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Source Term Evaluation Following MBLOCA and SBLOCA Scenarios in a Generic KONVOI-1300 NPP by Means of the ASTEC Code

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Motivation

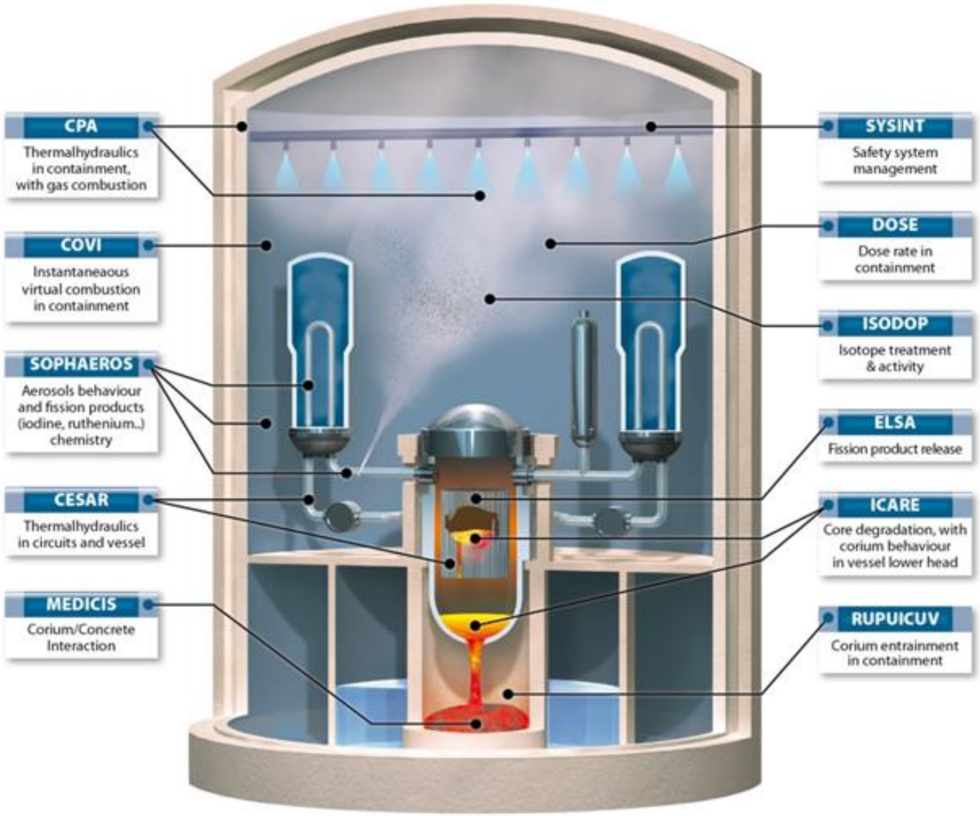
- KIT and Framatome GmbH launches in 2019 the German WAME project in the framework of the activity ‘Maintaining Competence in Nuclear Technology’ of the Federal Ministry of Economics and Technology (BMWi).
- Goal: developing a methodology to perform real-time Source Term (ST) predictions based on measurements and pre-calculated learning database from integral code calculations
  - improving the decision making and supporting the emergency and preparedness teams during Severe Accident (SA) events
- Efforts going to assess a database of ST evaluations for different SA scenarios to be employed by real-time program systems, i.e. the general Monte Carlo-Bayes framework MOCABA, developed by Framatome.

The WAME Strategy for the Assessment of the Learning Database

- A generic KONVOI-1300 NPP considered.
- Step 1: ST evaluation in selected SA scenarios by means of the Accident Source Term Evaluation Code (ASTEC), developed by IRSN (France)
- Step 2: Uncertainty Quantification of the ASTEC results
  - The Fast Source Term Code (FSTC) developed by KIT in the framework of the project
- Step 3: Learning Database Assessment
  - FSTC tool employed to propagate the uncertainties of the ASTEC input parameters → hundreds of samples obtaines → the database for MOCABA algorithm should cover as much as possible outcomes of simulated process depending on changes in input data
- ST predictions
  - Extended FSTC tool developed at KIT ↔ MOCABA algorithm implemented
  - Application of the extended FSTC tool to the learning database

