STABILITY ASSESSMENTS

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E-MUG Meeting - Brno – 2025, April 7-11th

Outline

1. MAAP5/MAAP6 Numerical stability studies

2. Examples of improvements in MAAP6

1- MAAP5/MAAP6 Numerical stability studies

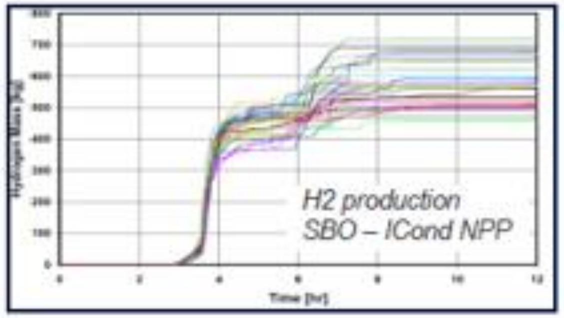
Motivation for the studies

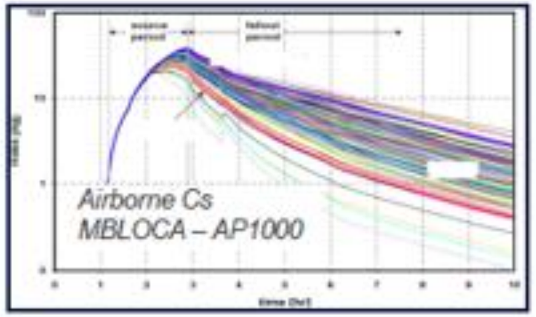
Feedbacks from using SA codes show that when uncertainties are propagated in a transient it is sometimes difficult to explain physically the discrepancies between the runs: small input discrepancies can lead to large discrepancies in the FoM:

- ***A pioneer work based on STCP*** *(Khatib-Rahbar et al., 1989)*
  - *Identification of input param.*
  - *Determination of pdf's*
  - *Random combination samp.*
  - *Calculation running*

  → ***Source Term uncertainties***
  - *Meltdown parameters*
  - *FP release coefficients*
  - *Chemical activities (MCCI)*
  - *Containment performance*

- ***Similar methodology based on MELCOR 1.8.5*** *(Gauntt R.O., 2005)*





1- MAAP5/MAAP6 Numerical stability studies

Motivation for the studies

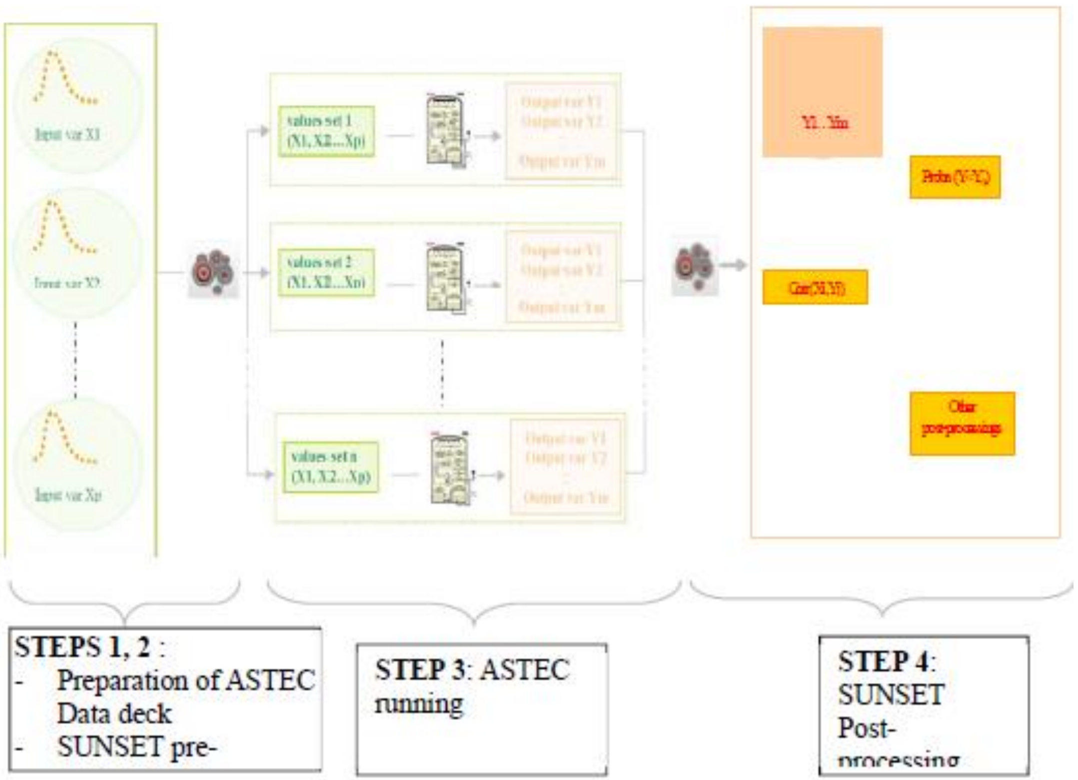


Figure 14: General sketch of uncertainty analysis using SUNSET and ASTEC

https://musa-h2020.eu/wp-content/uploads/2023/05/D3_1_review_of_uncertainty_methodologies_and_tools_applicable_to_SA_codes_for_the_prediction_of_ST_V1.pdf

1- MAAP5/MAAP6 Numerical stability studies

Motivation for the studies

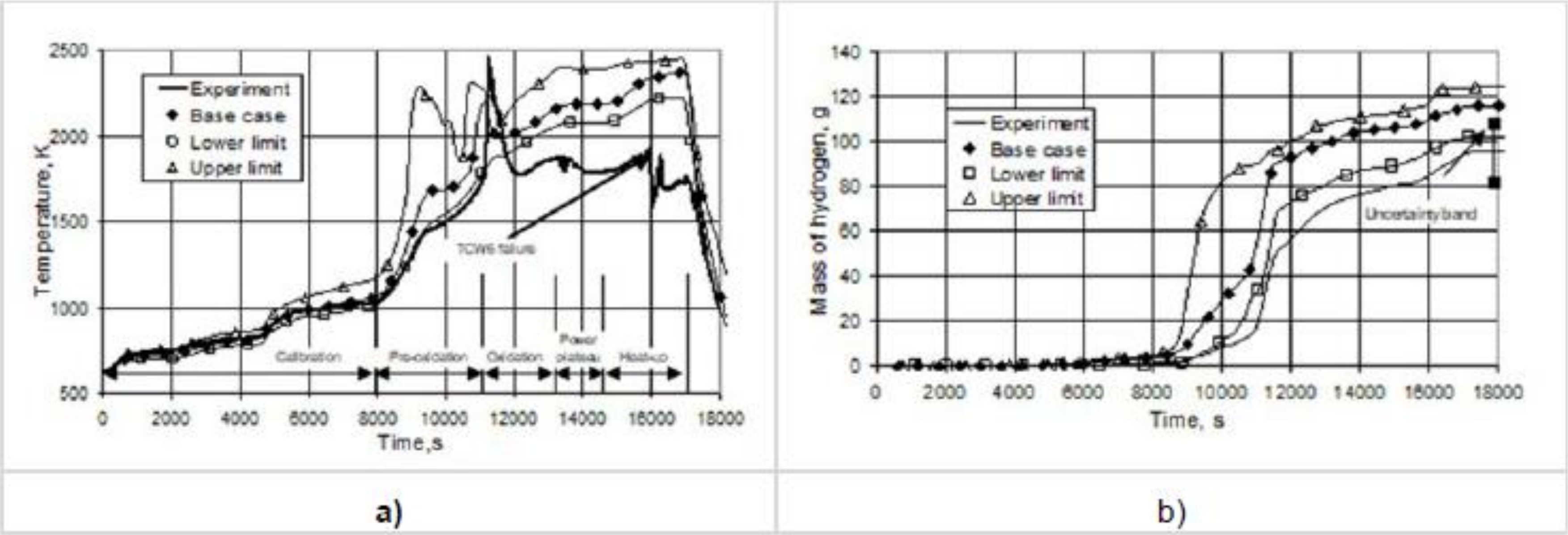


Figure 6: Results of ASTEC calculation of PHEBUS FPT1 experiment: a) fuel cladding temperature at 700 mm elevation; b) total hydrogen generation

https://musa-h2020.eu/wp-content/uploads/2023/05/D3_1_review_of_uncertainty_methodologies_and_tools_applicable_to_SA_codes_for_the_prediction_of_ST_V1.pdf

