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The TMI-2 severe accident: OECD-benchmark activities at KIT using ASTEC

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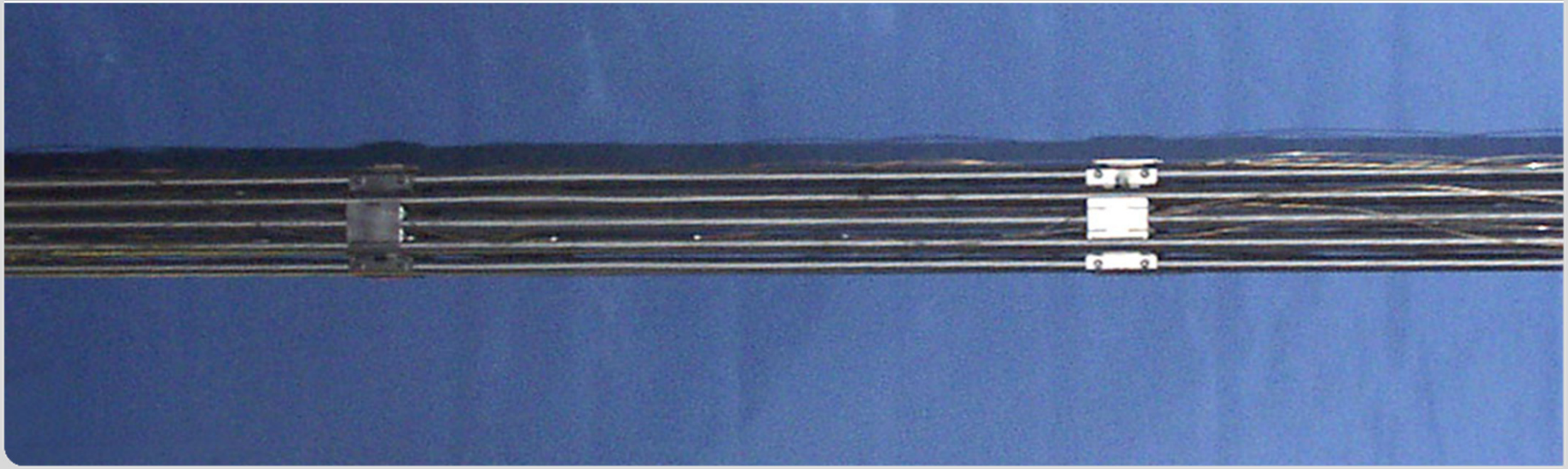


Outline of the Benchmark Exercise

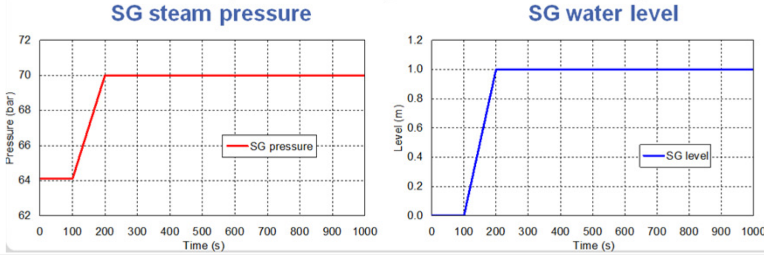
- BCs, Core degradation parameters
- Nominal TMI-2 s-s
- Chronology of main events
- code to code comparison of some results

GRS	Germany	ATHLET-CD
ENEA	Italy	ASTEC
IKE	Germany	ATHLET-CD
IRSN	France	ICARE/CATHARE
IVS	Slovakia	ASTEC
KIT	Germany	ASTEC & MELCOR
SANDIA	USA	MELCOR
TRACTEBEL	Belgium	MELCOR
RUB	Germany	ATHLET-CD
BARC	India	ASTEC
IBRAE	Russia	SOCRAT

Parameter	KIT_ASTEC
Zry-4 oxidation kinetics	**Cathcart-Pawel** (low temp. range) **Prater-Courtright** (high temp. range)
Cladding failure criteria (T = clad temperature) (ε = ZrO_2 layer thickness)	T > 2300 K and ε < 0.3 mm; T > 2500 K and ε > 0.3 mm
Melting temperature of oxide (UO_2 and ZrO_2)	**2550 K**
Debris formation criteria	***2300 - 2500 K***
Debris porosity and particle diameter	***Porosity = 40%,*** ***D = 3 mm***

- SG **Steam** pressure = **70 bar** after **t = 200 s**
- **Water level = 1 m after t = 200 s,**

controlled by auxiliary feed water injection



Introduction *(1)*

Steady state calculation:

- ✓ the goal : bring the NPP from the IC defined in the input deck to the real physical plant conditions (nominal power, hot shut down etc.) inspired by the plant regulations (e.g. feed water, spray, heaters)
- ✓ specific to thermal hydraulics calculations
- ✓ steady state calculation can be very long (more than 10000s)

Transient calculation :

- ✓ performed through RESTART calculations - using the ***.std** file
- ✓ EVENTS used for initiate event and the operator actions
- ✓ All regulations should be stopped (except the real plant regulations) and the physical properties (e.g. pressure, flow rate) of the plant should stay constant
- ✓ One has to make sure that the plant is in a stationary condition before launching the transient calculation

References:

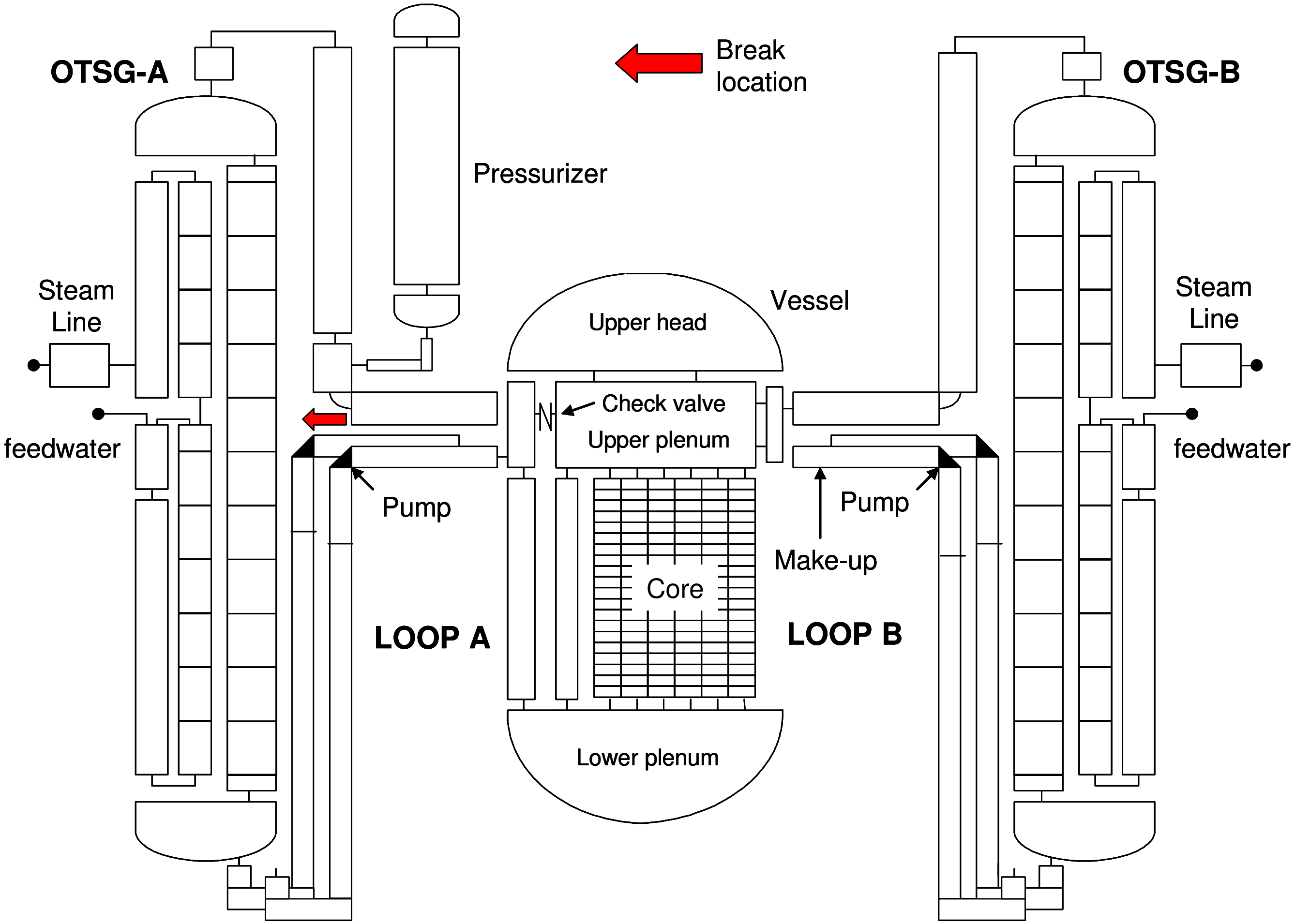
1. Bandini PNE 52 (1) 148-157. Recent advances in ASTEC validation on circuit thermal-hydraulic and core degradation.
2. Task Group **Specifications** (Ref.1,2,3,4).
3. Piar, L., Tregoures, N., ASTEC V2: CESAR physical & numerical modeling. ASTEC-V2/DOC/09-10 (DPAM-SEMCA-2010-380), Jan. 2011
4 Laurent FOUCHER *(Marchetto, Cranga, IRSN)* on *"Intro to plant apps (CESAR modul*e) */Complete reactor case/ how to define sequences*"
5. **Nuclear Reactor SA Analysis Apps** and **Management Guidelines:** AEKI, Budapest, -April 7-11, 2008
SEMINAR AND TRAINING **ON SCALING, UNCERTAINTY** AND **3D COUPLED CALCULATIONS** IN NUCLEAR TECHNOLOGY
3D S.UN.COP 2009 Royal Inst. of Technology, KTH Stockholm 12 – 30 Oct. 2009
6. Reports by Petruzzi; D Auria on *the "user effect";*
7. *E. Chojnacki , K. Chevalier-Jabet* about ASTEC-SUNSET coupling – a quick guideline given at CEA/IRSN

Introduction *(2)*

- The objectives and the scope of the BE on TMI-2 plant are clearly outlined: radial and axial core power profiles according to specification OECD MSLB Benchmark Report (1999) as well as ATMI plant geometry
- Three SA sequences: to investigate core reflood - / in the lower head until vessel failure different degree of in-vessel core degradation /melt progression: (molten corium relocation -slumping into LP)
- 1st transient calculation started from a sequence close to the one of the ATMI Benchmark, but without HPI in the late phase, and thus until vessel failure
- identifying low pressure scenarios: timely opening of the PORV etc
- **SCENARIO Nr.1: INITIAL EVENT -** small break of 20 cm^2 in the hot leg A, with contemporary loss of main feed water (t = 0 s)
- Reactor scram on high pressurizer pressure signal
- Auxiliary feed water startup at 100 s
- Primary pump shutdown when primary mass < 85 tons
- No HPI or LPI system actuation
- Free evolution of the transient until vessel failure

TMI-2 plant nodalization scheme- *geometry slide: courtesy G. Bandini*

Adaptation of ASTEC V1.3R2 input deck of previous ATMI-BE to new **ASTEC V2.0R1patch2-beta** code version used in the present analysis



- Revision according to new **Benchmark specifications**
- Use of **2D debris bed and magma models** for the late phase core degradation

CORE MESHING:

- 6 radial fuel rings
- 20 axial meshes
- Inconel grids added

TMI-2 nominal steady state: KIT-ASTEC modeling results

Parameter	Unit	ASTEC KIT	TMI-2
Reactor core power	MW	2772	2772
Pressurizer pressure	MPa	14.9	14.96
Temperature hot leg A	K	591	591.15
Temperature hot leg B	K	591	591.15
Temperature cold leg A	K	564	564.15
Temperature cold leg B	K	564	564.15
Mass flow rate loop A	kg/s	8820	8800
Mass flow rate loop B	kg/s	8800	8800
Pressurizer collapsed level	m	5.59	5.588
Pressurizer water mass	kg	14600	13710
Total primary mass	kg	222400	222808
Steam pressure SG A	MPa	6.41	6.41
Steam pressure SG B	MPa	6.41	6.41
Steam temperature SG A	K	567.0	572.15
Steam temperature SG B	K	567.0	572.15
Riser collapsed level SG A	m	3.21	-
Riser collapsed level SG B	m	3.21	-
Downcomer collapsed level SG A	m	4.52	-
Downcomer collapsed level SG B	m	4.52	-
Liquid mass SG A	kg	16800	-
Liquid mass SG B	kg	16800	-
Feedwater flow rate SG A	kg/s	772	761.1
Feedwater flow rate SG B	kg/s	772	761.1
Feedwater temperature SG A & B	K	511	511.15

