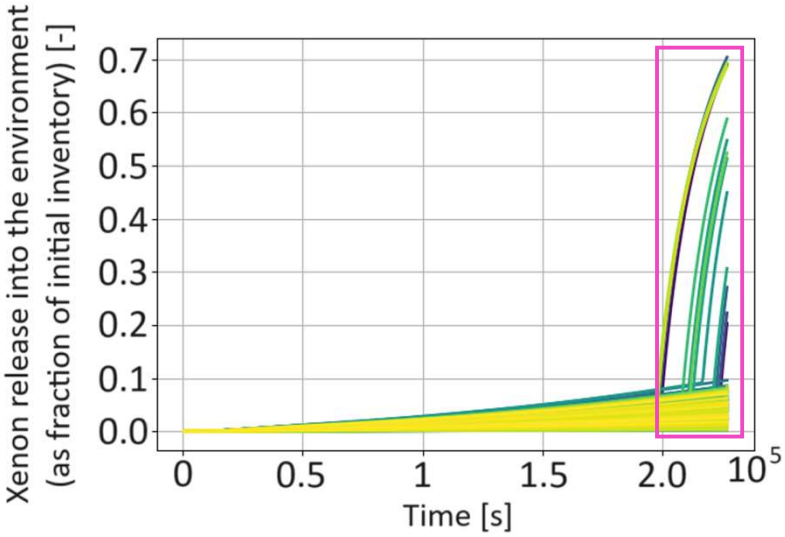
Event	Minimum (s)	Maximum (s)
Start of FPs release	464	684
20. tons of corium relocated to the lower plenum	844	17194
Lower head vessel failure	3064	29454
End of the corium slump to the cavity	3066	29533
Switch on filtered venting	196245	367073
Basemat rupture	187242	402073