1- MAAP5/MAAP6 Numerical stability studies

Motivation for the studies

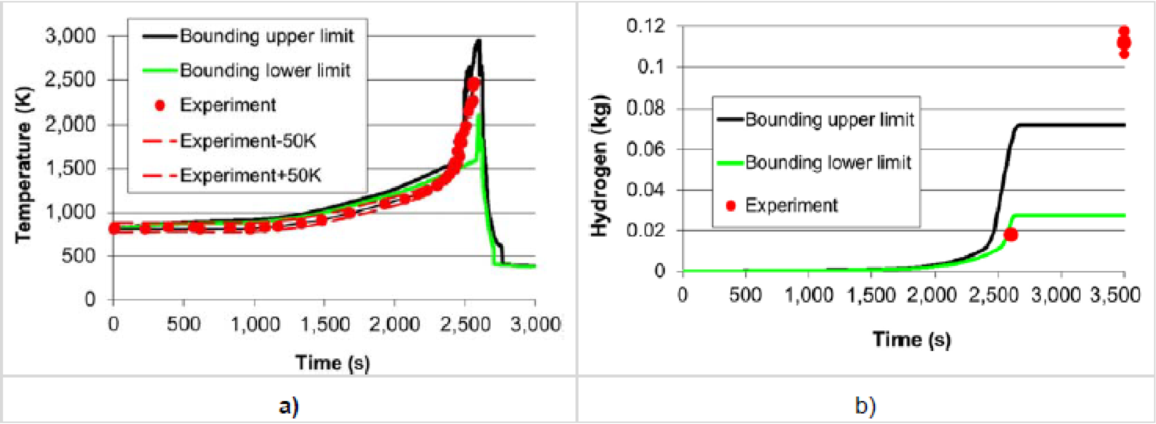


Figure 21: Results of ASTEC calculation of QUENCH-03 experiment: a) cladding temperatures of the fuel rod imitator from the outer ring at 750 mm height; b) amount of generated hydrogen

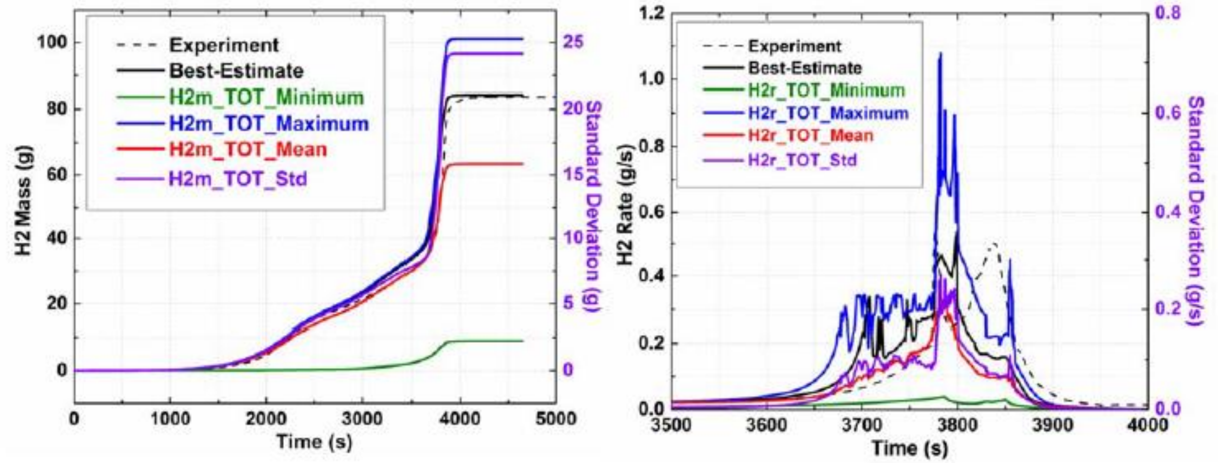


Figure 35: ASTEC/URANIE results: H2 mass and production rate [24]

EDF

1- MAAP5/MAAP6 Numerical stability studies

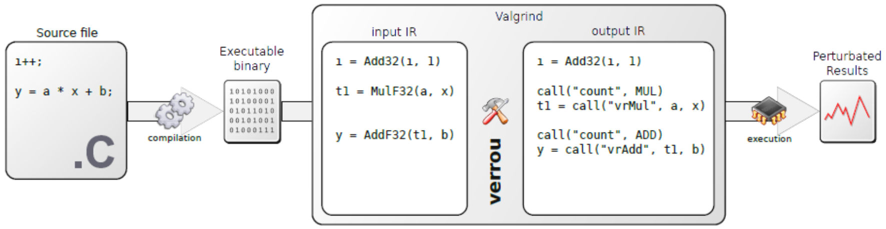
Introducing VERROU

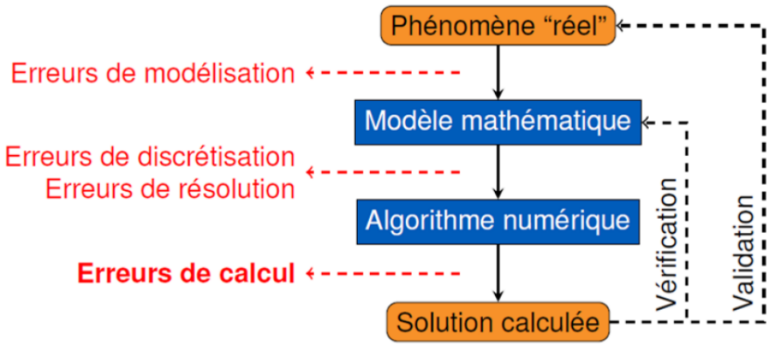
The physics of the SA are of course nonlinear and could explain some parts of the discrepancies.

EDF has developed a tool – called VERROU – that evaluates the round-off error of a code (SA code or not).

No need to have access to the source code, only an executable is necessary

```
$ valgrind --tool=verrou --rounding-mode=random PROGRAM [ARGS...]
```





1- MAAP5/MAAP6 Numerical stability studies

Introducing VERROU

VERROU modifies each floating-point operation to add a different rounding of the results (random by default).

Original code with two arithmetic operations	Result
`MWEXP=MWR+FMWR*DTR`	`MWEXP=593.`
Modified code (rounded upward) by Verrou	**Result**
`MWEXP=(MWR+(FMWR*DTR)+Δ)+Δ`	`MWEXP=593.00000000000006`

For types Float64, **Δ** perturbation is 10^{-16} = ± 0.0000000000000001

If the code has low floating-point errors, the significant digits of the results should be robust to a random rounding. If not, the numerical noise increases over time, the code is then unstable which may have impacts on the global results

1- MAAP5/MAAP6 Numerical stability studies

Introducing VERROU

VERROU can be used as a <u>diagnostic tool</u> to know whether a code is stable or not.