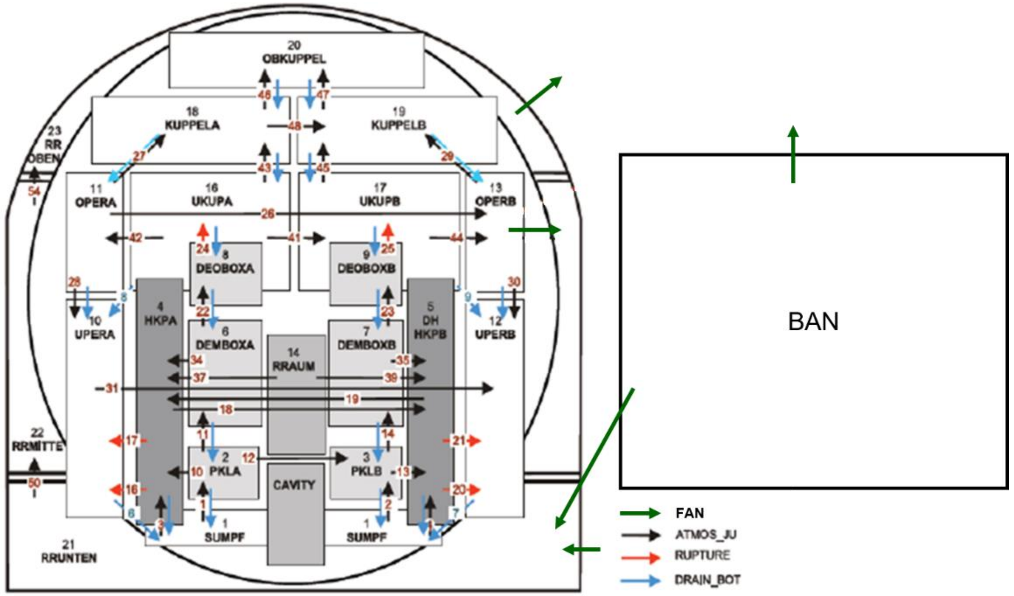
The ASTEC Code

- ASTEC is nowadays the reference European SA integral code able to analyze the complete accident scenario from the initiating event until radioactive release out of the containment in Gen. II and Gen. III water-cooled reactors.
- The code structure is modular, each of its modules simulating a reactor zone or a set of physical phenomena.
- ASTEC continuosly under improvement, also in the framework of the NUGENIA/SARNET Technical Area 2 AStec COMunity (ASCOM) project (2018-2022)



The ASTEC Model of the Generic KONVOI NPP

- The generic input deck available in the ASTEC release, originally developed by KIT, GRS, and IRSN in the framework of the CESAM project, has been revised and updated.
- Main improvements of the model:
  - All the ASTEC calculation modules activated → main in- and ex-vessel phenomena simulated, as well as the FP transport in the NPP
  - Containment and annulus leakages revised by employing more detailed plant data
  - External building model assessed
  - Realistic fuel inventories at the equilibrium cycle computed (SCALE6.2.3/ORIGEN-ARP) → core loaded with 193 Fuel Assemblies (48 U FA, 6 batches; 81 U-Gd FA, 6 batches; 64 MOX FAs, 4 batches)



F. Gabrielli, V. Sanchez, ASTEC Evaluation of the Radiological Source Term in a generic PWR Konvoi 1300 Plant, 9th ASTEC User's Club Meeting, KIT CN, 2019, September 24-26.
H. Nowack, W. Erdmann, N. Reinke, 2011. Application of ASTEC V2.0 to Severe Accident Analyses for German Konvoi Type Reactors, NURETH-14, Toronto, Ontario, Canada, September 25-30.

Severe Accident scenarios

- MBLOCA (12”) and SBLOCA (2”)
  - Fuel inventory at the End of the Equilibrium Cycle (328 effective full power days)
  - Break of the cold leg @t=0 s
  - SCRAM if Primary pressure <132 bar or containment overpressure > 30 mbar
  - Admission to turbine and main feed water pumps into the SG closed
  - Emergency Core Cooling System (ECCS) activated if two of the following three conditions are fulfilled containment overpressure >30 mbar, RCS pressure <110 bar or pressurizer liquid level< 2.30 m
  - Main Coolant Pumps (MCPs) coasted down and the pressure regulation is switched off
  - Activation of the Emergency Feed Water System (EFWS) when the liquid level of one SG falls below 4.50 m
  - HPIS (SBLOCA) and LPIS (MBLOCA) activated (T_gas in the primary > 650 °C) up to the tanks are empty → entering the SA
  - When the horizontal erosion reaches 4.4 m radius, the cavity and the spalt flooding (from GRS studies)

