Italian National Agency for New Technologies, Energy and Sustainable Economic Development

FIRST OUTCOMES FROM THE PHEBUS FPT1 UNCERTAINTY APPLICATION DONE IN THE EU-MUSA PROJECT

International Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-19)

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INTRODUCTION

- MUSA project was founded in HORIZON 2020 EURATOM NFRP-2018 call on “Safety assessments to improve accident management strategies for generation II and III reactor.
- It is coordinated by CIEMAT.
- Started on June 1st, 2019 and the planned duration is 48 months.
- Overall project cost is 5.768,452.50 Euros and 28 Organizations from 16 Countries are involved.
- On July 7th, 2018, MUSA project received the NUGENIA label recognizing the excellence of the project proposal.
- MUSA project aims to establish an harmonized approach for the analysis of uncertainties and sensitivities associated with SA analysis among EU and non-EU entities.

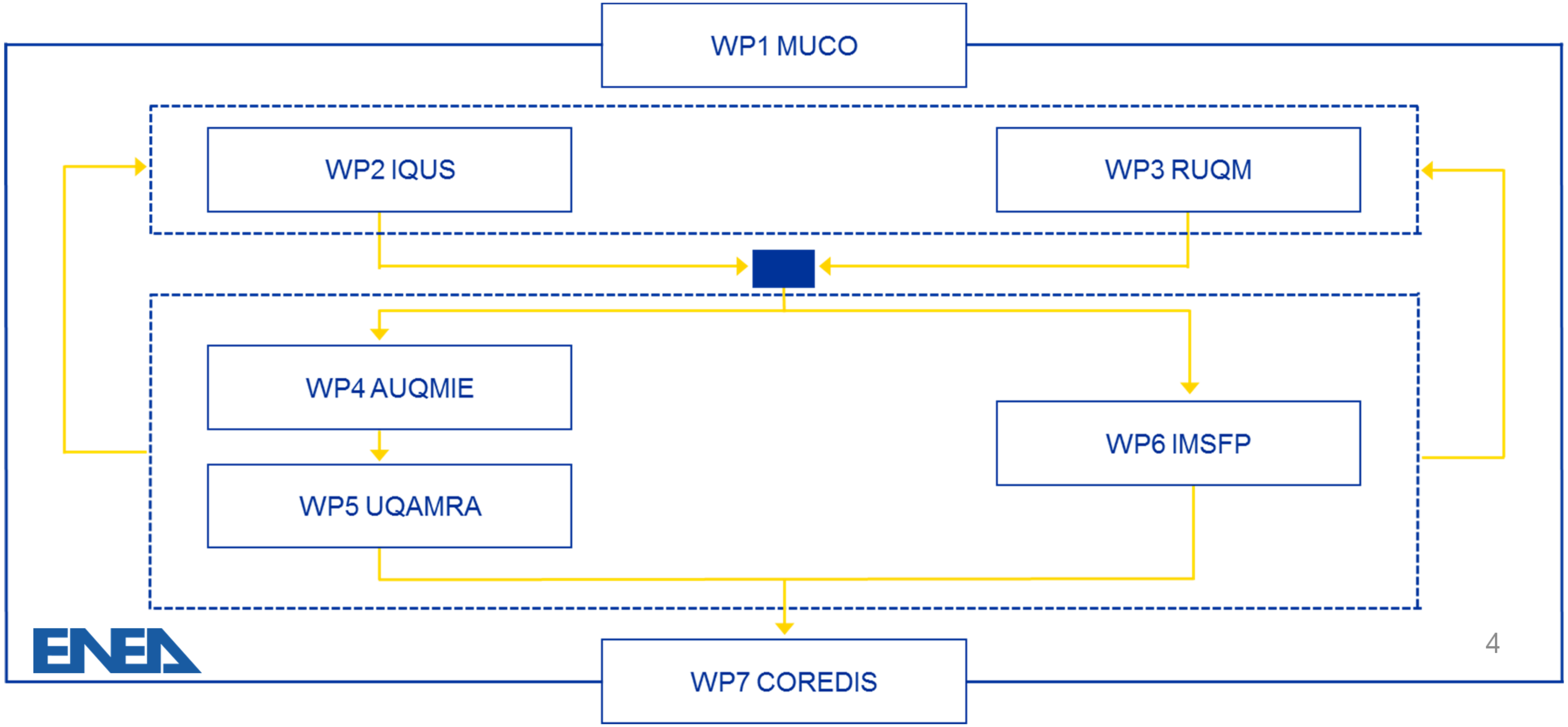
OBJECTIVES AND SCOPE

- To move beyond the state-of-the-art regarding the predictive capability of SA analysis codes by combining them with the best available UQ tools.
- To establish a harmonised approach for the analysis of uncertainties and sensitivities associated with Severe Accident (SA) analysis among EU and non-EU entities.
- To assess the capability of SA codes when modelling accidents
  - Identification and characterization of input & models uncertainties.
  - Adaptation of available Uncertainty and Sensitivity Analyses (UASA) methodologies.
  - Application to postulated NPP scenarios.
  - Building recommendations on how to bring BEPU to SA analysis.
- Gen II, Gen III & Gen III+ // Reactor & SFP // Source Term Focused/ SAMs

MUSA CONCEPTUAL FLOW CHART

- One of the main targets of MUSA is to move beyond the state-of-the-art regarding the predictive capability of SA analysis codes by combining them with the best available or improved UQ tools.