- Running the same calculation of MAAP several times with VERROU (random rounding):

```
valgrind --tool=verrou --rounding-mode=random ${MAAP} ${INP}
valgrind --tool=verrou --rounding-mode=random ${MAAP} ${INP}
valgrind --tool=verrou --rounding-mode=random ${MAAP} ${INP}
valgrind --tool=verrou --rounding-mode=random ${MAAP} ${INP}
valgrind --tool=verrou --rounding-mode=random ${MAAP} ${INP}
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valgrind --tool=verrou --rounding-mode=random ${MAAP} ${INP}
valgrind --tool=verrou --rounding-mode=random ${MAAP} ${INP}
```
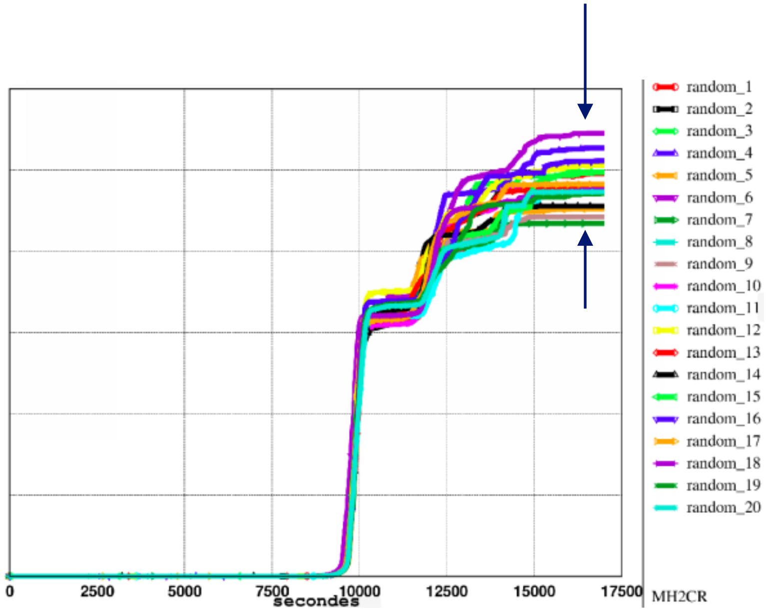
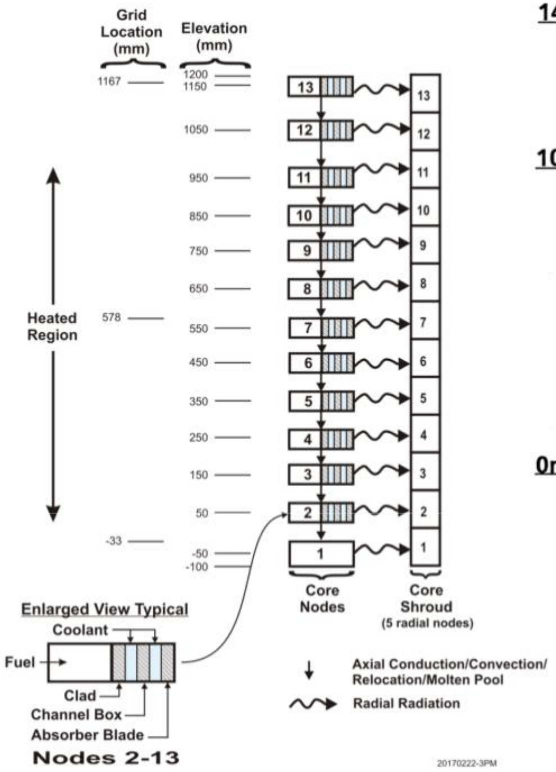
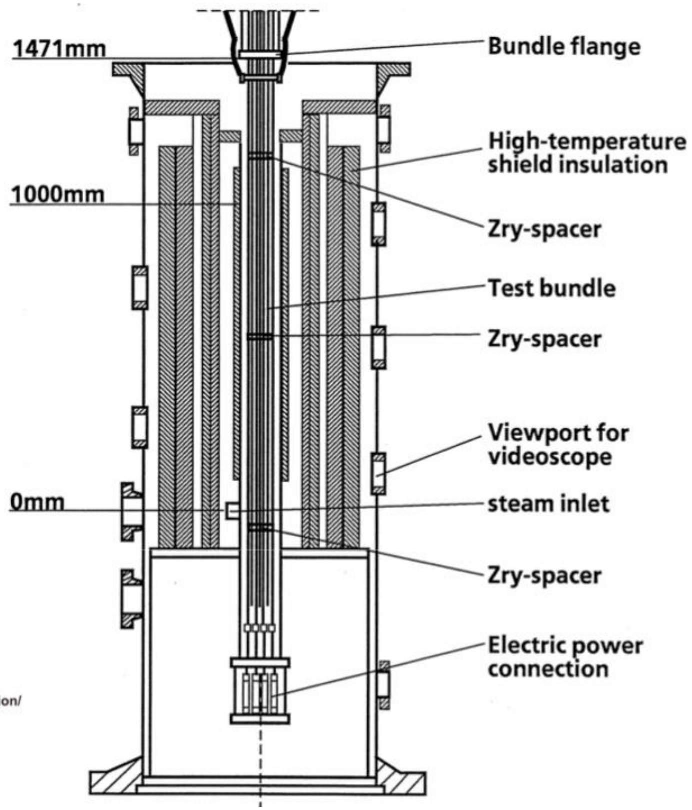

- Analyzing parameter of interest discrepancy

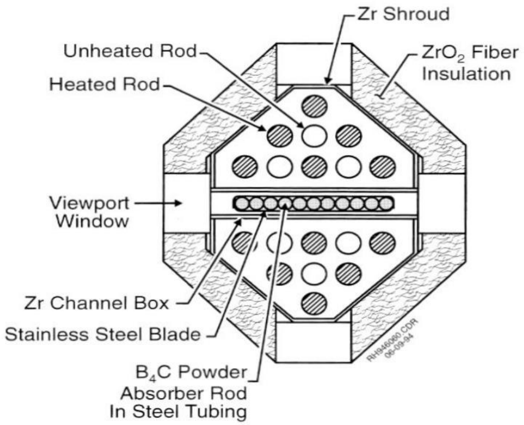


BENCHMARKS

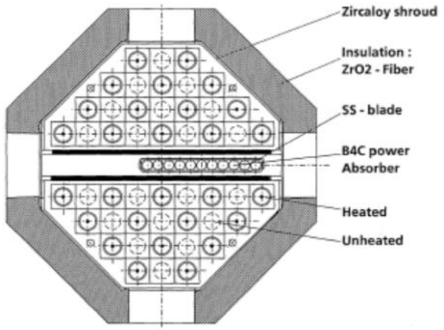
CORA-16, CORA-17, and CORA-18 MAAP5 Modeling (continued)







CORA-16 and CORA-17
Rod Arrangement

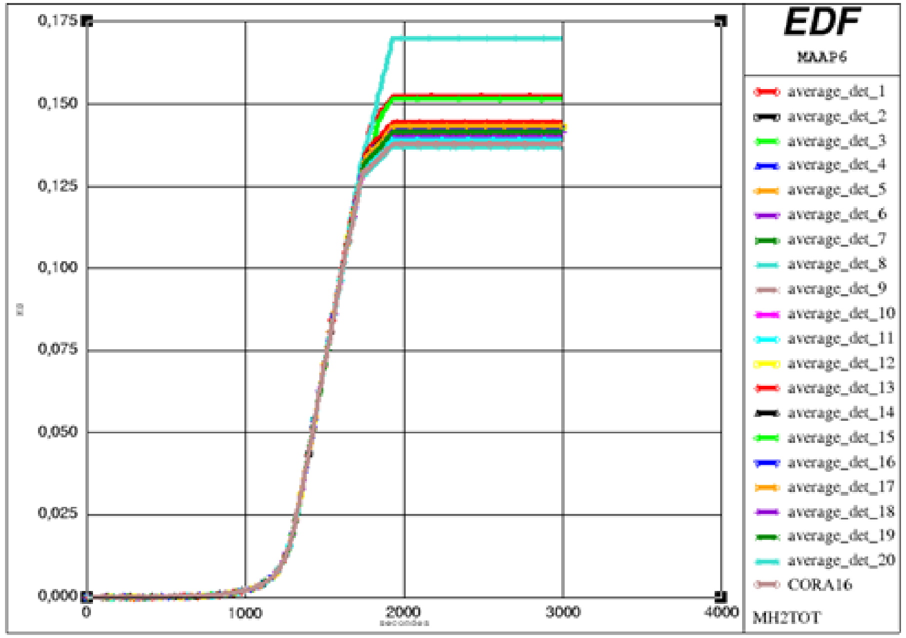


CORA-18 Rod Arrangement

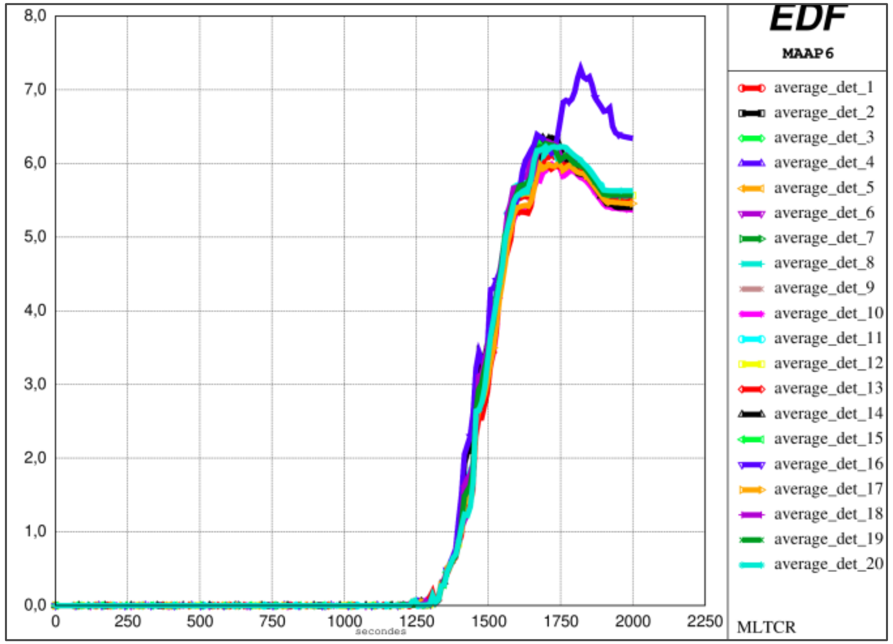
MAAP5 Benchmark of CORA Tests
Chan Y. Paik & Paul McMinn, Fauske & Associates, LLC (FAI)
2017 EPRI Safety Technology Week, MAAP User Group Meeting
Denver, Colorado, June 12-13 2017