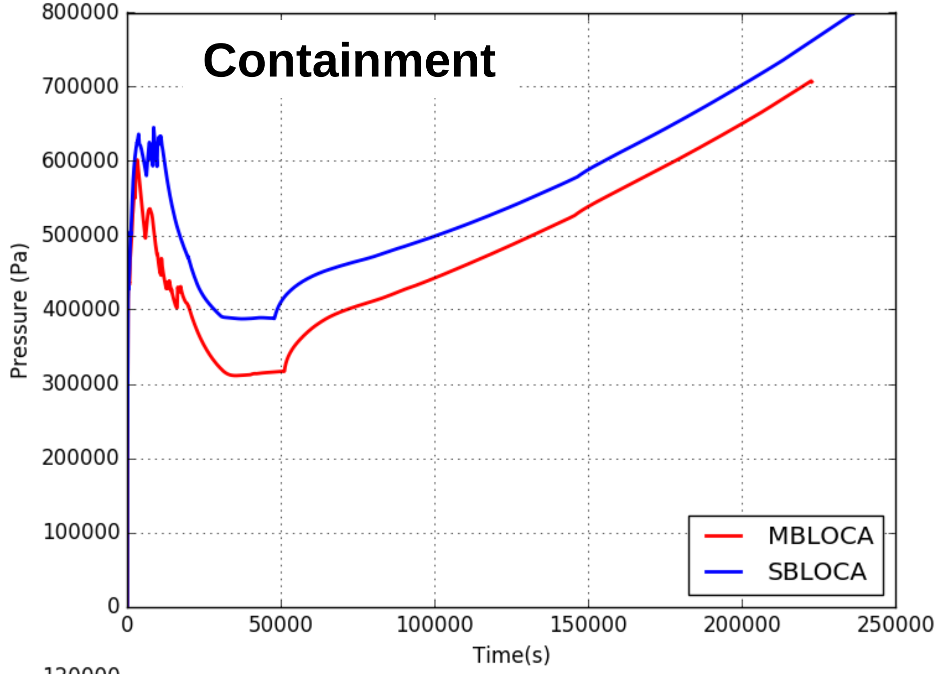
Motivation

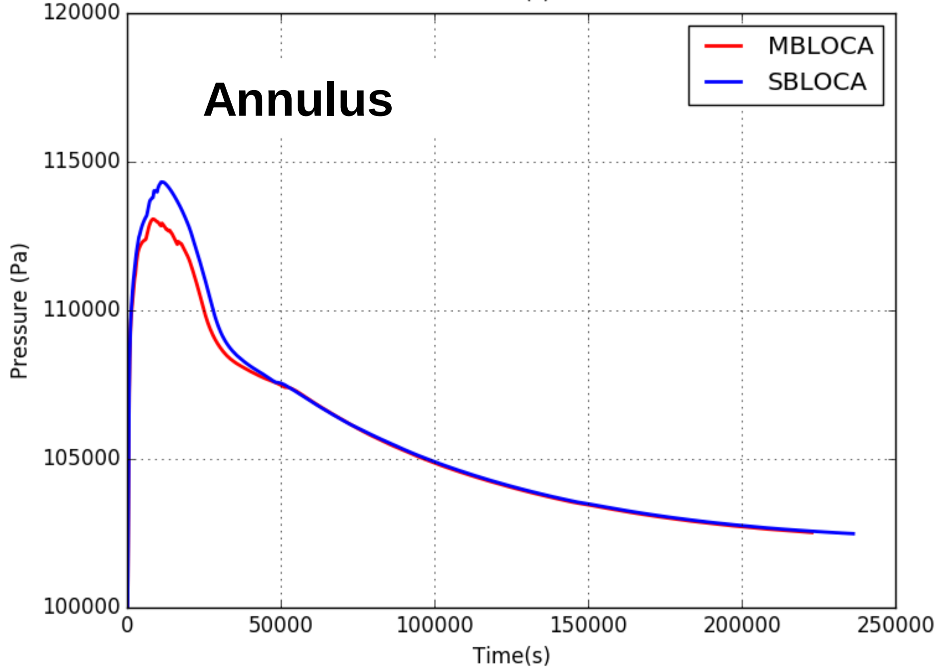
- Core degradation faster and more massive in the MBLOCA scenario
- Lower Pressure Vessel (LPV) failure and basemat rupture occur at about the same instant.

Event	MBLOCA	SBLOCA
FPs Release (s)	484	441
First Slump with FPs in the LP (s)	794	8123
20/50 Tons Relocated to the LP (s)	13304/16214	9709/10113
70/90 Tons Relocated to the LP (s)	16224/16244	
LPV Failure (s)	19892	19706
Basemat Rupture (s)	22732	23204
Total H2 In-vessel/Containm. (kg)	759/2339	863/2310

Containment and Annulus Pressure

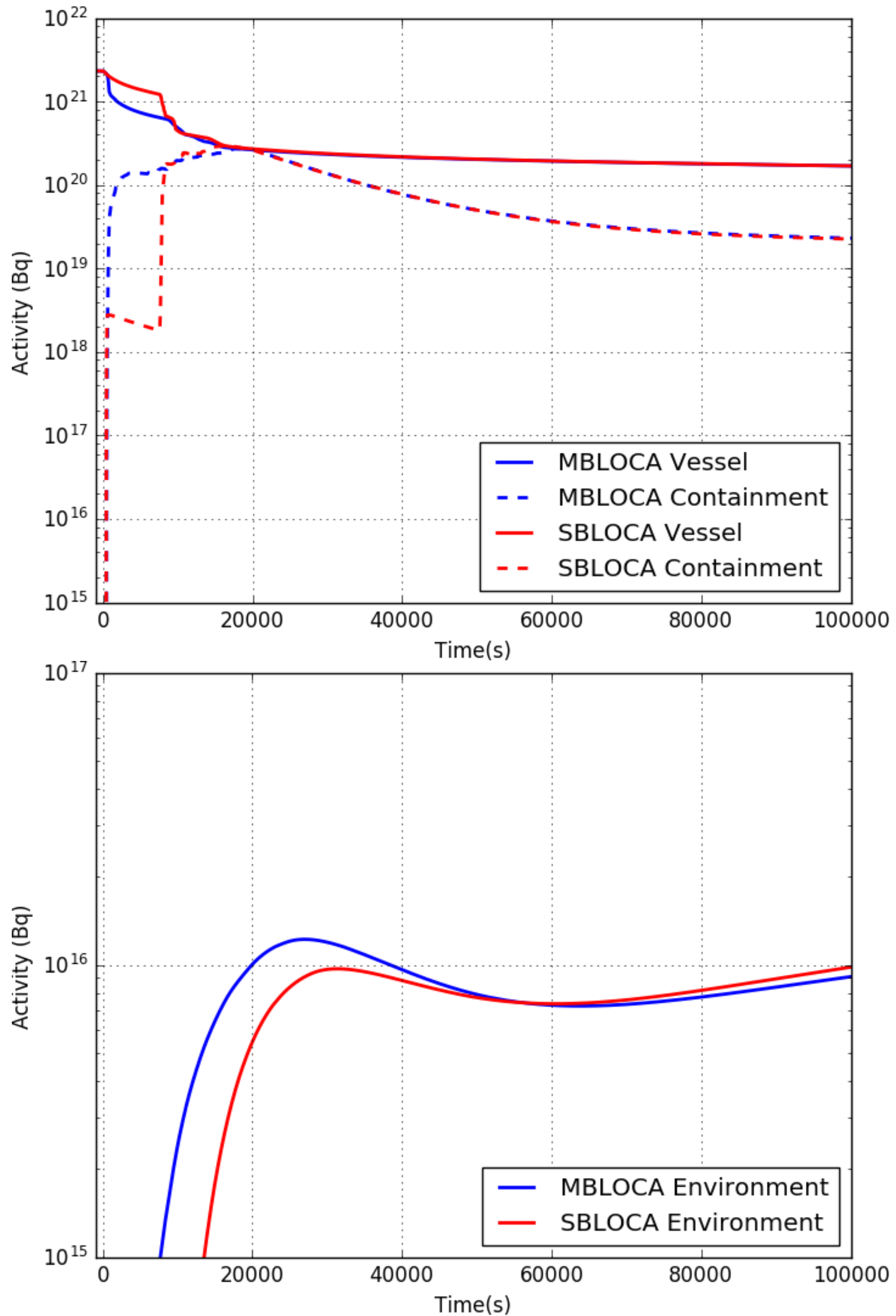
- Containment
  - Peak pressure during the in-vessel phase is about 6-6.5 bar.
  - Faster depressurization of the primary circuit in the MBLOCA than in the SBLOCA scenario → pressure in the SBLOCA is higher than in the MBLOCA accident.
  - H_2 production from the cavity flooding (at about 5e4 s) triggers the pressure increase up to 7 bar and 8 bar in the MBLOCA and SBLOCA scenarios, respectively (basemat rupture).
- The peak pressure in the annulus is about 1.12 bar, and decreases due to the release to the environment.