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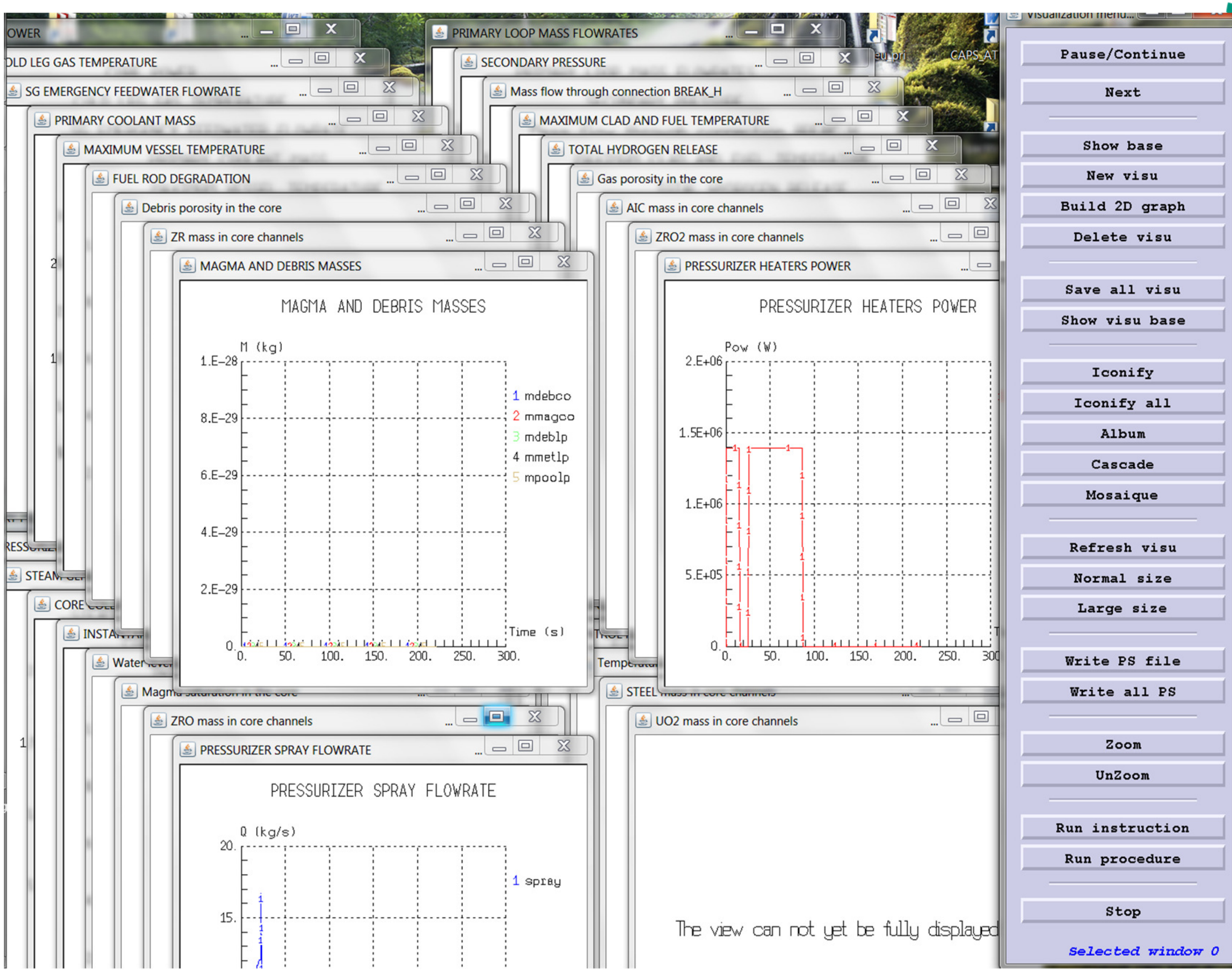
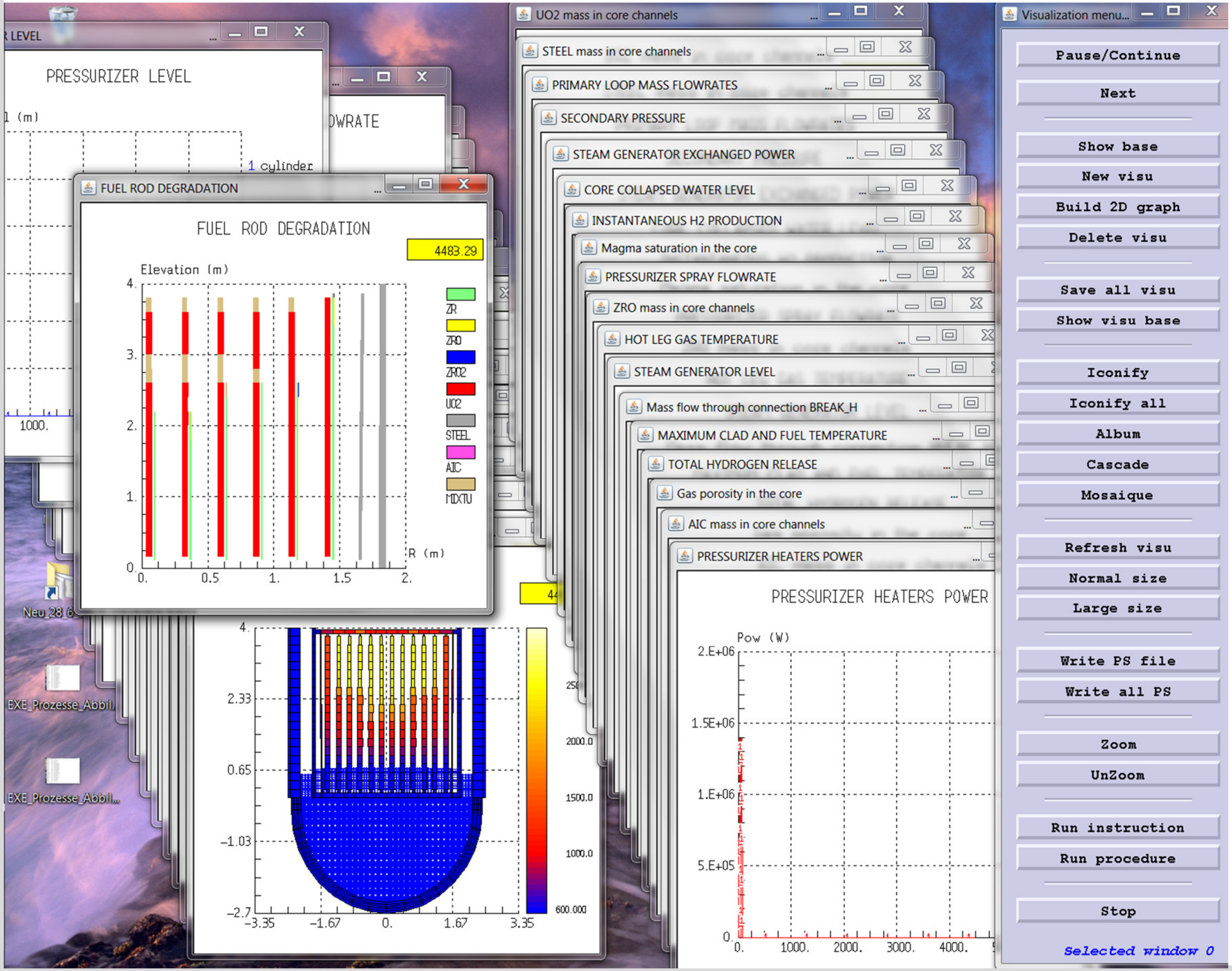
- ASTEC KIT s-s in good agreement with new TMI2 specifications
- Main deviations are:
  - Pressurizer water mass *(may depend on reference elevation for level measurement)*
  - SG steam temp. is under-predicted by 5 °C, with consequent over-estimation of the feed water flow rate to match the right SG power removal

ASTEC visualisation menu (ODESSA) / start of the transient



ASTEC online visualisation – some pick ups



Vessel rupture / late phase (end) of the transient

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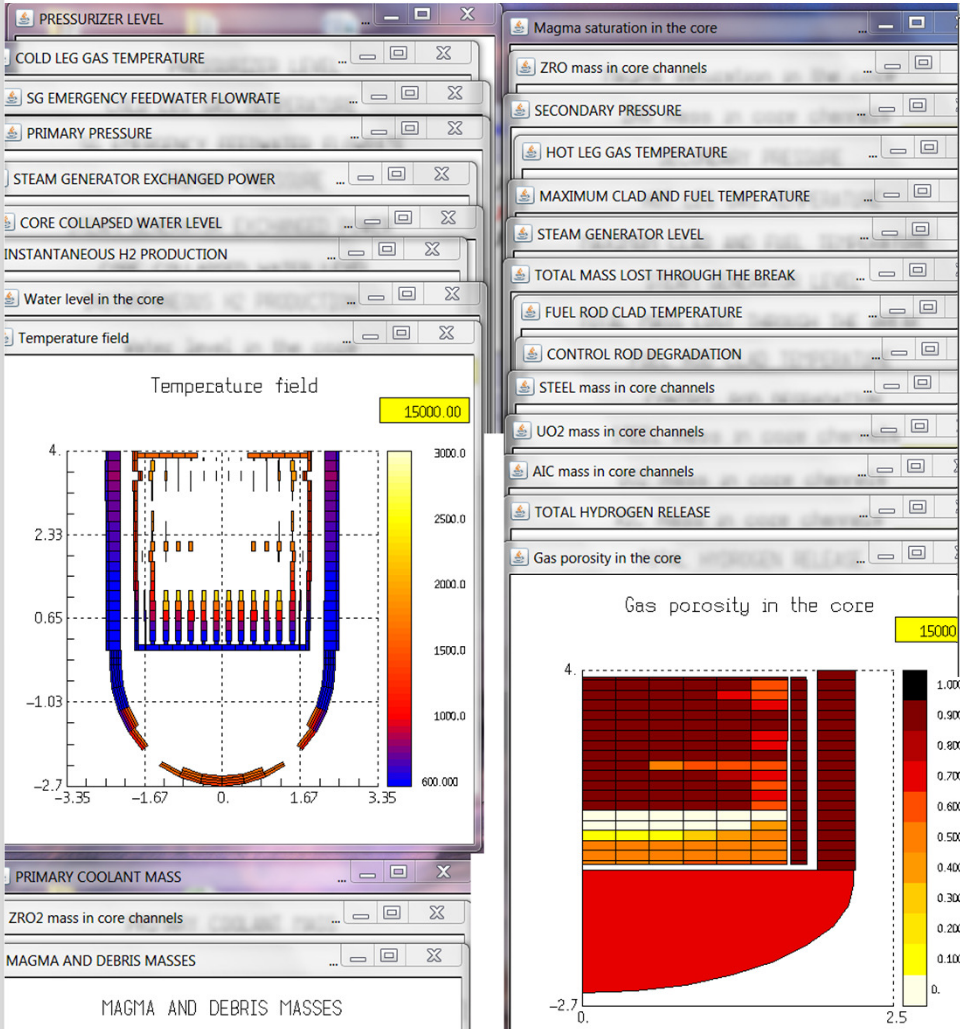
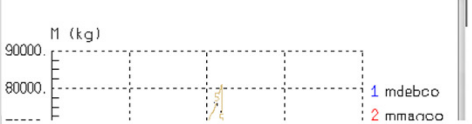
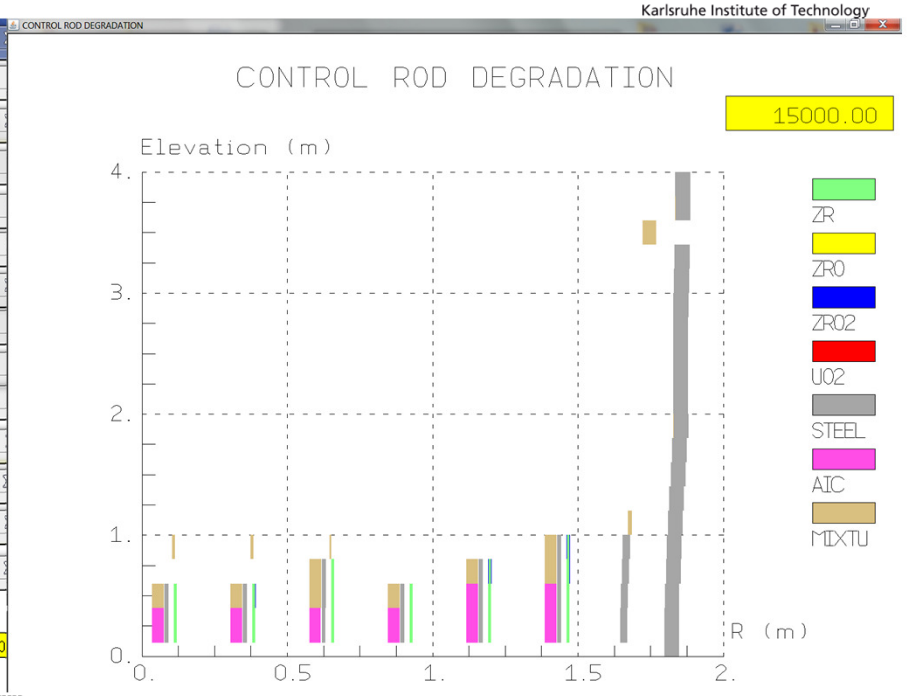




