F. Fichot - P. Chatelard - L. Bosland - S. Pignet

Research in support of the 4th 10-year periodic safety review on severe accidents

IRSN MEMBRE DE ETSON

EUROSAFE 2019

CONTENT

Context and issues of the 4th periodic safety review on severe accident

- French 900 MWe 4th periodic safety review (PSR) :
  - Life time extension
  - Fukushima accident lessons

- French utility performs ambitious modifications program to reduce off-site consequences in case of molten core accident

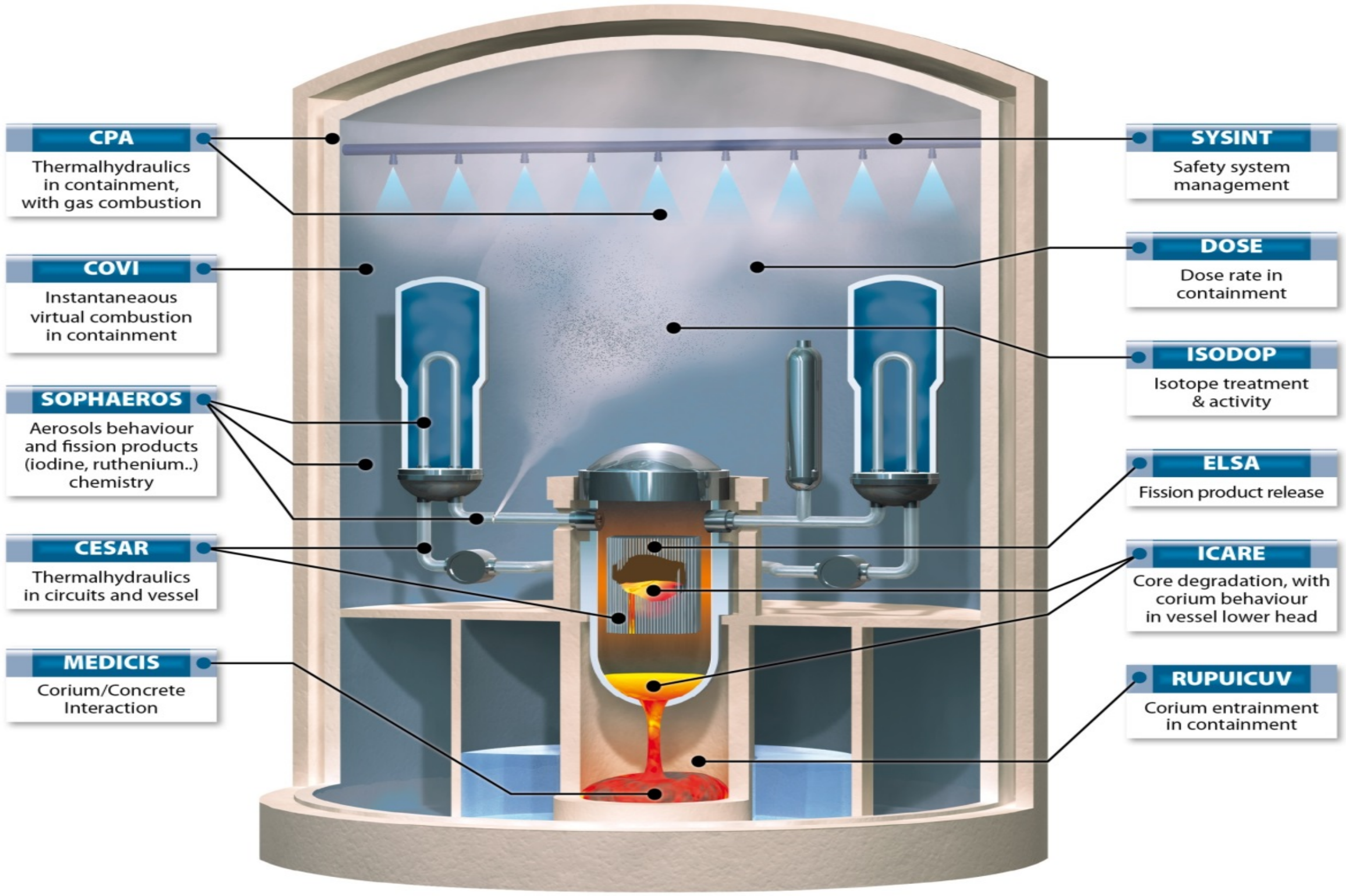
- IRSN researches on severe accident has been essential to assess this PSR
  - ASTEC code : integration of 20 years knowledge on severe accidents
  - MCCI phenomenology to ensure corium coolability
  - FP releases mitigation

