Comparison of PHEBUS FPT1 uncertainty applications using MELCOR 2.2 with three different methodologies

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OUTLINE and INTRO

Goal of this activity is applying and testing Uncertainty Quantification (UQ) methodologies with MELCOR 2.2 against the PHEBUS FPT1 test using three different methodologies and the same MELCOR input deck:

- RAVEN (Sapienza) - SA/UT_1
- DAKOTA coupling with Python scripts (ENEA) - SA/UT_2
- DAKOTA with a SNAP/MATLAB mixed approach (UNIPI) - SA/UT_3

- Probabilistic method to propagate the input uncertainty used, considering the aerosol miscellaneous constants as input uncertain parameters.
- Aerosol suspended mass in the containment's atmosphere has been selected as FOM.

Framework

- Management and Uncertainties of Severe Accidents (MUSA) project, founded in HORIZON 2020 and coordinated by CIEMAT (Spain), aims to establish a harmonized approach for the analysis of uncertainties and sensitivities associated with SAs.

- The Uncertainty Quantification Methods against Integral Experiments (AUQMIE) WP4, coordinated by ENEA, is aimed at applying and testing Uncertainty Quantification (UQ) methodologies against the internationally recognized PHEBUS FPT1 test.

- The results obtained through the three UQ coupling frameworks have been compared considering the main statistical values of the selected FOM distribution along the entire test and on the maximum value of the FOM

MELCOR /RAVEN coupling procedure developed

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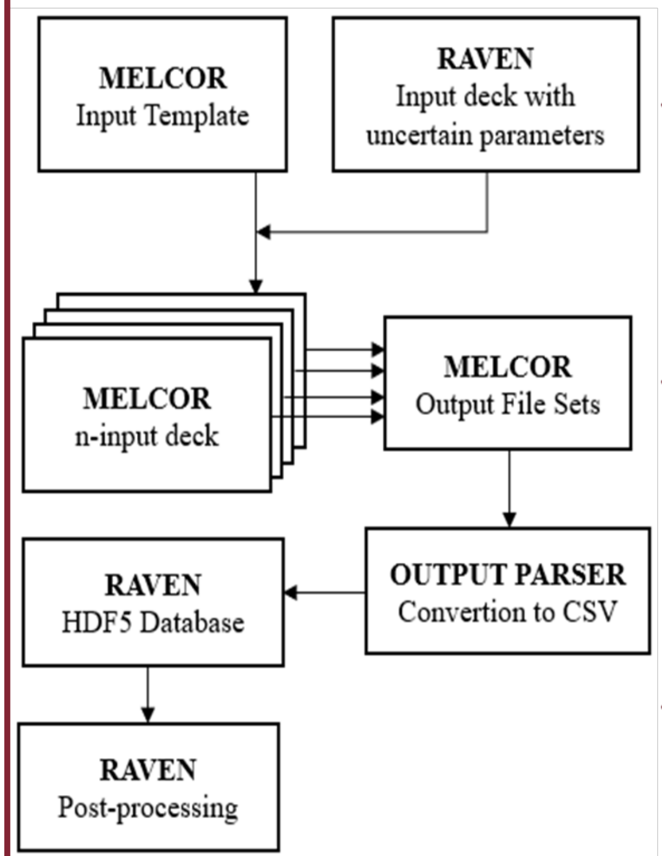


Initial Sampling of:
- Physical parameters
- Initial Conditions
- Transition Conditions, i.e., time of a transition event

Runs the system simulator using the values previously sampled and eventually applying a random noise to some parameters

Converts each .PTF file in csv. To overcome the handling of large datafiles the interface allows to create a CSV file with only variables required by the users. So is possible to obtain an HDF5 database which comprises variables from all MELCOR packages (CVH, FL, COR, RN etc.)