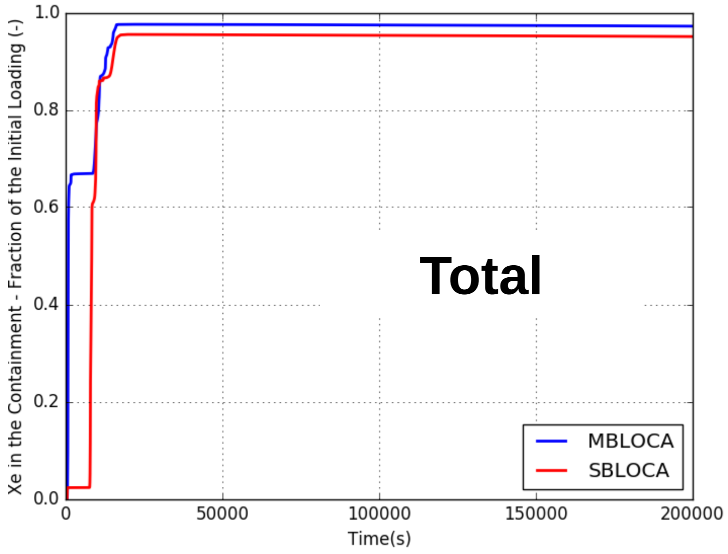
Activity

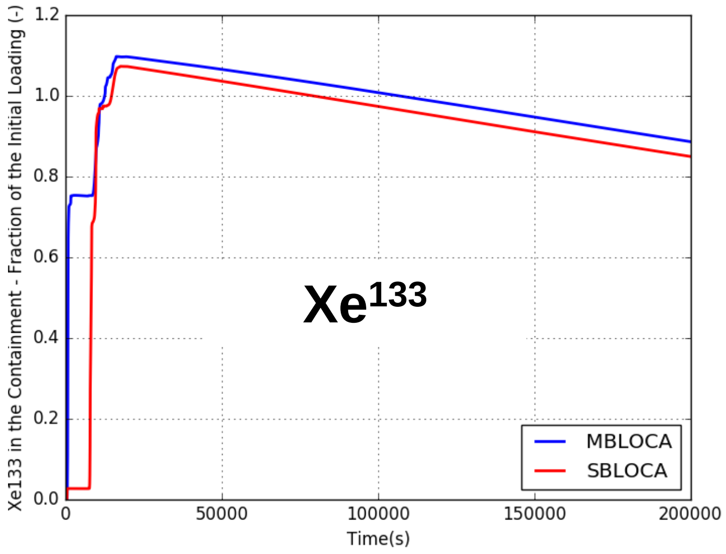
- In the SBLOCA, the delay in the material slump leading to the massive FPs release from the vessel is visible.
- Further, about 15% of the initial activity in the core is transported to the containment until RPV failure and about 10^{16} Bq are released into the environment.