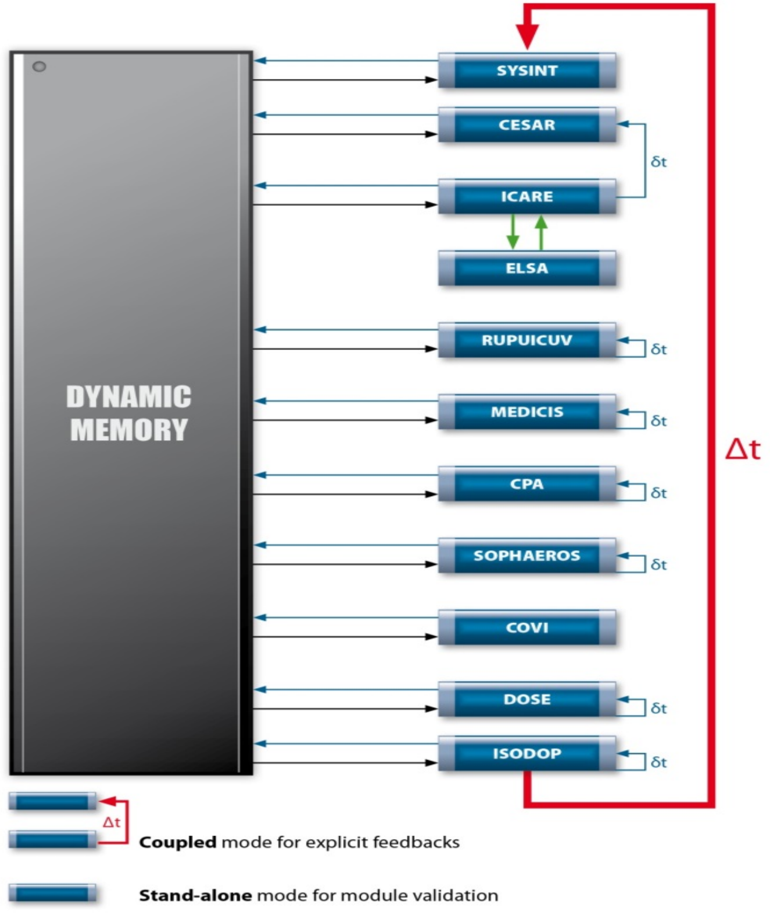
ASTEC : Accident Source Term Evaluation Code

Integral **code** developed by IRSN **for LWRs** (present/future PWR, BWR, VVER) **source term severe accident calculations**

- **Main objectives**
  - Applications to PSA level 2, including uncertainty analysis,
  - Accident management studies,
  - Investigations of NPP behaviour in SA conditions, including source term evaluation,
  - Support and interpretation of experiments,
  - Support to emergency response tools,
  - Basis for a better understanding of SA physical phenomena.
- **Main requirements**
  - Comprehensive coverage of SA main phenomena, accounting for their interactions,
  - Accounting for safety systems and their availability (SAM),
  - High level of model validation,
  - Modularity, flexibility, user-friendliness, easy model incorporation.

General architecture of the ASTEC V2.1 major version





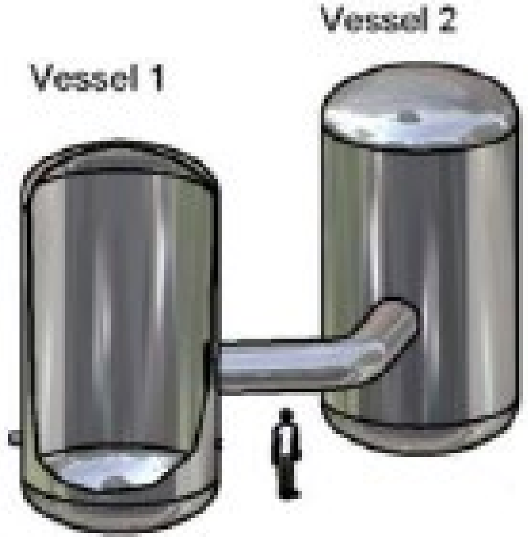
ASTEC V2.1 validation : example of containment thermal-hydraulics models (CPA module assessment through different scales)