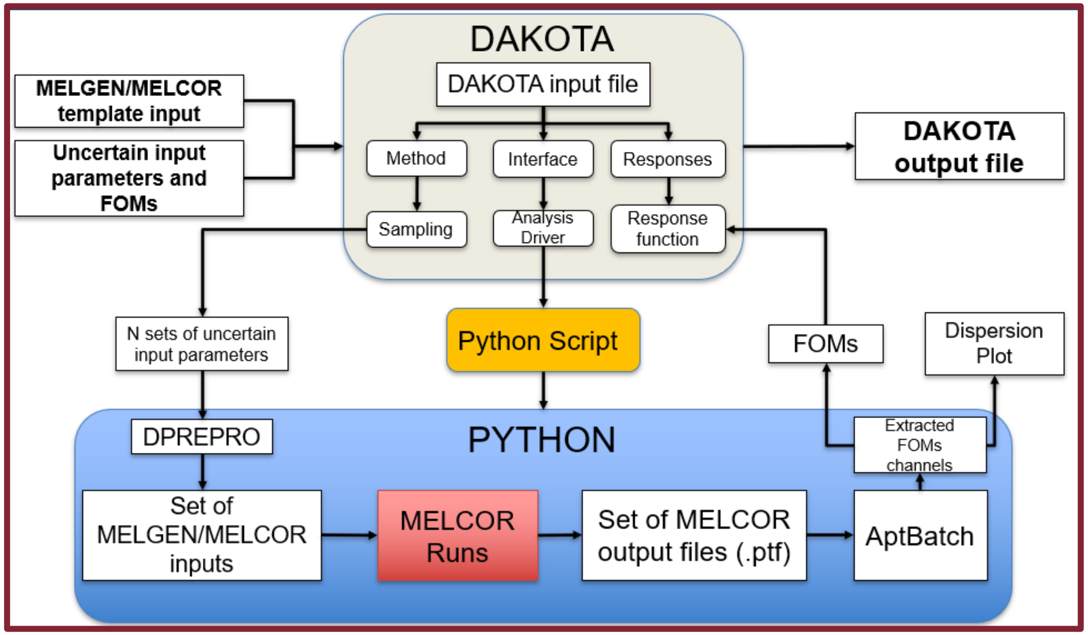
RAVEN (Risk Analysis Virtual Environment) open-source tool developed at INL to perform parametric analysis based on the response of complex system codes and to quantify the safety margins related to safety-related events.

MELCOR/DAKOTA coupling procedure developed

DAKOTA (Design Analysis Kit for Optimization and Terascale Application) is an open-source software developed in C++ by SNL designed to perform sensitivity analysis, UQ, optimization, parameter estimation, parametric and uncertainty analysis in a fast and automatic way.

In a first coupling procedure ENEA in collaboration with University of Palermo used a Python script for the substitution of the sampled input uncertain parameters trough DAKOTA in the set of MELGEN/MELCOR inputs, run MELCOR simulations and extract the desired FOMs channels through the AptBatch executable.

The FOMs value are returned to DAKOTA, which performs the uncertainty analysis and writes the output file with the UQ results.



MELCOR/DAKOTA coupling procedure developed

UNIPI developed a MELCOR/DAKOTA coupling with a SNAP/MATLAB mixed approach. The mixed approach exploits SNAP build-in capabilities to configure the uncertainty analysis and to manage the calculations, whilst the user-developed MATLAB script performs the actual analysis. The management of the MELGEN/MELCOR calculations is managed by SNAP, through the DAKOTA toolkit, and to automatically run them employing the maximum number of core processors allowed by the machine. Additional calculations are carried out to compensate for eventual code run failures.
MATLAB analyses the simulations results collected in external data files or MELCOR plot files and performs the statistical analysis with the evaluation of correlation coefficients.

SNAP/MATLAB mixed approach

SNAP

- Uncertainty Configuration:
  - N° of runs
  - Input Parameters
  - Distributions
  - Sampling
- Management of Code Runs:
  - Parallel computing

