Plant Applications with MELCOR 2.2: CIEMAT's Experiences

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Areas of Work

Uncertainty Quantification in SAs

Hydrogen Management

- PARs behavior

DBA/DEC-A Analysis

Uncertainty Quantification in SAs

Frame

- EU-MUSA project: Towards a harmonized approach for the UaSA application to SAs.

Objective

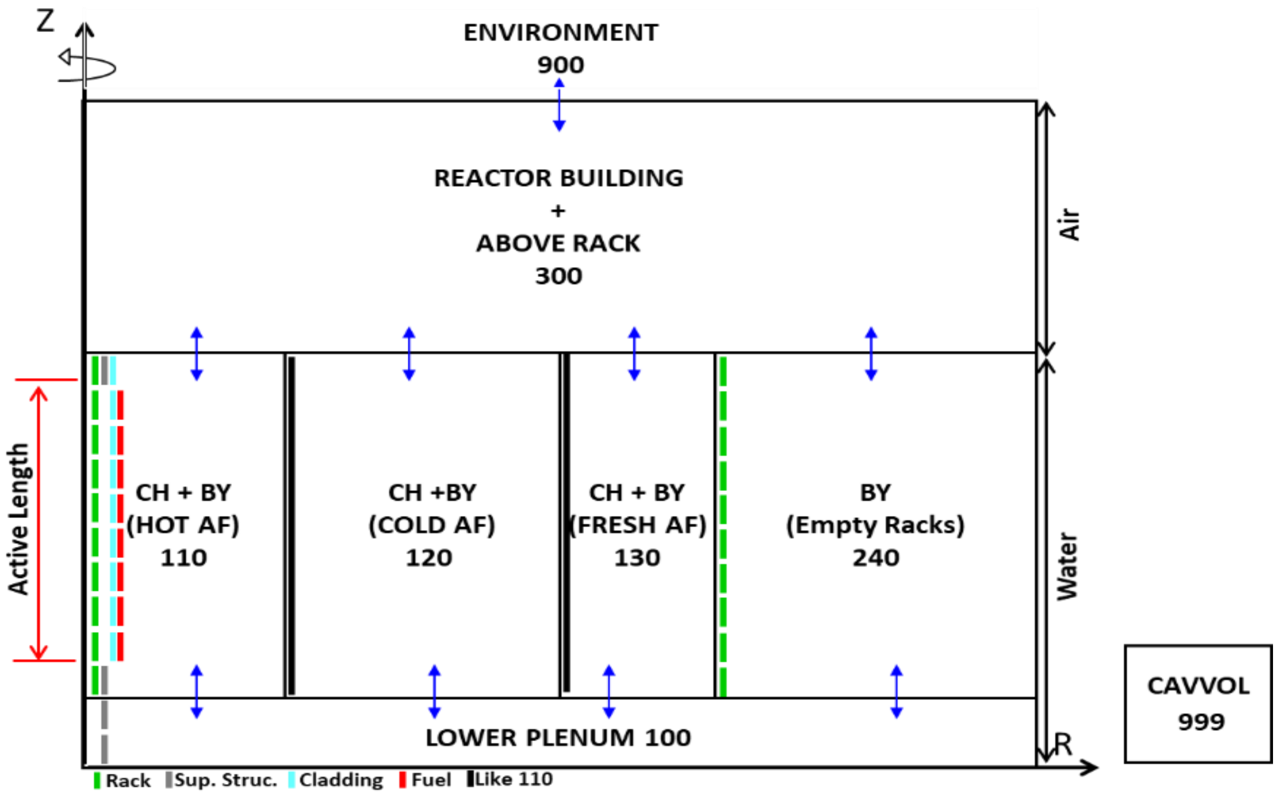
- Innovative management of SFP (Spent Fuel Pool) accidents (WP6).

Scope

- MELCOR v2.2 code.
- SFP-BWR.

WP6: MELCOR EM (v2.2.15254)

CVH/FL Nodalization

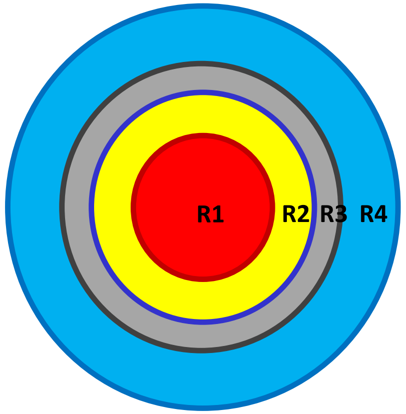


- 8 CVs, 15 FLs
- SFP walls represented by concrete HSs (adiab. Cond.) at the outer surface (**No HS_LBR/RBR card**)
- EM focused on ST
  - **FP initial masses**: WP6 specifications

