Sensitivity studies of main uncertain core degradation parameters on severe accident consequences

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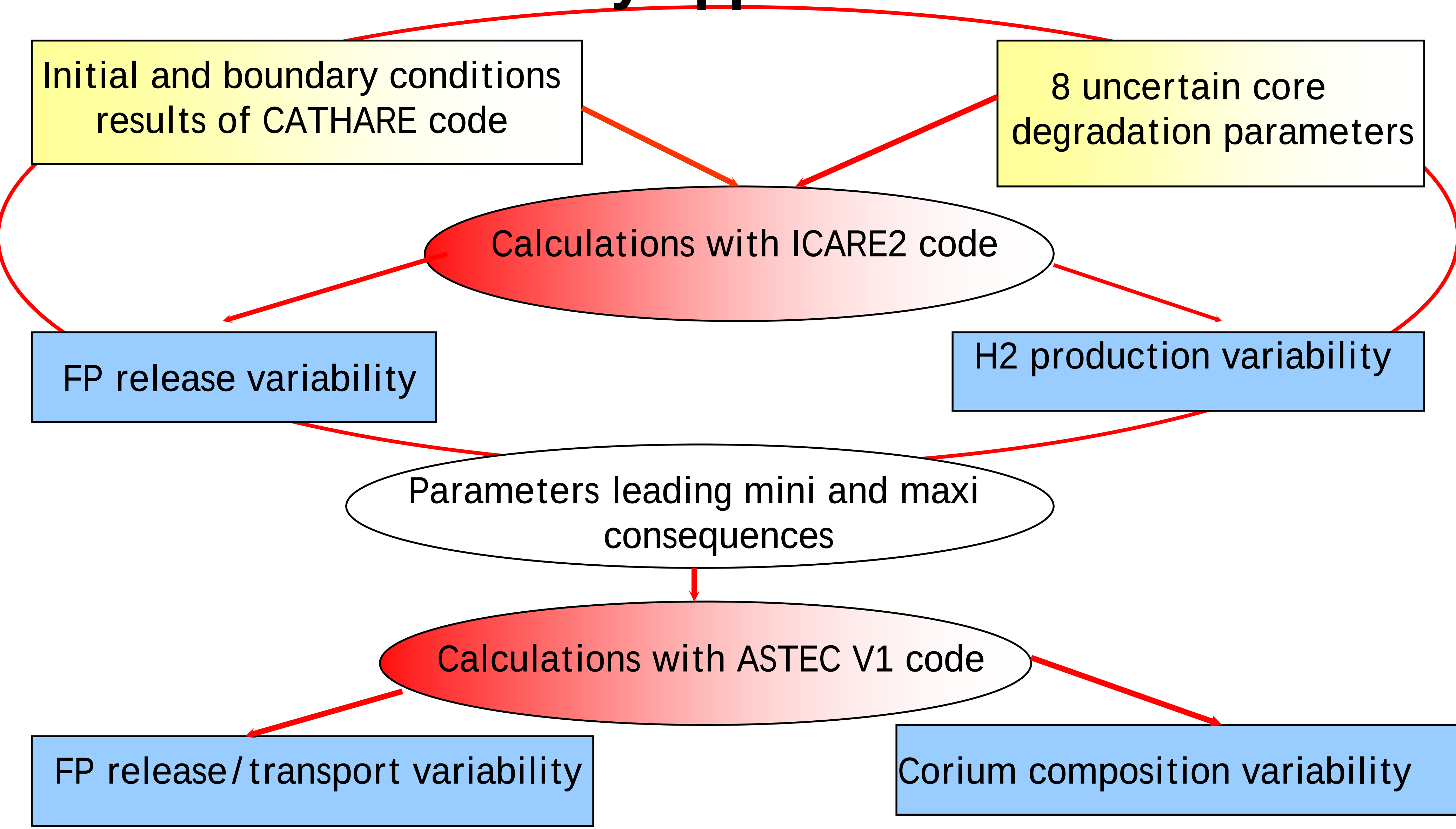
Study approach



Study approach - Uncertain parameters

Choice of 8 parameters distributed in terms of the limits of their range of uncertainties