- The achievement of the overall objective is assured by a consistent and coherent work program, reflected by the technical WP



APPLICATION OF UQ METHODS AGAINST INTEGRAL EXPERIMENTS (AUQMIE) - WP4

- WP4, led by ENEA (Italy), is aimed at applying and testing UQ methodologies, against the internationally recognized PHEBUS FPT1 test.
- Considering that FPT1 is a simplified experiment but remains a representative SA scenario, the main objective of the WP4 is to train project partners to applicate UQ to SA analyses.
- WP4 is also a collaborative platform for highlighting and discussing results and issues arising from the application of UQ methodologies, already used for design basis accidents, or in MUSA used for SA analyses.
- WP4 application:
  - Creates the technical background useful for the MUSA full plant and spent fuel (WP4 and WP5).
  - Provides a first contribution for MUSA best practices and lessons learned (WP3).

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WP4 FOMS

- FOMs, ST focused, that have been identified in the WP2 for the reactor case application and that have been considered relevant for the WP4.

  - Release of iodine from top of the bundle [% of i.i.]
  - Release of cesium from top of the bundle [% of i.i.]
  - Cesium retention in the circuit [% of Cs released from the core]
  - Aerosol amount in the containment atmosphere [g]
  - Total gaseous iodine amount in the containment atmosphere [g]
  - Total iodine aerosols amount in the containment atmosphere [g]
  - Total deposited/adsorbed iodine amount in the containment [g]

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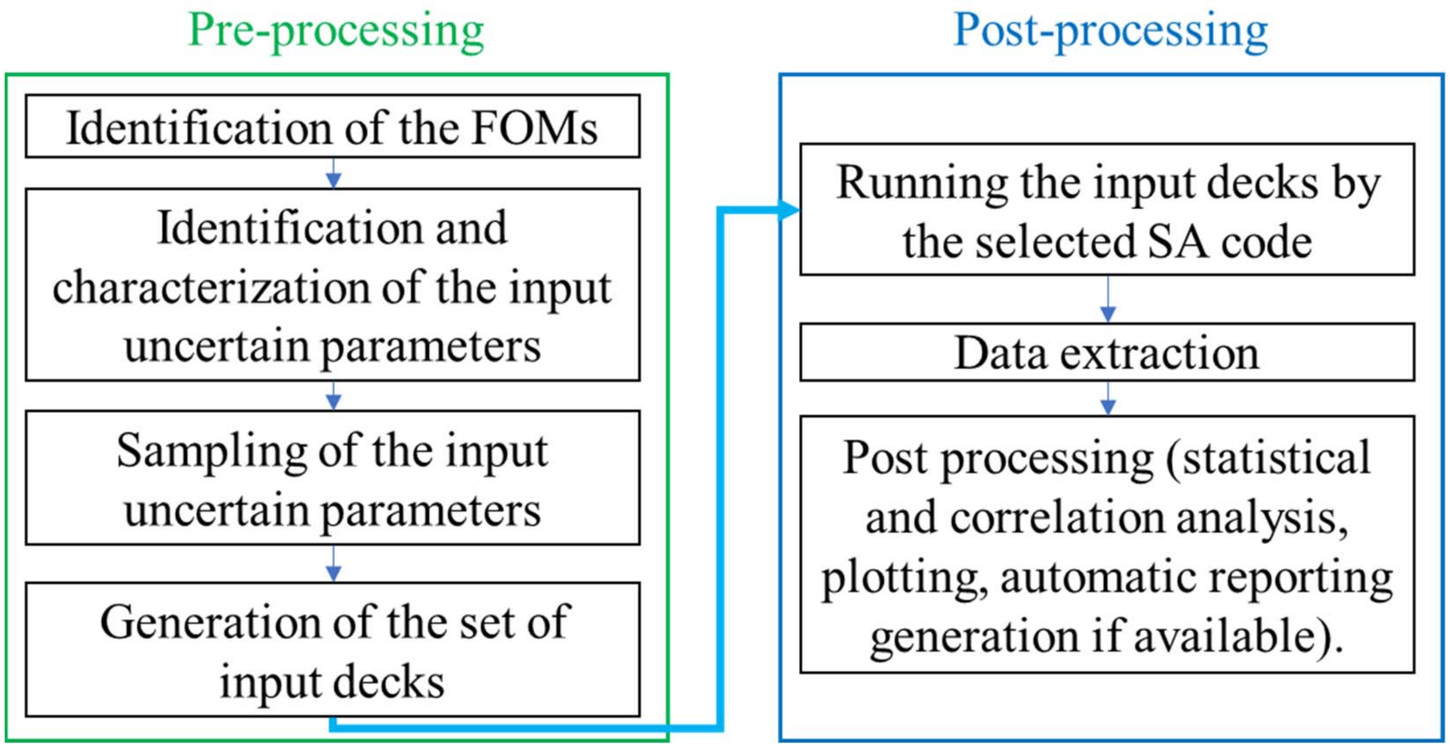
WP4 PARTNERS AND ADOPTED SA CODES AND UT