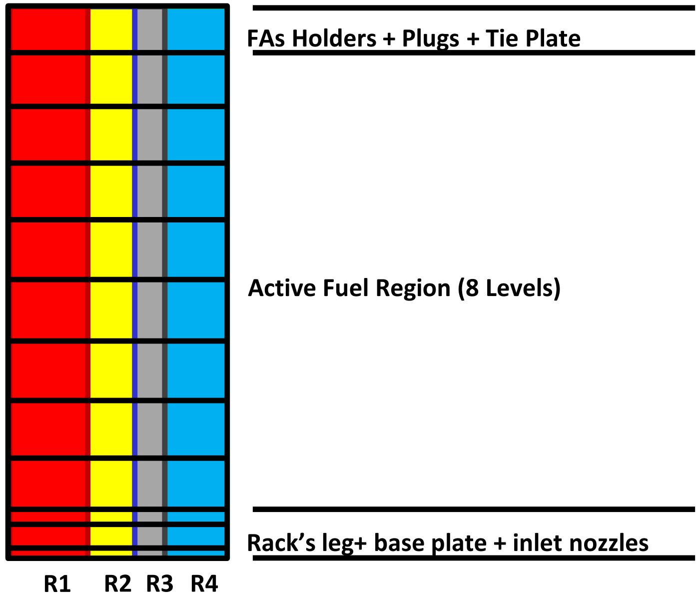
  Manual input through RN package (“***RN1_FPN***” card)
- Main Initial Conditions:
  - Liquid level: over the fuel racks (~ 4.5 m)
  - Pool temperature: 373.16 K
  - Atmosphere temperature: 353.16 K
  - Pressure: 1.0 bar (1.0136E+05 Pa)
  - **Reactor Building is not modeled**

WP6: MELCOR EM (v2.2.15254)

COR Nodalization



R1: Hot FAs (1.9 MW)
R2: Cold FAs (0.5 MW)
R3: Fresh FAs (0.0 MW)
R4: Empty Racks

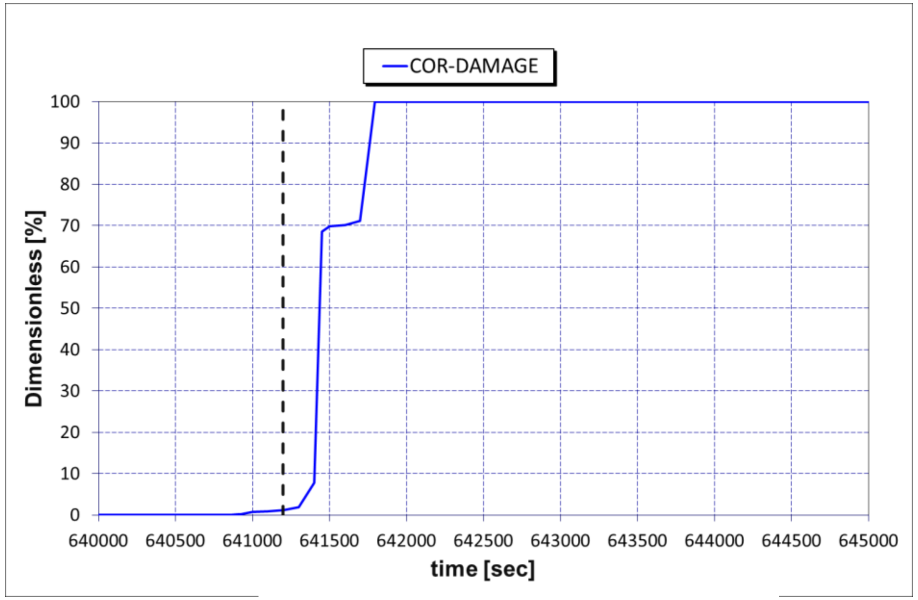


- **SFP-PWR MELCOR option**
- Racks were grouped in 4 radial rings
- **Decay Power**: 2.4 MW (1.9 Hot FAs + 0.5 Cold FAs)

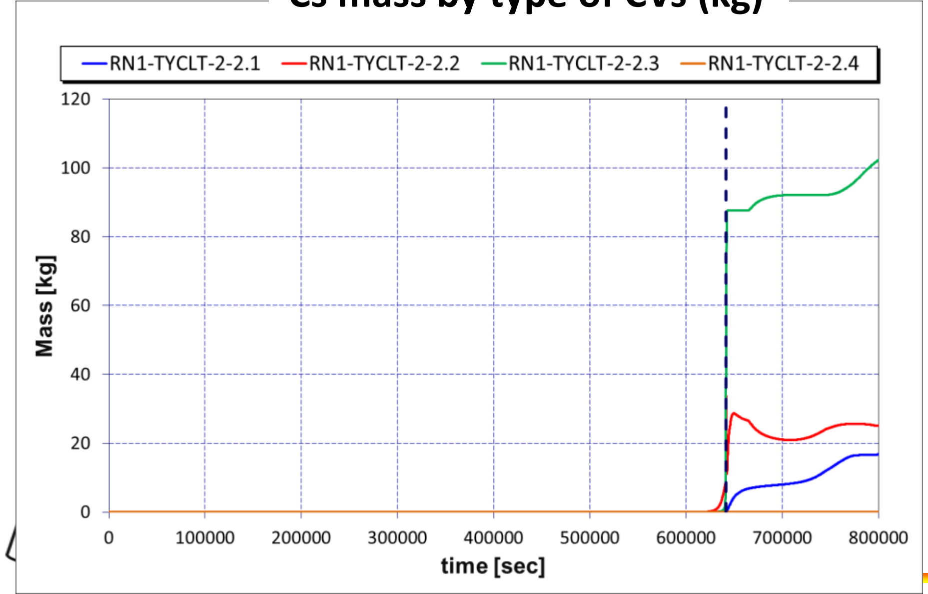
  Input through control function (“***DCH_DPW***” card)
- Axial direction: the racks and the spent fuel were subdivided into 12 levels (8 levels for active fuel)

RC Results

Fraction of the core fuel degraded (%) (COR-COR DAMAGE)