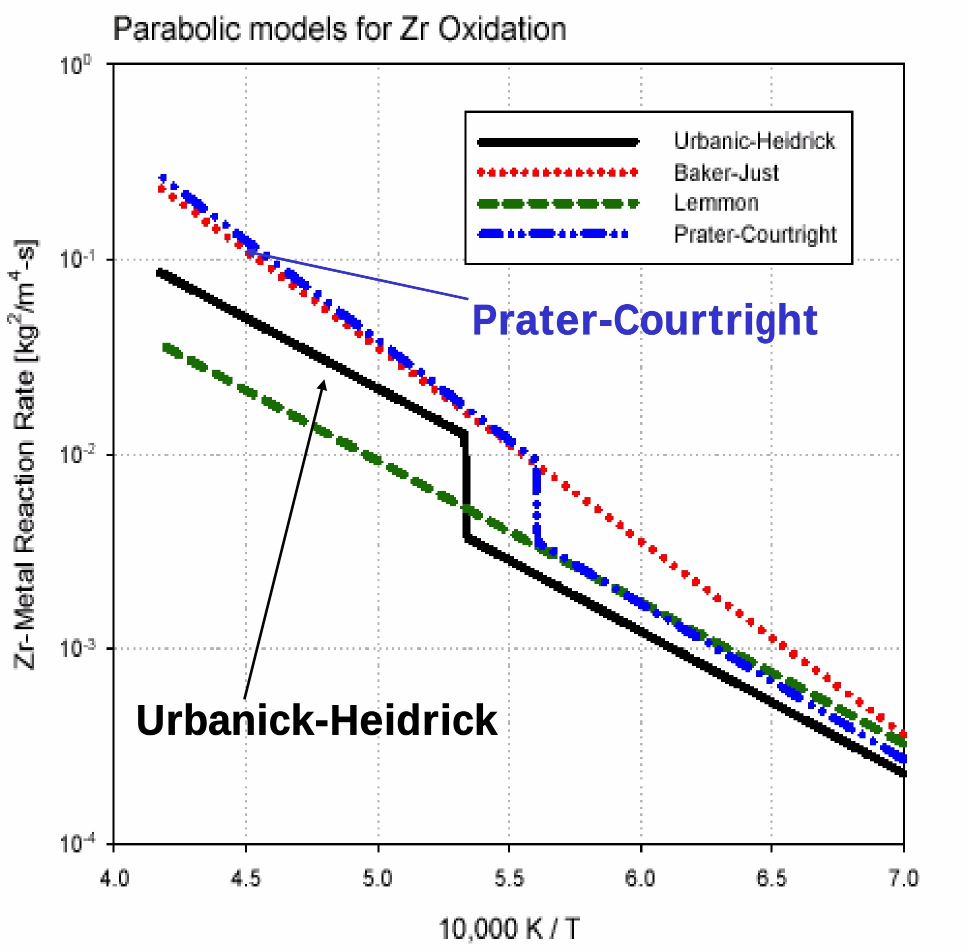
- Analysis of test results
- Analysis of accidental transient results
- Expert advices

1. Residual power during the transient
2. Oxidation kinetics of Zircaloy cladding
3. Protective effect of the zirconia layer
4. Dissolution limit of the fuel and oxidized cladding by liquid Zircaloy
5. Oxidation of U-O-Zr mixture
6. Criteria concerning the loss of oxidized cladding integrity
7. Fuel velocity of materials during relocation
8. Fuel and cladding relocation (function : solidus and liquidus temperatures)

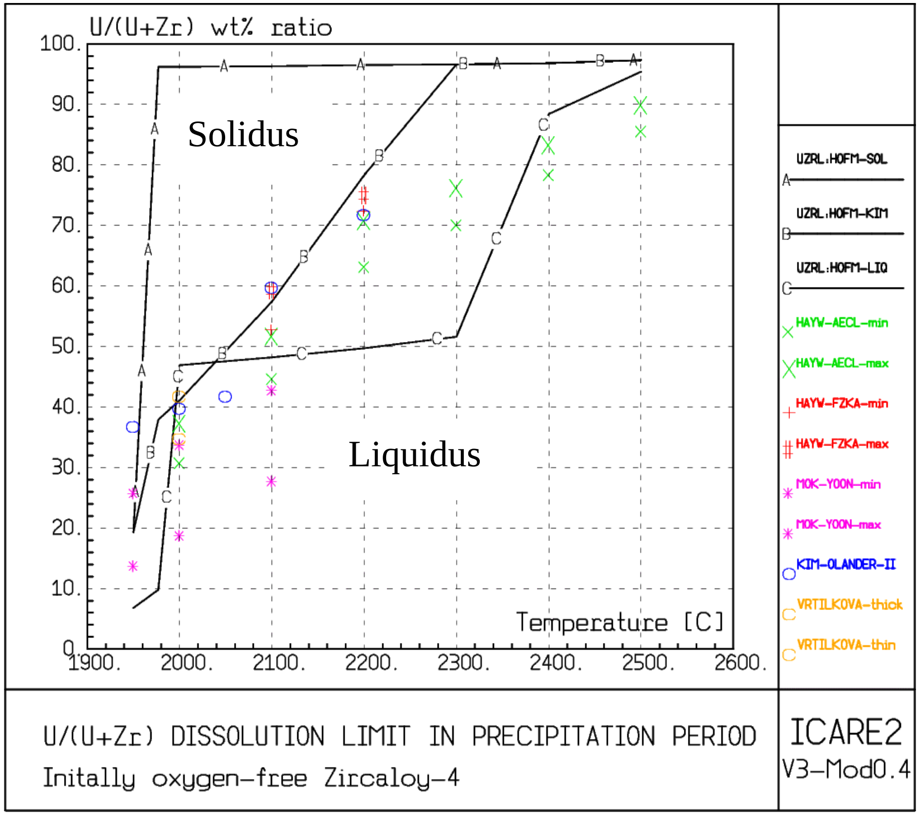
Possible options	1- Standard case	2	3
Residual power	➢ of values versus time given by a specific table	Computed by code (f= FP release)	
Oxidation kinetics	Urbanick-Heidrick correlation with zirconia layer growth	Prater-Courthright correlation	Previous correlation with O2 mass gain
Zirconia layer protection effect	NO	YES	
Solubility limit of uranium in U-Zr-O	Liquidus T°	Solidus T°	
Oxidation mixture	NO	YES	
Cladding oxide shell criteria	$T > 2260$ K and $e_{ZrO2} < 160$ µm or $T > 2280$ K and $e_{ZrO2} < 200$ µm or $T > 2340$ K and $e_{ZrO2} < 220$ µm or $T > 2380$ K and $e_{ZrO2} < 240$ µm or $T > 2450$ K and $e_{ZrO2} < 300$ µm	$T_{clad} > 2600$ K if $e_{ZrO2} < 250$ µm or $T_{clad} > 2700$ K	
Candling velocity	1 cm/s	60 cm/s	
UO2, ZrO2 relocation T°	Tsolidus = 2550 K Tliquidus = 2650 K	Tsolidus = 2800 K Tliquidus =2850 K	