U&S analysis results





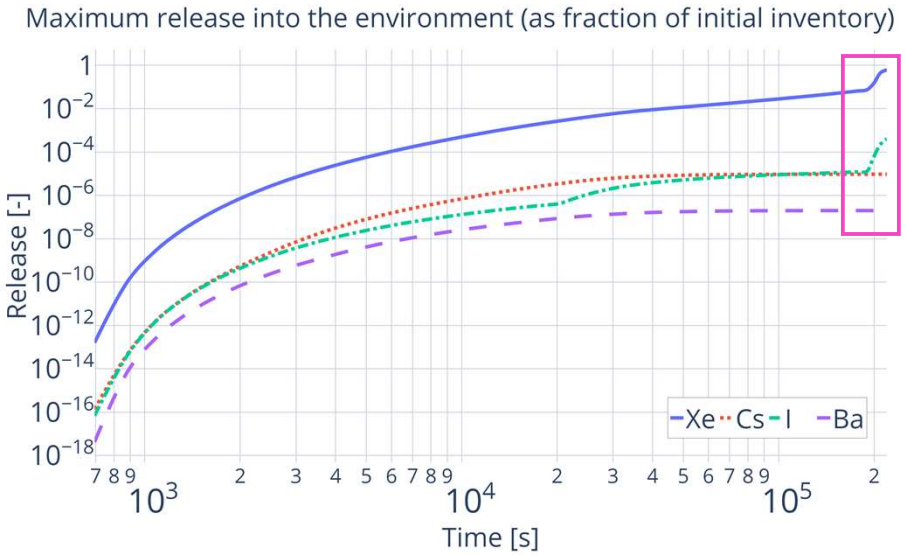


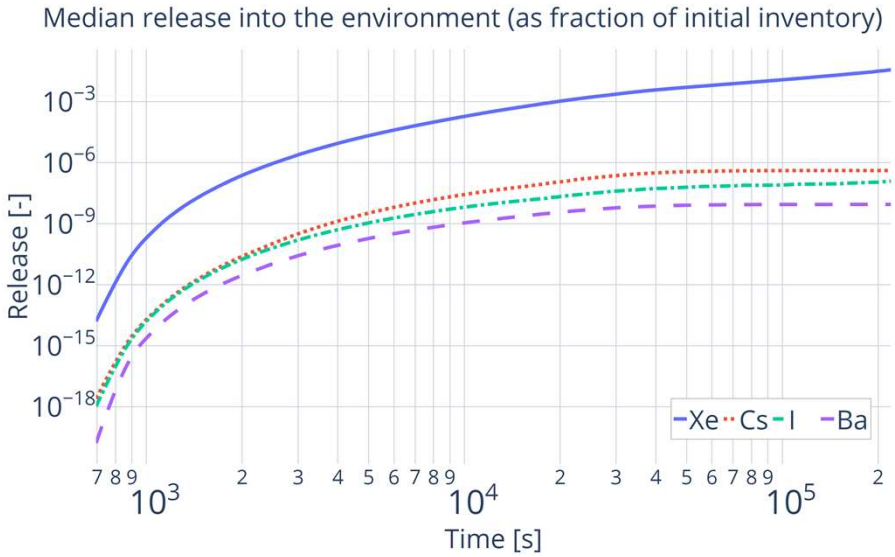


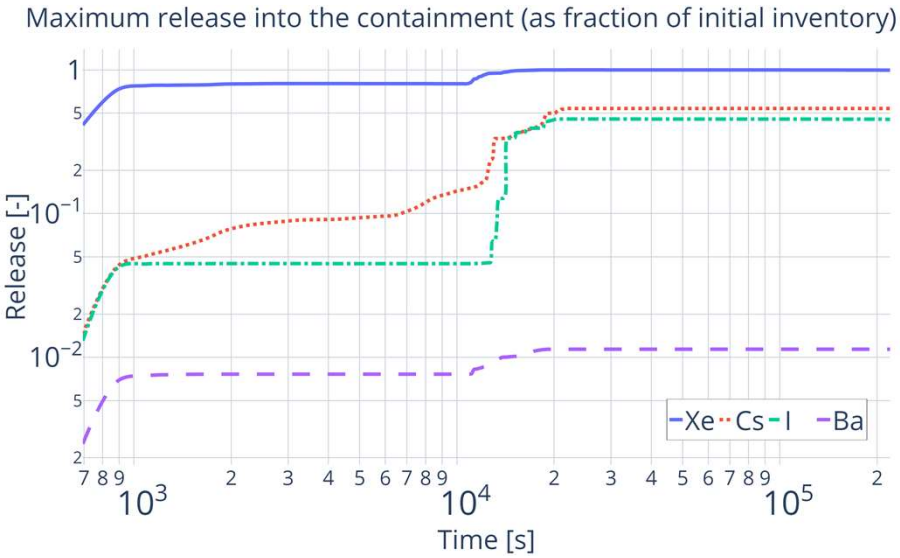
- FCVS activation

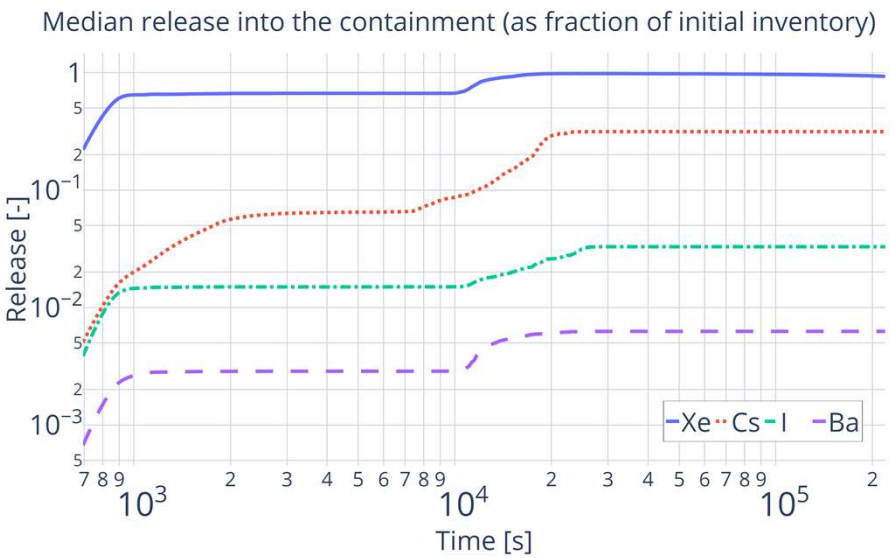
U&S analysis results

- FCVS activation

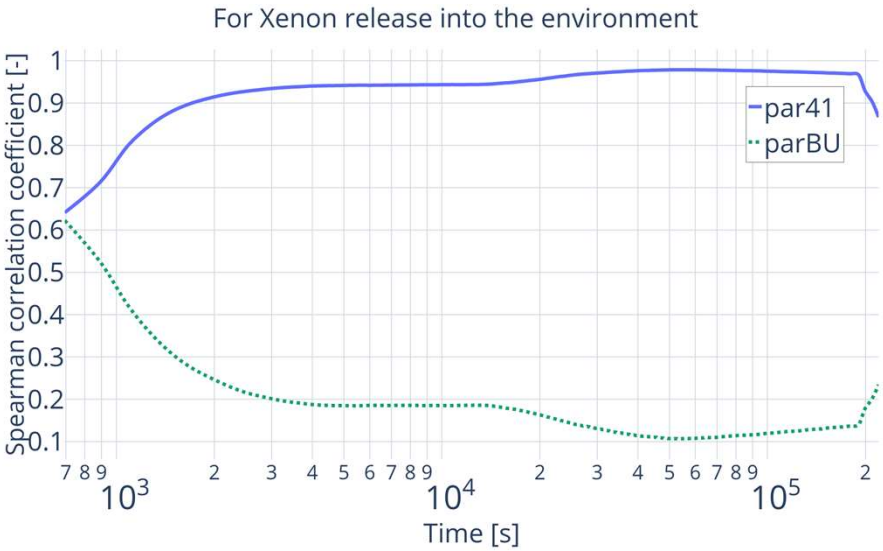


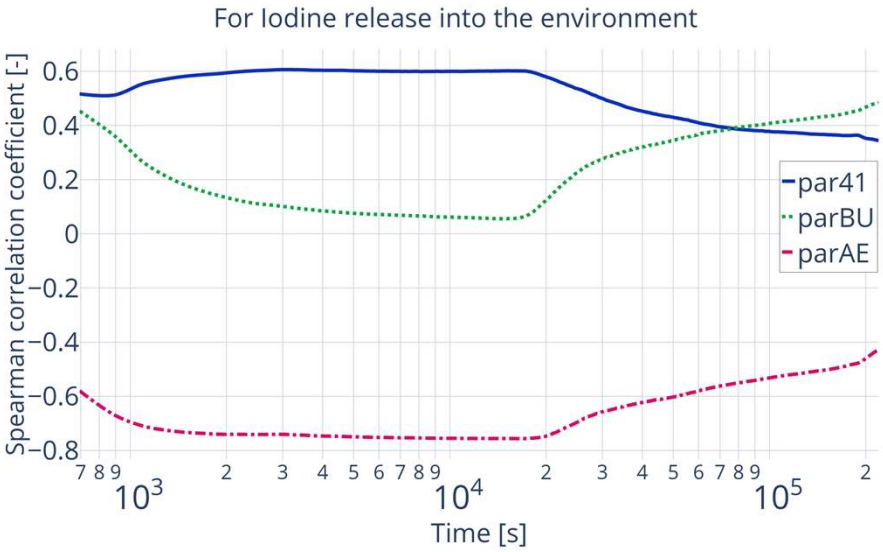


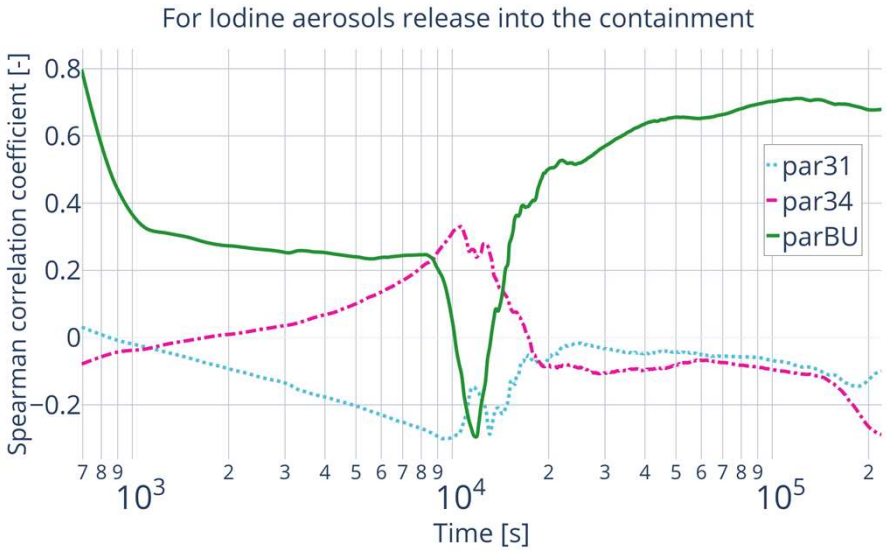




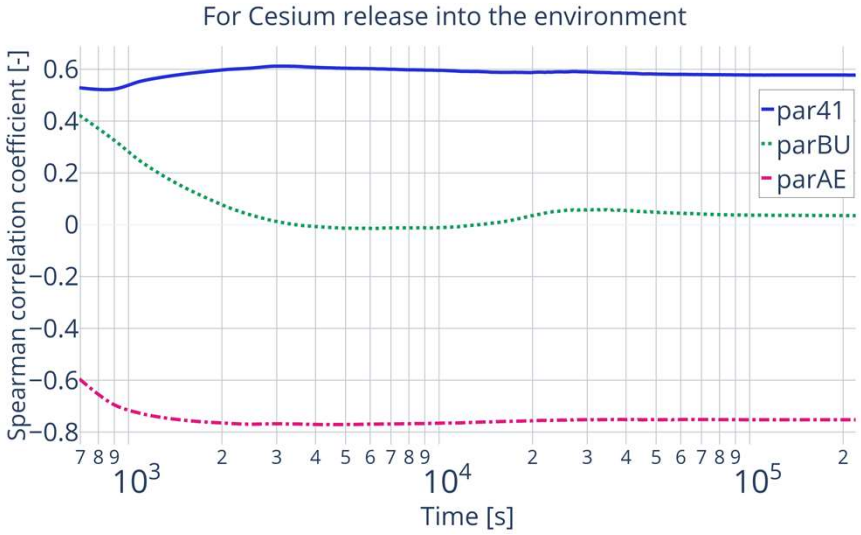
U&S analysis results

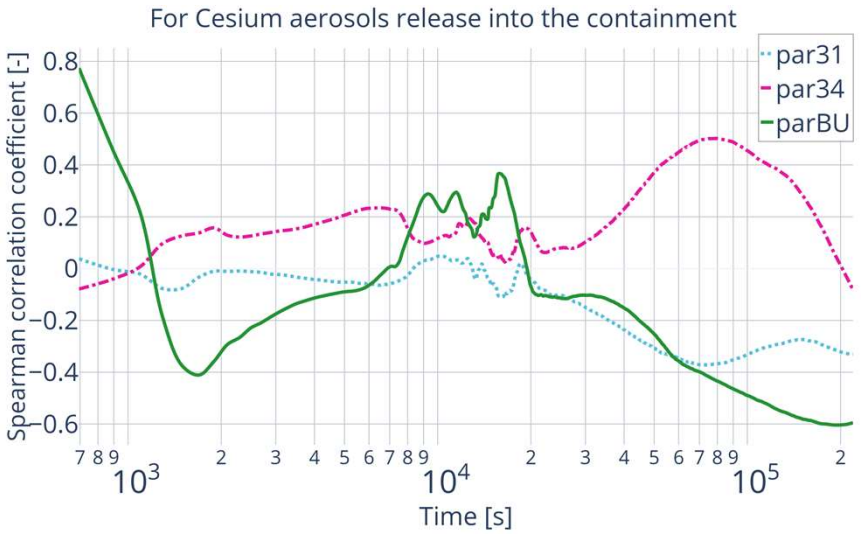


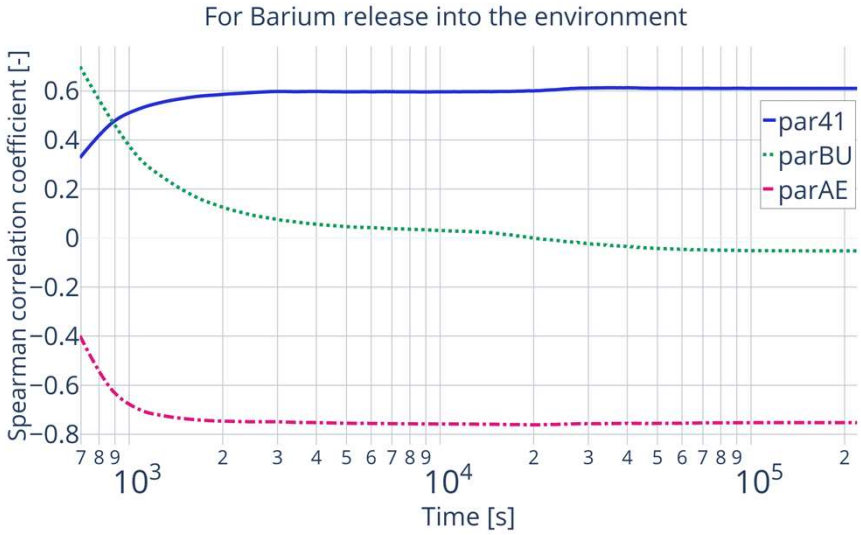


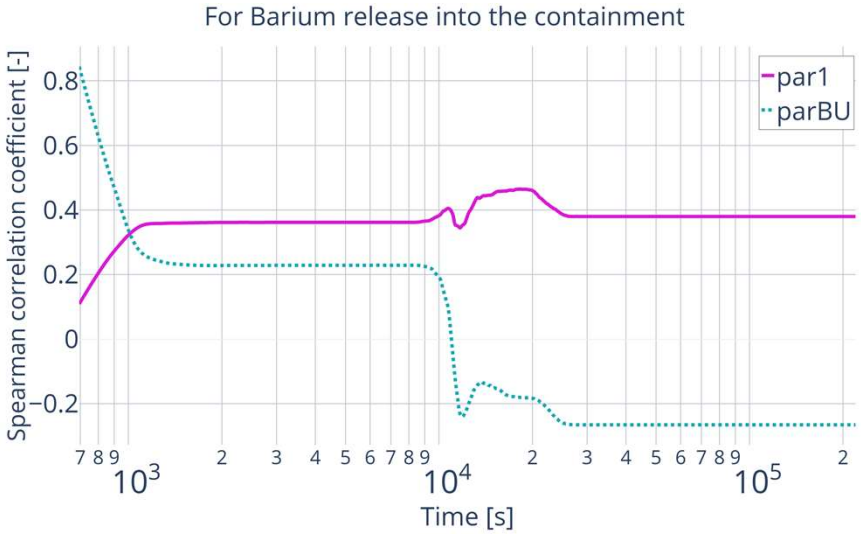


U&S analysis results



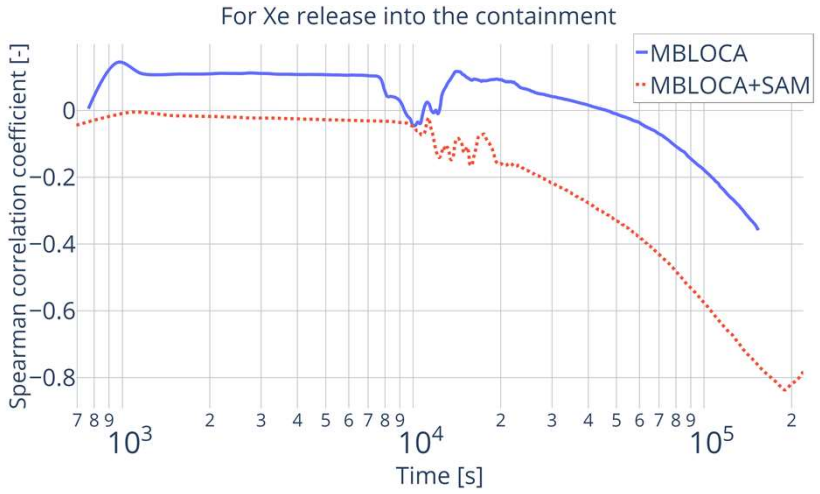






U&S analysis results

- Release into the environment is correlated with par41 (containment leakage) and parBU (burnup) as in previous MBLOCA analysis
- For Iodine, Cesium and Barium release into the environment now is also affected by parAE (Filter efficiency for aerosols)