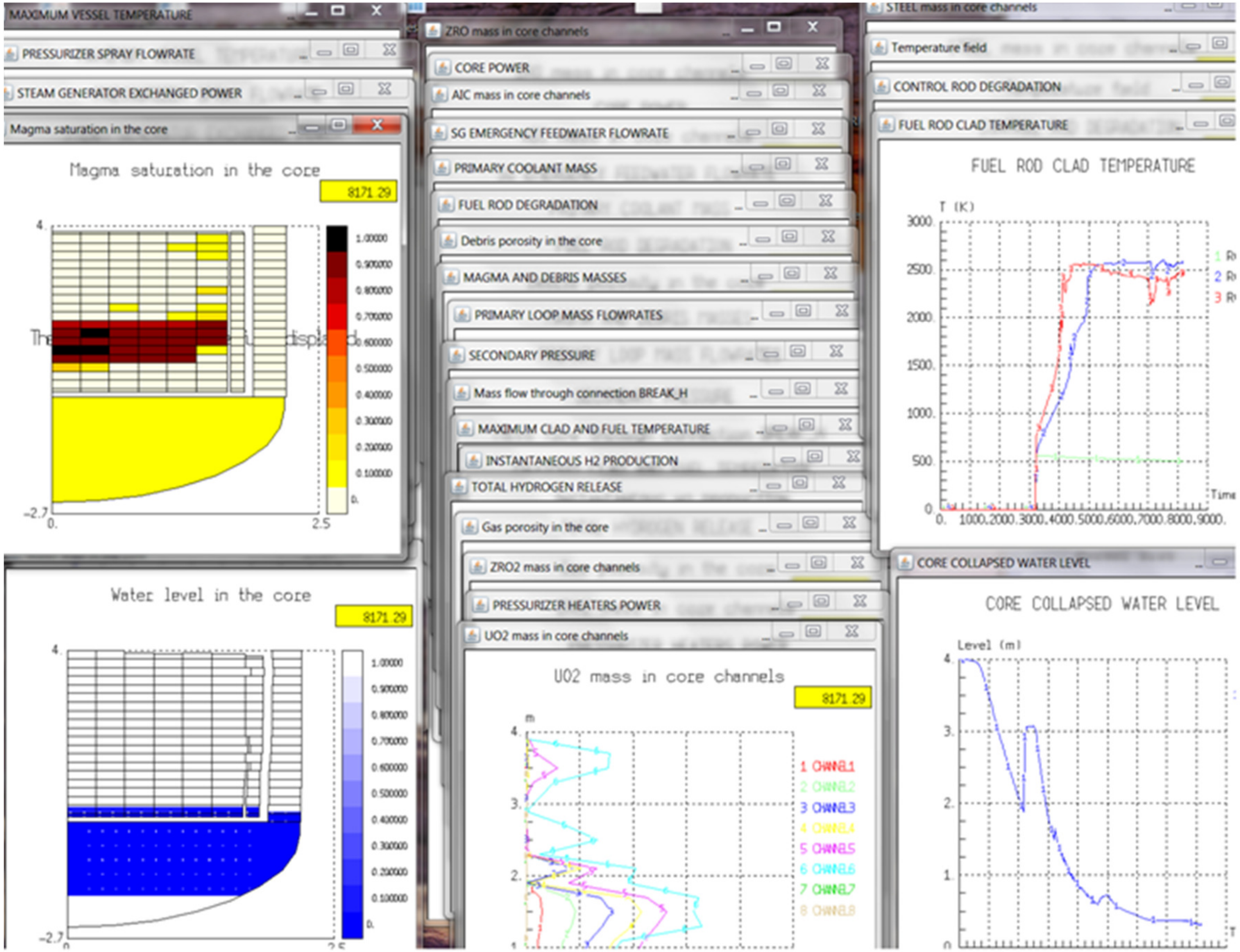


explanation of the degradation phenomena given in ASTEC manuals

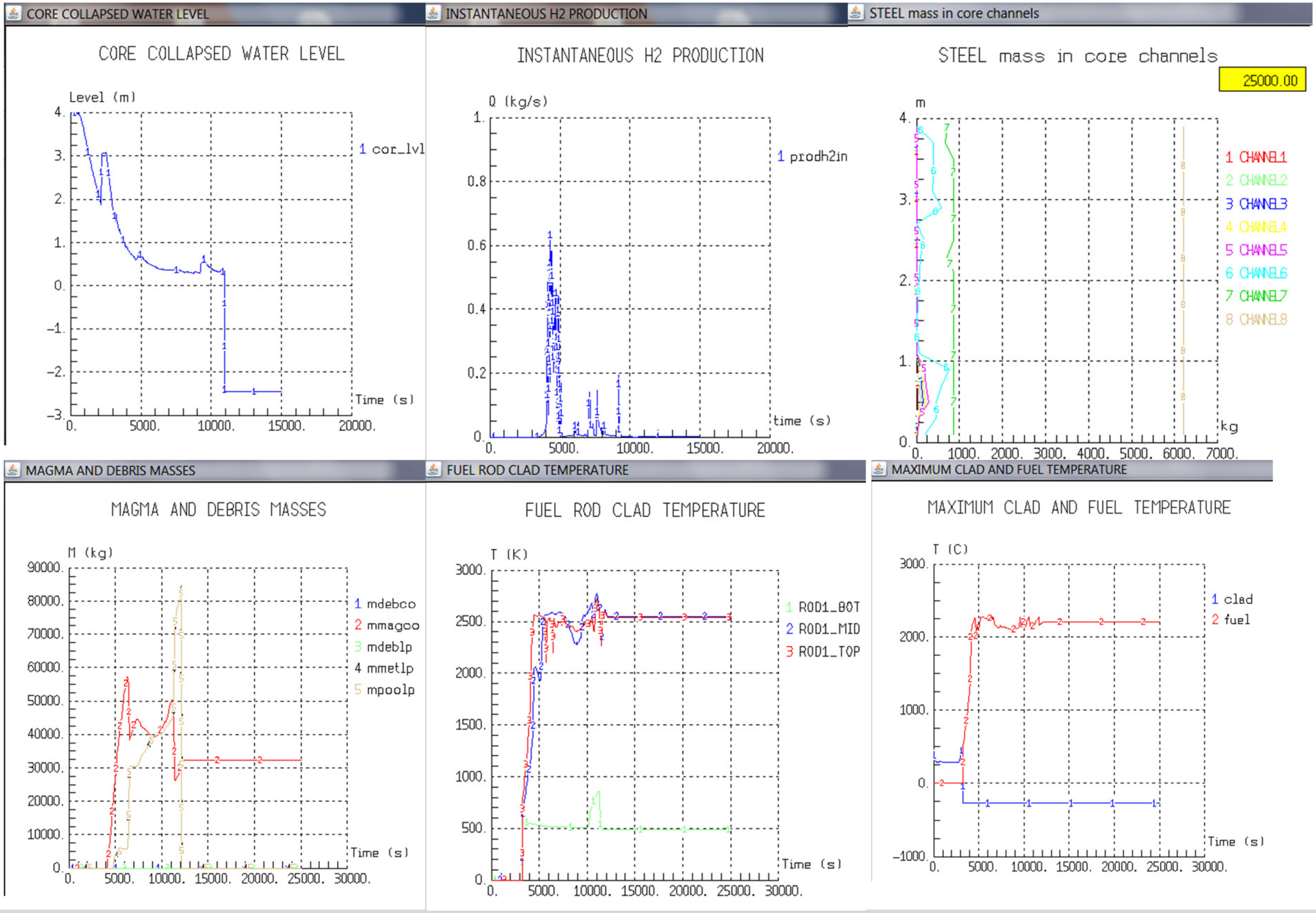
Preliminary analysis / blind BE stage 2:

An interesting result: **vessel failure** at ASTEC simulation reproducible not during the expected **12000** s, but *about 2 min* later

ASTEC online visualisation – pick ups at mid-time



Some other ASTEC TMI-2 transient results

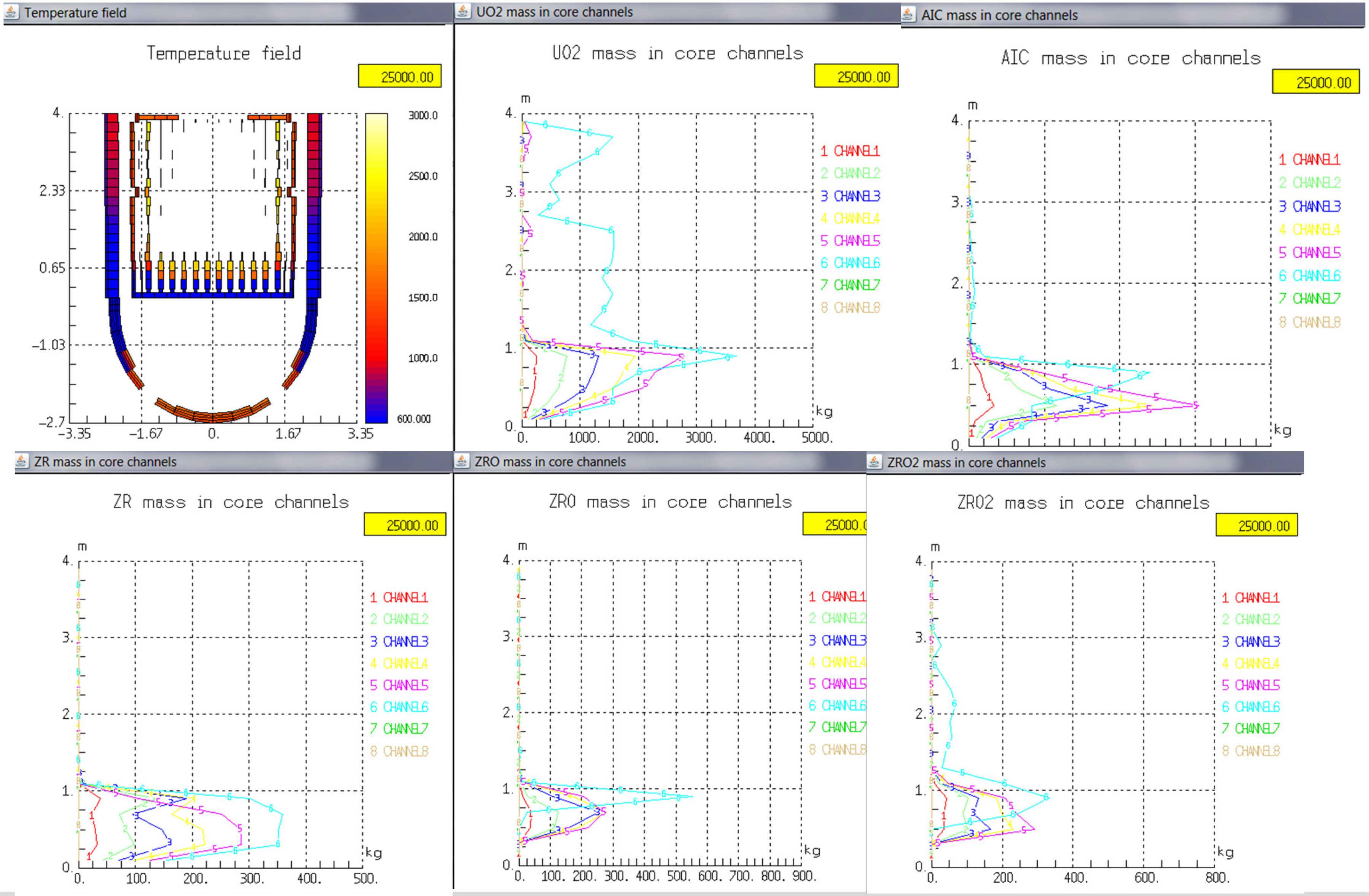


Chronology of main events- a quick look table (*BE Stage 1*)

EVENT	Time (s)/ ASTEC KIT
Break opening & main feed water loss	0
Pressurizer PORV opens	17.1
Reactor scram	21.8
Pressurizer PORV closes	25.3
Full steam generator dryout	27.0
Startup of auxiliary feedwater	100.3
Pressurizer is empty	128
Stop of primary pumps	2177
First fuel rod clad perforation/burst	3737
First clad melting and dislocation	4040
First ceramic melting and dislocation	-
First molten material slumping in L. P.	4681
Vessel failure	10937

- First fuel rod perforation occurs at t = 3737 s due to Zry clad dissolution by Inconel grids
- Molten material slumping into the LP through the core by-pass after baffle melting
- First material slumping at t = 4681s followed by further massive molten material slumping
- Vessel failure at t = 10937 s by rupture criteria

End state after vessel failure, design of ASTEC-axial profiles: *ENEA/ KIT*



Discussion points

- ✓ Key-role for ASTEC in SARNET2 (WP5) since models at the current State of the Art

- ✓ What is happening in the coolant circle / vessel during core degradation until vessel rupture:
  - “melt drops down into a cavity zone of the containment – pronounced peaks…”

- ✓ Urbanic- Heindrick vs. best fit (Schanz` recommendation) kinetics of Zry oxidation by steam

- ✓ Coupling with SUNSET for sensitivity studies (propagation of uncertainties) related study: GRS, SUSA-approach of 1992 for “code to code” data set comparisons /final report

- ✓ Analysis of base case results regarding transient thermal hydraulics of the TMI-2 accident Different hypothetical, but plausible SA-scenarios

Conclusions

- ASTEC has the potential to simulate real plant performance (some evidence given here)
→ special ASTEC strength is, that it is based on empirical correlations and up-to-date physics

•Dynamic behavior (time dependences; evolution)/ profiles developed can be visualized online …

•Developing new skills / some insight into **FORTRAN** structures, philosophy behind ASTEC…

•Reference input deck adopted.. being developed by G. Bandini, ENEA & an anonymous at IRSN

•Java Data Editor JADE/ PSPAD: both -good for working with ***.f –files I** can recommend it here (color coding !)