Study approch - Uncertain parameters

Variability of oxidation kinetics correlation



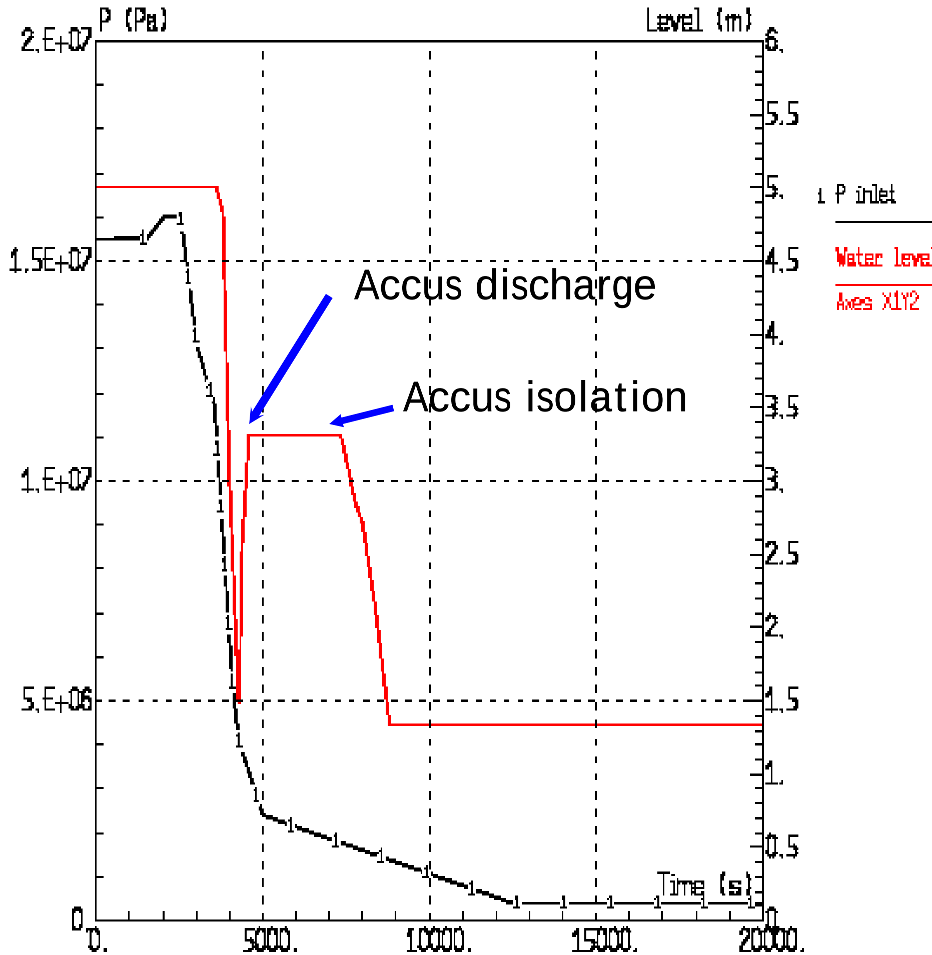
Solubility limit of uranium in the (U,Zr,O) mixture for the UO2/liquid zircaloy interaction



Study approch - Transient description

Chronology of events (approximative times):

- t=0 : loss of all SG feed-water systems
- t≈30 s : scram reached as SG level <-0.7m
- t≈2500s : fully opening of all PORVs
- t≈3800s : beginning of cladding oxidation, first core uncovery
- 200s later : start of accumulators discharge
- t≈7900s : accumulators isolation
- t≈8500s : final core uncovery, core heating and second phase of cladding oxidation