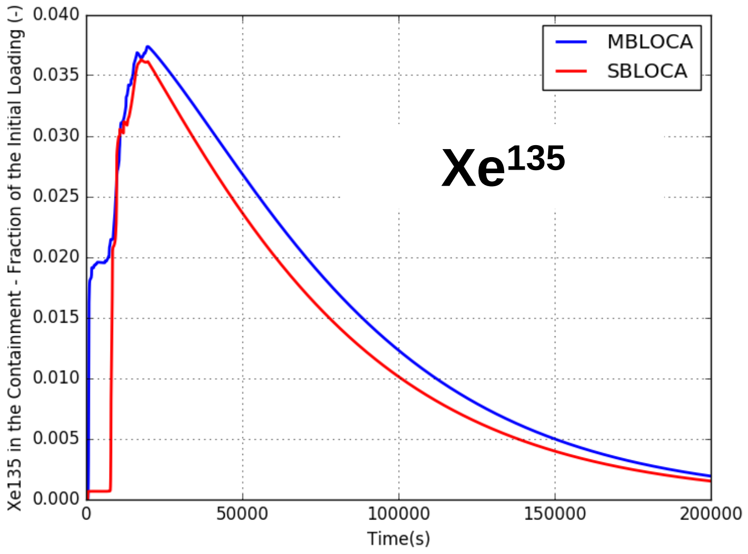


Noble Gases Release in the Containment

- Noble gases are almost completely released into the containment

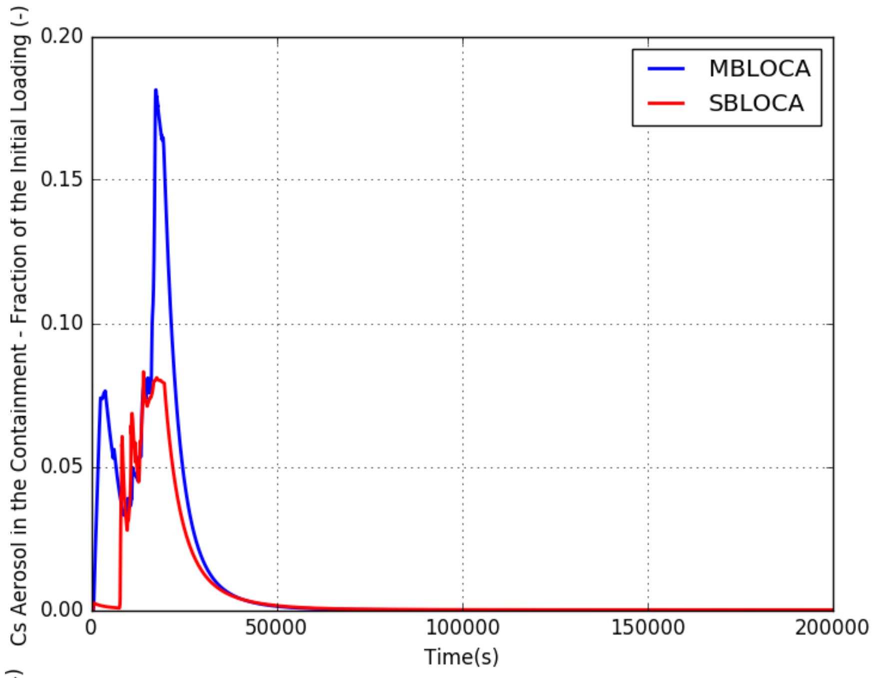


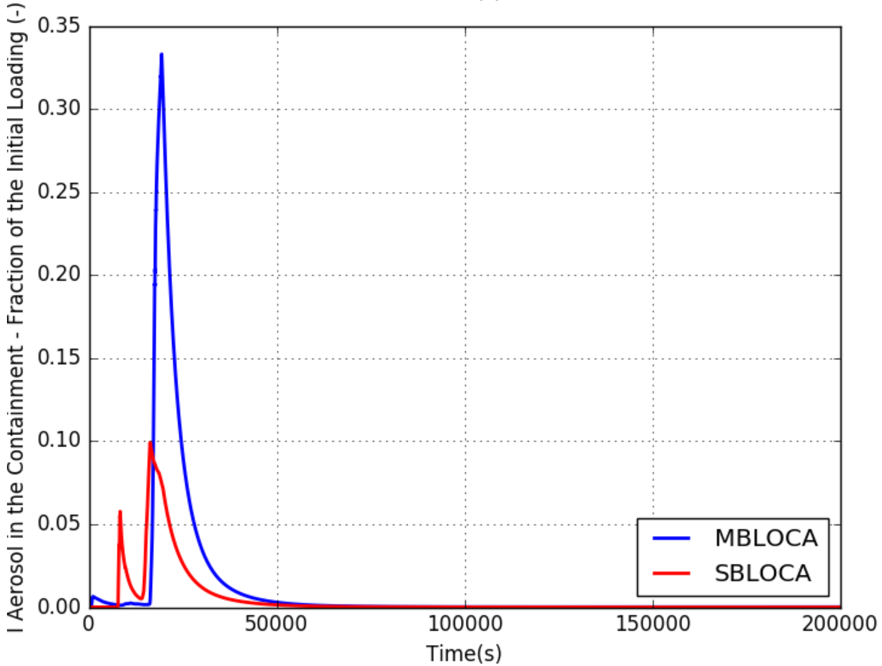




Cs and I Aerosols in the Containment

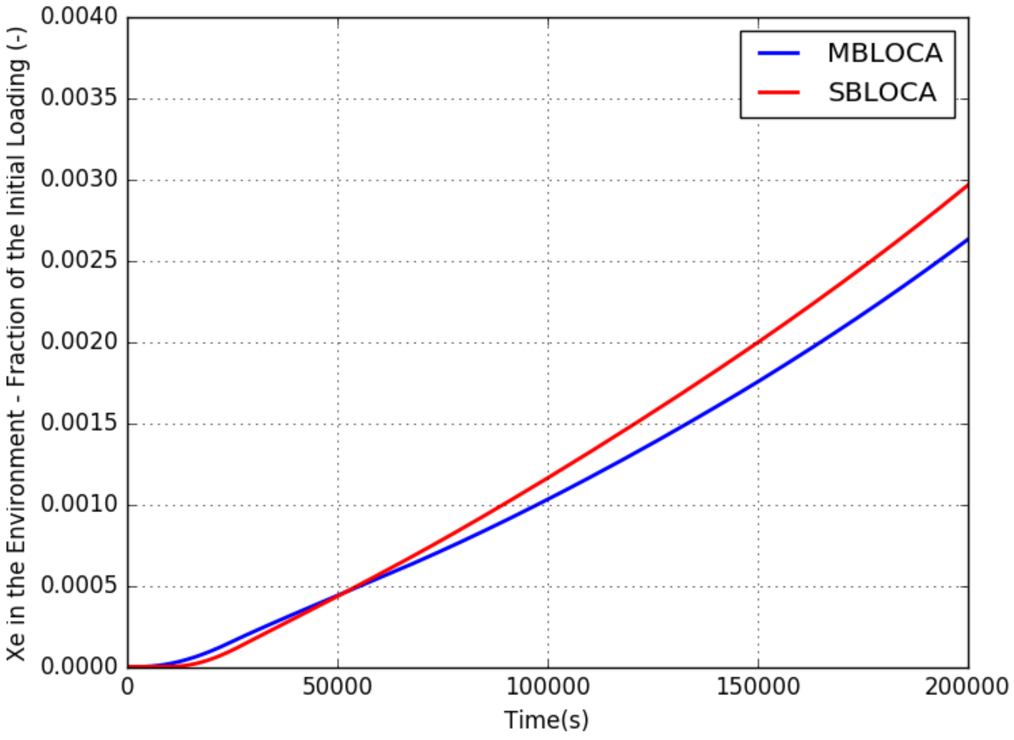
- Cs Aerosols
  - The mass fraction reaches about 17% for the MBLOCA scenario and to about 7% for the SBLOCA scenario, the largest amount being retained in the primary circuit.
- I Aerosol
  - Much larger release in the MBLOCA than in the SBLOCA (the maximum mass fraction reaching about 32%).
- Higher retention potential in the RCS during the SBLOCA than in the MBLOCA scenario, due to the different thermal-hydraulic conditions there, i.e. larger pressure values in the SBLOCA.