MATLAB

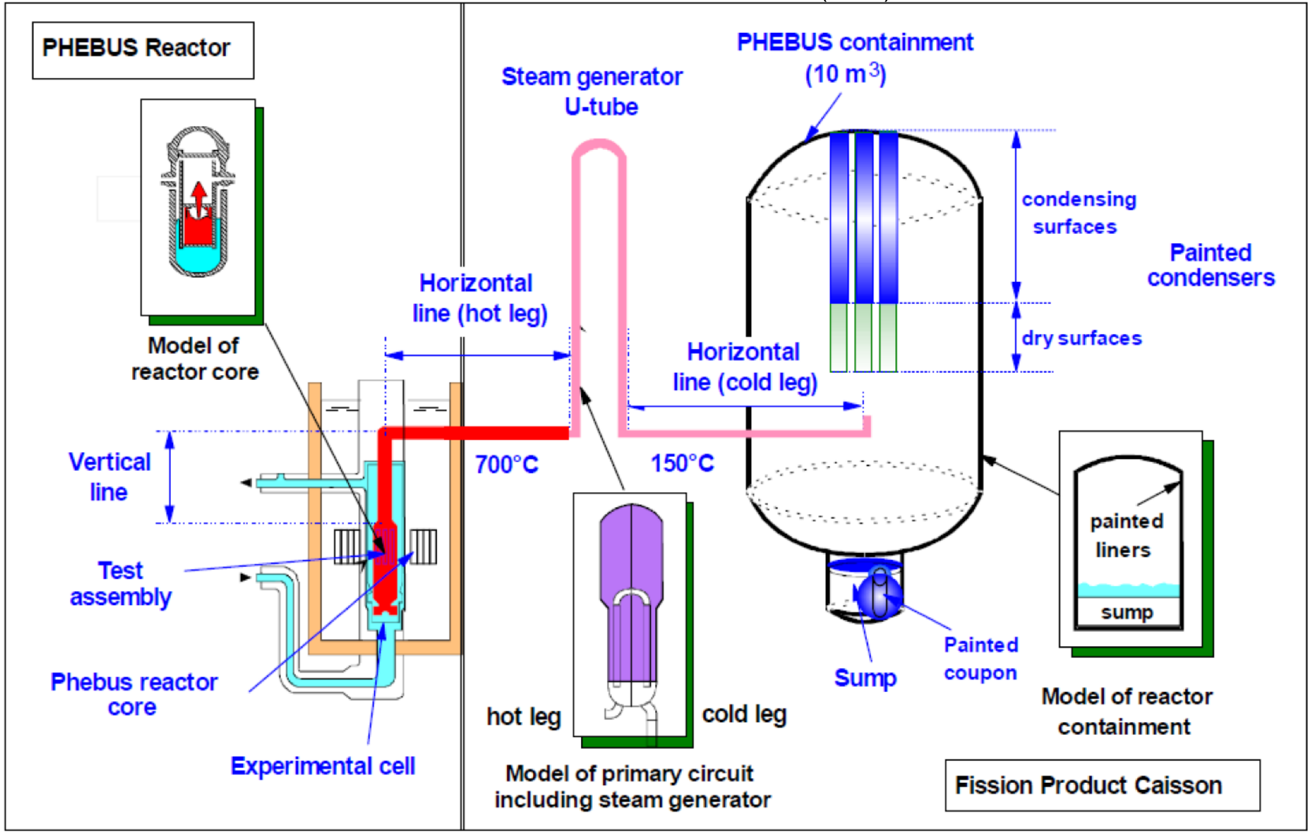
- Statistical Analysis:
  - Time-dependent/Max-value
  - max, min, mean, median, standard deviation, CDF, PDF, skewness, kurtosis, …
- Correlation Coefficients:
  - Time-dependent/Max-value
  - Pearson & Spearman
- Plots & Brief Report

PHEBUS FPT-1

Source: IPSN. Final Report FPT1, IPSN/CRS/SEA/PEPF Report SEA1/00, IP/00/479; Institut de Protection et de Surete Nucleaire (IPSN): Cadarache, France, 2000.

Phebus test fuel bundle was composed of 20 fuel rods, similar to PWR rods, with an additional 1 m absorber rod.

The fuel test bundle was surrounded by an insulating zirconia shroud which was inserted into an in-pile tube cooled by pressurized water. The experimental cooling circuit of the facility was composed of a PWR primary circuit.
A tank with a volume of about 10 m^3 simulated a scaled PWR containment