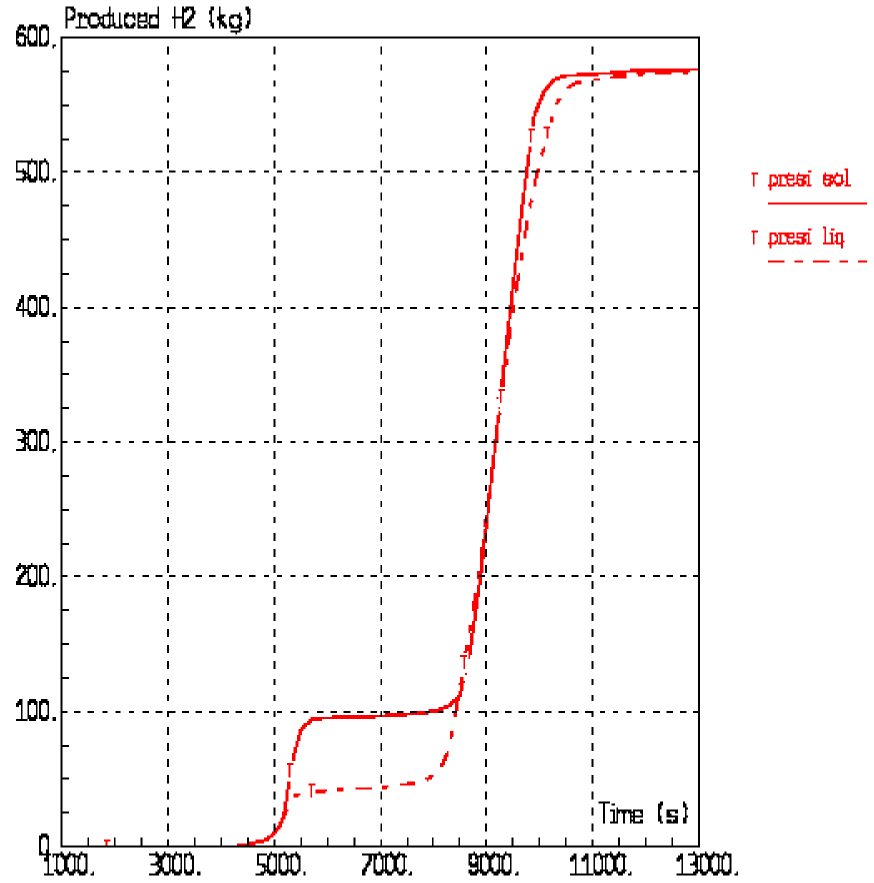


REP 900 Calculation

Primary circuit pressure evolution and core water level

Impacts on hydrogen production

- Two oxidation phases
- First phase : impact of dissolution limit on H_2 production ; factor 2 (total mass equivalent)
- Minimum H_2 = 320 kg : U-O-Zr mixture relocation velocity = 60cm/s
- Maximum H_2 = 580 kg: mixture oxidation and oxidation kinetics limited by the gain in O_2 mass
- Impact also on H_2 production kinetics : 0.1 to 0.4 kg/s