•captured trends are consistent with the (intuitive) expectation

•Results are dependent on the imposed BC, IC…the output is satisfactory to us

•Tables, figures and spread sheets were submitted to the BE-chairman, G. Bandini, ENEA
•1st results were presented at WGAMA/ OECD Meeting in Paris;
•2nd stage (5 new ASTEC-runs) for TMI-2 BE purposes (ref. input deck): further upgraded transients were obtained/sent to the chairman in time/ presented in Paris, OECD / discussed there

•Actions foreseen for the 2nd stage: main requirements are fulfilled, work completed:

•Recommendations and suggestions for the BE 3rd stage followed/ (comments)

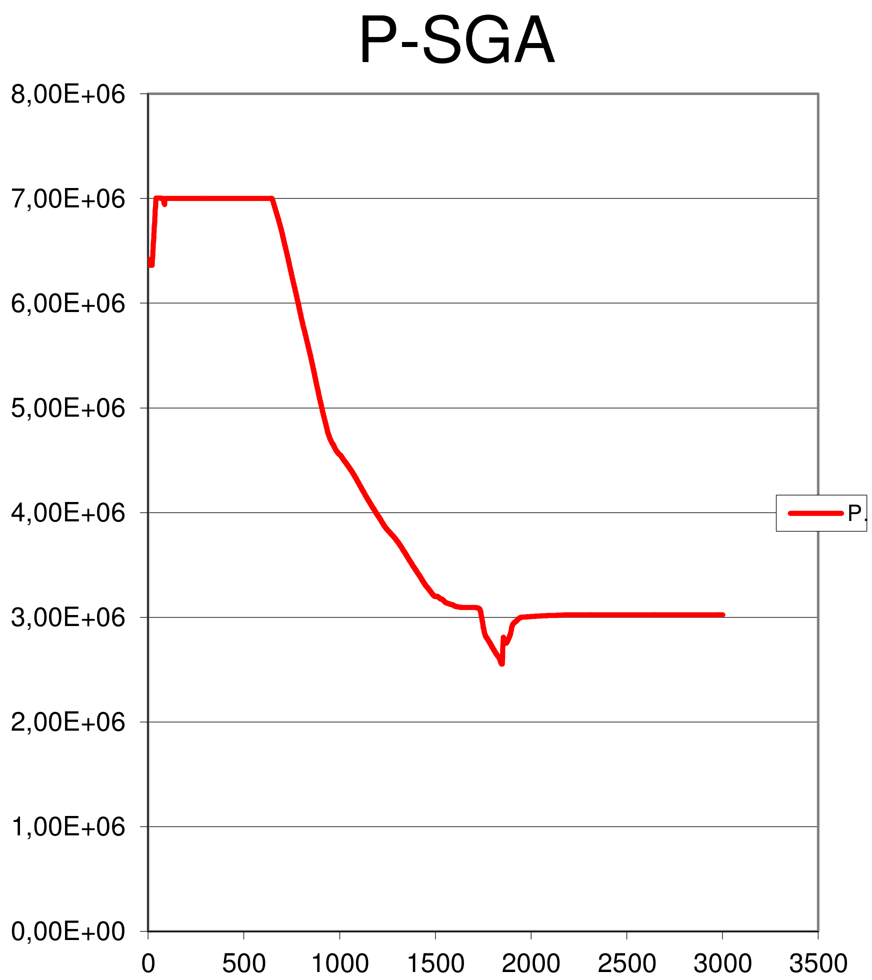
•actual outcomes: new standardized EXCEL plots (transients) – were delivered to ENEA, Bologna and presented shortly in Paris OECD/ NEA – some of you were present there

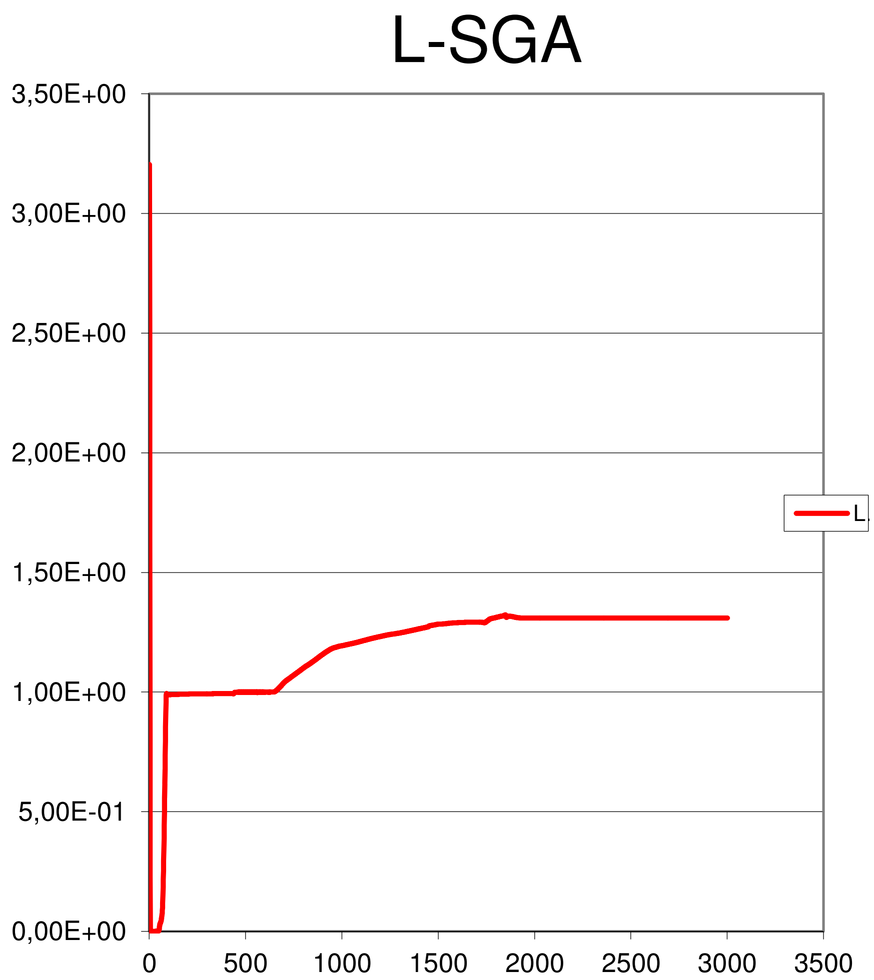
Outlook

- ✓ specific goals / further ASTEC activities: TMI-2 NPP SA (reflood map, sensitivity..)
- ✓ Continuing work with ASTEC v2.0r1p2 (beta) / SUNSET –coupling/ parameter studies
- ✓ Safety Injection - further modeling, if needed
- ✓ sensitivity study on important and/or uncertain key parameters in order to evaluate their impact on core degradation, core coolability and H_2 production **should** be performed
- ✓ additional *Uncertainty Analysis* with SUNSET or SUSA / GRS
- ✓ An ERMSAR paper will be prepared in cooperation with G. Bandini, ENEA et al.
- ✓ Mandatory post processing – further work still to be continued on :
  - ICARE: global modeling (developing of modified inputs decks /BCs…)
  - early phase modeling (HT, mechanical behavior, chemistry, movement of material)
  - late phase modeling (material relocation, HT, mechanical aspects)
  - ICARE: chemistry + mechanics + degradation + FP & decay heat

    ICARE vessel structure/ vessel (detailed) meshing

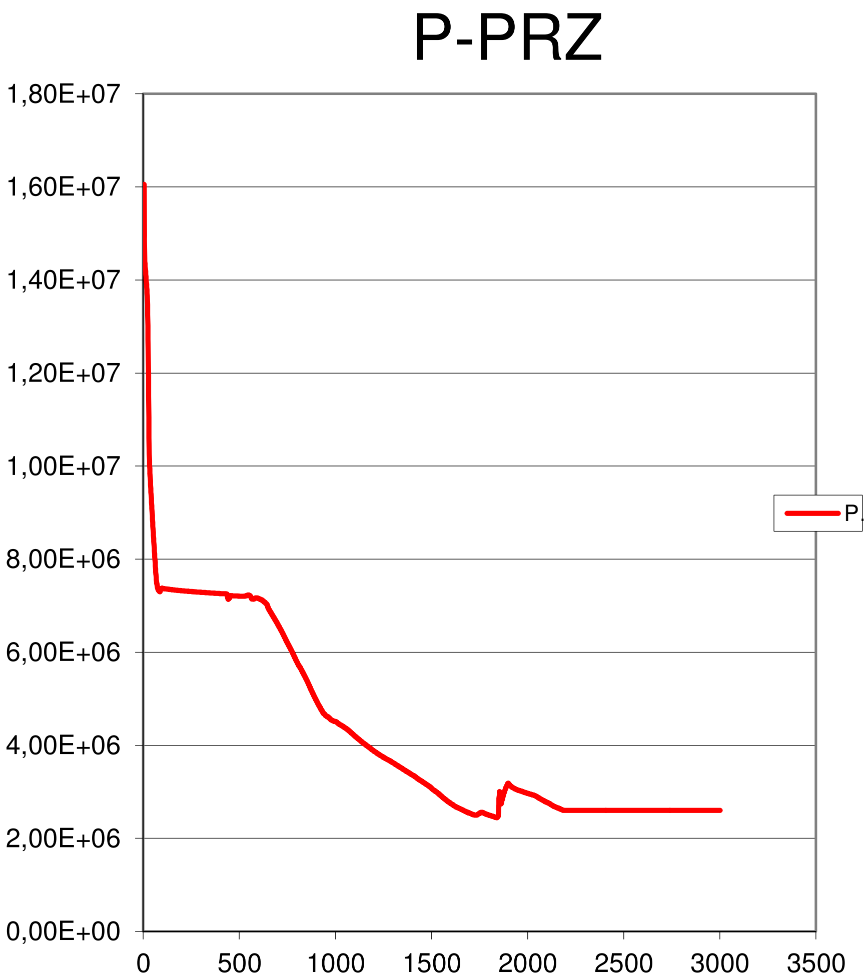
SG A Pressure / Pa and SG A riser collapsed level/ m

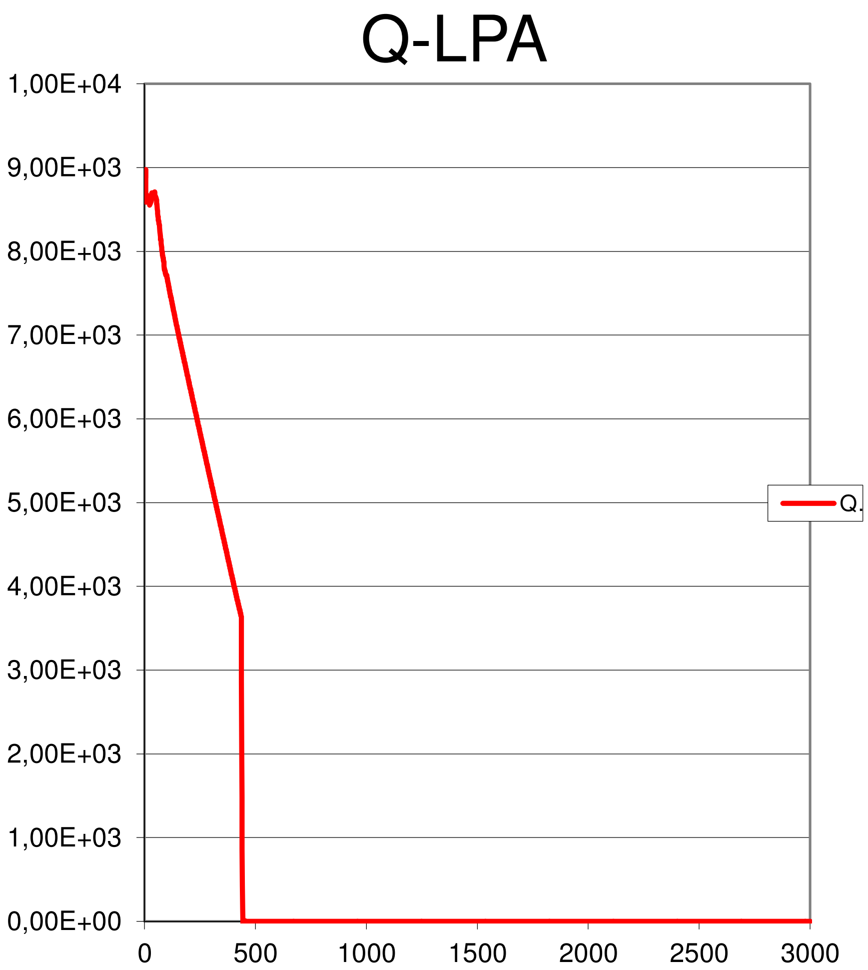




-remark: OX- time instants: 5s here, to be consistent with the BE-EXCEL spreadsheet for all participants-

Pressuriser Pressure /Pa and Loop A mass flow rate [kg/s]