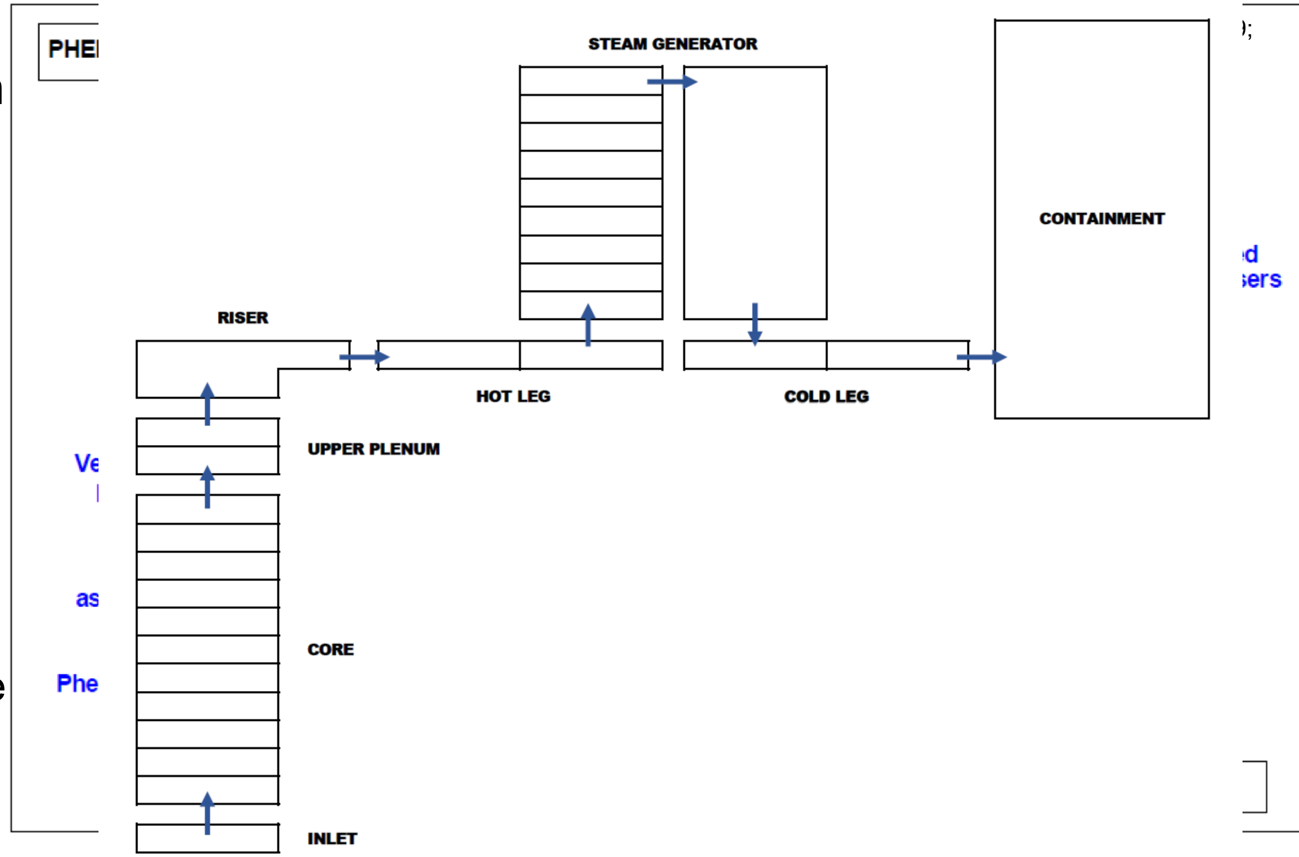
The FPT1 experiment involved the **degradation** of a bundle made of 18 irradiated fuel rods, two fresh fuel rods and a silver-indium-cadmium control rod.

MELCOR 2.2 model

PHEBUS FPT1 input-deck based to USNRC input with few modifications. The MELCOR nodalization used for the following application is 30 CVs and 68 HSs

Modification:

- Corsor-Booth High release model has been employed
- Silver release model has been activated to model the radionuclide release from the core and to allow release of material from Ag/In/Cd control rod, respectively



FPT-1 test description

Pre-oxidation
- test fuel bundle heated
- initial cladding oxidation and hydrogen generation

Oxidation
- characterized by an initial rump of both bundle power and steam mass flow rate
- subsequent constant mass flow rate with the oxidation runaway and temperature escalation.

Heat-up
- began about 14500 s after the start of the test with a second power ramp,
- causing the liquefaction of the bundle material

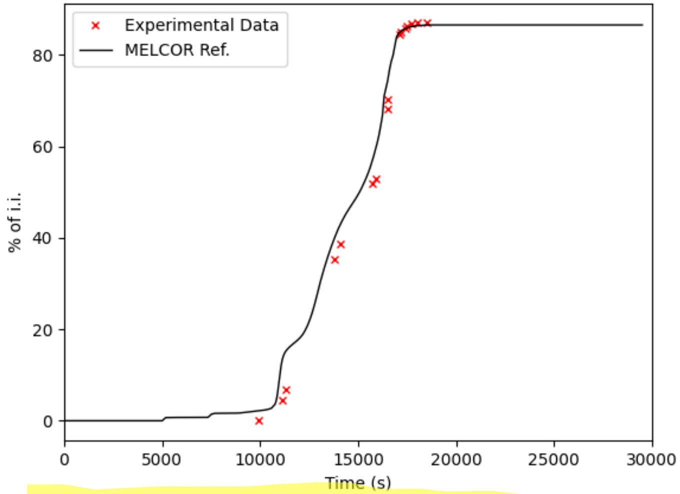
Cooling
- At about 17000 s the shutdown of the system was activated and the cooling period began.

Airborne aerosols settling
- At the end of the cooling period, about 18000 s after the start of the test, the containment isolation took place to study the airborne aerosols settling in the containment.