PARTNER	SEVERE ACCIDENT CODE	UNCERTAINTY TOOL
CIEMAT	MELCOR 2.2	DAKOTA 6.12
CNPRI, SNERDI, CNPE, NPIC	There are four companies in China participating in the MUSA project, and CNPRI is the representative.	
CNSC	MELCOR	Python scripts
ENEA	MELCOR 2.2	DAKOTA
Energorisk	MELCOR 1.8.5	DAKOTA
EPRI	MAAPv5.05	Python w/associated packages, DAKOTA 6.10
GRS	AC^2	SUSA 4.2
INRNE	ASTEC 2.2	SUNSET
KIT	ASTEC v2.2	URANIE 4.1
LEI	ASTEC V2.1.1.6	SUNSET V2.1
	RELAP/SCDAPSIM mod3.4	SUSA 4.1
PSI	MELCOR 2.2	DAKOTA 6.12.0
SSTC	MELCOR 1.8.6, 2.1/2.2	SUSA 4.0
Tractebel	MELCOR 2.2	Python script
TUS	ASTEC 2.1.1.	SUNSET
UNIPI	MELCOR 2.2	DAKOTA 6.13.0
UNIRM1	MELCOR 2.2	RAVEN v2.1
USNRC	MELCOR 2.2	DAKOTA
VTT	MELCOR 2.2	DAKOTA with SNAP 3.1.3

WP4: EXAMPLE OF MAIN TASKS TO BE PERFORMED TO DO AN UNCERTAINTY ANALYSIS

- The application of a deterministic code, as SA code, together with an UT requires two main phases:
  - pre-processing and
  - post processing phase.



CHALLENGES

From the analysis of the first results, it can be underlined that four major challenges have been identified by the partner:

- SA code and UT coupling (e.g., scripts);
- Managing of the failed calculations and debugging;
- Extraction of the data for the post processing;
- Eventual implementation in the cluster of the SA code and UT.

WP4: CURRENT OBSERVATIONS

The first critical analyses of the results showed that:

- o Partners adopted the probabilistic method to propagate input uncertainties.
- o The Wilks formula has been in general used (e.g. 95%, 95%);
- o In order to couple SA code with UT, scripting is in general necessary to automate the process
- o SA codes could be sensitive to the choice of the input uncertainty parameters and the related range.
- o Codes crashes have been in general observed along the code applications and different approaches have been taken to handle failed calculation.
- o Different post processing approaches can be used in order to characterize various aspects of the UA.

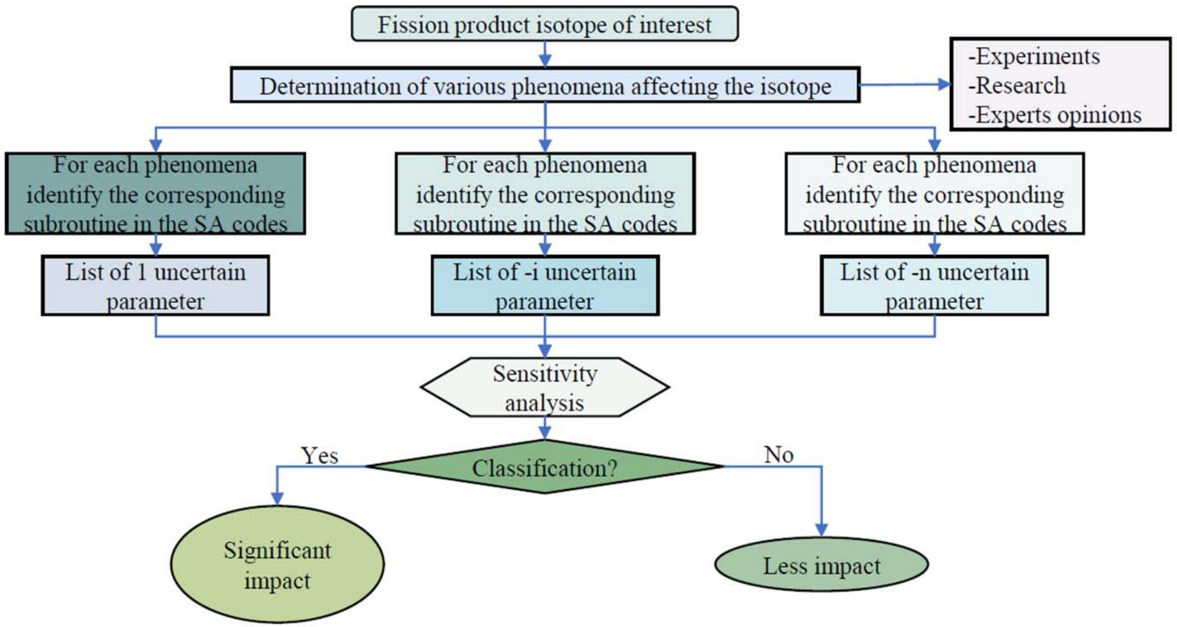
LESSONS LEARNED

- The following points have been extensively discussed to extract the first lessons learned in WP4:

  - o Identification and characterization of the input uncertain parameters,
  - o Coupling of the UT with the SA code
  - o Management of the failed calculations,
  - o Post processing of the data and the SA code.