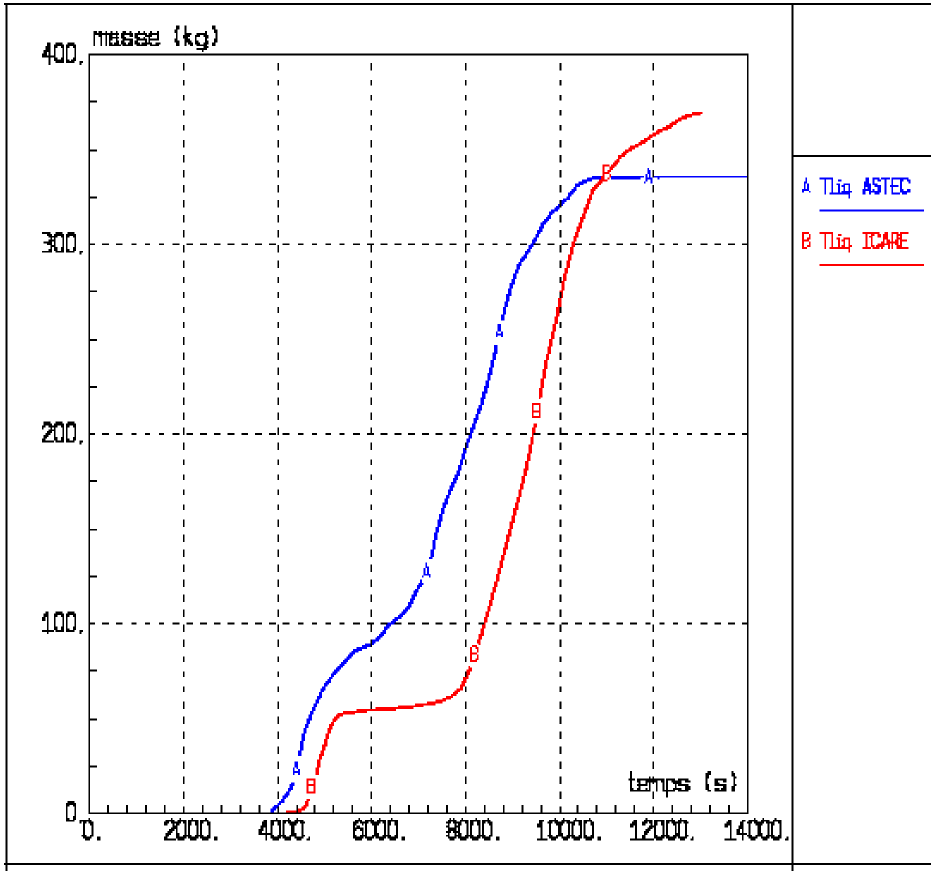


REP 900 Calculation, option Equilibre et oxid no
Cumulative H2 Production

Impacts on hydrogen production

- ASTEC and ICARE2 calculations with very similar modelling option conduct to different kinetics and ≈ equivalent total mass
- Start of cladding oxidation ≈ same time
- When accumulators begging to discharge, water level of ICARE2 is ≈30 cm upper
- During accumulators discharge water level remains constant with ICARE2 and continuous to decrease with ASTEC V1

ASTEC calculates cladding oxidation of upper part of the core during accumulators discharge