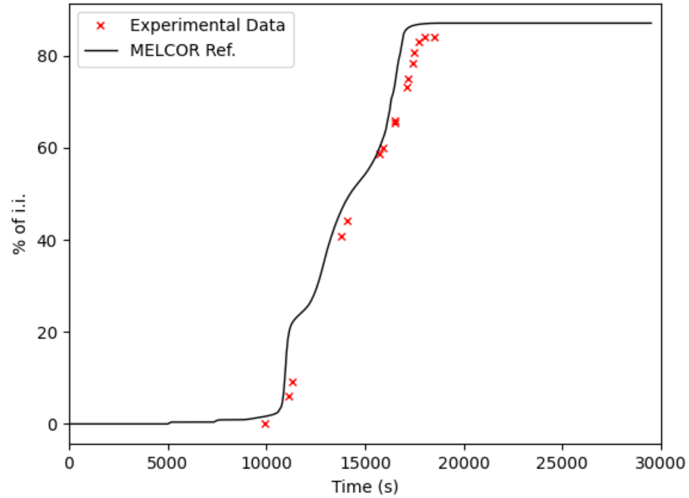
Chemistry
- about 64 h, the aerosols deposited on the containment floor were washed out into the sump water. The temperature of the containment atmosphere was increased and conditions were kept constant for about 18 h before the termination of the test to investigate the iodine chemistry in the sump

Reference calculation

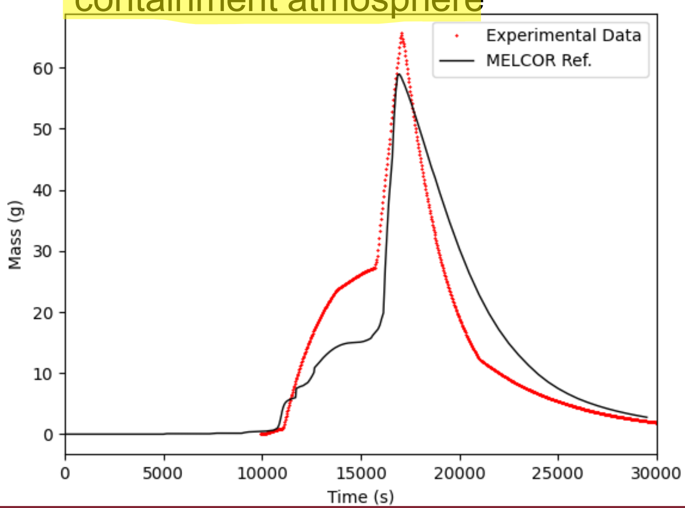
Release of I from the test fuel bundle



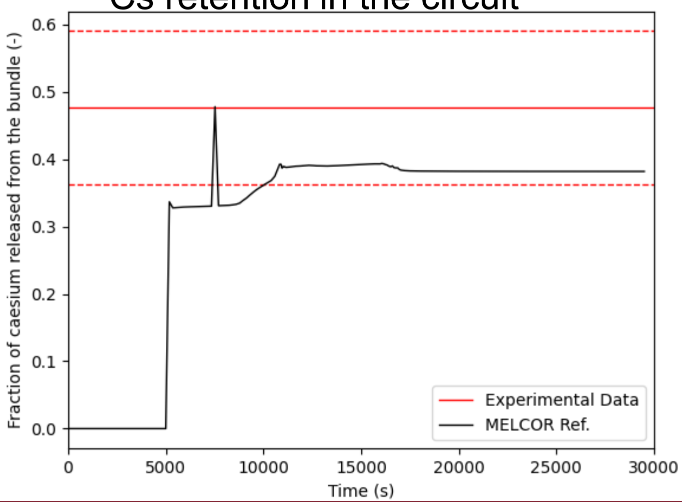
Release of Cs from the test fuel bundle



Aerosol suspended mass in the containment atmosphere



Cs retention in the circuit



Input uncertainty parameters selected

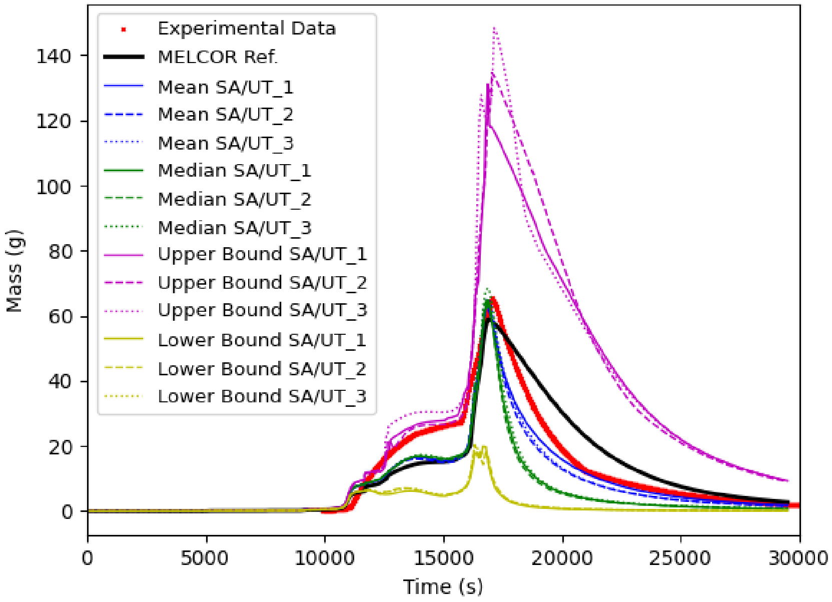
- 1 FOM is investigated and for the two-sided tolerance interval: 93 code runs required for probability/confidence level 95%/95%.
- Considering potential failures of code runs, 130 code runs carried out
- Failed code runs have not been considered for the uncertainty analysis