Break mass flow rate [kg/s]
and Total primary mass/ kg *(liquid & steam)*

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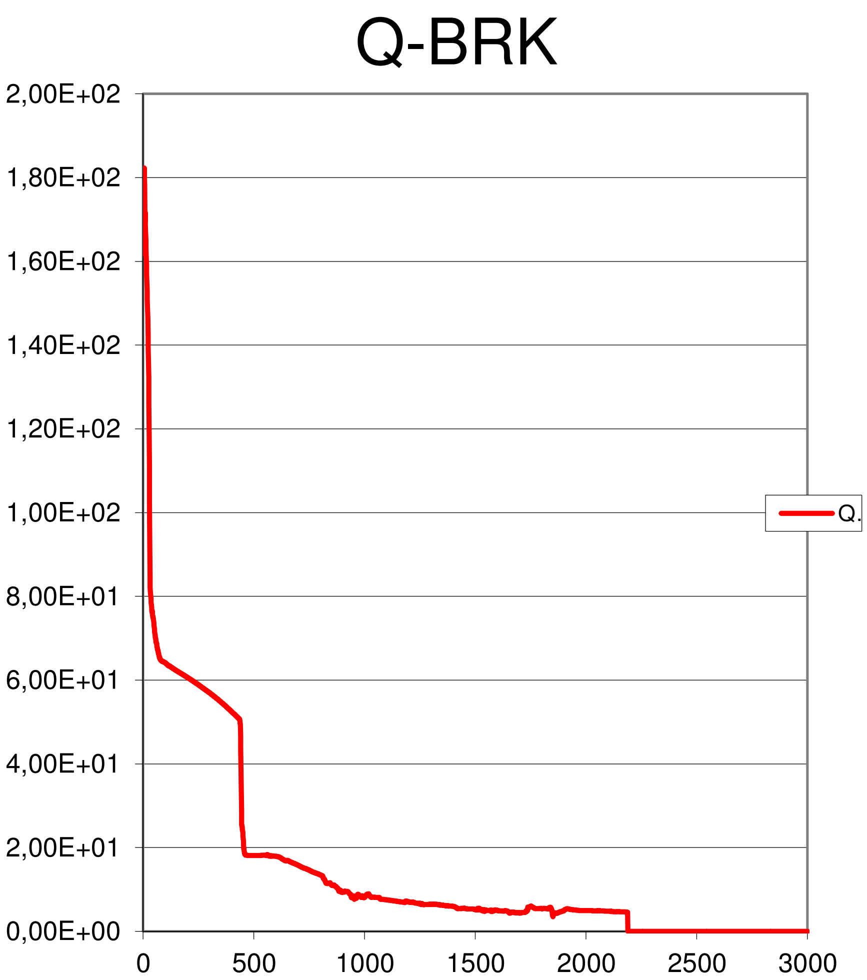
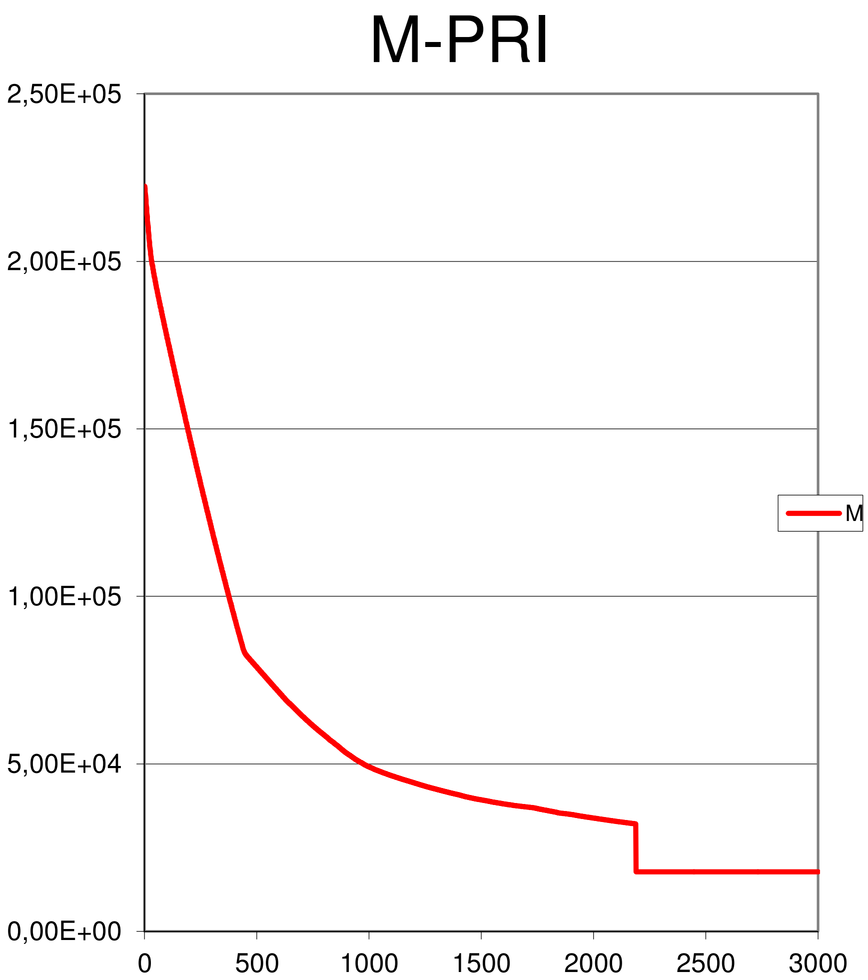
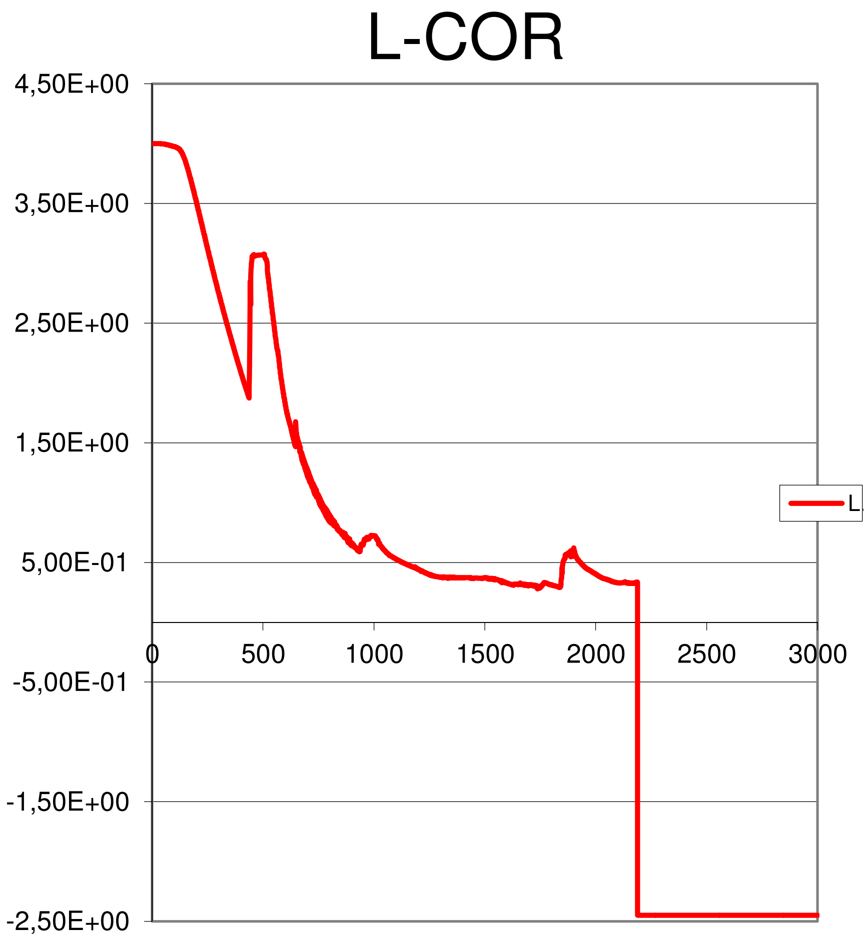
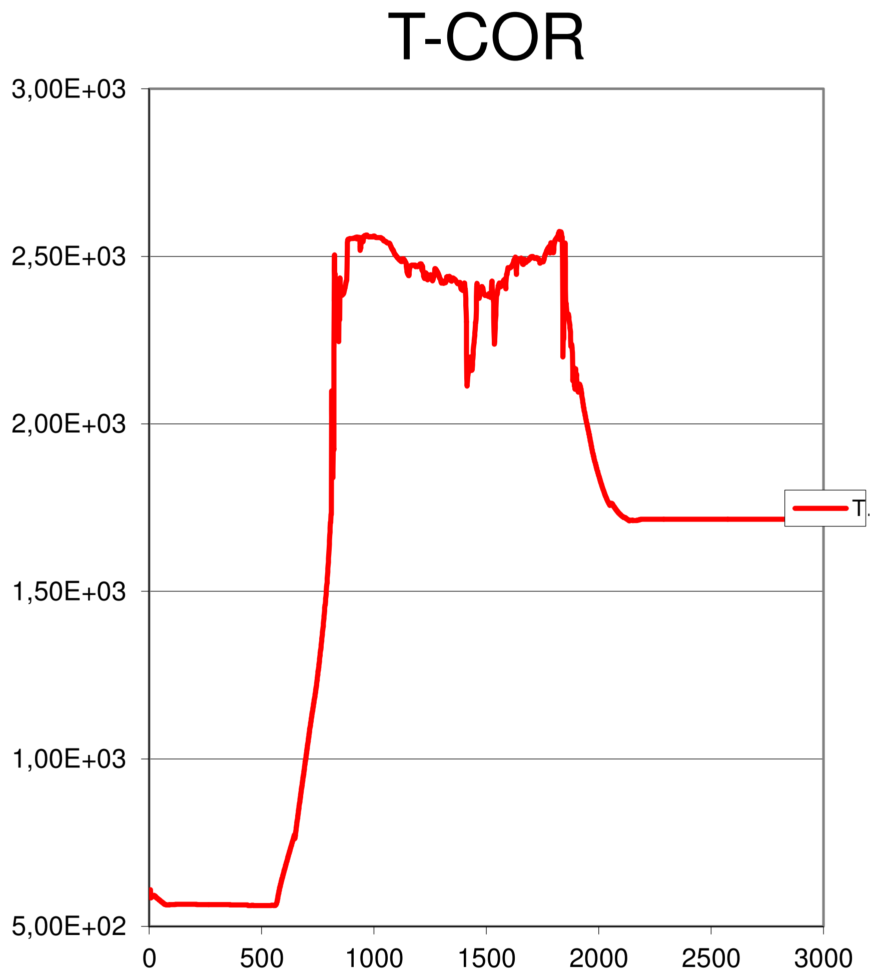