Cs mass by type of CVs (kg)



Stumbles:

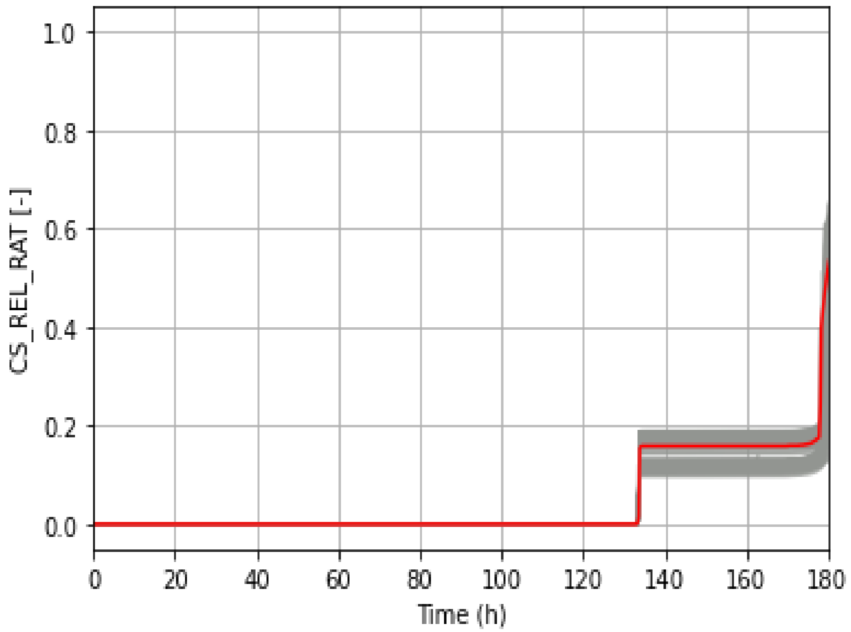
- Error 65: radiation subrutines
  - SFP-PWR option
  - No HS_LBR/RBR cards
  - COR_TST 0
- Error related to THs
  - Simplified nodalization
- MELCOR 2.2.15254 (no run with subsequent versions)

RC analysis:

- RC analysis is done with default values of the code
- Time onset of FPs release ~ 7.4 d
- 1% of degraded core as criteria to stop the computation (WP6 specifications)

Uncertainty Analysis Results

- **Home-built python scripts** (MELCOR 2.2/DAKOTA 6.7)
- ***Input-driven uncertainty propagation*** *(15 features selected)*
- ***Simple Random Sampling (SRS)***
- ***Order statistics (Wilks;*** *93 runs to get 95/95)*
- ***FOMs targeted:*** *t_{onset}; Release of key RNs (NG, Cs, Ru)*



Statistical parameter	Xe	Cs	Ru
MELCOR reference case (%i.i.)	24.21	24.21	0.12
Mean (% i.i.)	17.33	17.01	0.16
Median (% i.i.)	18.07	17.10	0.15
Lower bound (% i.i.)	11.44	11.25	0.08
Upper bound (% i.i.)	44.42	39.55	0.28
Standard deviation (% i.i.)	3.71	3.43	0.05

Some lessons learned

RC application:

- The scenario outlined is heavily conditioned by some hypotheses and assumptions made (i.e., the absence of "containment building"). This prevents from withdrawing meaningful generic conclusions from the calculations done. Nevertheless, substantial insights have been gained from the application of UaSA to SFPs.
- Despite the oversimplification of the scenario, modeling SFPs with SA codes still pose challenges related to the fuel assemblies distribution in the pool (notably other than in nuclear reactors) and to the first stages of the accident, when complex steam and air flows through fuel assemblies likely occur during the fuel assemblies uncover.
- MELCOR radiation model with the SFP-BWR core option could not be successfully activated, so that a SFP-PWR type core has been used as a "surrogate". This is an additional constraint that makes it hard to use the results for any generic physical interpretation.

Hydrogen Management

PARs behavior

Frame

- SAMHYCO-Net (NUGENIA/TA2) and OECD-THEMIS project.
- CIEMAT contribution to the analyses of THAI-HR (Hydrogen Recombination) tests.