ASTEC-ICARE2 H2 Sequence Calculation

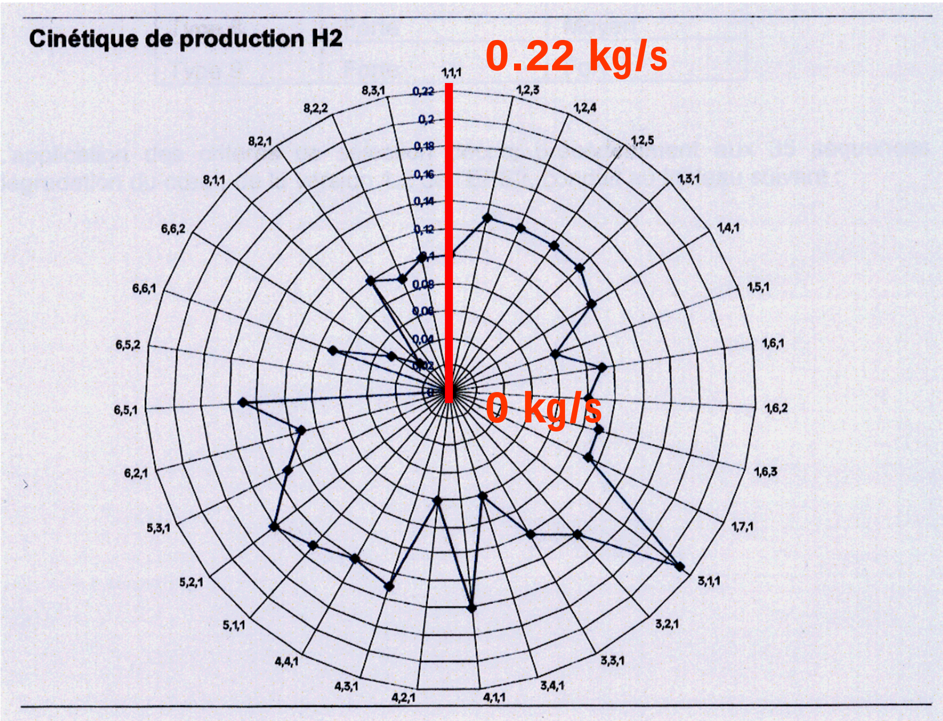
Base case, comparison between the codes

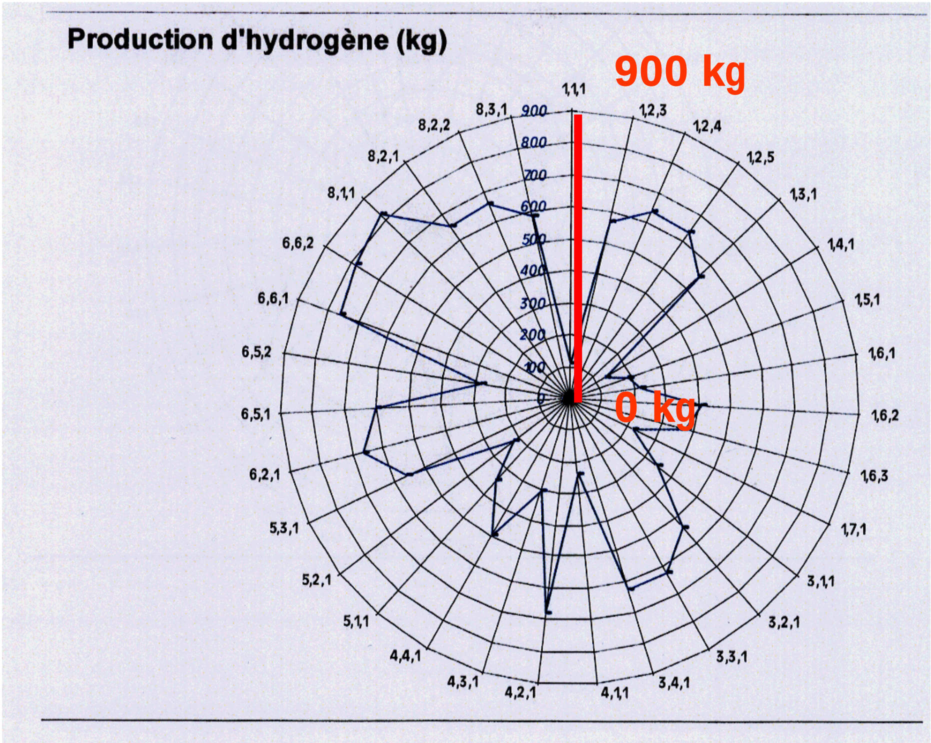
Impacts on hydrogen production

Variability of hydrogen production kinetics and total mass obtained in the calculations of different accidental transients is in the same range

Kinetics varies from 0,02 and 0,22 kg/s (mean flow rate)

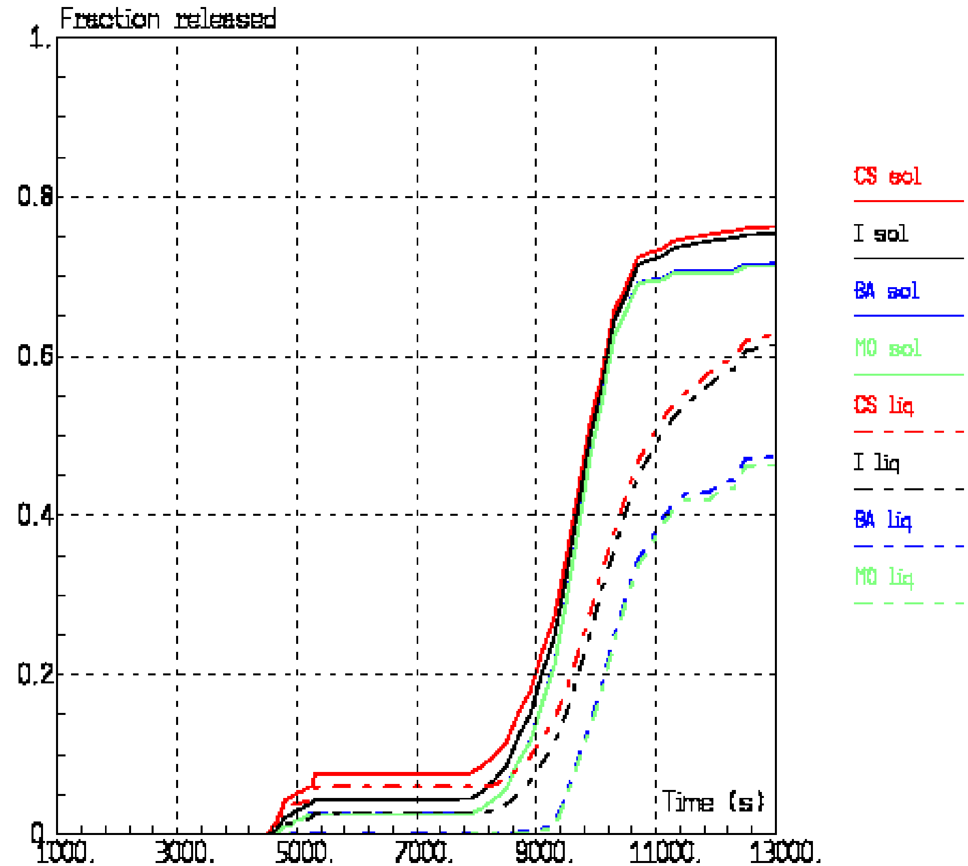
Mass varies from 100 to 800 kg





Impacts on fission product release

- Modification of ICARE2 to allow semi-volatile fission product release when the fuel is liquefied
- Fission product release is strongly correlated to the quantity of fuel liquefied
- Dissolution up to the solidus temperature lead to increase:
    1. Semi-volatile fission product release by a factor of 3 (Barium and Molybdenum)
    2. Volatile fission product release by a factor of 1,5 (Iodine and caesium)