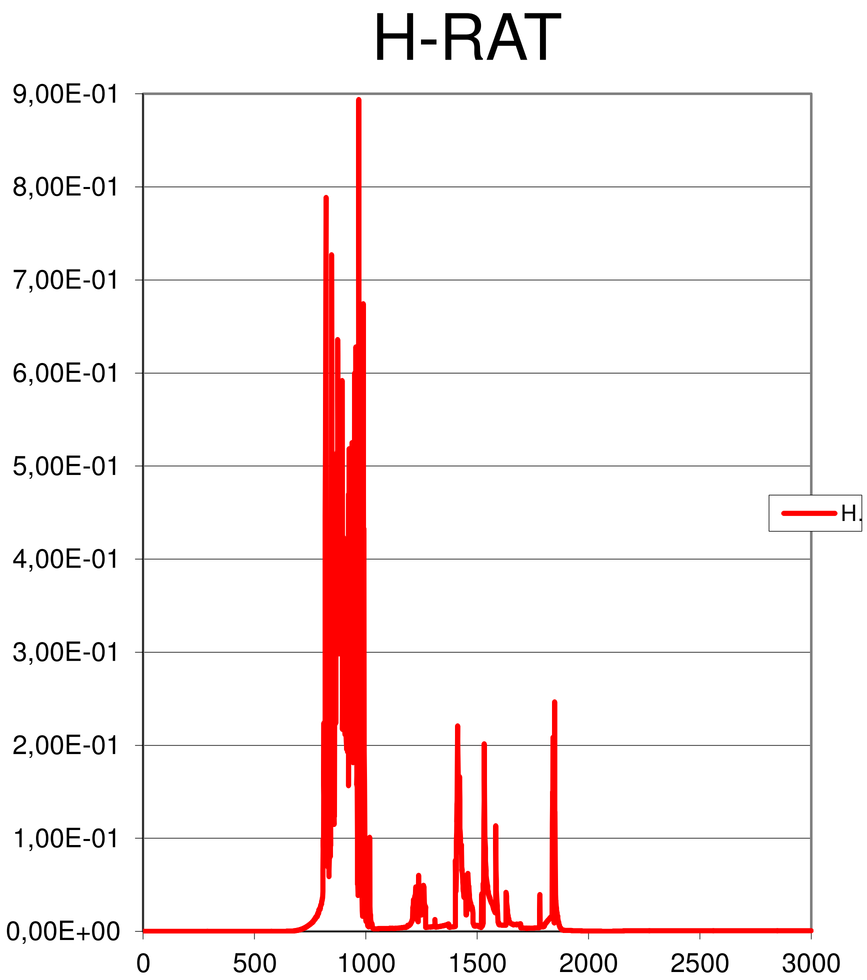


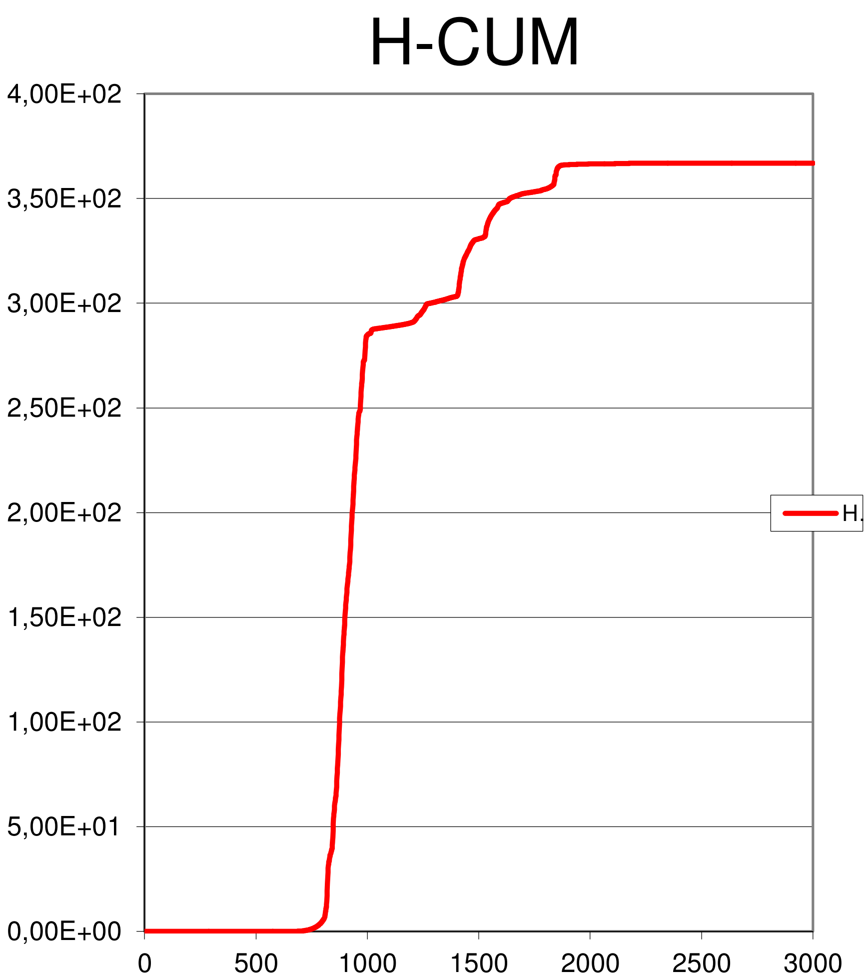
Core collapsed water level/ m *(from core bottom)* and Fuel rod clad temp. at core top/K *(central ring)*





Instantaneous hydrogen production rate [kg/s]
Cumulated hydrogen production/kg





Hot leg A temp/ K *(close to surge line connection)*
Cold leg A temp/ K *(close to pump location)*

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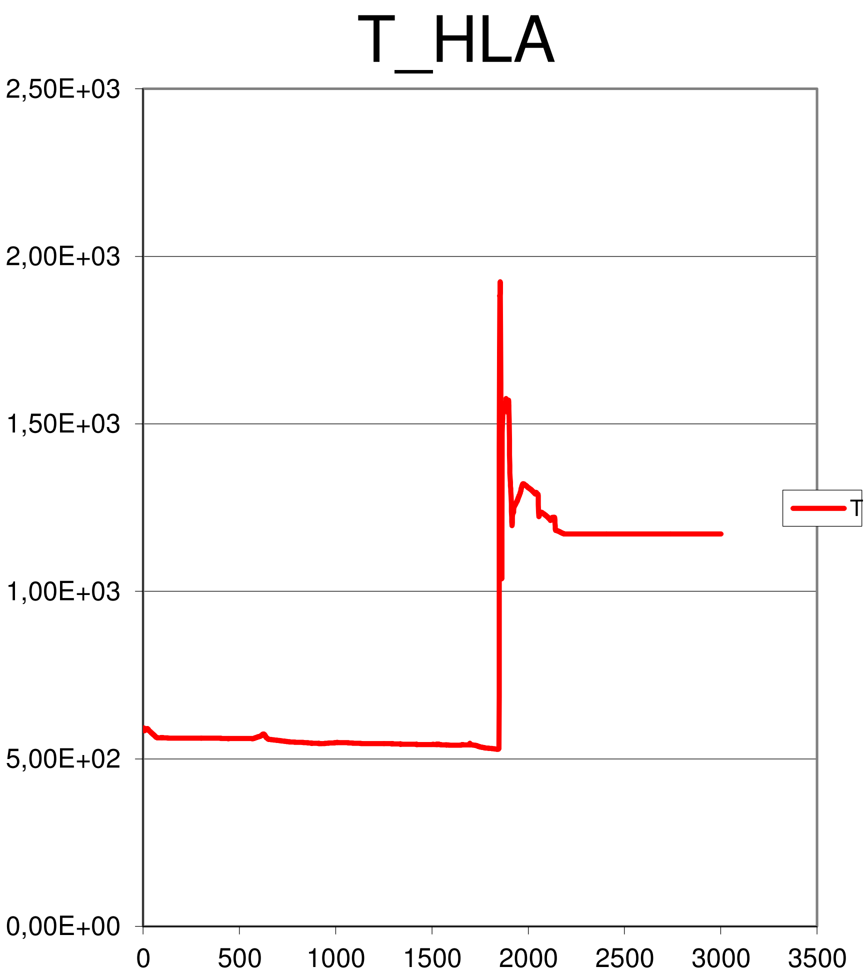
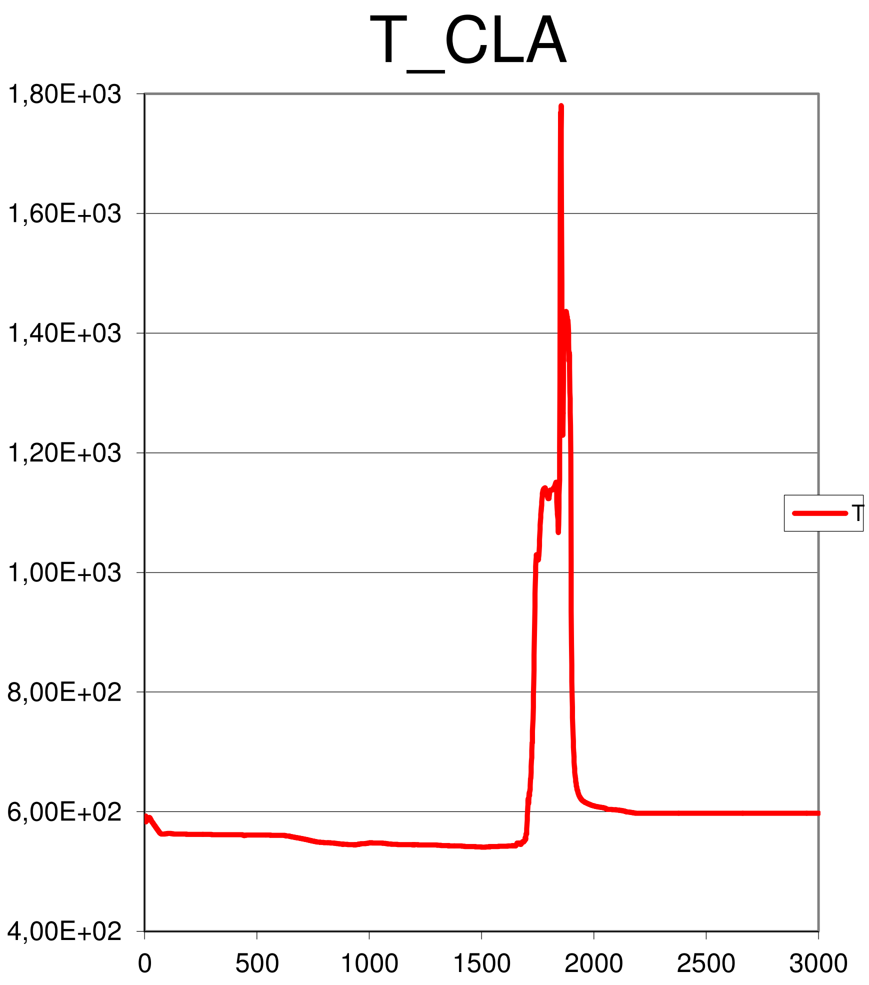
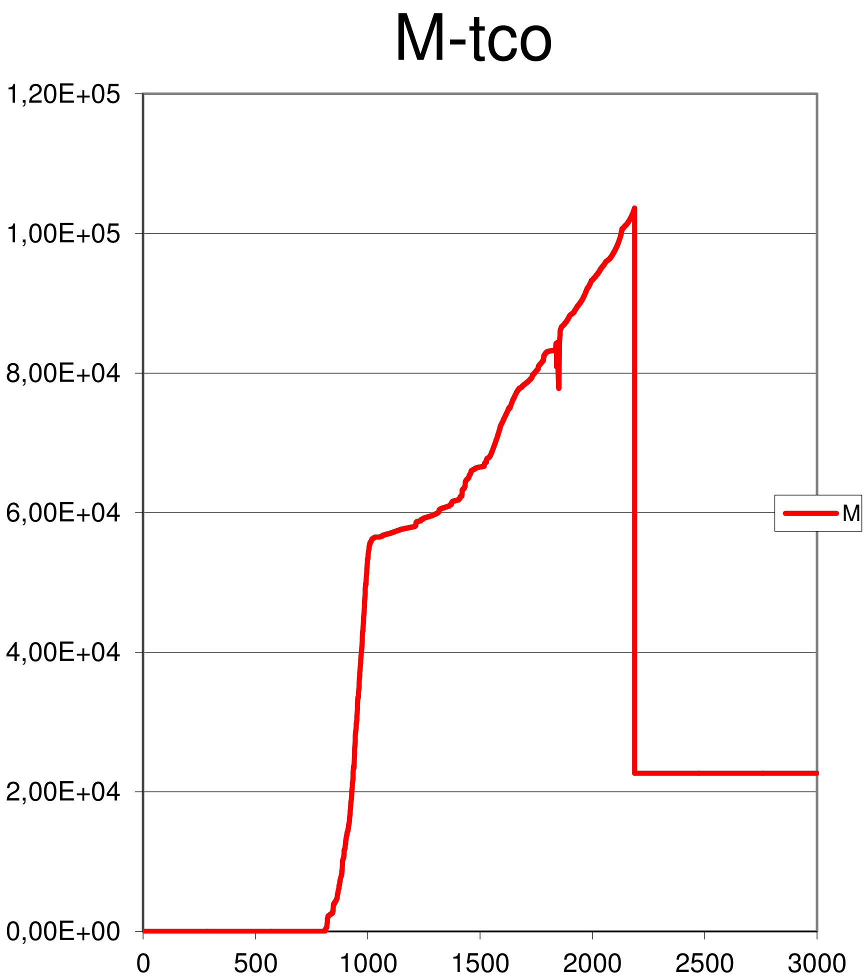
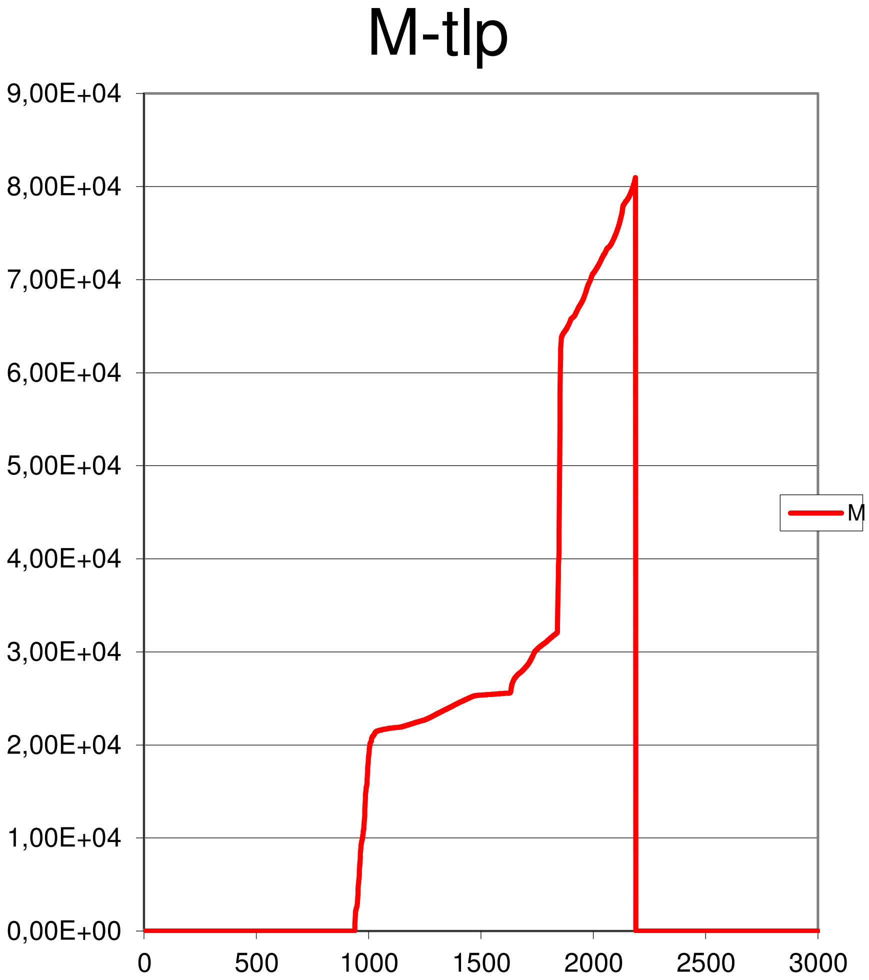