CORA16

Before update



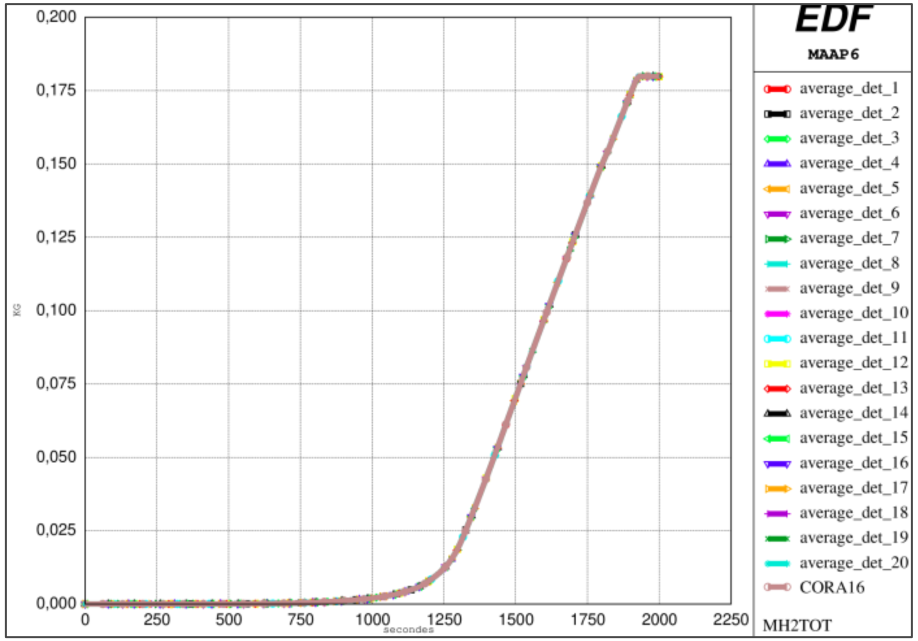
Total hydrogen production in core
`0.135 < MH2TOT < 0.169`



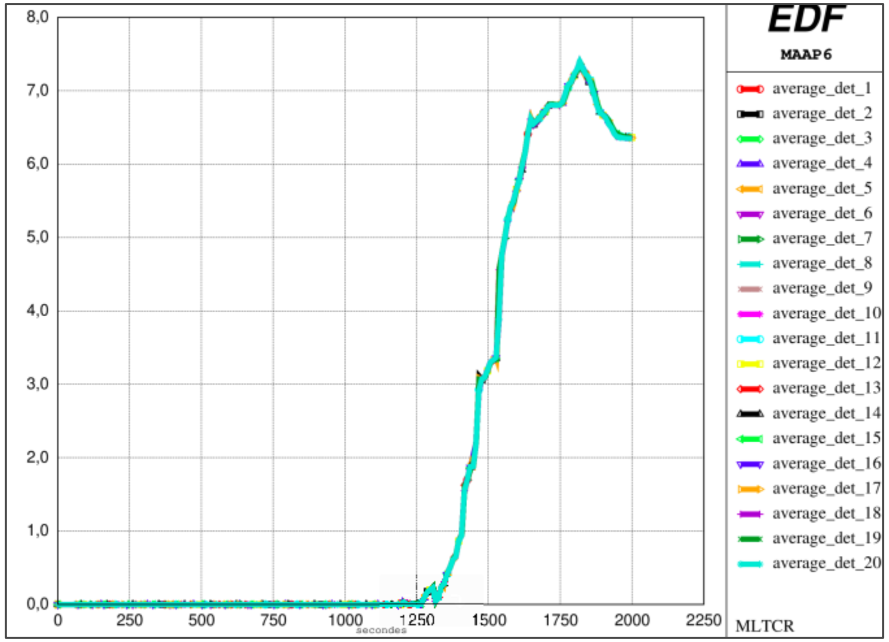
Mass of molten core material
`MLTCR_max < 7.3`

CORA16

After update



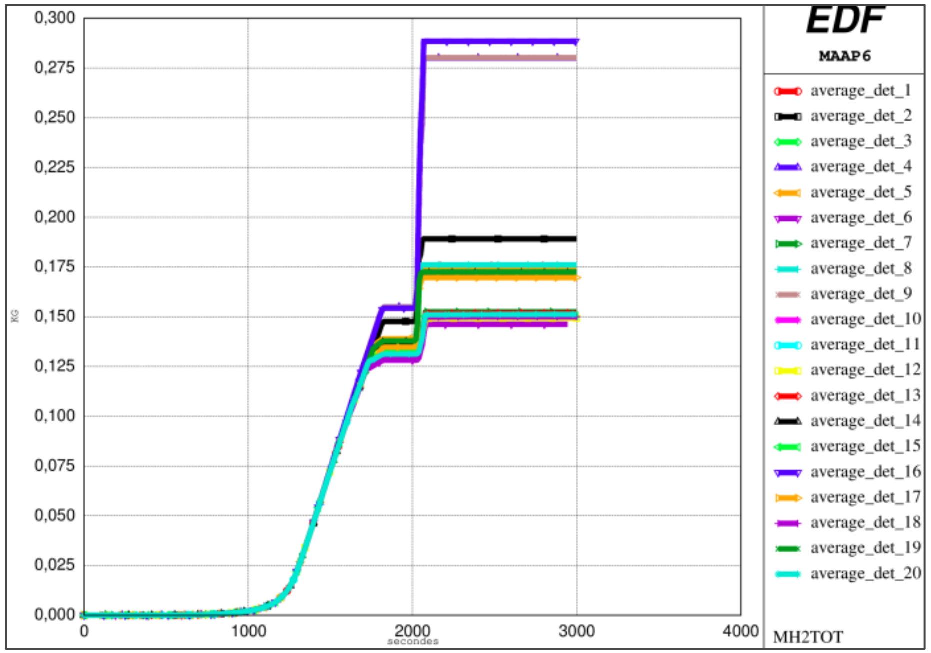
Total hydrogen production in core
MH2TOT = 0.180