TOSQAN ISP47 : 7 m^3

condensation test spray efficiency

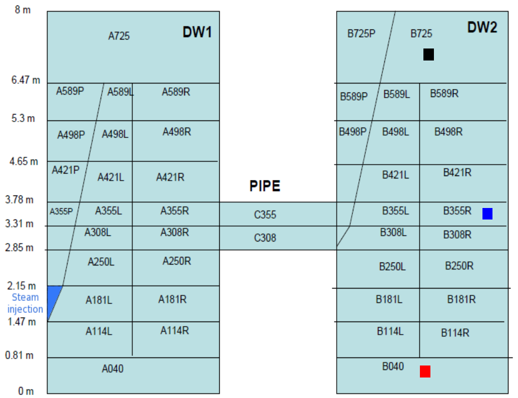
THAI HM2 : 60 m^3

H2 stratification

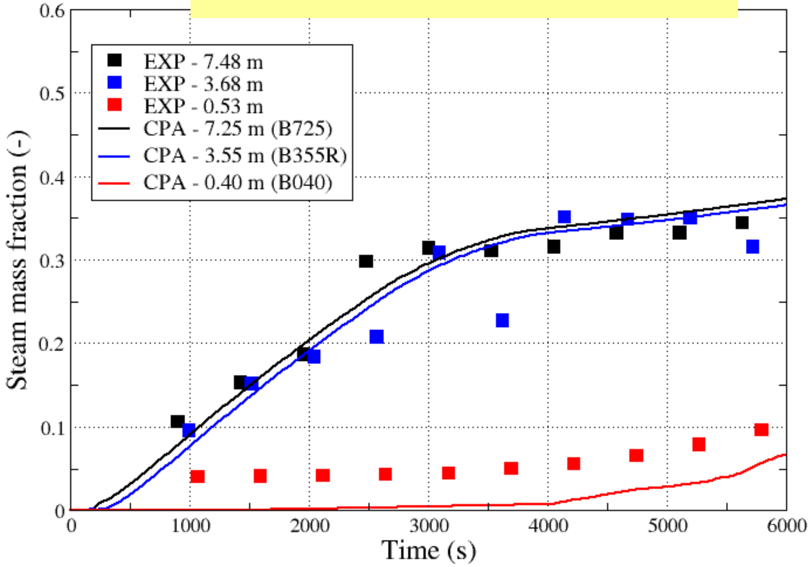


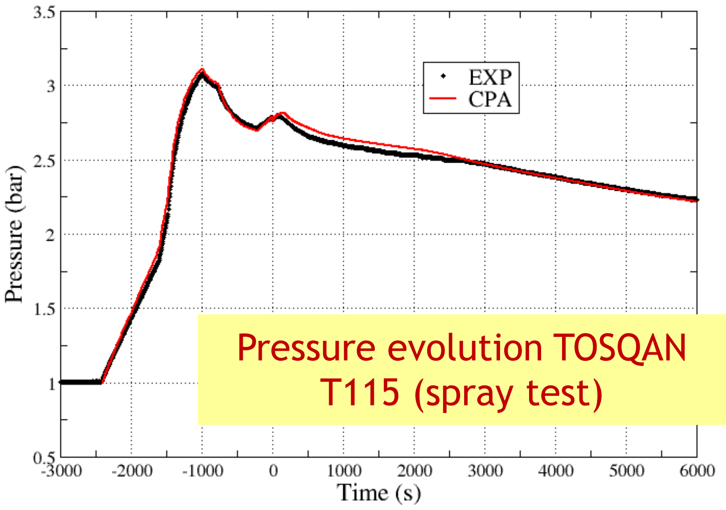
PANDA 9-9bis : 2*90 m^3

Gas mixing, stratification, condensation/evaporation