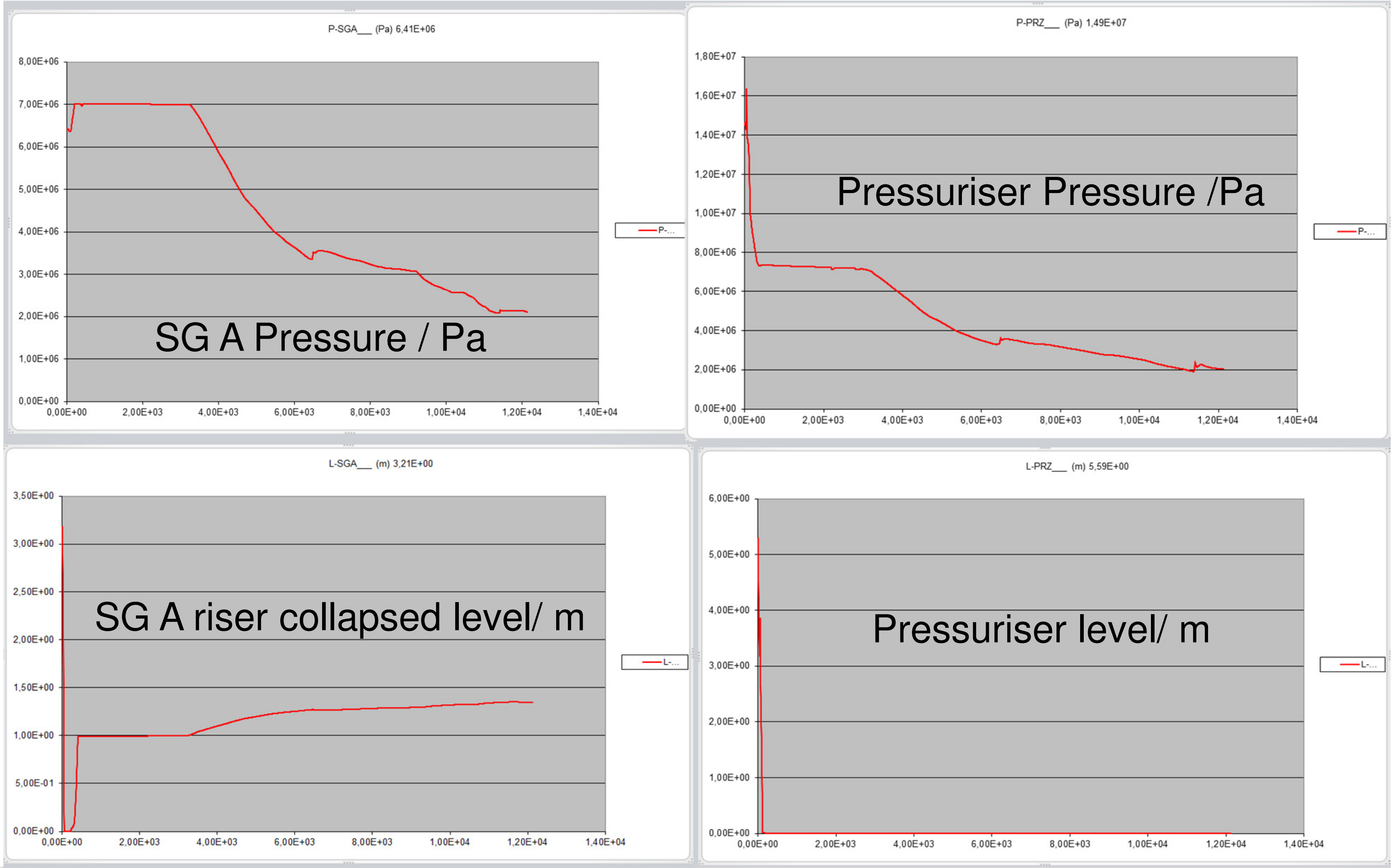


Total mass of molten material/ kg *(ceramics & metals)*
Total mass of molten material in the LP/ kg *(ceramics & metals)*

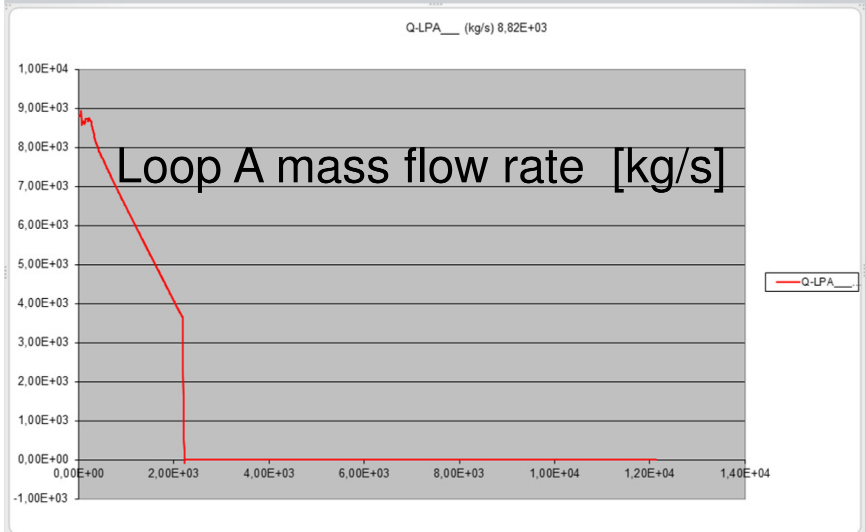


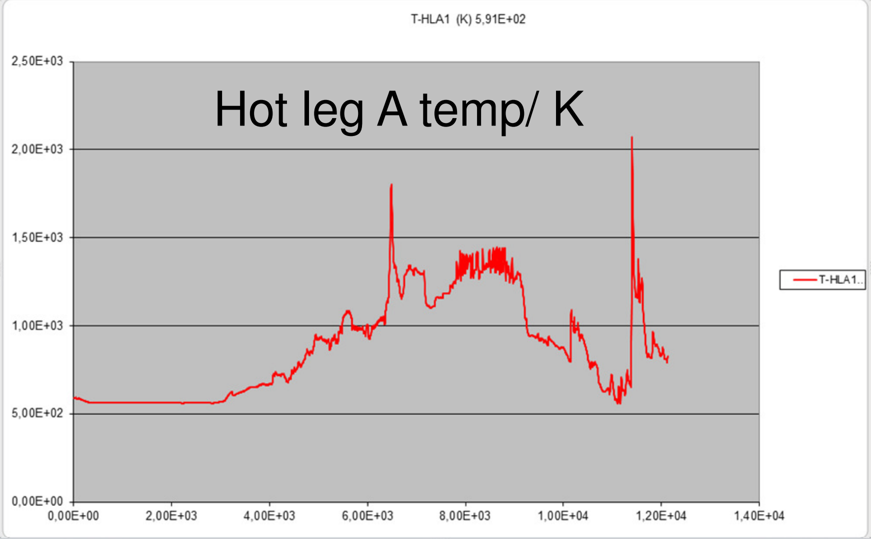


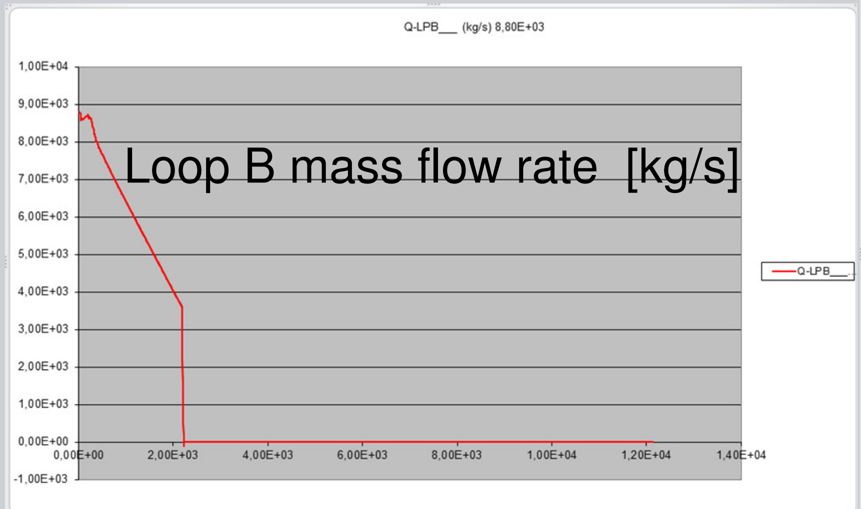
Stage 2-transients*(1)*/ Δt [1s]- a preliminary study

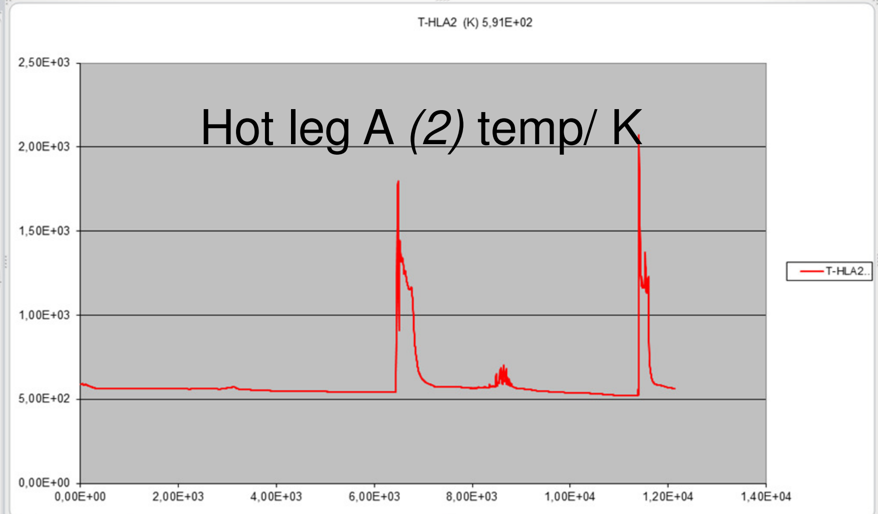


Stage 2-transients*(2)*/ Δt [1s]