Mass of molten core material
MLTCR_max < 7.3

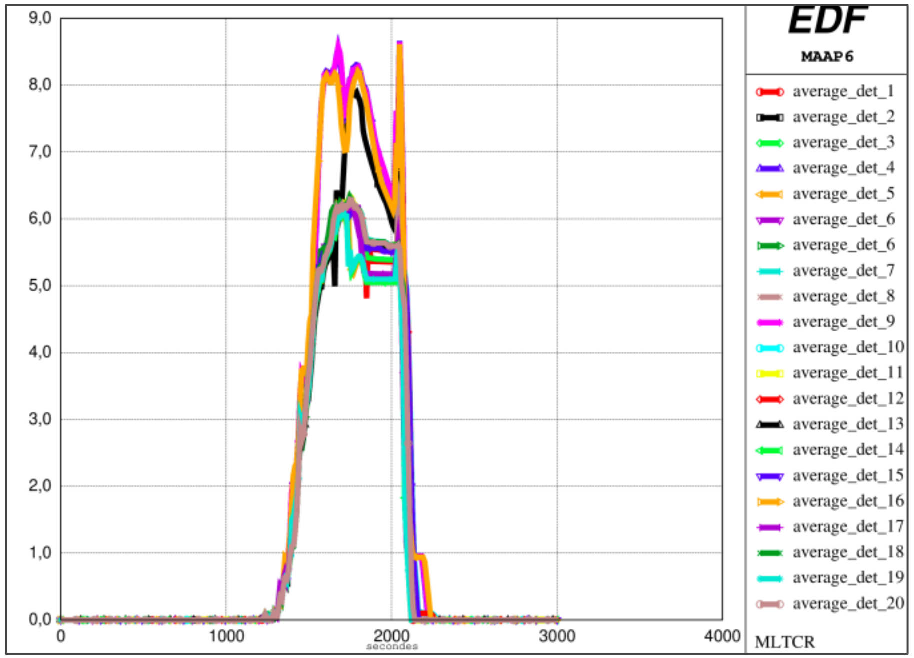
CORA17

Before update



Total hydrogen production in core

0.145 < MH2TOT < 0.285

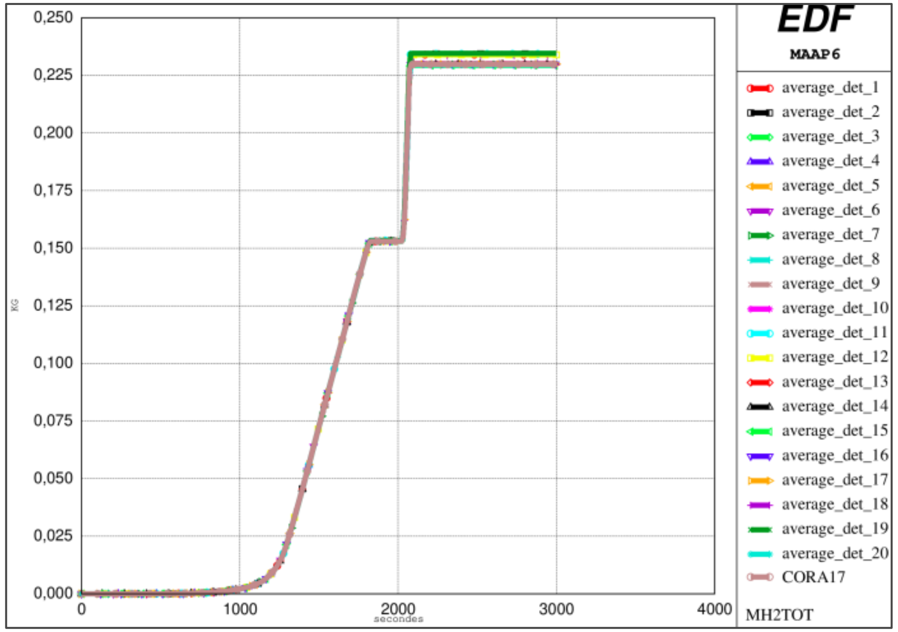


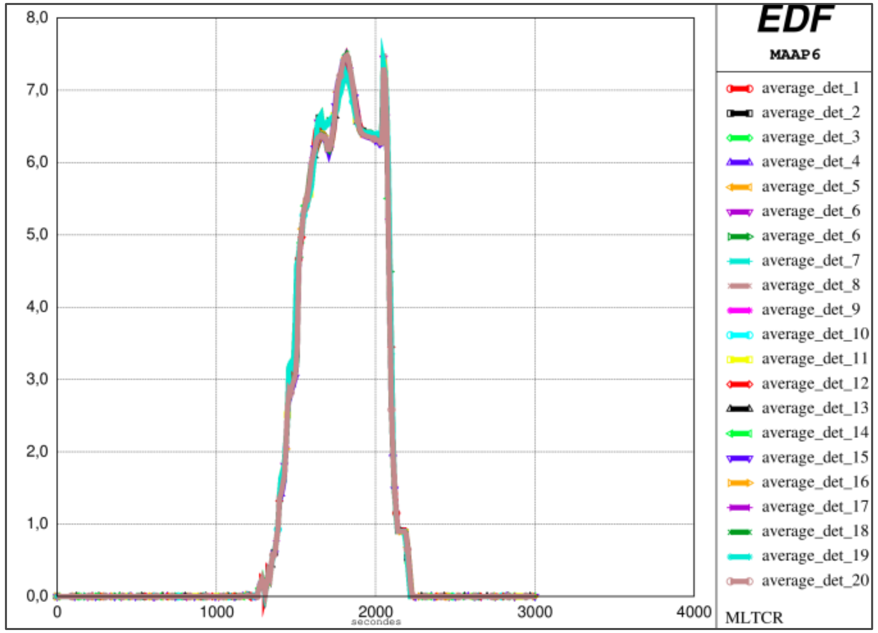
Mass of molten core material

MLTCR_max < 8.5

CORA17

After update



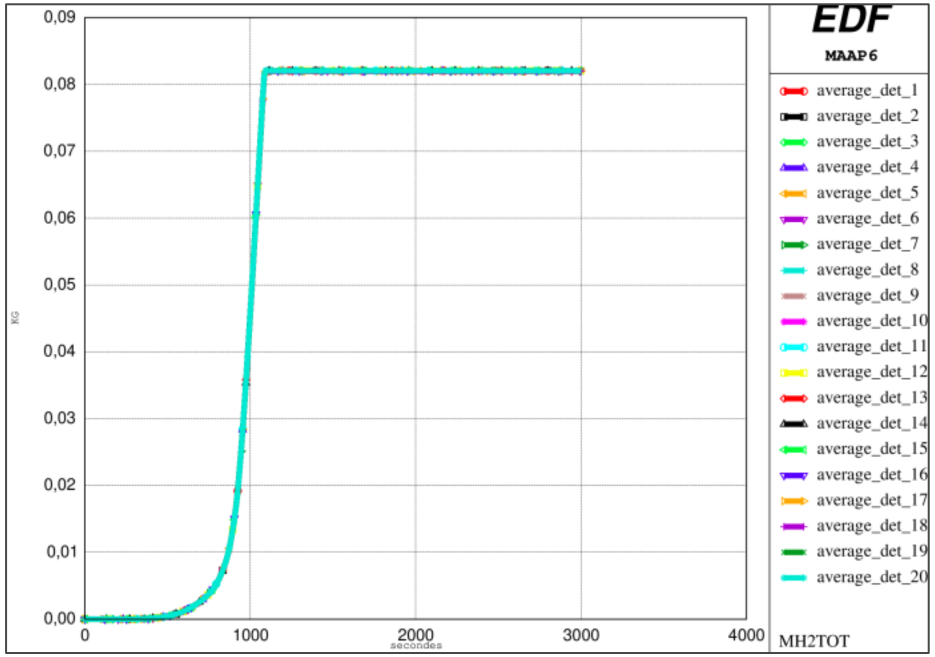


Total hydrogen production in core
`MH2TOT = 0.235`

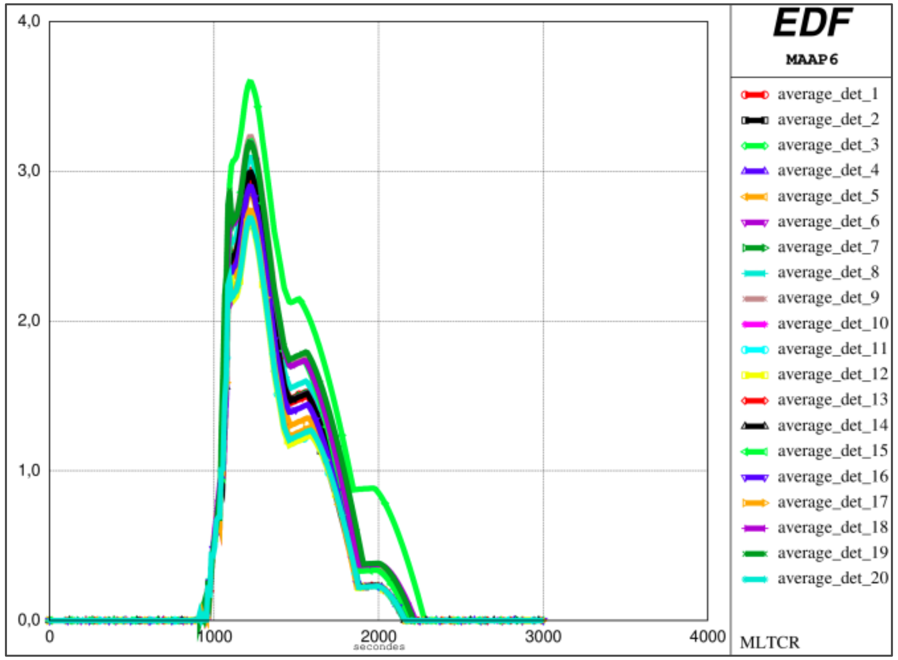
Mass of molten core material
`MLTCR_max < 7.5`

CORA18

Before update



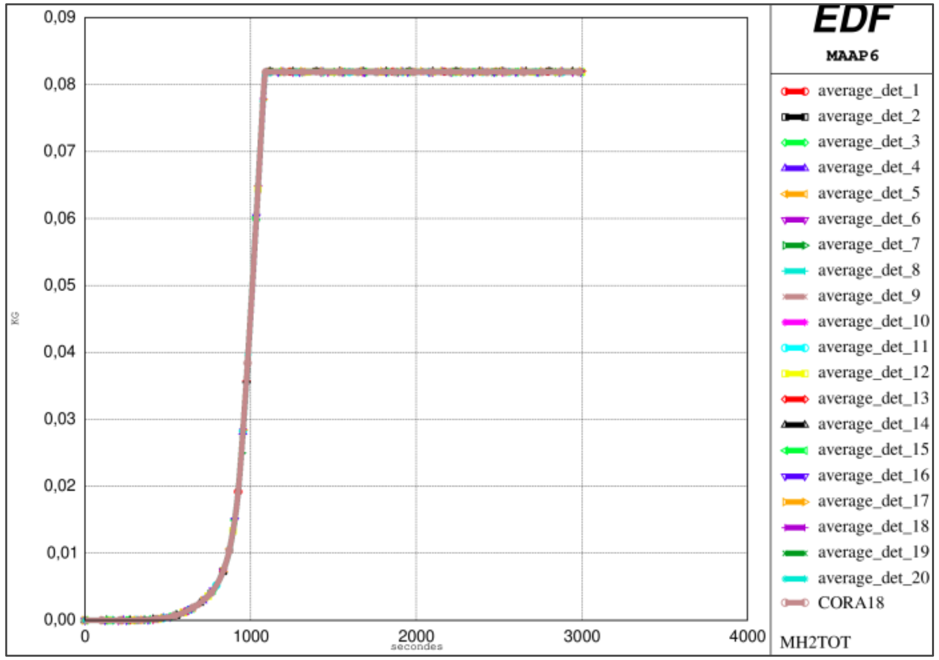
Total hydrogen production in core
MH2TOT = 0.085