IDENTIFICATION AND CHARACTERIZATION OF THE INPUT UNCERTAIN PARAMETERS IS A CRUCIAL TASK

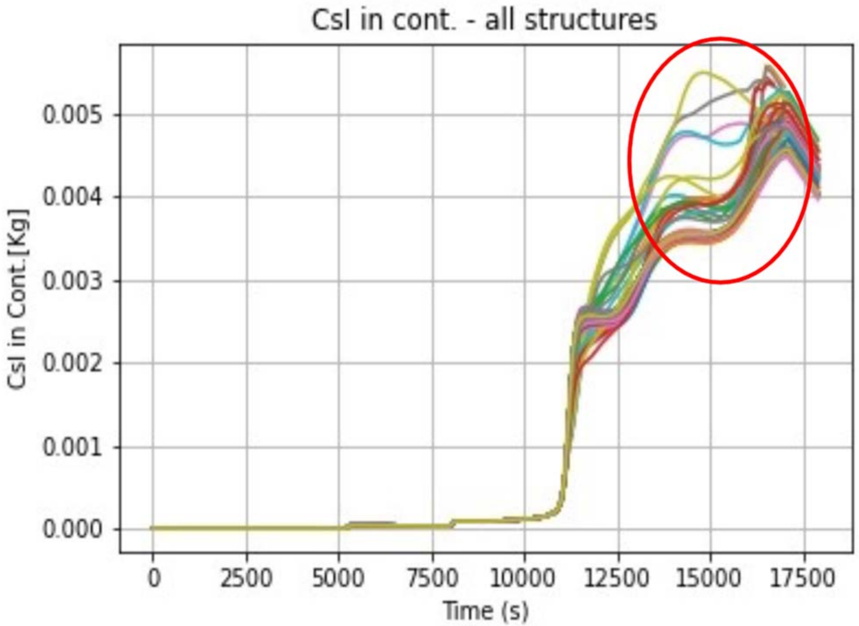
- Selection of uncertain input parameters should be done with care and the PDF and range should be based on references or engineering judgment.
- In general, experimental data, analytical data and expert judgement are necessary.

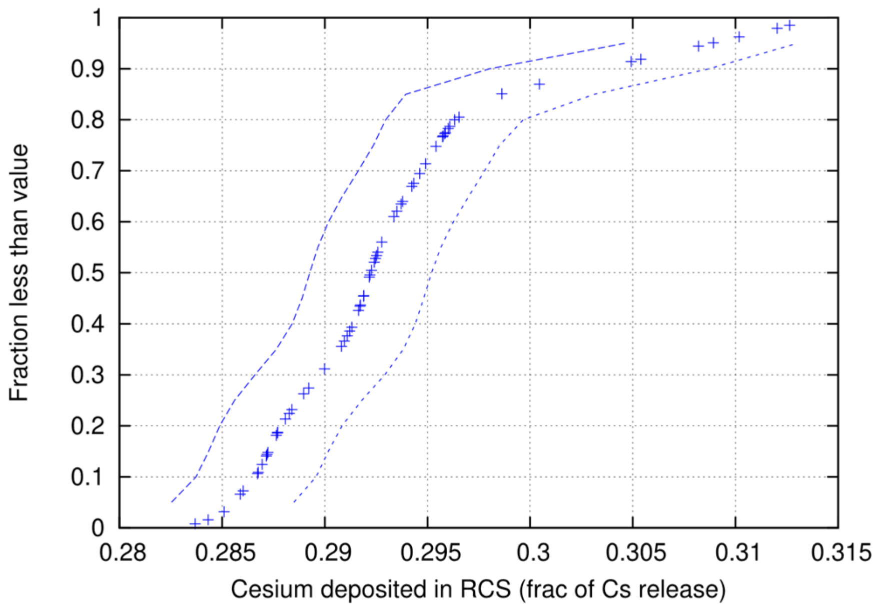


OUTLIERS AND MANAGEMENT OF THE FAILED CALCULATIONS

Certain combinations of input uncertain parameters can affect more the FOMs behavior

The management of the failed calculations is important because, as example, the failed runs can affect the calculated FOM PDF, which may be distorted





COUPLING OF THE UT WITH THE SA CODE

- The coupling of the UT with the SA code is a necessary step to automate the process;
- Need to balance the user flexibility and tool robustness.
- Scripting, even less user-friendly and time demanding, resulted extremely powerful and flexible to automate the UA process, also for selecting ad-hoc statistical and post-processing techniques.
- Every step should be:
  - Controllable,
  - Traceable/reproduceable
  - Detect potential errors during the implementation and alert the user.
- GUI have shown to be more user-friendly, but some limitation has been observed:
  - Post-processing capability,
  - Management of failed calculations

POST PROCESSING OF THE DATA

- The post processing of the data is a key element of the uncertainty application.
- The analyses can be done:
  - Particular point of the FOM (e.g. the maximum value of the aerosol in the containment)
  - Time dependent.
- Time dependent analyses permits to:
  - Analyze the statistical behavior of the FOM considered along the scenario evolution;
  - Compute the degree of statistical correlation in all phases of the transient (Dynamic PDF is considered very useful and the explanation of the PDF variation with time can be an added value of the analyses)
- Some partners considered different threshold values to characterize the relationship between the uncertain input parameters and the FOM and a common consensus should be reached.