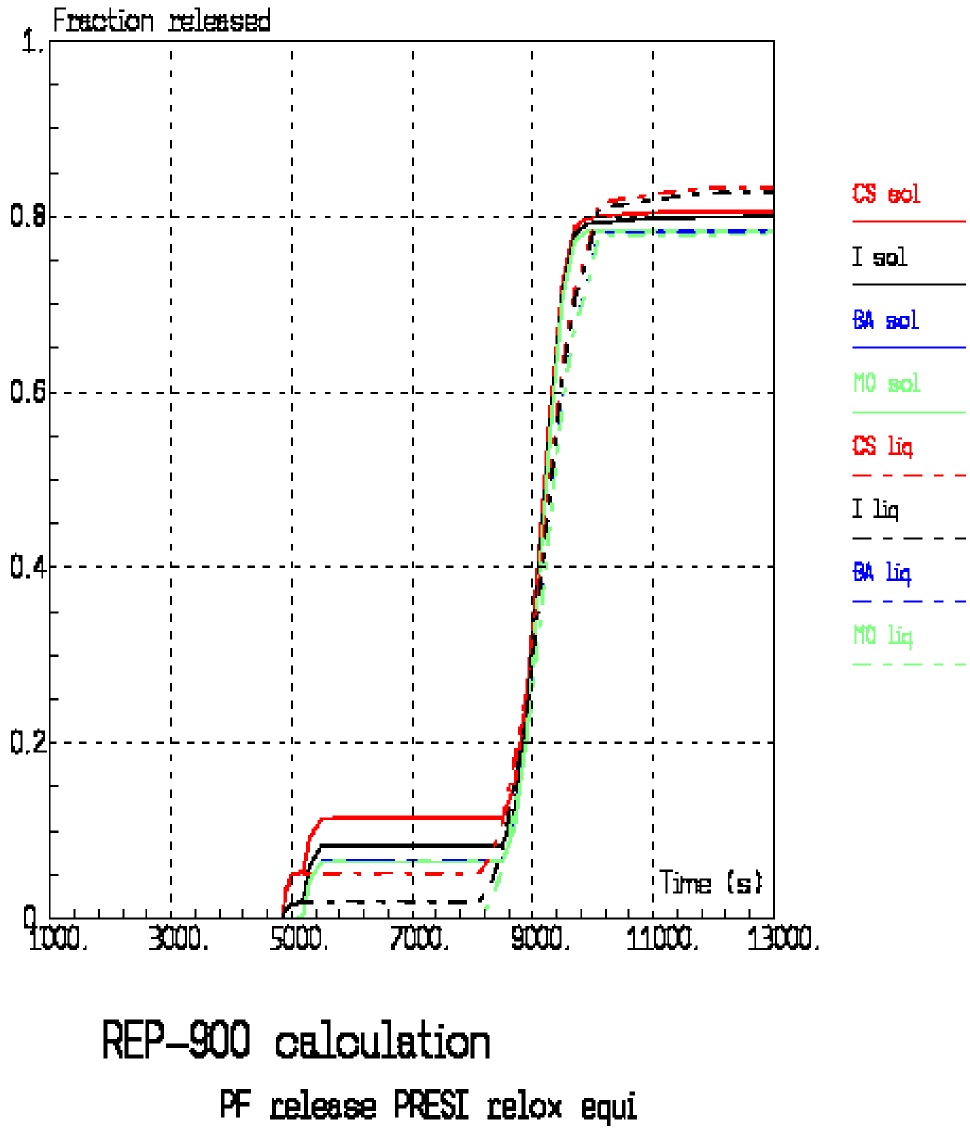
REP-900 calculation

PF release base case

Impacts on fission product releases

- Maximum fission product release (80%) is obtained with the same values of parameters that maximum H_2:
  - mixture oxidation
  - oxidation kinetics limited by the gain in O_2 mass

- Main ASTEC calculations results:
  - Mo combines with Cs and Rb
  - less important quantities to combine with I
  - I combines with other compounds to form organic iodine and gaseous caesium iodine