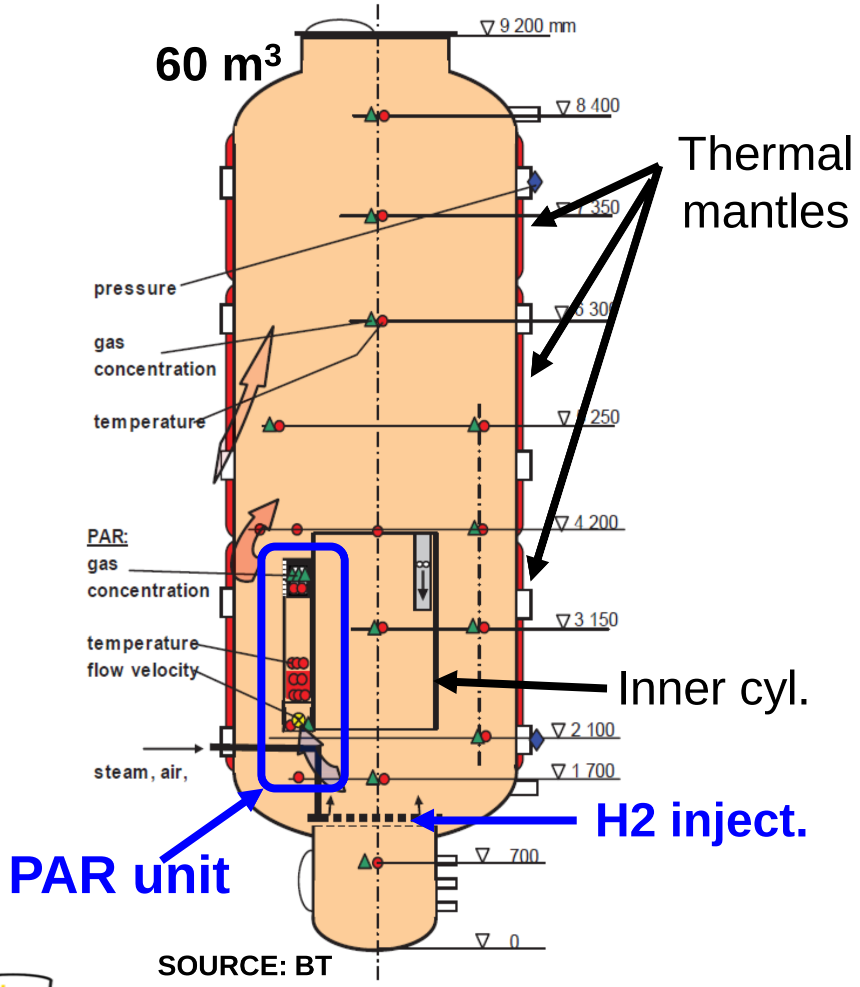
Objectives

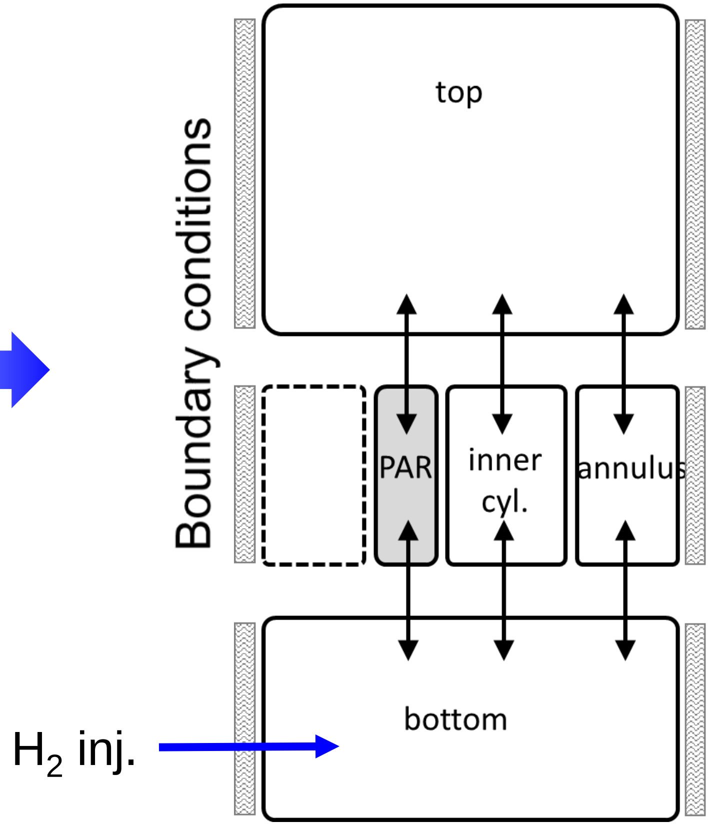
- Assess the predictability of MELCOR for PAR's recombination rate.
- Analyse updated recombination rate correlation for PARs efficiency.

Scope

- MELCOR v2.2 code.
- FRAMATOME's design PARs.

THAI facility / MELCOR EM





Modelling:

- 5-node approach
- Form losses through the PAR volume set to capture the experimental velocity

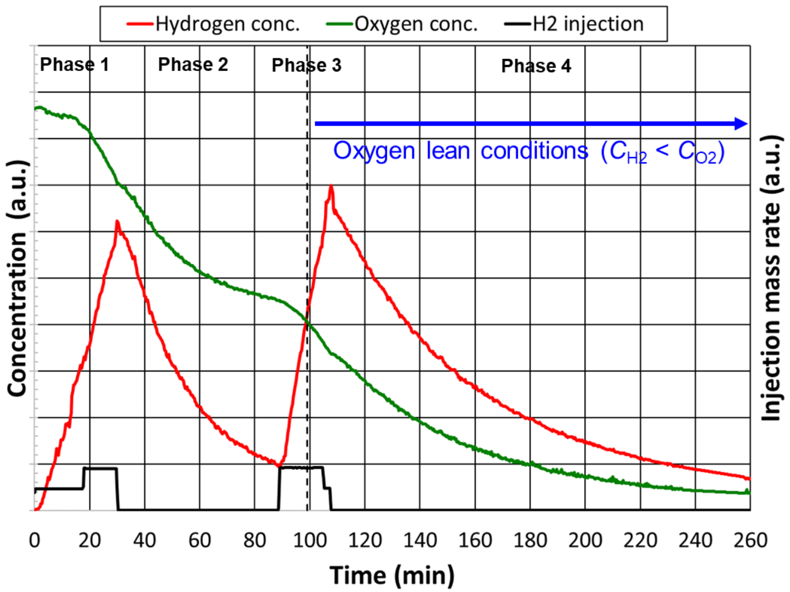
BC (TFs):

- Wall T
- Injection mass rates

Initial conditions:

- Gas composition
- T & P

HR-11 test / Model Approach



Correlation dependency is suitable to be implemented in lumped parameter codes.