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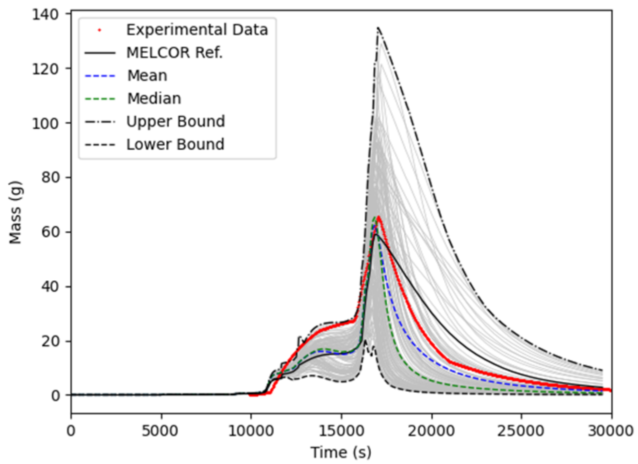
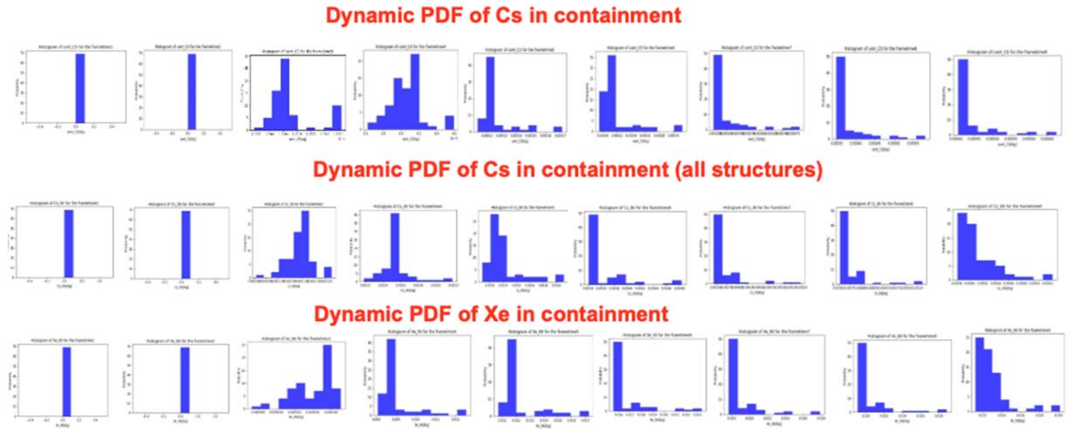
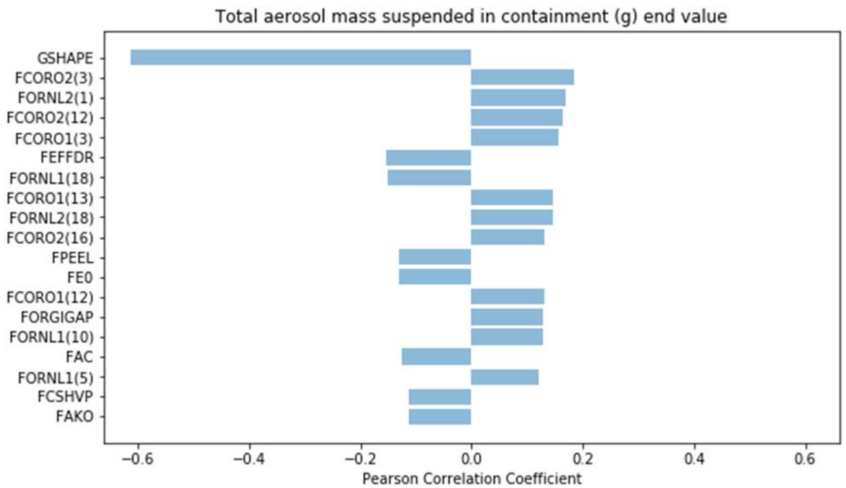
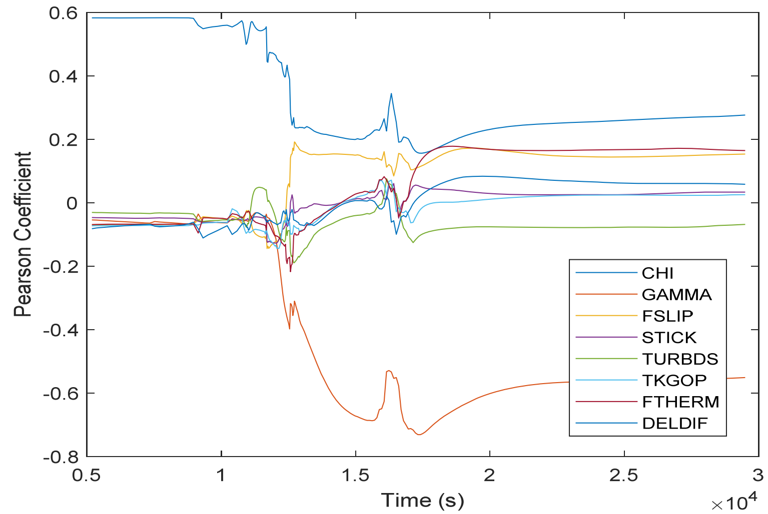
WP4: POST-PROCESSING - EXAMPLES OF STATISTICAL AND CORRELATION ANALYSIS ON THE FOM