Name	Distribution Type	Mean	Parameters	
Aerosol dynamic shape factor [CHI] (-)	Beta	1	α	1
			β	1.5
			min	1
			max	5
Aerosol agglomeration shape factor [GAMMA] (-)	Beta	1	α	1
			β	1.5
			min	1
			max	5
Particle slip coefficient [FSLIP] (-)	Beta	1.257	α	4
			β	4
			min	1.2
			max	1.3
Particle sticking coefficient [STICK] (-)	Beta	1	α	2.5
			β	1
			min	0.5
			max	1
Turbulence dissipation rate [TURBDS] (m^2/s^3)	Uniform	0.001	min	0.00075
			max	0.00125
Ratio of the thermal conductivity of the gas over that for the particle [TKGOP] (-)	Log-Uniform	0.05	min	0.006
			max	0.06
Thermal accommodation coefficient [FTHERM] (-)	Uniform	2.25	min	2
			max	2.5
Diffusion boundary layer thickness [DELDIF] (m)	Uniform	1.00E-05	min	0.000005
			max	0.0002

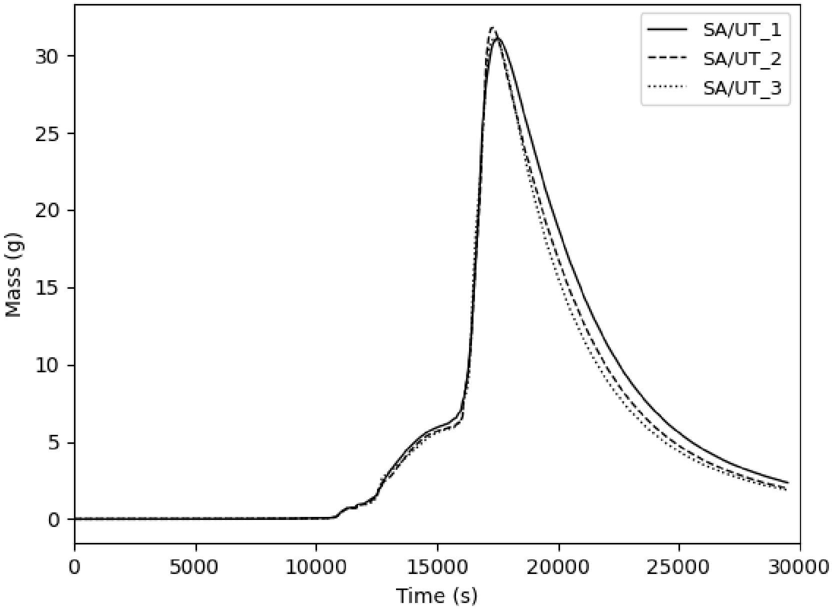
Comparison among the three methods: time-dependent analysis

the MELCOR/RAVEN (SA/UT_1) results in 16 failed runs, the MELCOR/DAKOTA with Python scripts (SA/UT_2) in 10 failed runs and the MELCOR/DAKOTA with a SNAP/MATLAB mixed approach (SA/UT_3) in 17 failed runs.

Main statistical parameters evaluated



Standard deviation evaluated



A general agreement between the mean value and the experimental data has to be highlighted
Considering a single variable FFTBM the AA is about 0,4 for each framework: 0,4 for SA/UT_1, 0,43 for SA/UT_2 and 3