PAR's recombination rate:

- Mass sinks 'CV_SOU': H_2, O_2 **(CFs)**
- Mass sources 'CV_SOU': H_2O_v **(CFs)**

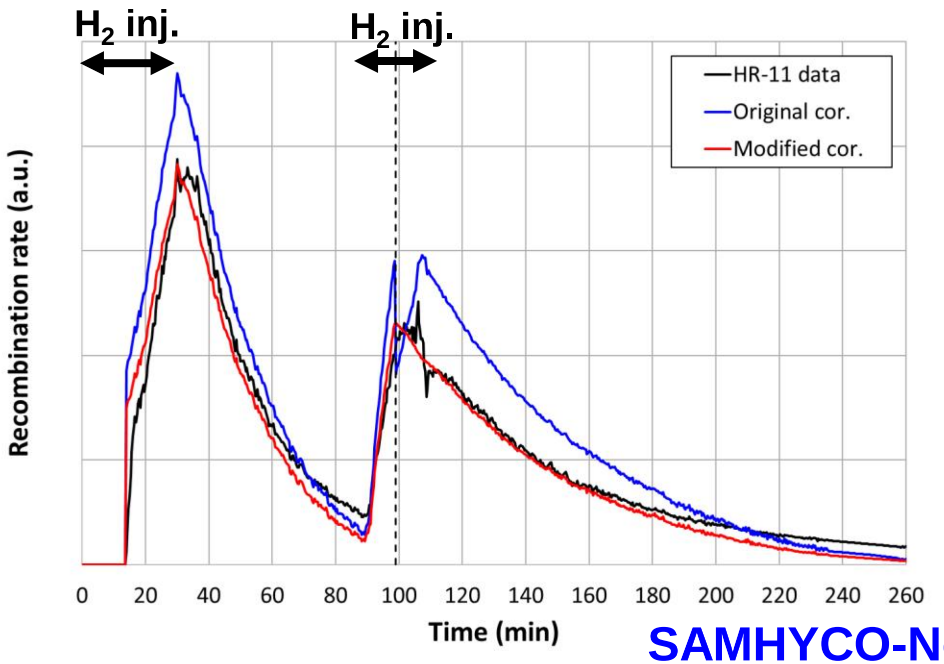
FRAMATOME's Original correlation

$$R_{H2} \propto C_{H2} \cdot \eta \cdot (k_1 \cdot P + k_2) \cdot \tanh(C_{H2} - C_{min})$$

$$\eta = 1 \quad if\ C_{O2} \geq C_{H2} \quad (Oxygen - rich\ cond.)$$
$$\eta = 0.6 \quad if\ C_{O2} < C_{H2} \quad (Oxygen - lean\ cond.)$$

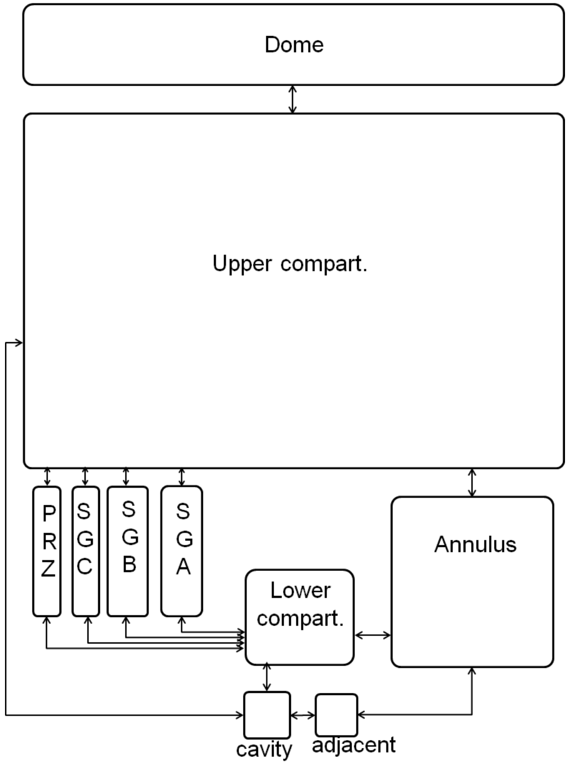
Modified correlation

$$R_{H2} \propto \min(C_{H2}, C_{O2}) \cdot (k'_1 \cdot P + k'_2) \cdot \tanh(C_{H2} - C_{min})$$



Plant application: MELCOR EM

PWR Containment



10-node approach

Sequences

- *2" LOCA with fan coolers in the containment*
- *2" LOCA with cont. sprays & cavity flooding*
- *Double-ended guillotine LOCA with fan coolers and sprays*
- *Station Black-Out*