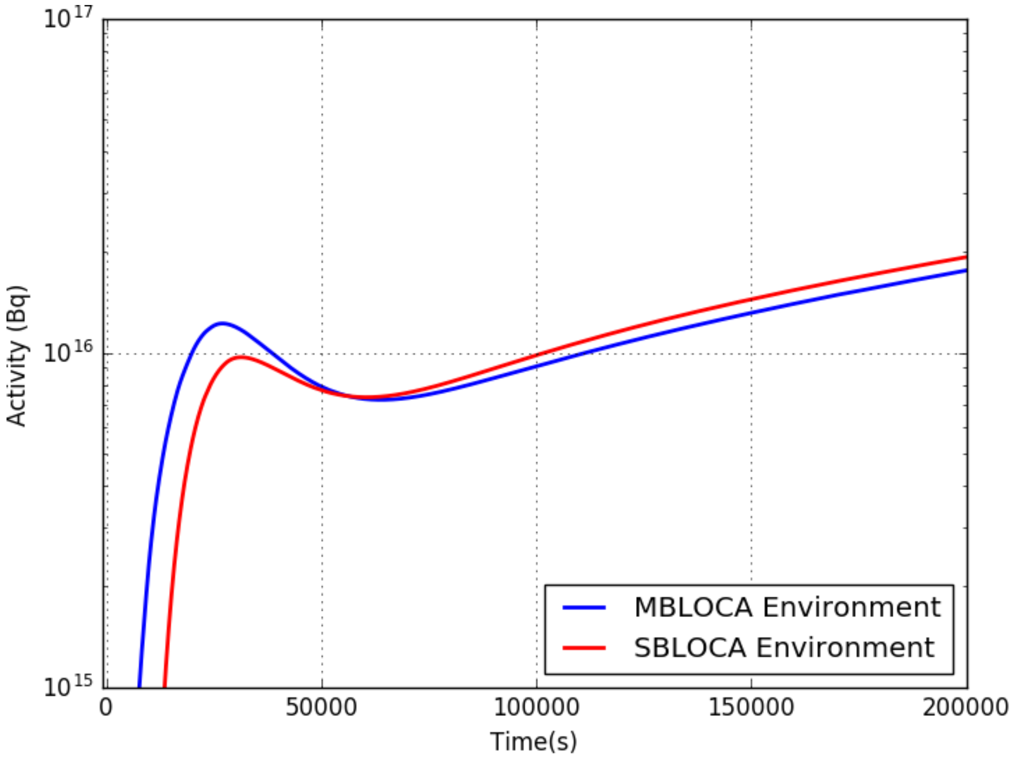




Xe release to the Environment

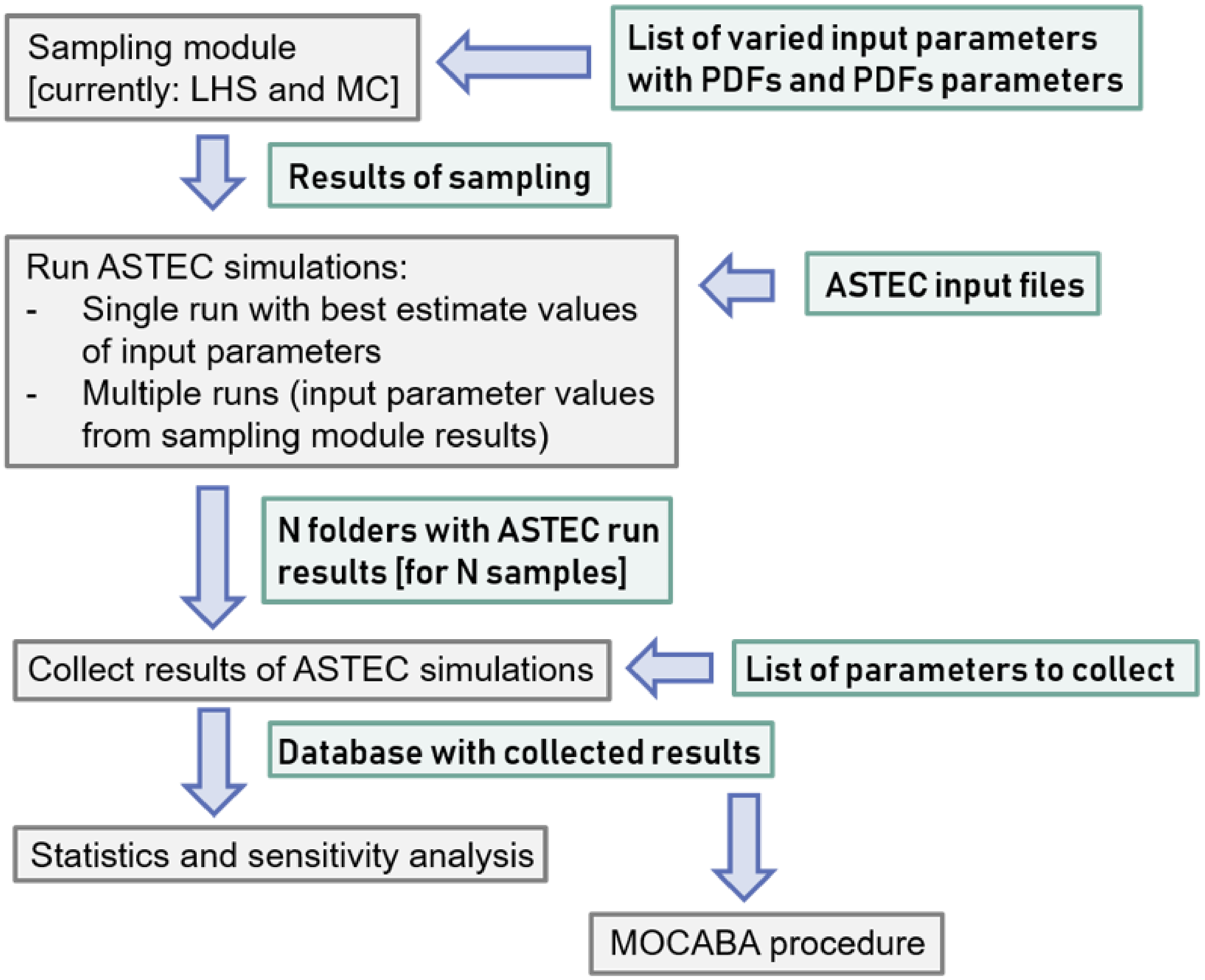
- About 0.3% of the initial noble gas core inventory leaks from the annulus in both scenarios.





The Fast Source Term Code Tool

- Python scripting
- Two versions:
  - For UQ
  - For UQ + ST prediction (MOCABA algorithm employed)
- FSTC application to ASTEC
  - Propagation of the uncertainty of the input parameters
  - Multi ASTEC runs
  - Statistic and Sensitivity Analysis
  - Application of the MOCABA procedure to the database



Assessement of the Database for MBLOCA ASTEC Analyses

- 16 ASTEC input parameters varied by means of Monte Carlo sampling (Latin Hypercube Sampling)