- Release into the containment for all FPs is affected by parBU. For Xe – now also by par41. For Ba – by par1-par5a; for Cs and I aerosols – by par31-par37 as in previous MBLOCA analysis



Conclusions and outlook

- ✓ In the frame of the MUSA project performed simulations of MBLOCA scenario with applying SAM (filtered containment venting)
  - In total 900 simulation results were analyzed in the frame of the MUSA project (300 simulations for each of the: MBLOCA, MBLOCA+SBO, MBLOCA+SAM)
- ✓ For simulations ASTEC SA code and KATUSA tool for U&S analysis are used
- ✓ The uncertainty of the FP release to the environment has been evaluated
  - Contribution to the application of U&S analysis to support the emergency and prepardeness strategy in case of severe accidents

Conclusions and outlook

Karlsruhe Institute of Technology

- ✓ Influence on the FPs release of previously used uncertain parameters and new parameter related to the filtered venting is investigated

→ Difference between results of simulations MBLOCA with/without SAM should be investigated more thoroughly

→ Are more calculations required in case of SAM to have a good statistics? (FCVS was activated in 48 simulations from 300)

→ Investigate different statistical methodologies/interpretation of the results?

↪ KIT/Framatome database of SA simulation results could be used for the ST predictions (see application of MOCABA framework and FSTC tool)

↪ U&S analysis importance for a reliable characterization of the source term (see KIT studies with ASTEC-KATUSA-JRODOS for, i.e., BWR, VVER-1000)

Thank you for your attention!

Acknowledgements