Steam mass fraction in Vessel-2 PANDA 9bis TEST



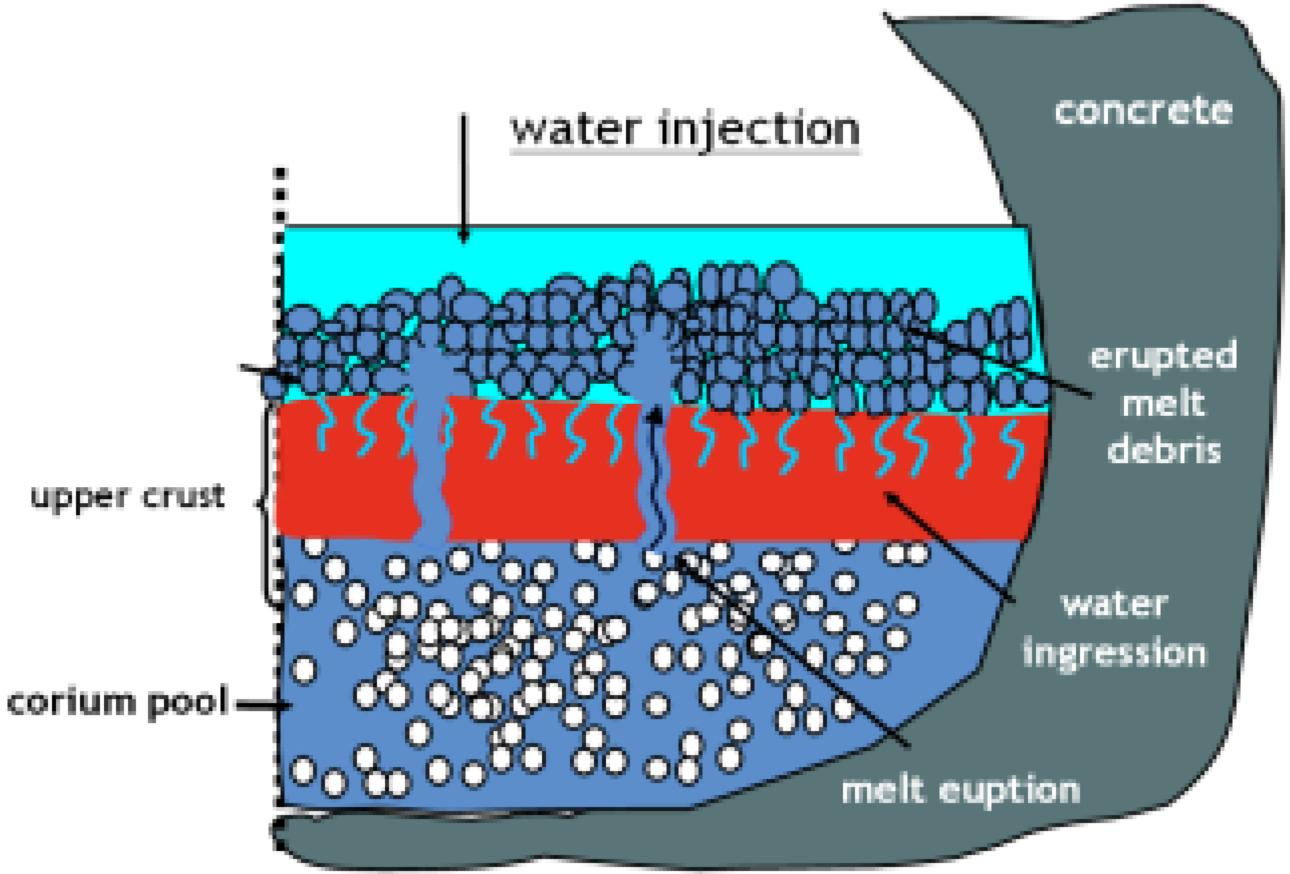


Pressure evolution TOSQAN T115 (spray test)

Molten core concrete interaction

3 mechanisms for heat transfer through the crust :
- Conduction
- Melt eruption
- Water ingression