  - Probability Density Functions (PDFs) assessed based on literature.
- Sampled ASTEC parameters governing
  - FP release from the fuel
  - integrity of the clad
  - aerosol behavior in the circuits and in the containment
  - containment leakage
  - fuel burn-up, e.g. fuel inventory
- FSTC tool employed for propagating the uncertainties → 300 ASTEC calculations run

The MOCABA Algorithm

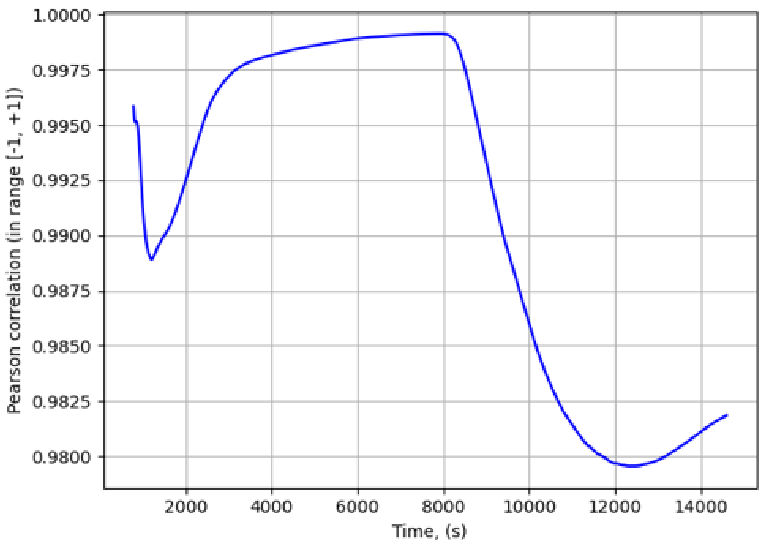
Source Term Predictions: Preliminary Results

- Two subsets of the ASTEC/FSTC results:
  - **200 samples used as a training database for the ‘prior’ part of the MOCABA**
  - **100 samples used for verification of the trained model** → Each sample from this ‘verification’ set is considered as an individual ‘measurement’.