CONCLUSIONS

- In the process of evaluation of applicable methods of UaSA to the SA field and definition of best UQ application practices in SA analyses, the WP4 exercise contributed to solve some of the issues encountered in these first applications and identify the first lessons learned on:
  - Identification and characterization of the input uncertain parameters
  - Management of the failed calculations
  - Coupling of the UT with the SA code
  - Post processing of the data
  - SA code.
- This exercise has been a good opportunity for all partners to identify and to share the issues encountered during the application of UQ that require further discussions
- The current status of the activity does not allow to draw a comprehensive conclusion on the main sources of uncertainty for the various FOMs; however, for example, the miscellaneous aerosol constants and heating power showed a major correlation on the aerosol mass in the containment.

THANKS FOR YOUR ATTENTION

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MUSA STRUCTURE

- The achievement of the overall objective is assured by a consistent and coherent work program, reflected by the technical WP, which includes:
  - WP1, MUSA COordination and project management (MUCO),
  - WP2, Identification and Quantification of Uncertainty Sources (IQUS),
  - WP3, Review of Uncertainty Quantification Methodologies (RUQM),
  - WP4, Application of UQ Methods against Integral Experiments (AUQMIE),
  - WP5, Uncertainty Quantification in Analysis and Management of Reactor Accidents (UQAMRA),
  - WP6, Innovative Management of SFP Accidents (IMSFP), and
  - WP7, COmmunication and Results DISsemination (COREDIS).

ANALYSIS OF SA AND UT COUPLING SCRIPTING

- When GUI is not already available, the use of scripting to couple SA code and UT (e.g. Python, Pearl, Fortran, MATLAB, Visual Basic, etc.) is needed.
- Scripting:
  - High time demanding process;
  - Requires a teamwork;
  - Powerful but is not user friendly as a GUI;
  - UT and SA code dependent;
  - Could be characterized by a limited portability by one input-deck to another;
  - Several tools and programming languages may be adopted in the same SA and UT coupling to perform the various steps.
- Compatibility issues between UT and SA code have been underlined by several partners:
  - These issues have been solved with further scripting, which is high time demanding:
  - One partner preferred to develop its own UT to have a major flexibility;
  - Another partner initially preferred to develop the pre-processing phase manually.

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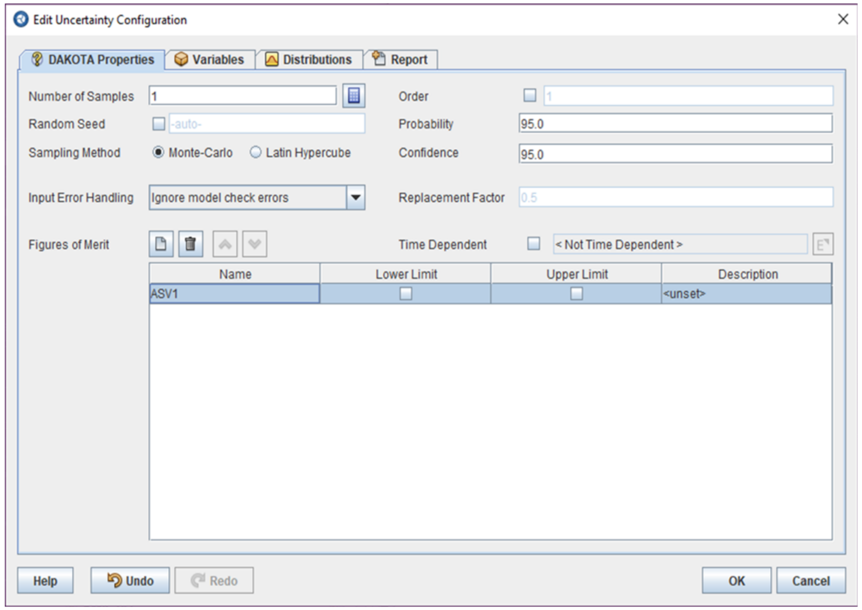
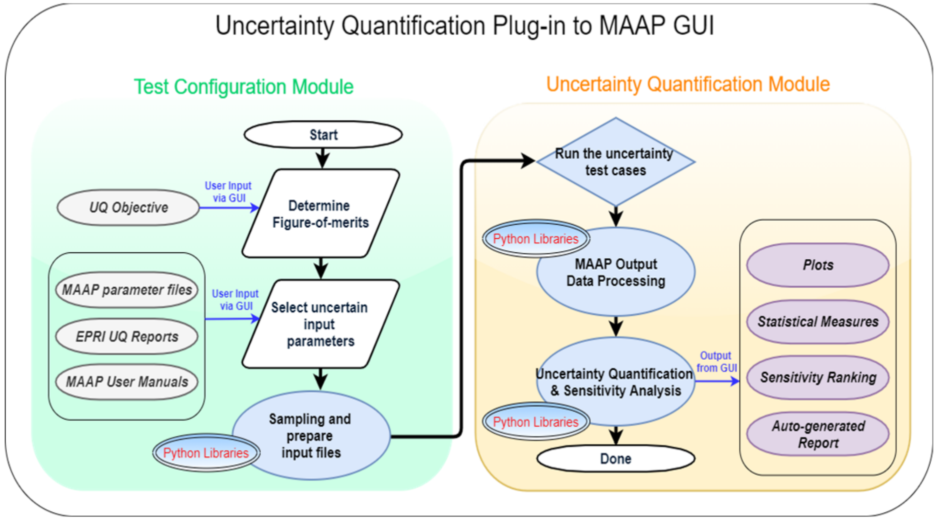
ANALYSIS OF SA AND UT COUPLING GUI

- Main advantage:
  - User-friendly;
  - Requires less time to be used.