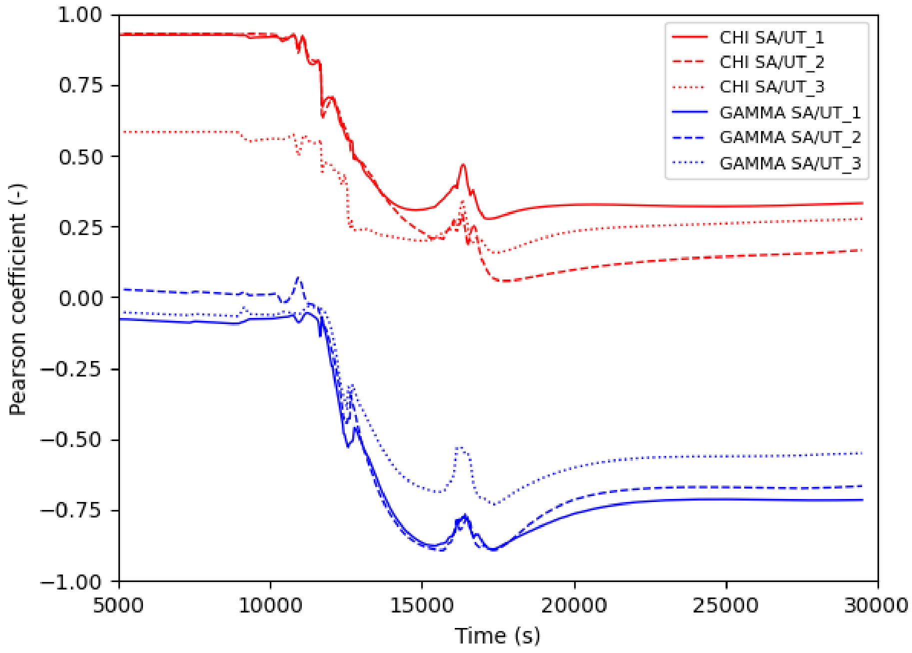
Comparison among the three methods

All the Pearson coefficients evaluated for the maximum value of the FOM present the same statistical behavior: all three coupling frameworks clearly show a linear moderate correlation of the maximum value of CHI and a negative linear and monotonous significant correlation with GAMMA. Some differences have been underlined in relation to the Spearman coefficient for CHI but, for the three coupling frameworks, the coefficient value is closed to the threshold between moderate and low correlation.
Since in the application of the different coupling framework the same code version and the same input-deck have been used, the main discrepancies in the results could be caused by the different input uncertainty parameters sampled values due to the different random seed. Furthermore, the different sampled value of input uncertainty parameters (or the different combination of them) and, eventually, the different computational environment [36], could influence the number of failed runs. These ones could lead a variation of the input uncertainty parameters resulting PDF shapes, affecting the statistical analysis. Further studies are under development to characterize this aspect.

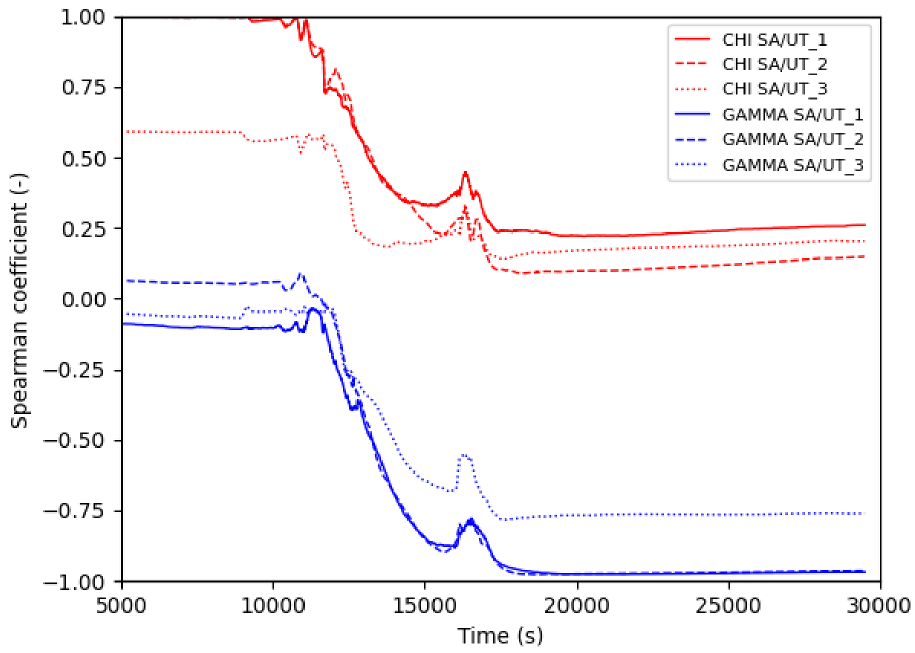
Correlation coefficient	SA/UT_1	SA/UT_2	SA/UT_3
Pearson CHI	0.310	0.212	0.201
Pearson GAMMA	-0.837	-0.841	-0.684
Spearman CHI	0.333	0.231	0.194
Spearman GAMMA	-0.827	-0.836	-0.696

Comparison among the three methods: time-dependent analysis

Pearson's coefficients for CHI and GAMMA



Spearman's coefficients for CHI and GAMMA



- CHI present a significative correlation in the thermal calibration phase
- GAMMA during the heat-up period