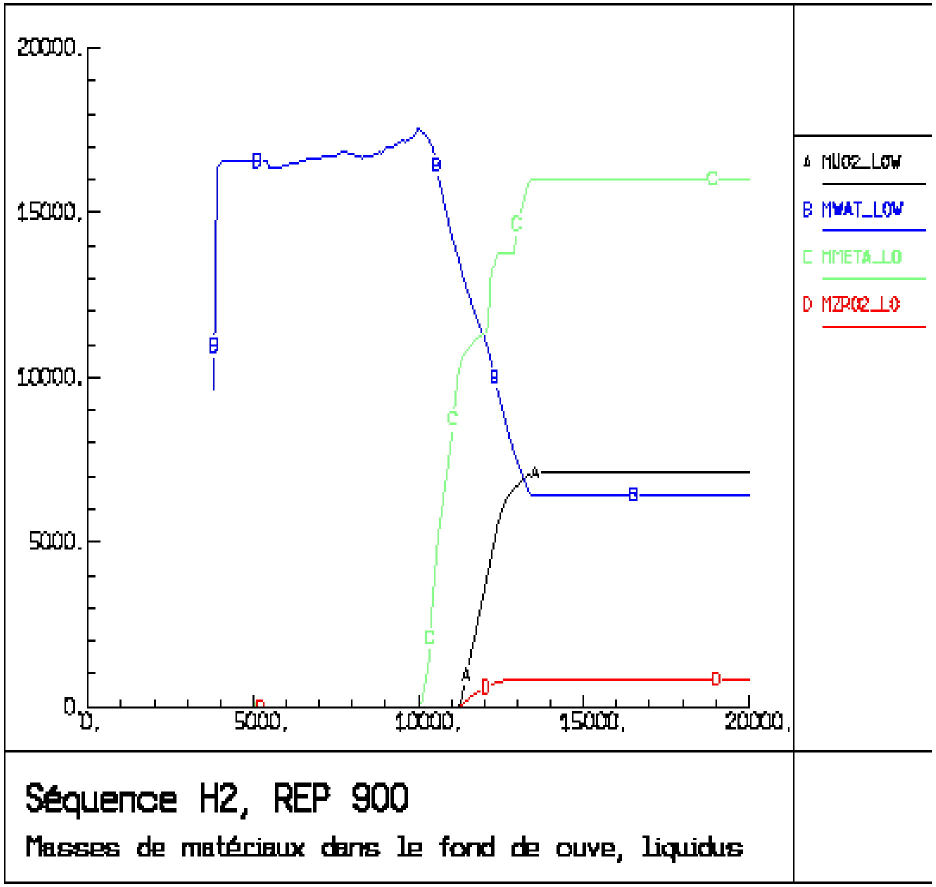
Impacts on the corium composition

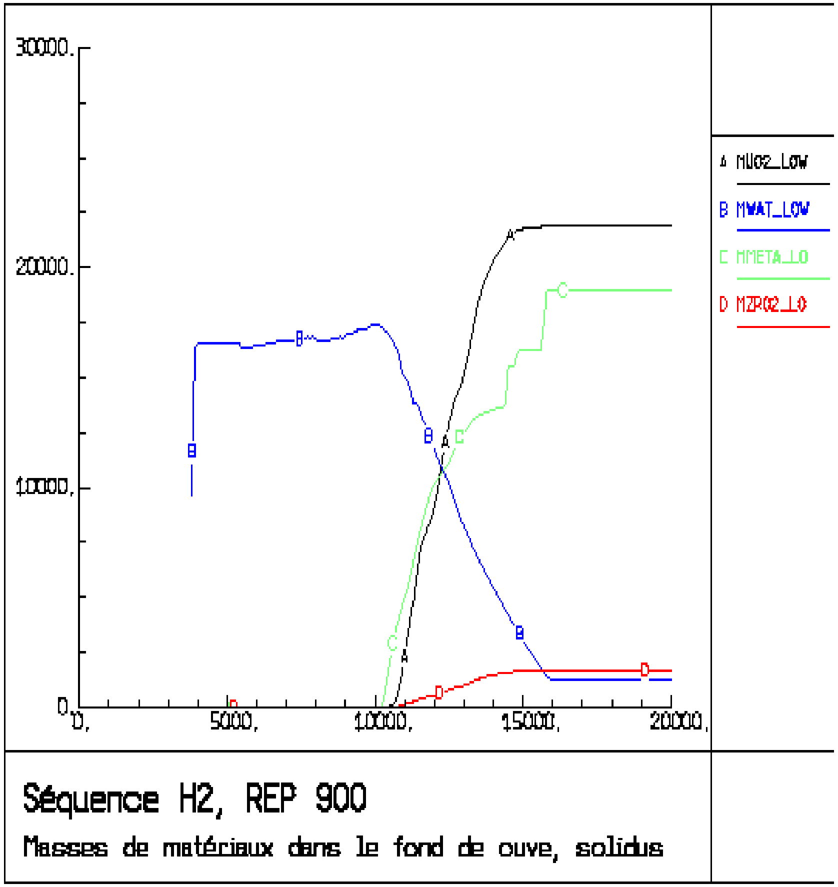
- Great variability of corium composition : proportion between the oxide and metallic phases can vary by a factor of 3

- Composition mainly results from the oxidation rate of core materials and the quantity of fuel dissolved by liquid Zircaloy :
  - Low oxidation rate : large mass relocation of metallic materials before UO_2 and ZrO_2 relocation
  - Important fuel dissolution (threshold temperature equal to solidus temperature) : large mass of UO_2 is relocated to the lower plenum and conducts to reduce metallic materials fraction.

Impact on the corium composition

Dissolution threshold temperature impacts on corium composition : solidus temperature conducts to important UO_2 dissolution and a decrease of metallic materials fraction





Conclusions

- *Impacts of main uncertain core degradation parameters*
  - *Almost a factor of 2 on mass H_2 produced*
  - *A factor of 4 on H_2 flow rate*
  - *Fission product release is strongly correlated to fuel liquefied quantity*
  - *A factor of 3 on semi-volatile fission product release*
  - *A factor of 1.5 on volatile fission product release*
  - *Variation of the iodine gaseous release and of caesium airborne from the primary circuit break*
  - *Metallic materials fraction can vary from a factor 3*
- *The most influential uncertain parameters :*
  - *U-Zr-O mixture oxidation*
  - *Dissolution limit of fuel and oxidized cladding*