- Major issue with the GUI is its limited flexibility compared to scripting:
  - For the statistical analysis, the user can only use the options already available:
    - ✓ If the users want to adopt other statistical parameters, this cannot be performed unless the GUI developers implement the needed features, or a mixed approach (e.g. GUI + scripting) is adopted:
  - If there are some bugs in the GUI that requires the developer intervention
    - e.g. the Issue of managing the failed calculation has been identified in one of the GUI used and the solution required interactions with the GUI developer.

ANALYSIS OF SA AND UT COUPLING GUI





Examples of SA and UT coupling through GUI: SNAP DAKOTA properties view (left) and Uncertainty Quantification Plug-in to MAAP GUI (right).

MANAGING OF THE FAILED CALCULATIONS AND DEBUGGING

- Calculations' failure is another issue that has been shared by many partners:

  - Managing the calculation failures added supplementary effort to the code users:
    - Debug the errors,
    - Need for handling the missing code runs from a solid statistical point of view.

  - For one of the involved codes, changing one parameter related to the aerosol constants reduced the failures from 80% to 0%.

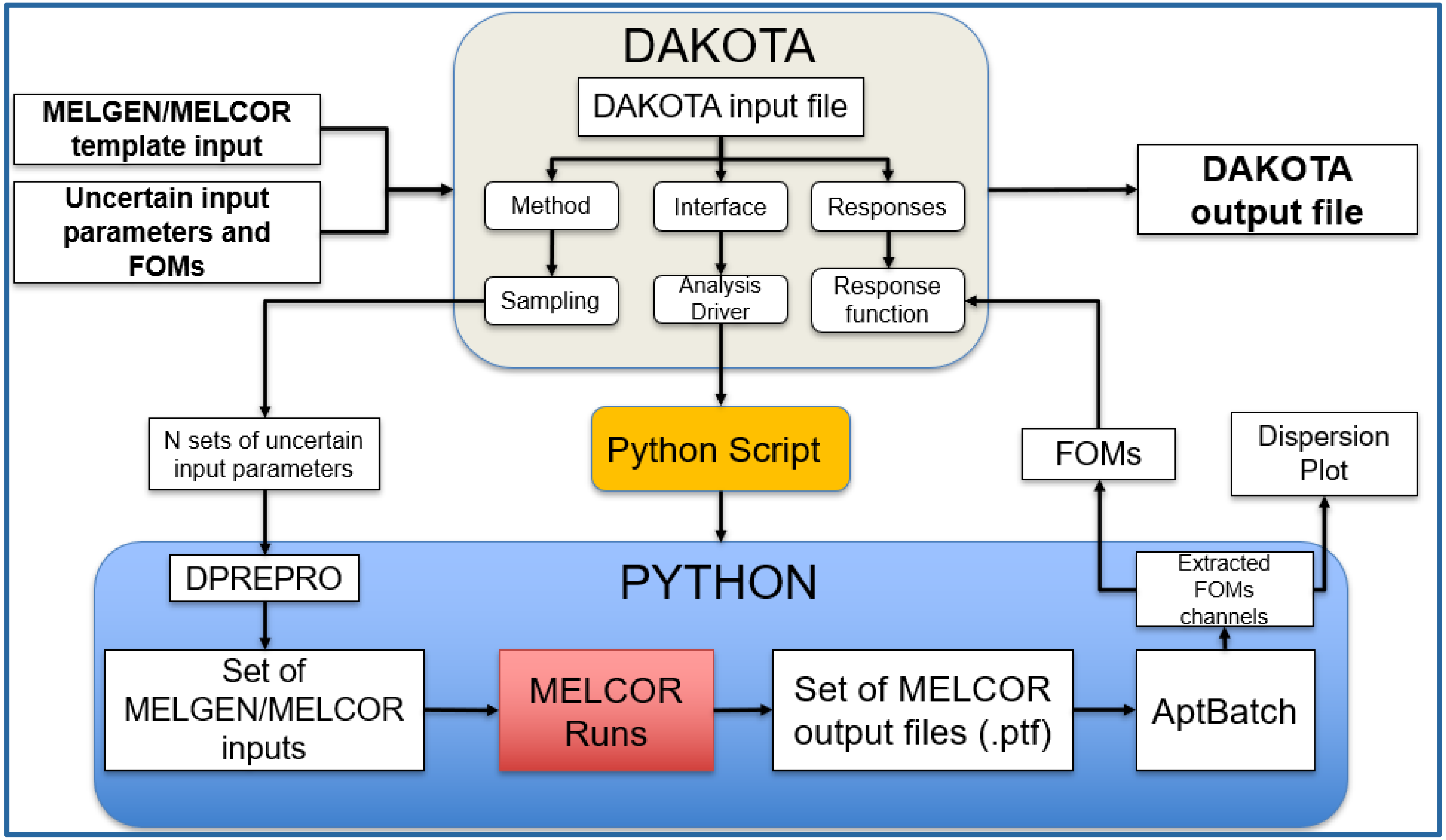
  - Importance of the user effect in the selection of the reference value for the UQ and the PDF characterization.