Mass of molten core material
MLTCR_max < 3.5

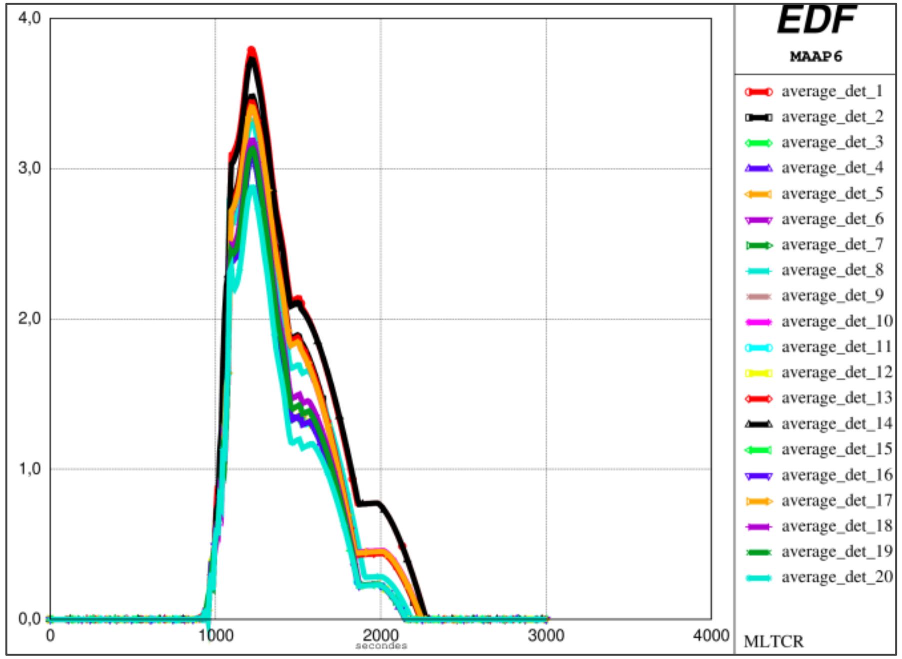
CORA18

After update



Total hydrogen production in core

MH2TOT = 0.085



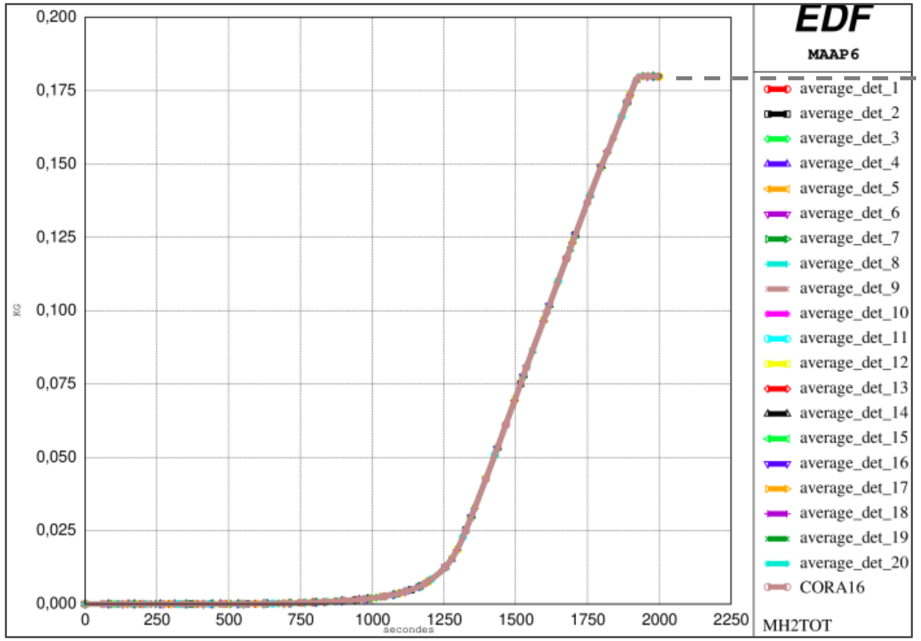
Mass of molten core material

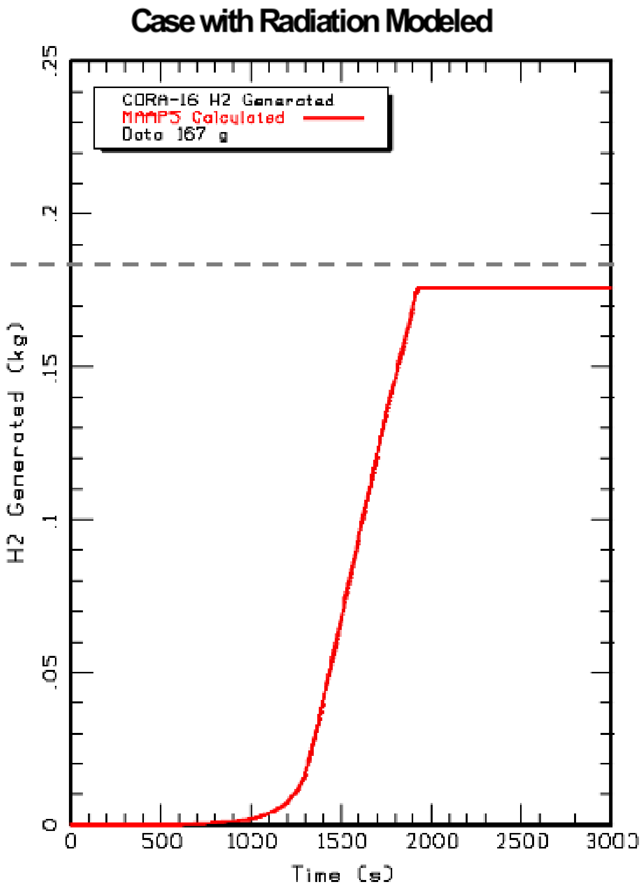
MLTCR_max < 3.8

Comparison with CORA experiments

Presented at 2023 EPRI Safety Technology Week, MAAP User Group Meeting
Manchester, UK, 2023, June

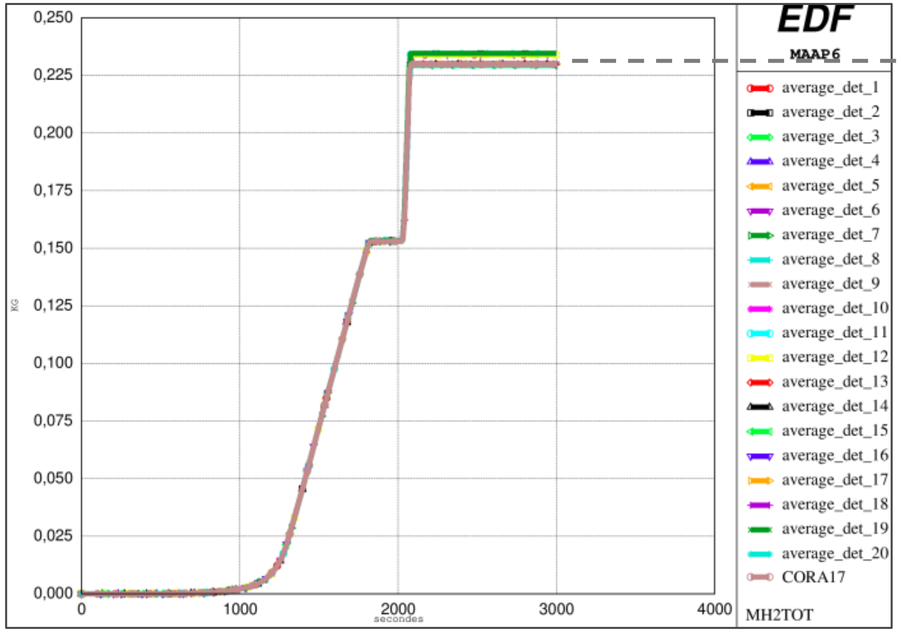
CORA16

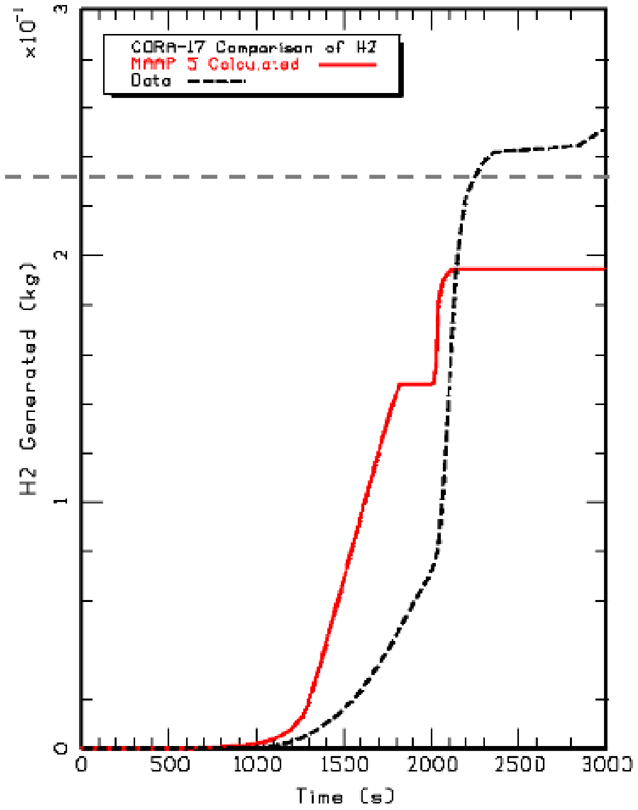




Total hydrogen production in core is slightly overestimated :
180 g (calculation) versus 167 g (experiment)