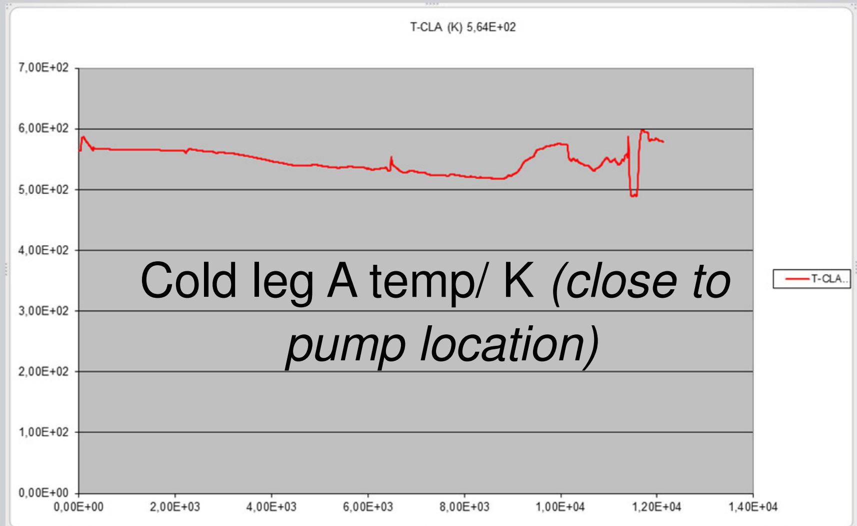


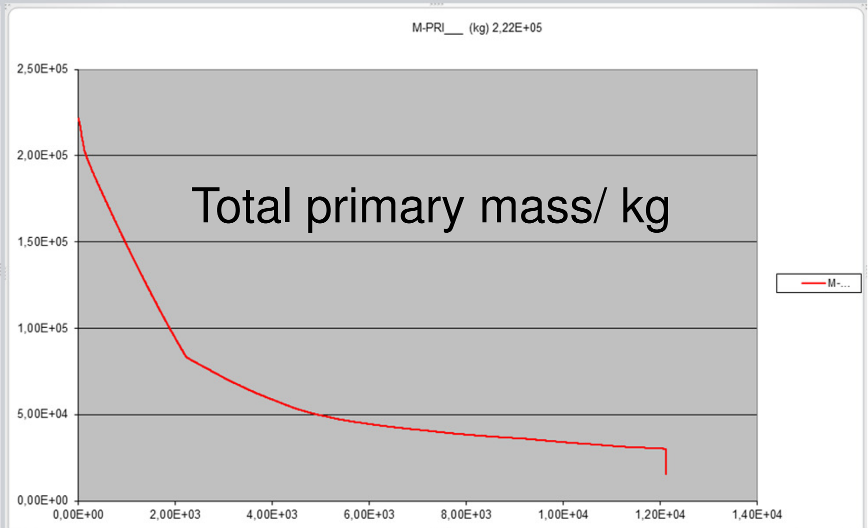


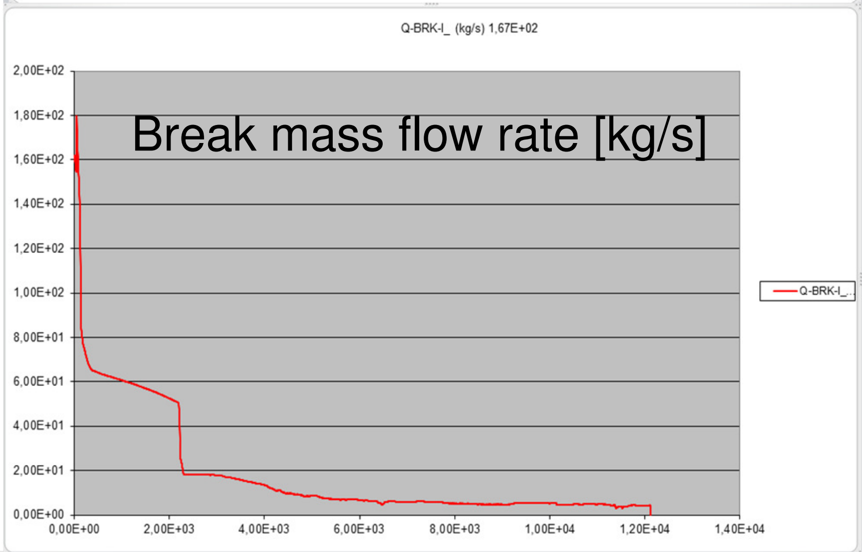


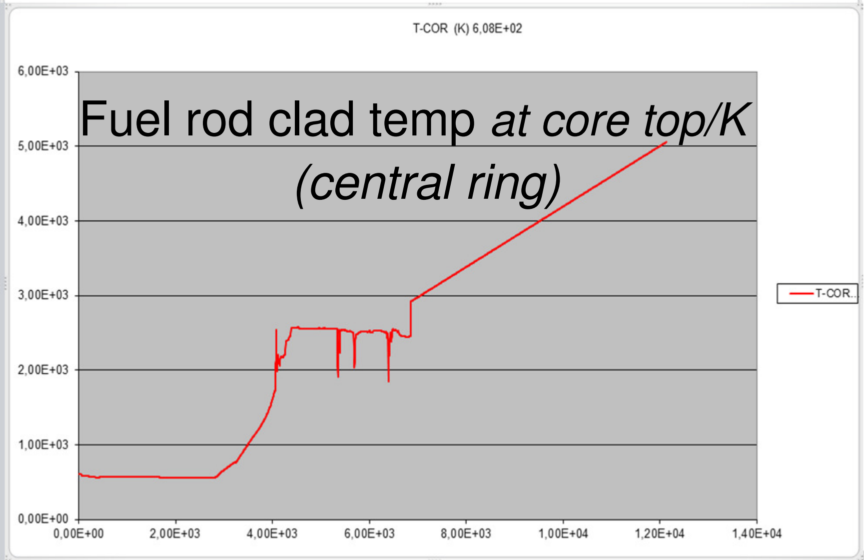


Stage 2-transients*(3)*/ Δt [1s]









Stage 2-transients*(4)*/ Δt [1s]

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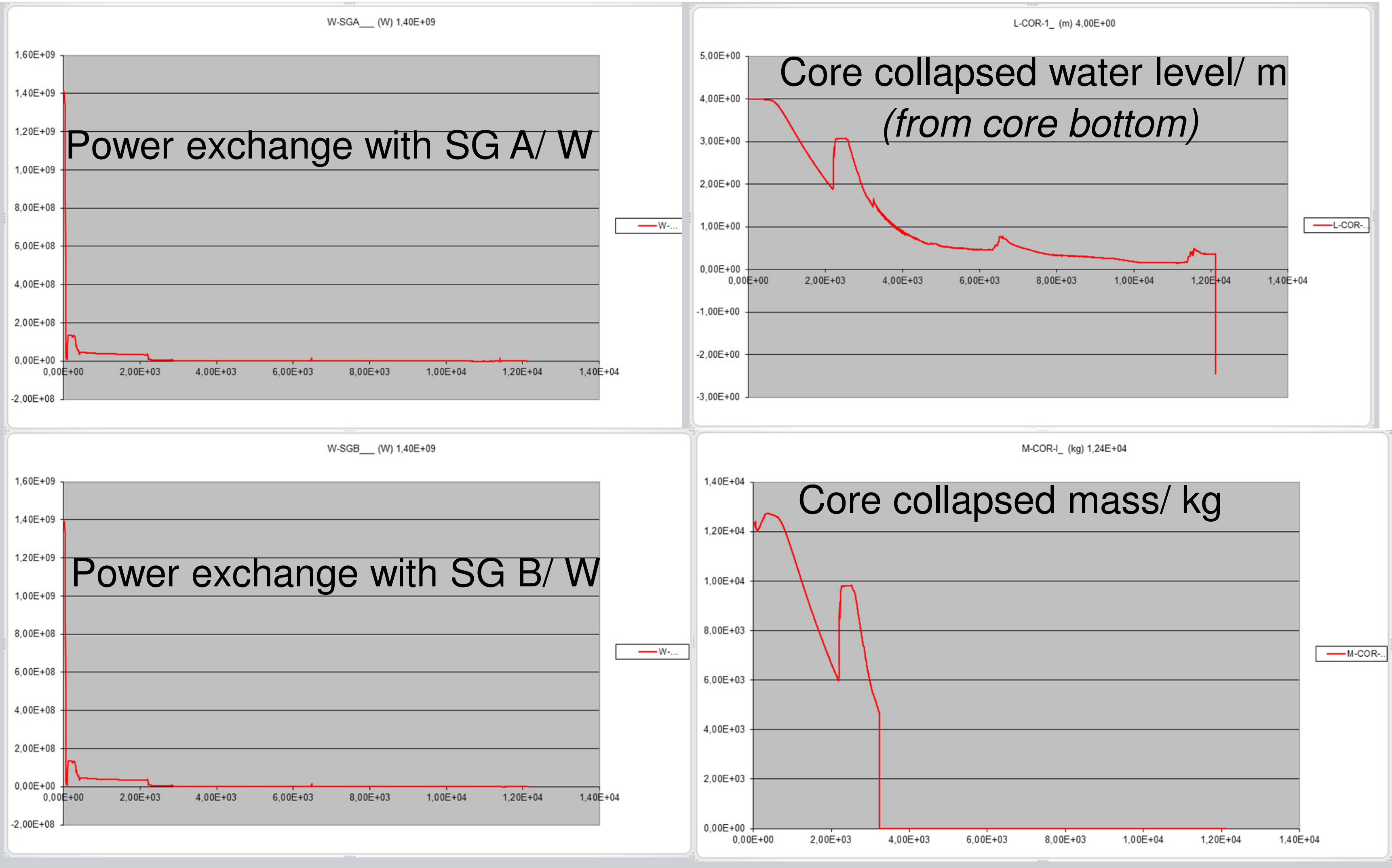
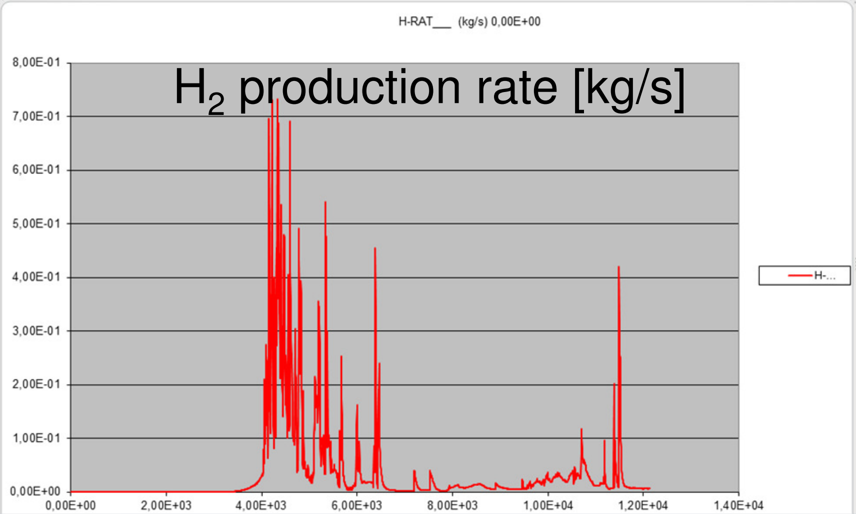
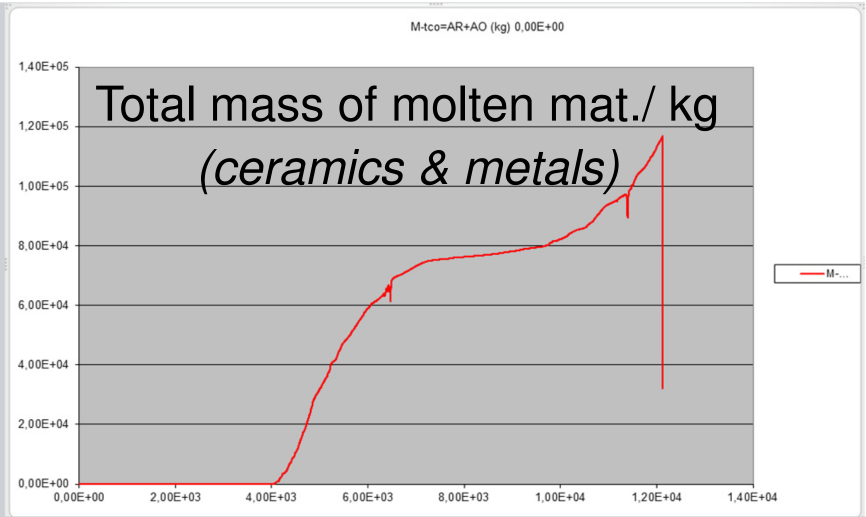
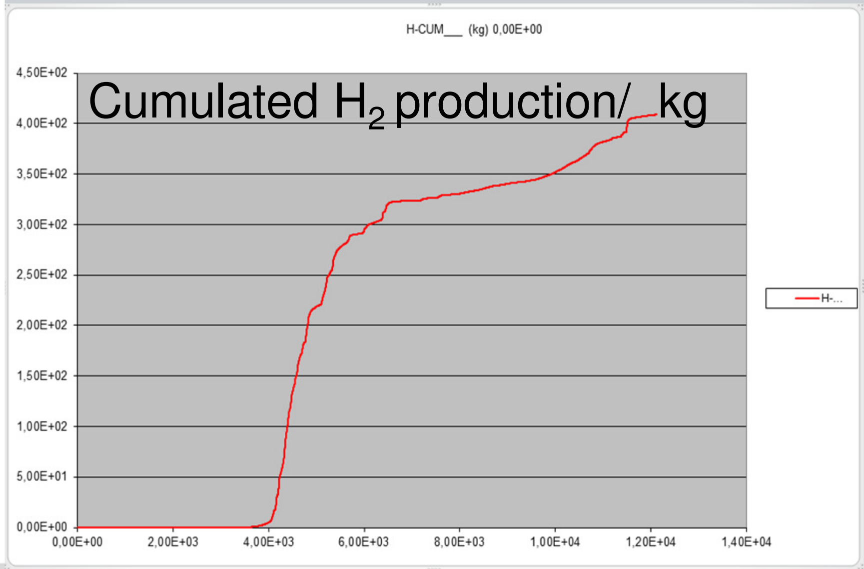
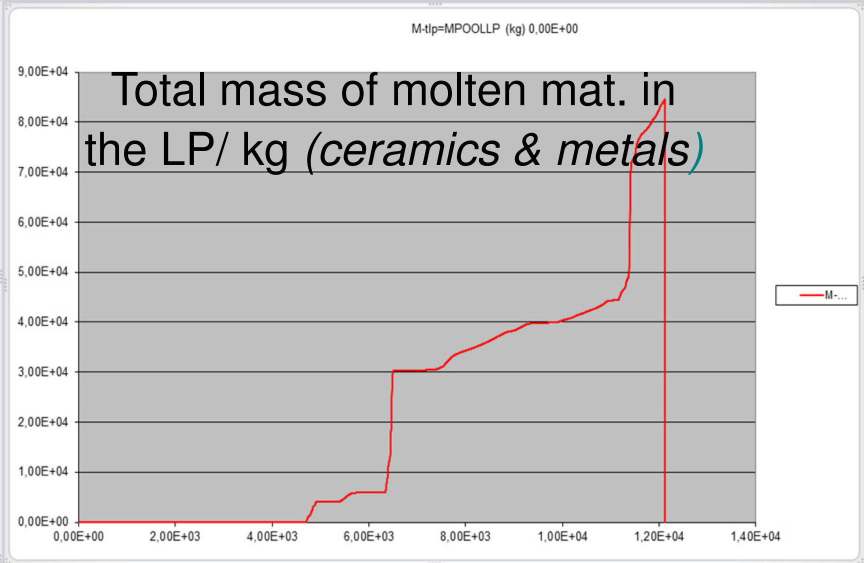


Stage 2-transients *(5)*/ Δt [1s]









Acknowledgements

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Training course on the use of ASTEC V2.0-rev1 hosted 2011 at CEA/IRSN and the FJOH_SS 2011 Rüppurr, KIT/ INR are greatly acknowledged, too.

thank you all !

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- The activity is carried out by a Task Group including members from WGAMA and SARNET-2;   the work itself is funded by NUCLEAR/ KIT