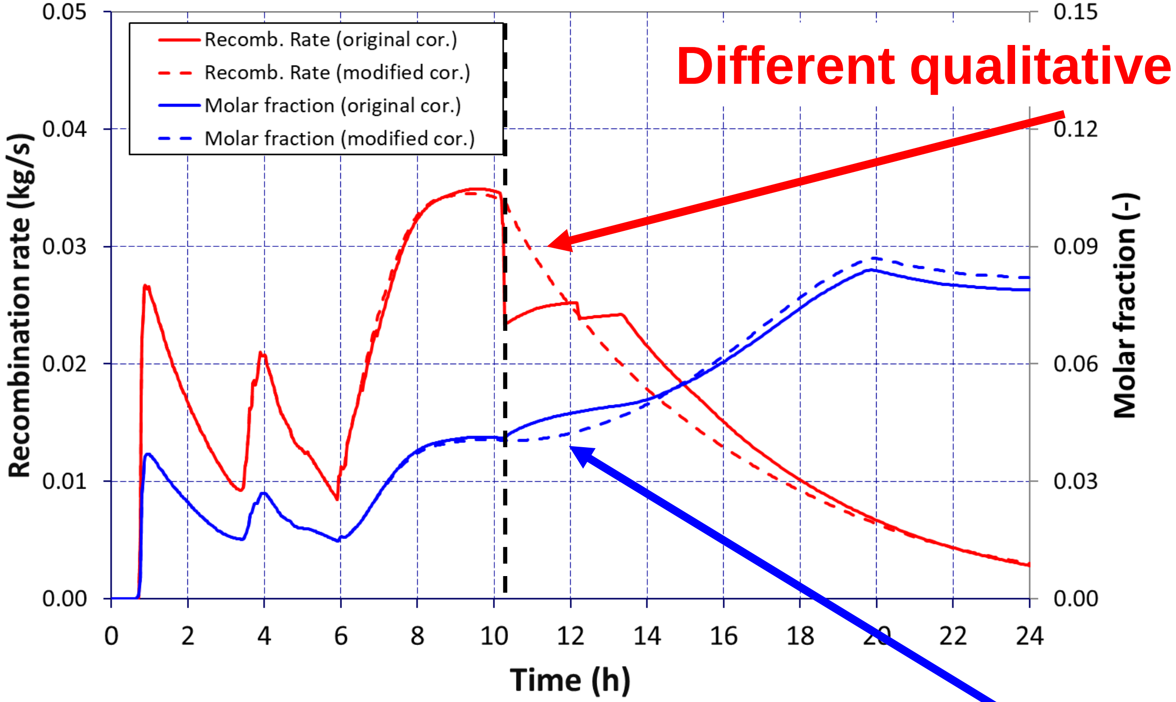
PARs distribution: 24 Framatome FR-1500 PARs

Compartment	# of PARs
Cavity	-
Cavity adjacent chamber	1
Lower compartment	1
SGA compartment	1
SGB compartment	1
SGC compartment	1
PRZ compartment	1
Upper compartment	13
Dome	3
Annulus	2

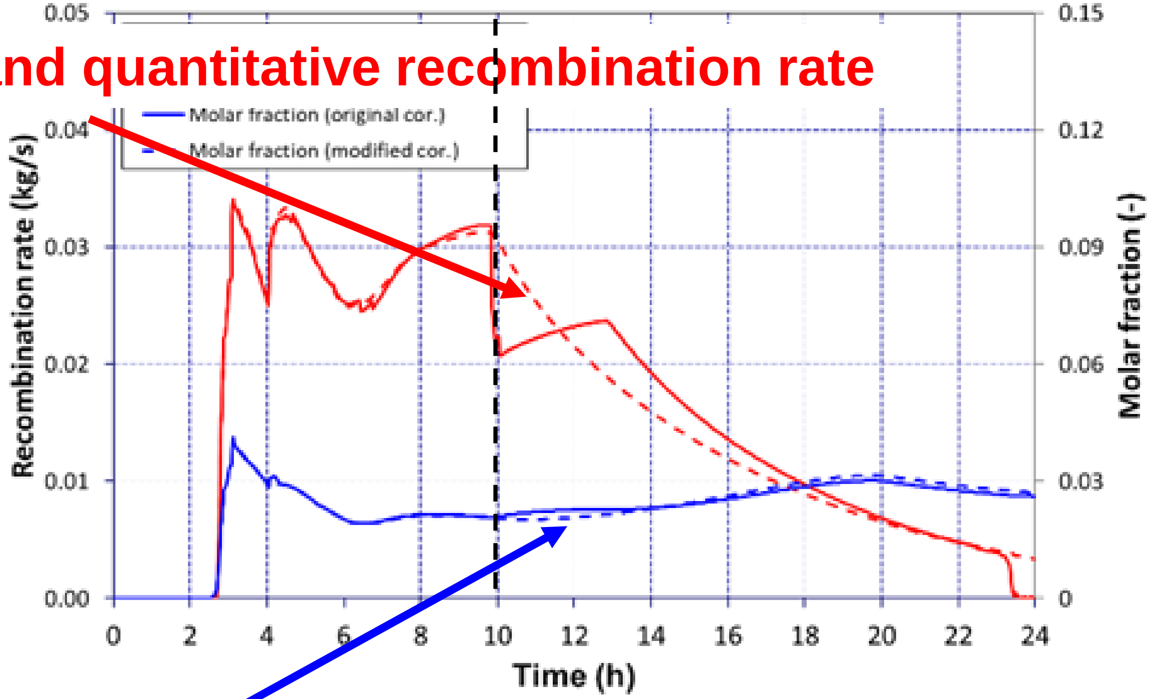
Results (Upper containment)

Different qualitative and quantitative recombination rate

SBLOCA + fan coolers



SBO



Very similar results for hydrogen molar fraction

high R_{H2} ➡ low X_{H2} ➡ low R_{H2}

Similar results for the four analyzed sequences

Some Remarks

- MELCOR model with a **reduced number of nodes** seems suitable to reproduce experiments for Hydrogen behavior
- Control Functions (CFs) in MELCOR **provide high flexibility** to implement general correlations for PARs' recombination rates.
- Comparison of correlation's modification in accident sequences simulated with MELCOR can lead to:
  - A **significant difference in the recombination rate** (oxygen lean conditions) **BUT**
  - **A slight effect on the hydrogen molar fraction**.