Spearmann's coefficients comparison among the three methods

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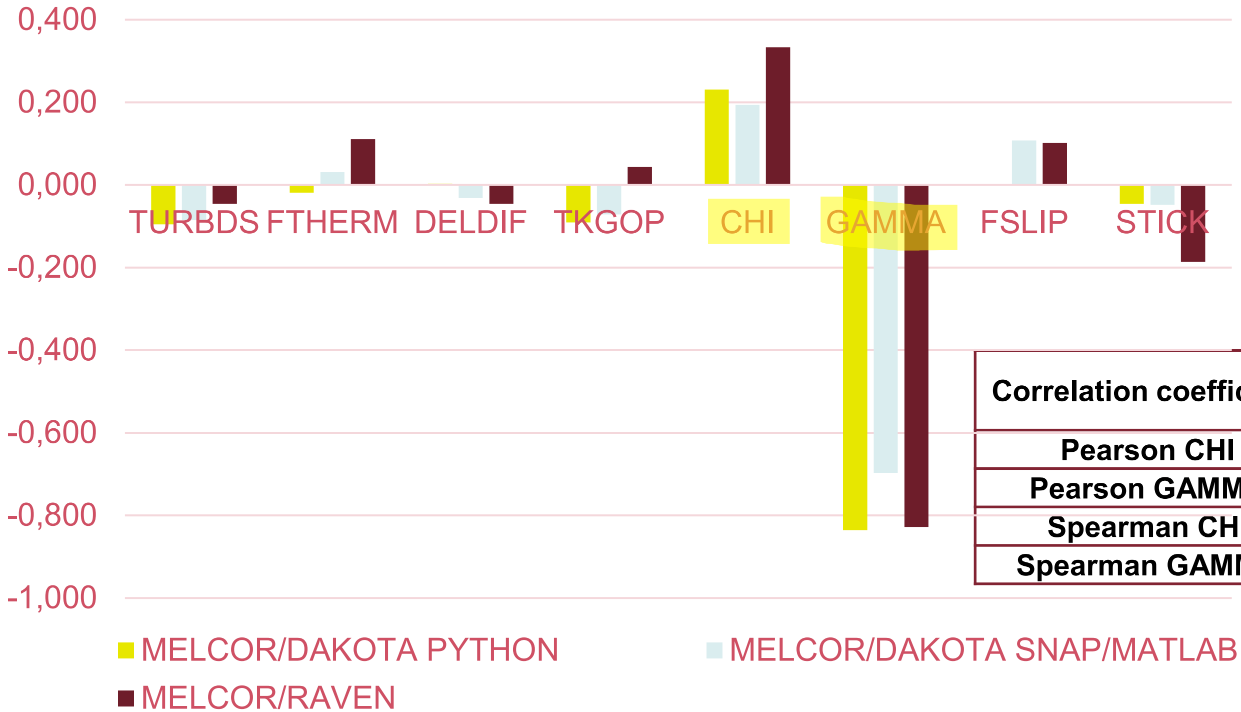
- Some differences have been underlined in relation to the Spearman coefficient
- Small discrepancies could be caused by the different input uncertainty parameters sampled values due to the different random seed.
- Furthermore, the different sampled value of input uncertainty parameters (or the different combination of them).
- These ones could lead a variation of the input uncertainty parameters resulting PDF shapes, affecting the statistical analysis.



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CONCLUSIONS

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- In the framework of MUSA WP4, a partial UQ analysis of the Phebus FPT1 test has been done considering three coupling frameworks of the SA code MELCOR with different UTs. All the three coupling frameworks applied the probabilistic method to propagate input uncertainty and the Wilks approach to define the number of simulations to be performed. The aerosol miscellaneous constants (CHI, GAMMA, FSLIP, STICK, TURBDS, TKGOP, FTHERM, DELDIF) have been considered as input uncertainty parameters and the aerosol mass in suspension in the containment atmosphere is the FOM.
- The experimental data of the FOM lie within the uncertainty band. Before the uncertainty analyses, an accuracy evaluation has been done on the FOM for the reference case. The statistical analysis and the correlation analysis have been evaluated considering both a time dependent and a scalar value analysis on the maximum value of the FOM. The three UQ frameworks and the different input uncertainty parameters sampled values resulted in slight differences in the results and in the number of failed code runs. In the time dependent analyses, in general, a qualitative agreement with the experimental data is shown especially in relation with the mean value. The correlation analysis, evaluated both in the time-dependent and in the scalar value approach, underlines a statistical linear and monotonous correlation with CHI and GAMMA parameters. Considering the preliminary nature of this analysis, further analyses are in progress to characterize the Wilks based statistics, the role of the failed runs in the uncertainty analysis and how to assess them from a rigorous statistics point of view.

THANKS FOR YOUR ATTENTION

ACKNOWLEDGMENTS

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