EXTRACTION OF THE DATA FOR THE POST PROCESSING

- Different approaches have been adopted to extract the required data from each specific SA code.
  - Each partner could have different ways to extract the data from a specific SA code
  - Currently there are no common code user guidelines.

- It has been also observed
  - Some compatibility issues of UT (or base programming language) and code plot variable (syntax problem)
  - UT could have problem to access the SA code data file.

EXTRACTION OF THE DATA FOR THE POST PROCESSING



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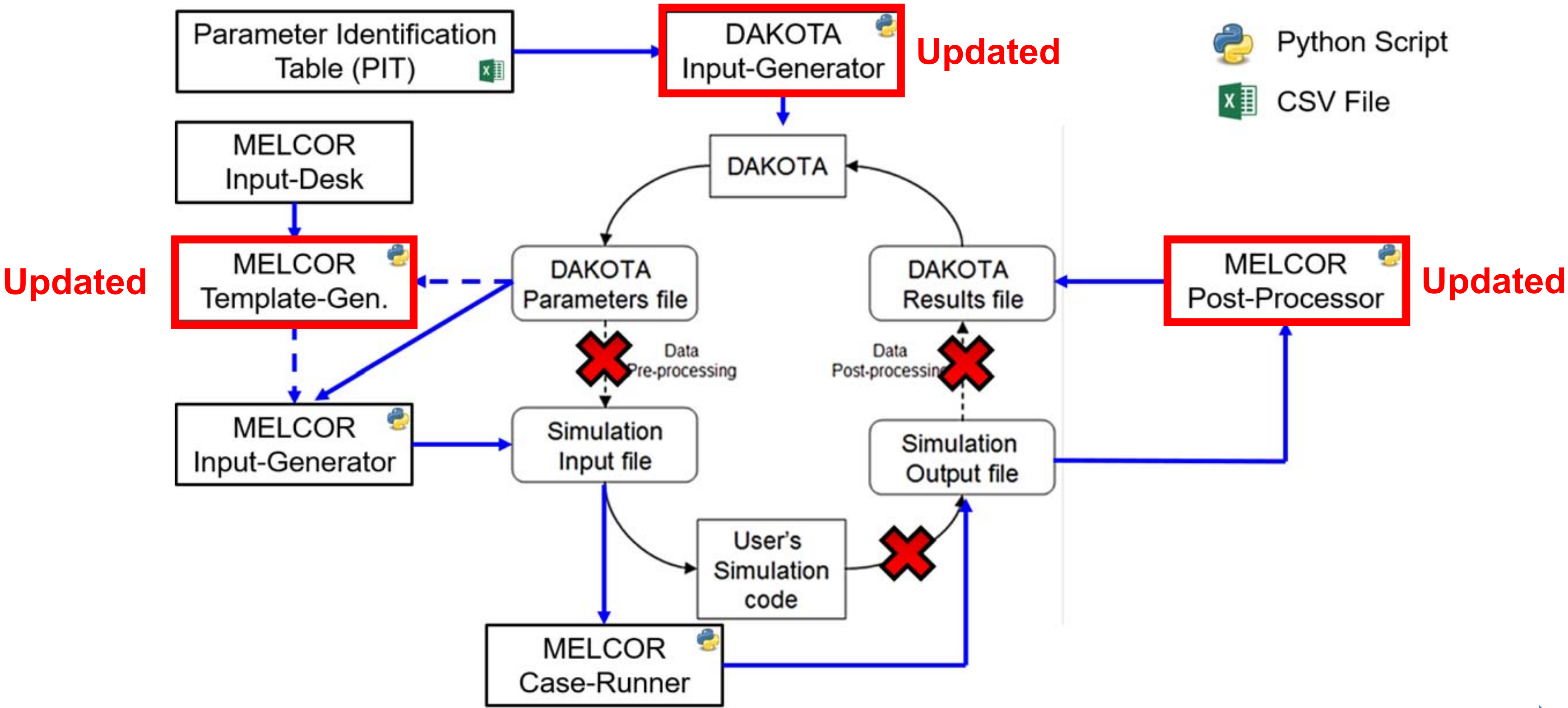

EVENTUAL IMPLEMENTATION IN THE CLUSTER OF THE SA CODE AND UT

- Implementation issues have been observed depending on the dimension and number of users of the cluster.
  - Big clusters:
    - ✓ Root access right is fundamental to set the SA and UT;
    - ✓ Need for the management of the code license node (e.g. dynamic token, etc.);
    - ✓ Less flexible:
    - ✓ it is necessary to contact the administrator of the cluster for route actions and more time is in general needed.
  - Small clusters are more easily manageable;
- In addition, it has been referred some compatibility issues between SA codes (e.g. 32 bit) and the cluster (e.g. 64 bit).
    - Handled adding libraries in the cluster (using root access rights).
- The use of GUI in the cluster should still be verified.