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 847441. This paper reflects only the author's view, and the European Commission is not responsible for any use that may be made of the information it contains.

Contacts: KIT, INR; Stakhanova Anastasia, anastasia.stakhanova@kit.edu

References

- *Stakhanova, A.,* Gabrielli, F., Sanchez-Espinoza, V.H., Hoefer, A. and Pauli, E., 2022. Uncertainty and sensitivity analysis of the QUENCH-08 experiment using the FSTC tool. *Annals of Nuclear Energy*, *169*, (2022), p.108968. DOI: https://doi.org/10.1016/j.anucene.2022.108968
- *Stakhanova, A.,* Gabrielli, F., Sanchez-Espinoza, V.H., Pauli, E., Hoefer, A., Uncertainty and sensitivity analysis of the ASTEC simulations results of a MBLOCA scenario in a generic KONVOI plant using the FSTC tool. In *Proceedings of 10th European Review Meeting on Severe Accident Research (ERMSAR-2022),* 2022, pp.861-872.
- *Stakhanova, A.,* Gabrielli, F., Sanchez-Espinoza, V.H., Pauli, E., Hoefer, A., Uncertainty and sensitivity analysis of the ASTEC simulations results of a MBLOCA scenario in a generic KONVOI plant using the FSTC tool. *Annals of Nuclear Energy, 192*, (2023), p.109964. DOI: https://doi.org/10.1016/j.anucene.2023.109964
- Sanchez-Espinoza, V. H., Gabrielli, F., Imke, U., Zhang, K., Mercatali, L., Huaccho, G., et. al., KIT reactor safety research for LWRs: Research lines, numerical tools and prospects. Nuclear engineering and design, 414, (2023), p. 112573. DOI: https://doi.org/10.1016/j.nucengdes.2023.112573
- Brumm, S., Gabrielli, F., Sanchez-Espinoza, V. H., *Stakhanova, A.,* et. al., 2024, Uncertainty Quantification for Severe-Accident reactor modelling: results and conclusions of the MUSA reactor applications work package. *Under review in Annals of Nuclear Energy*