DBA/DEC-A Analysis

DBA/DEC-A Analysis

Frame

- EU-R2CA project: Reduction of radiological consequences of DBA and DEC-A.

Objective

- Development of harmonized methodologies and innovative management approaches and safety devices for the evaluation and for the reduction of the consequences of DBA and DEC-A accidents in operating and foreseen nuclear power plants in Europe.

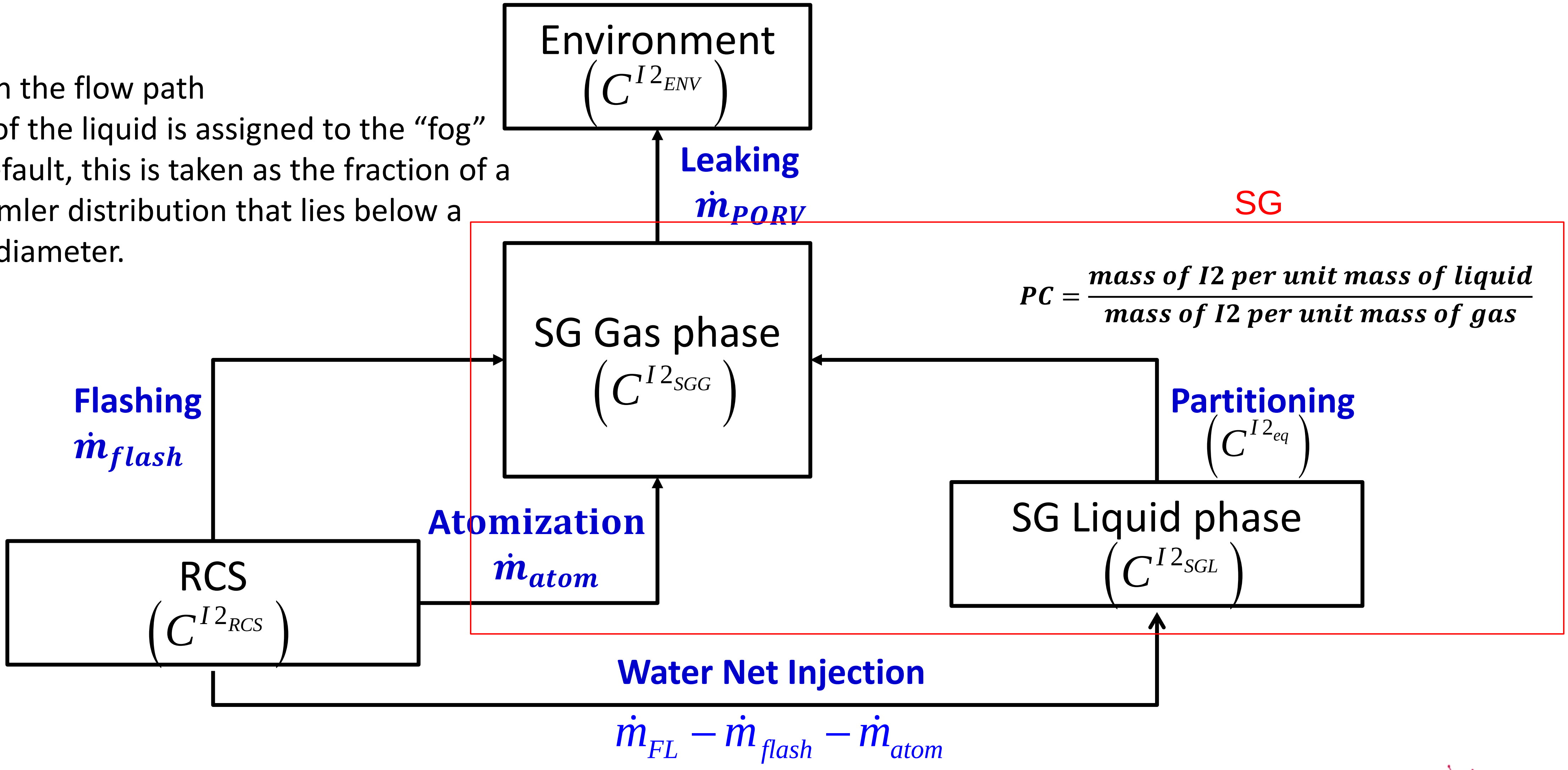
Scope

- Development of methodologies.
- Improvement of evaluation tools (MELCOR)
  - Iodine transport model extension.
- Evaluation of a series of reactor cases: LOCA and SGTR.