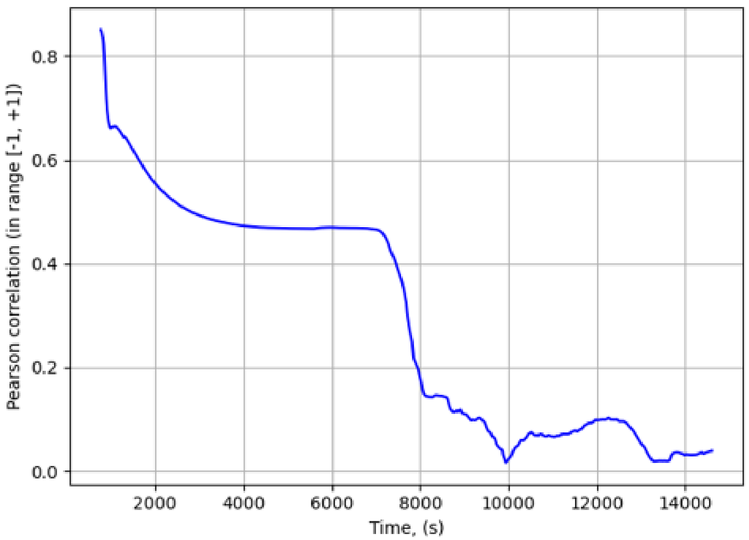
- The amount of Xe released to the environment has been predicted by means of the FSTC/MBLOCA tool by using the **total dose rates** in **containment** and **annulus** as ‘**observable**’ parameters.

Pearson coefficients of the Xe release to the environment

vs. Total Dose in the Annulus

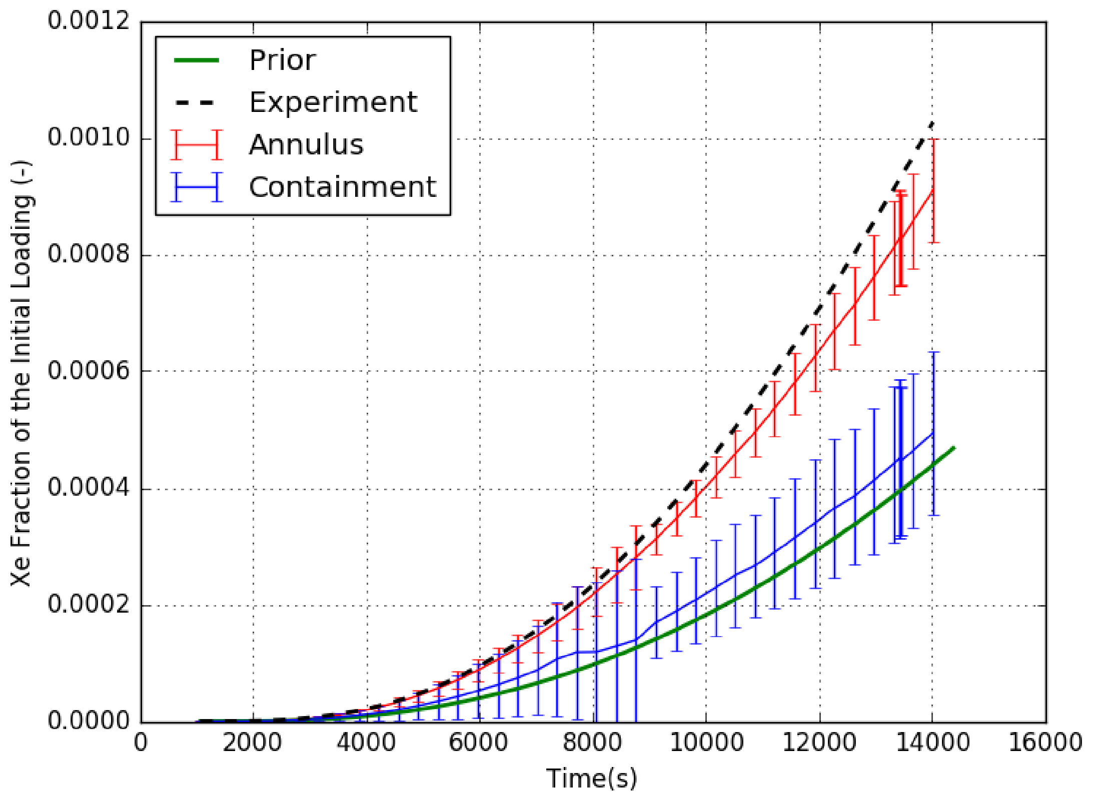


vs. Total Dose in the Containment



Xe Source Term Predictions: Preliminary Results

- 'Measurements' up to 8764 s have been considered
- When the measurements in the contaiment are employed, the predicted ST is near the prior ST → the containment dose rate looks not a suitable observable to improve the ST prediction.
- **A quite good prediction is obtained if the dose rate in the annulus is employed as an observable**.
  - The dose rate in the annulus and the Xe release are strongly correlated, which is not the case for the dose rate in the containment.
- **The MOCABA algorithm and, more in general, the FSTC/MOCABA strategy looks able to predict the ST in a SA scenario.**



Conclusion and Outlook

- KIT and Framatome GmbH have launched the WAME project with the goal to develop a novel real-time program system to improve decision making in SA events in NPPs.
- The system relies on the assessment of a **learning database** of the results of the UQs of ASTEC simulations by means of the FSTC tool to be employed by the MOCABA algorithm for ST predictions.
- The MBLOCA and SBLOCA SA results in a generic KONVOI NPP show that the code is able to perform detailed ST analyses and it has the necessary flexibility for applying the WAME strategy.
- A learning database for the MBLOCA scenario has been assessed.
- **First preliminary results show the capability of the FSTC/MOCABA framework to predict the FP release to the environment.**
- Additional analyses are going on to further improve the ASTEC/FSTC/MOCABA platform.
- Databases for other SA scenarios are under assessment.

Acknowledgements

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