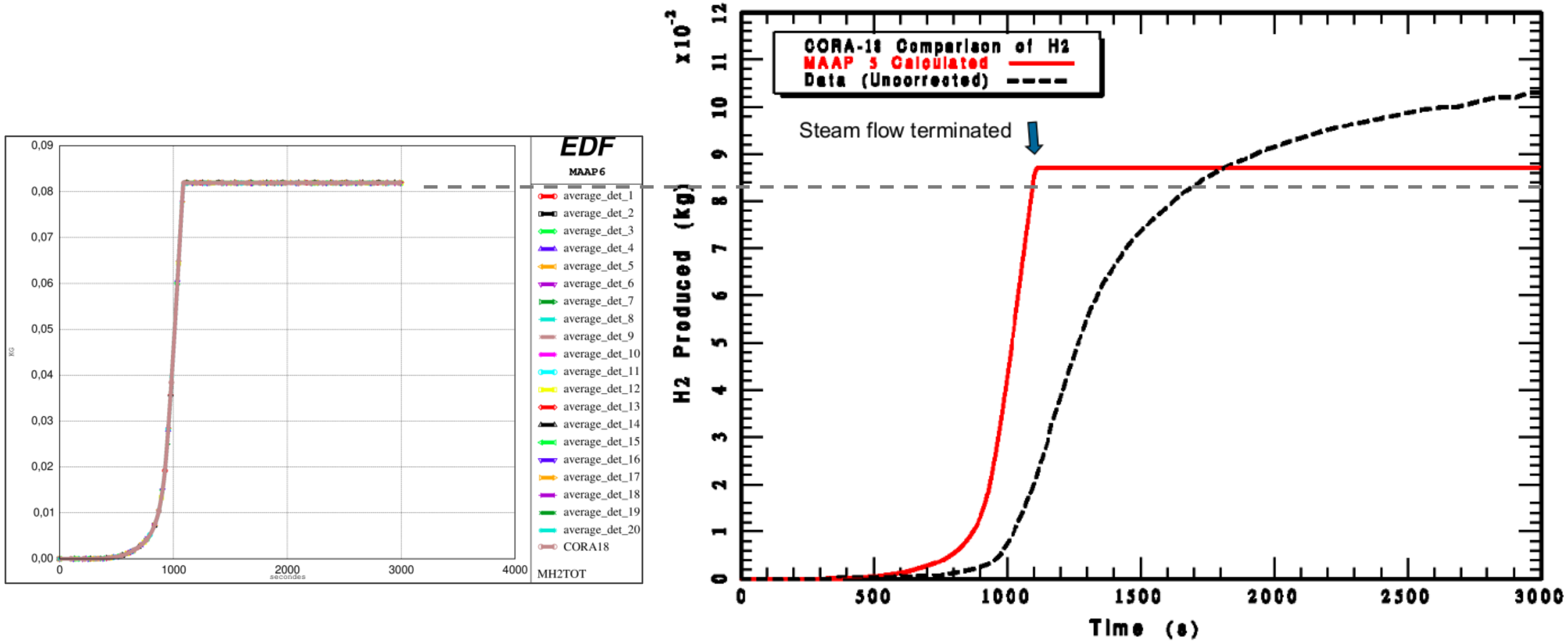
CORA17





Total hydrogen production in core is slightly <u>underestimated</u> :
235 g (calculation) versus 250 g (experiment)

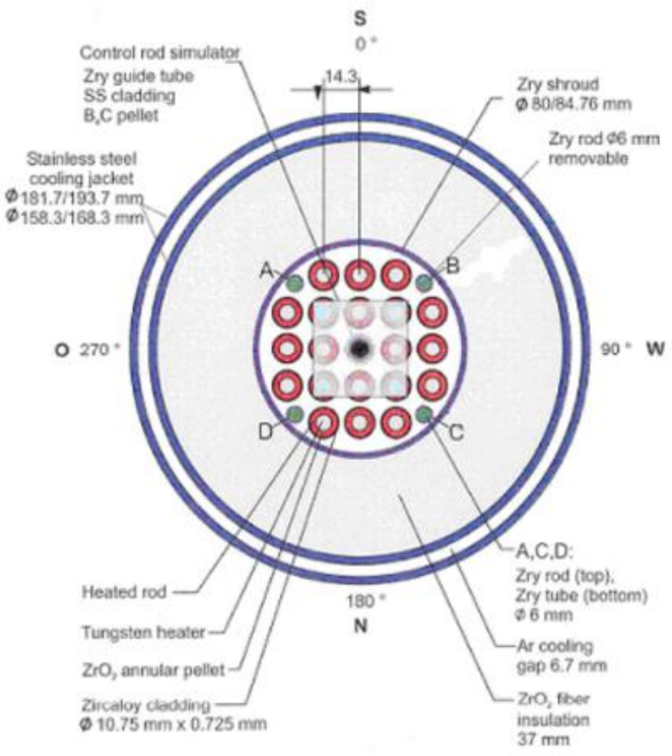
CORA18



Data uncorrected, inlet steam flow was terminated at 1080 s

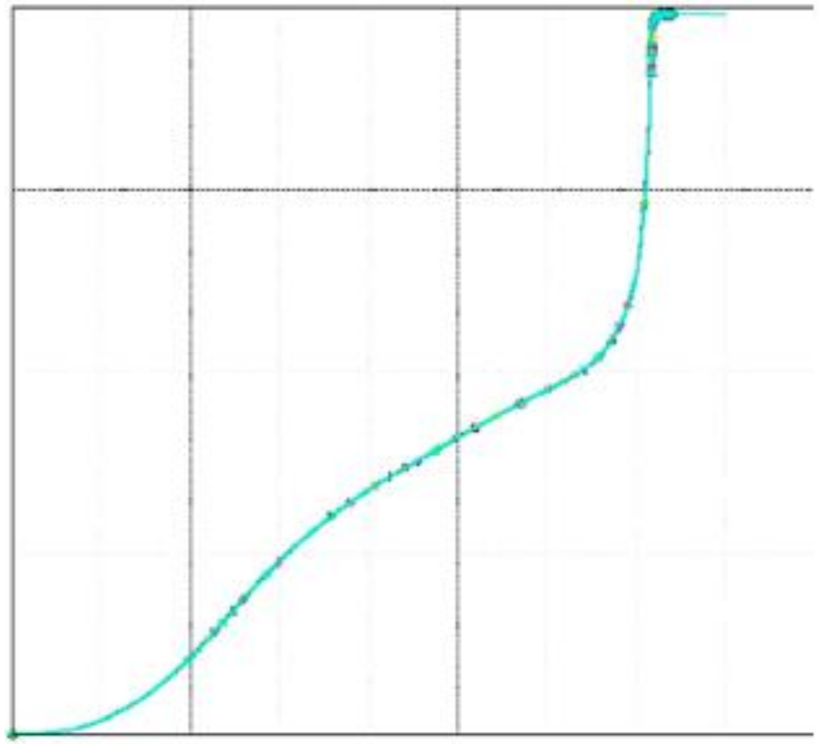
QUENCH TESTS

The QUENCH tests were a follow-up of the CORA program. The main goal of QUENCH tests was to improve the modeling associated with reflooding of degraded core: quenching, oxidizing of cladding, hydrogen production, etc. The experimental set-up QUENCH includes a bundle of non-prototypic (ZrO_2) electrically heated rods having Zircaloy cladding along with other components inside of a Zr shroud. Reflooding of the bundle is ensured with injection of water or steam.