Coolability of corium relies on the 3 mechanisms



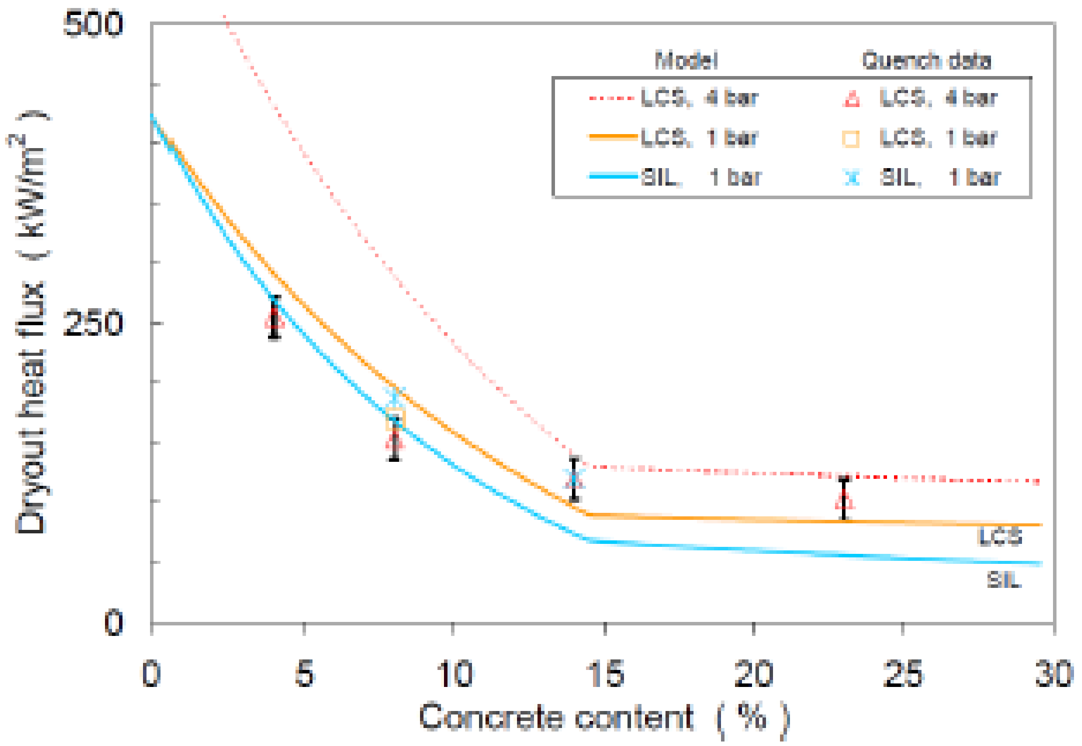
Concrete basemat

SiO_2
CaO
Al_2O_3
Fe
CO_2
H_2O

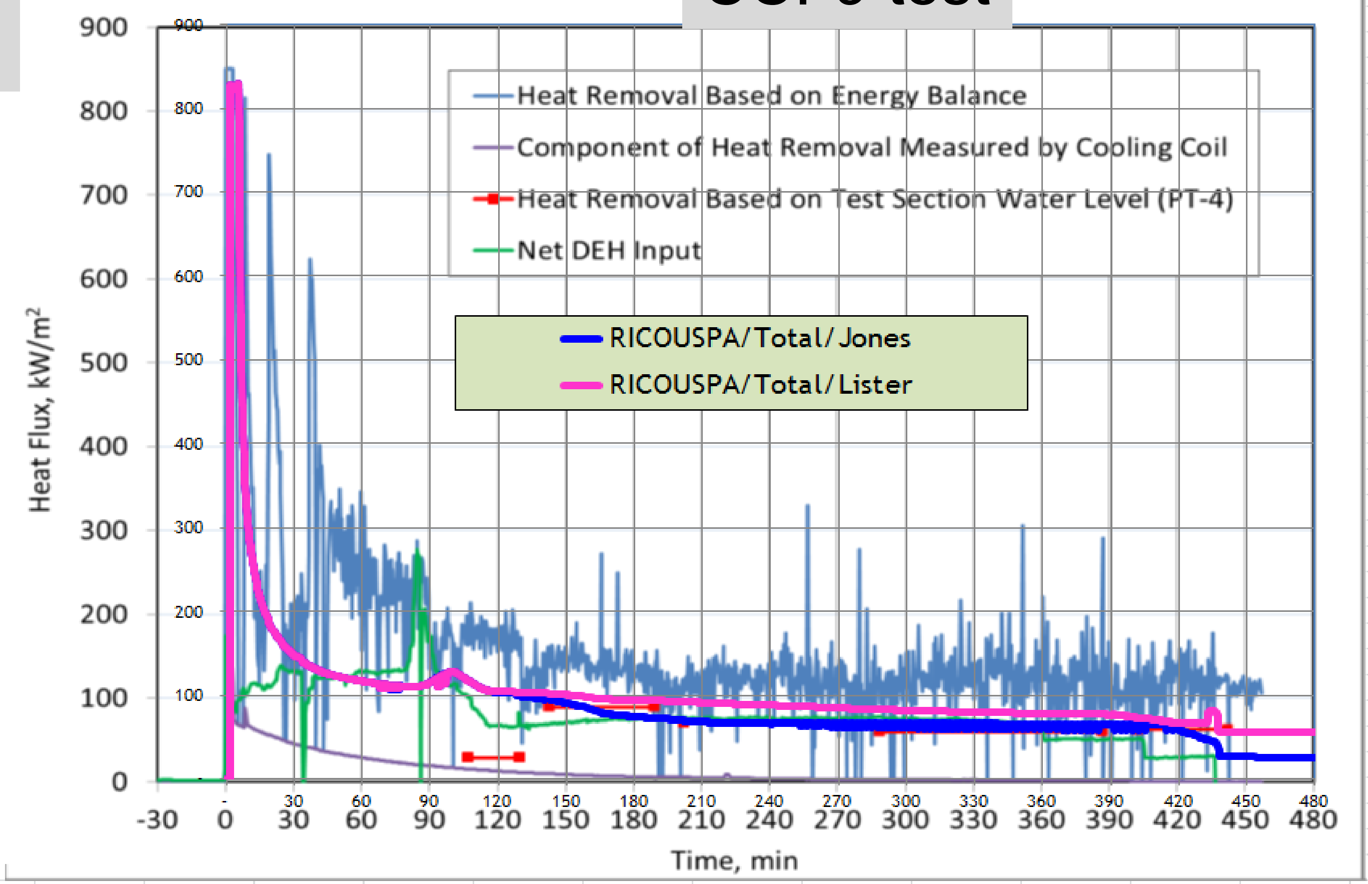
MCCI : State of the Art

- Small scale test (SWICCS performed by ANL) has been analyzed to improved corium to water heat exchanges modelling
- ASTEC has been validated on integral experiments (CCI)