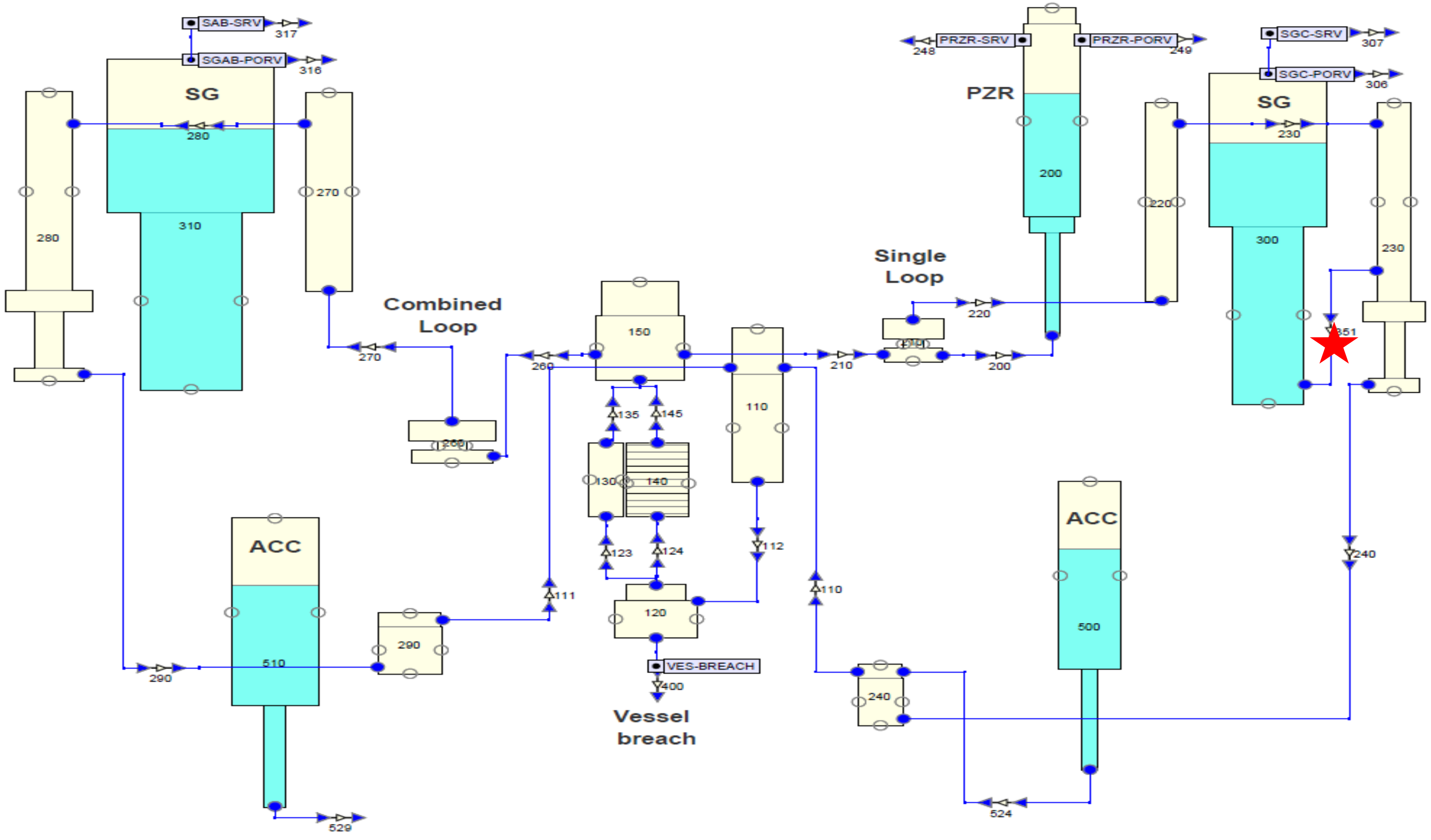
Iodine Transport model: CIEMAT's extension

Flash model

- Activated in the flow path
- A fraction of the liquid is assigned to the "fog" field. By default, this is taken as the fraction of a Rosin-Rammler distribution that lies below a maximum diameter.



MELCOR EM (v2.2.18019)



NPP: 30 CV and 44 FL

RCS: 2 loops

RPV: 5 CVs

Core: 4 radial rings, 14 axial levels

SSs: HPSI, LPSI, ACS

ST (Iodine spiking model):

Absolute release rate, normalized to plant power : 1.09 Ci/h • MWe

(James P. Adams, Corwin L. Atwood. The iodine spike release rate during a steam generator tube rupture. Nuclear Technology, 361-371, October 1994.)

Main Steam Line Break (MSLB) before MSIV (Main Steam Isolation Valves) with a double ended rupture of 3 SG tubes at the cold leg side tube sheet **(DEC-A)**

Preliminary Results & Further Work

An extended iodine transport model has been implemented in MELCOR to consider the effect of water vaporization in the SG in the release and transport of iodine from fuel to the environment and tested in a DEC-A SGTR sequence. From the preliminary results:

- In the scenario modeled, there is no damage in the fuel rods; therefore, the main radioactive source to the environment comes from the iodine release from the reactor trip until the end of the transient.

- An iodine spiking model to bring the activity release to the secondary side has been proposed and implemented. At this time, this model should be reviewed and improved to consider the removal of iodine by the radioactive decay and by the reactor water cleanup system.

- According to the preliminary results, partitioning appears as the dominant mechanism in the iodine release to the environment.

FINAL REMARKS

- MELCOR has become an essential tool for CIEMAT in the area of LWR analysis.
- CIEMAT is profusely using MELCOR in research and application activities.
- MELCOR has been the backbone of CSN-CIEMAT agreements, and it will be again.
- New environments for CIEMAT use of MELCOR: Uncertainties, SFPs, DBA & DEC-A.
- CIEMAT's expertise on SA analysis with MELCOR being used in other technologies.

Thank you for your attention