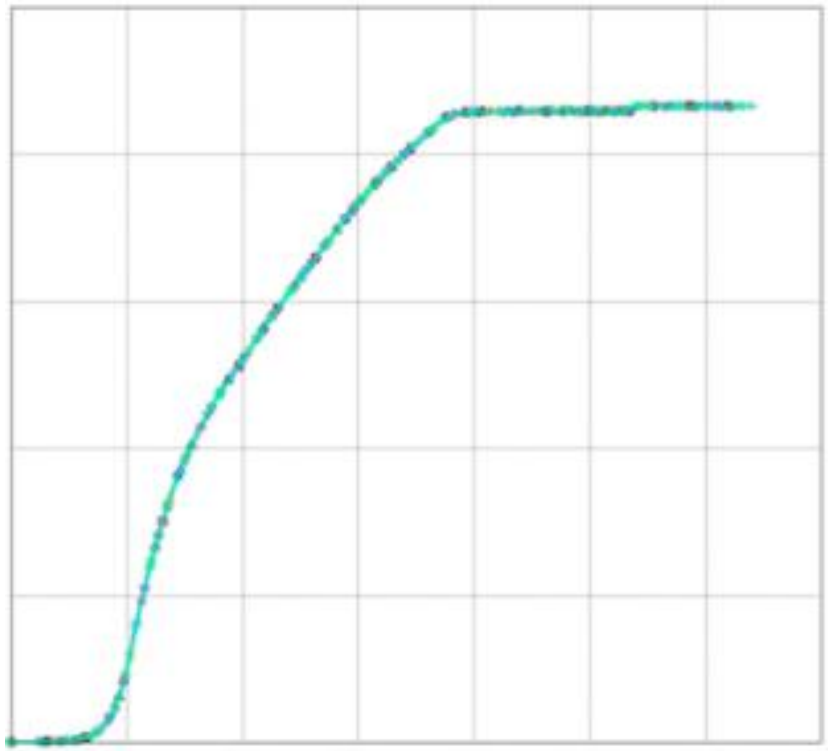


QUENCH TESTS

The investigated QUENCH tests are perfectly stable



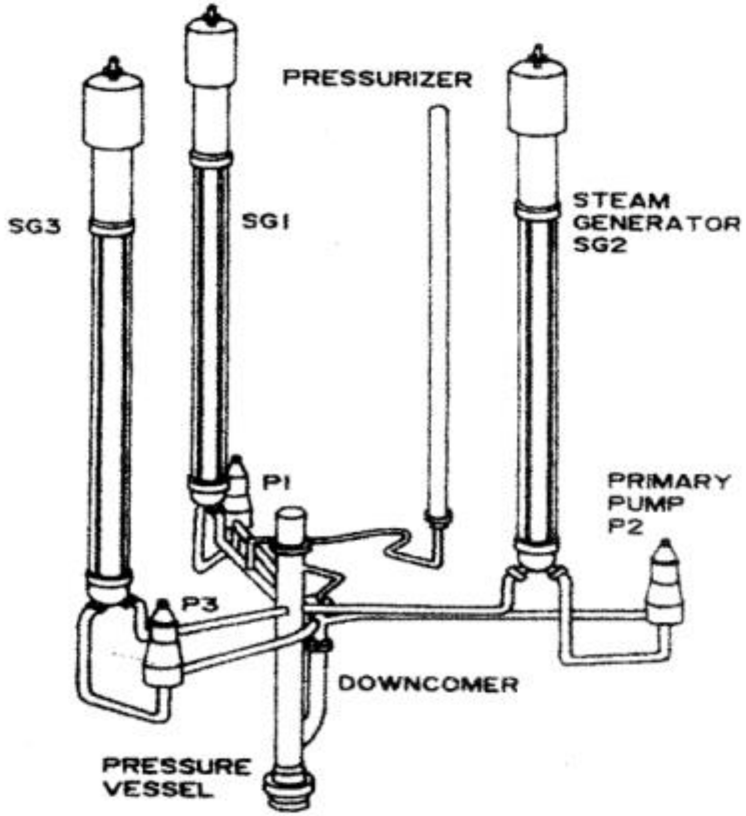
QUENCH 6



QUENCH 10

BETHSY – TEST 91B

The BETHSY test program was part of a French strategy for PWR severe accident management performed during late 1980s for validation of the CATHARE code. The BETHSY facility shown below represents a scaled down model of a 3-loop 900 MWe EDF (1:99) PWR – Heights keep the real dimensions (for gravity head).

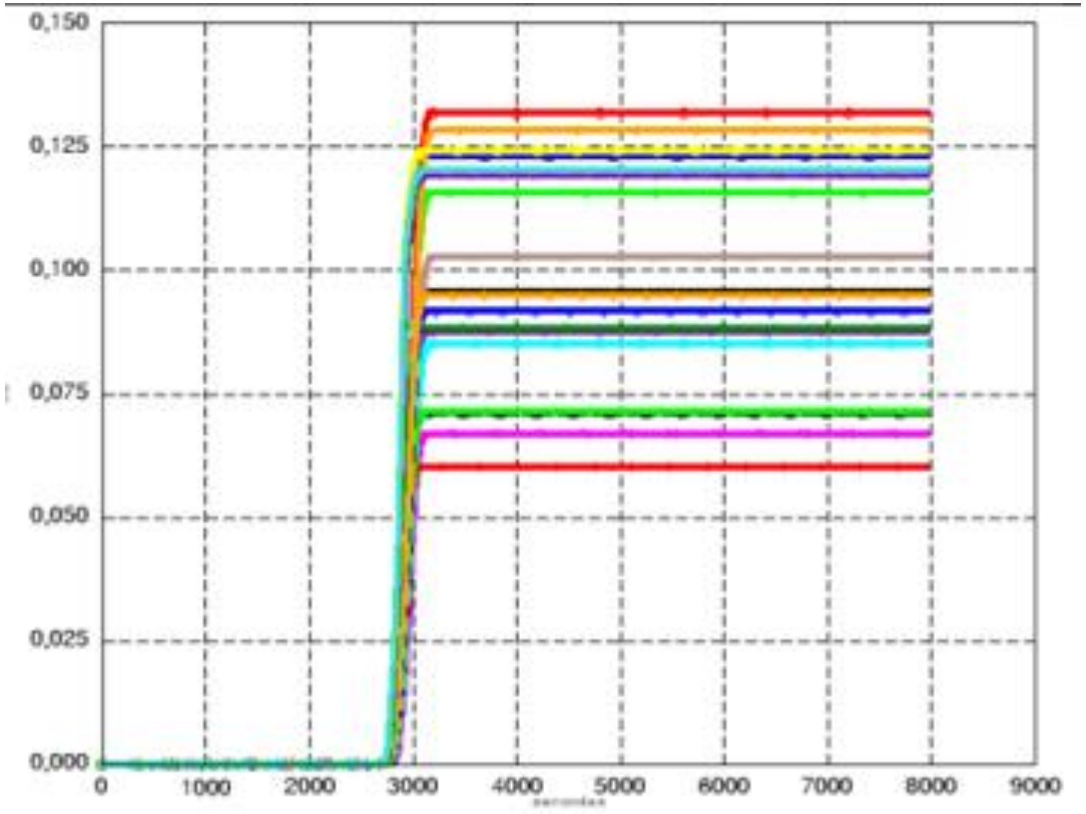


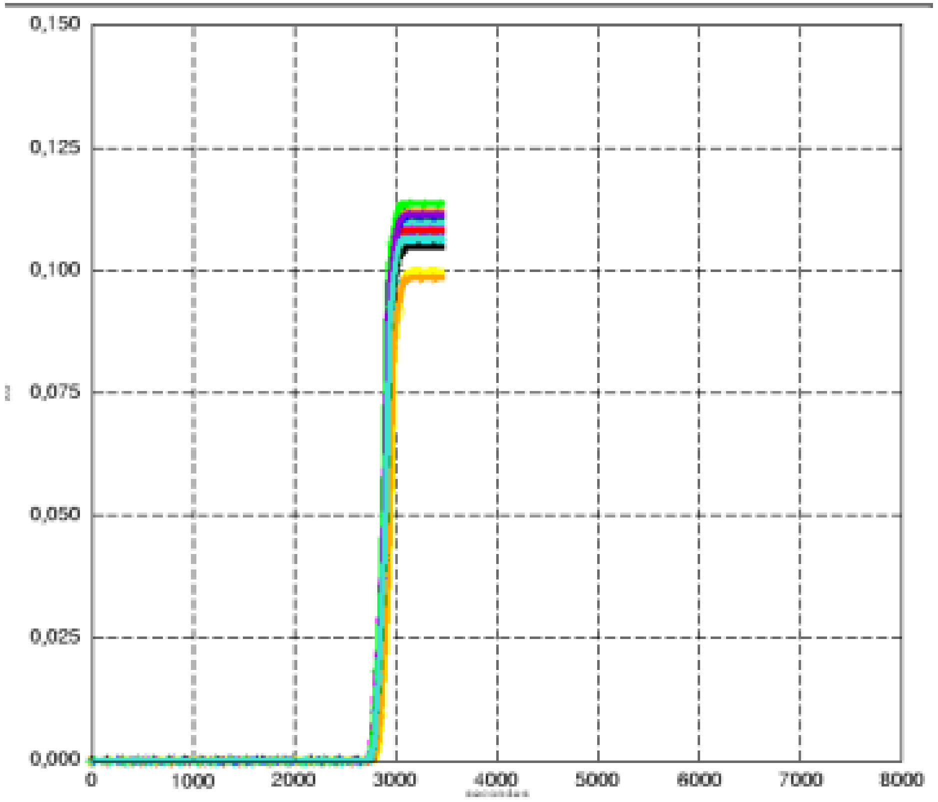
BETHSY – TEST 91B

Before update

After update

Mass of H_2 generated





Conclusion

VERROU is a powerful tool enabling to diagnose instabilities in SA codes.

Finding the origin of the instabilities is often a complicated task (use of debugger) but worth in order to improve the SA evaluations (TH, FP releases…)