Dryout heat flux laws from SWICCS test



CCI-9 test



MCCI remaining issues

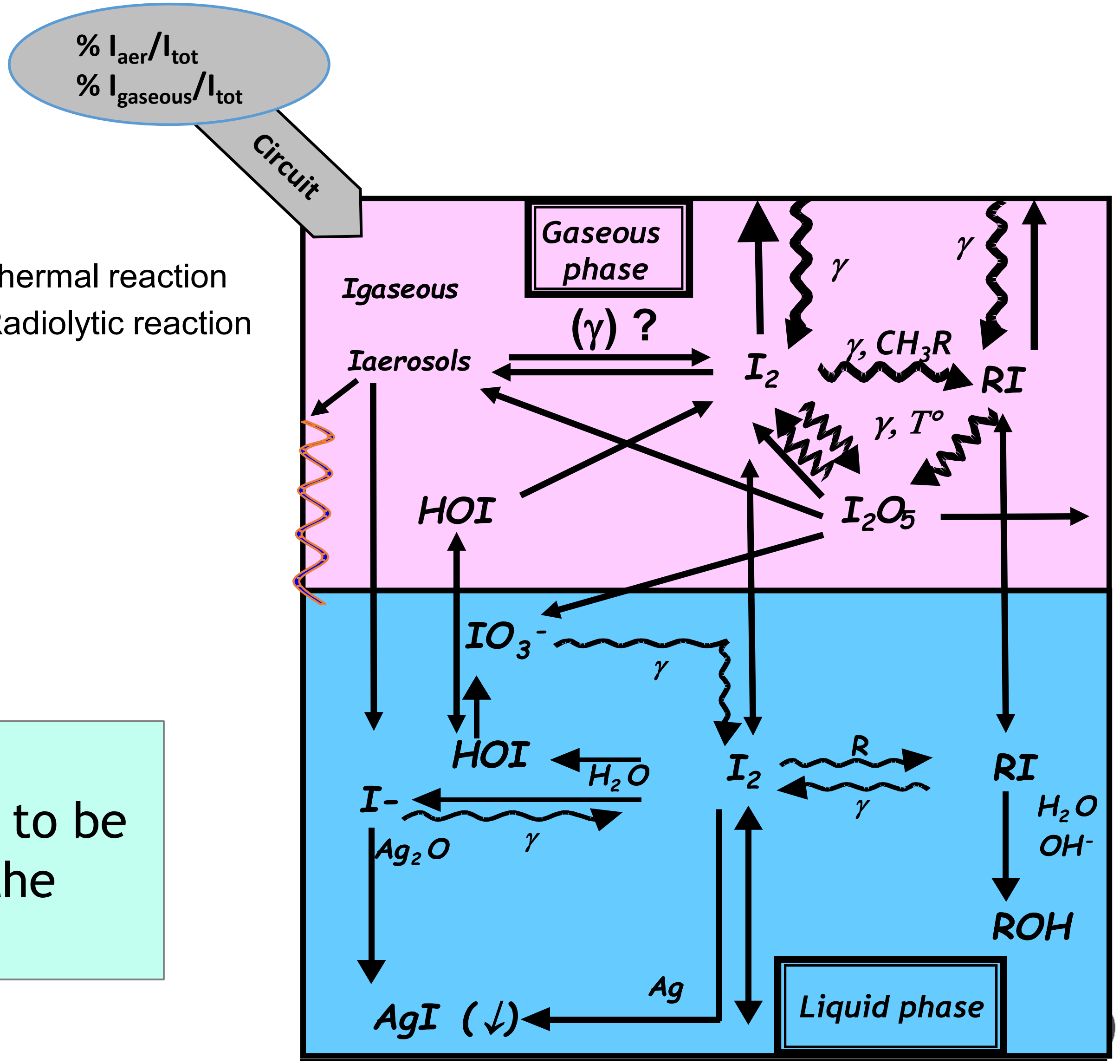
- Water ingression appears as the most efficient process to freeze corium when it is spread over a large surface
- Uncertainties on its efficiency lead to threshold effect on basemate ablation
- Existing understanding of the formation of cracks within the frozen corium crust involves mechanical and thermal properties of the solid corium.
- The effect of the presence of a significant mass fraction of metal on those properties is unknown.
  - need to assess the existence of water ingression for metal contents in the range 10-40%
- The effect of the presence of a large mass fraction of concrete on those properties is also unknown.

Starting OECD ROSAU program will address these issues.

General picture of the ASTEC V2.1 simulated phenomena concerning iodine chemistry in containment

<u>Key-safety issue</u>
The competition between formation/decomposition processes of Iodine species governs the Iodine volatility in the containment
(**short term ≠ long term**)

Thermal reaction
Radiolytic reaction



Because of this complex and sensitive phenomenology, uncertainties evaluation needs to be developed for source term evaluations. This is the goal of H2020 project MUSA launched this year.

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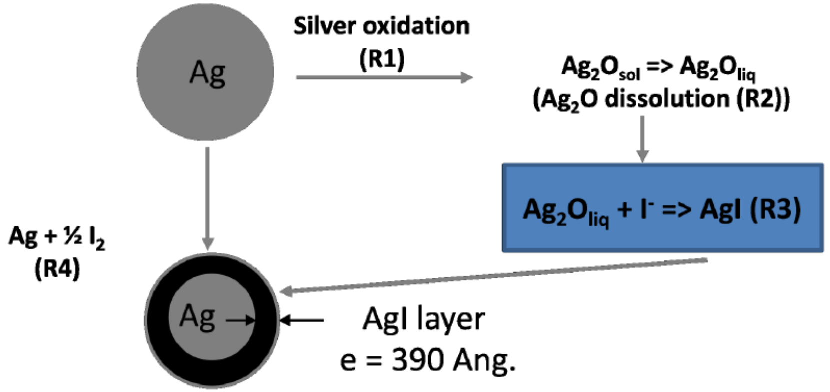
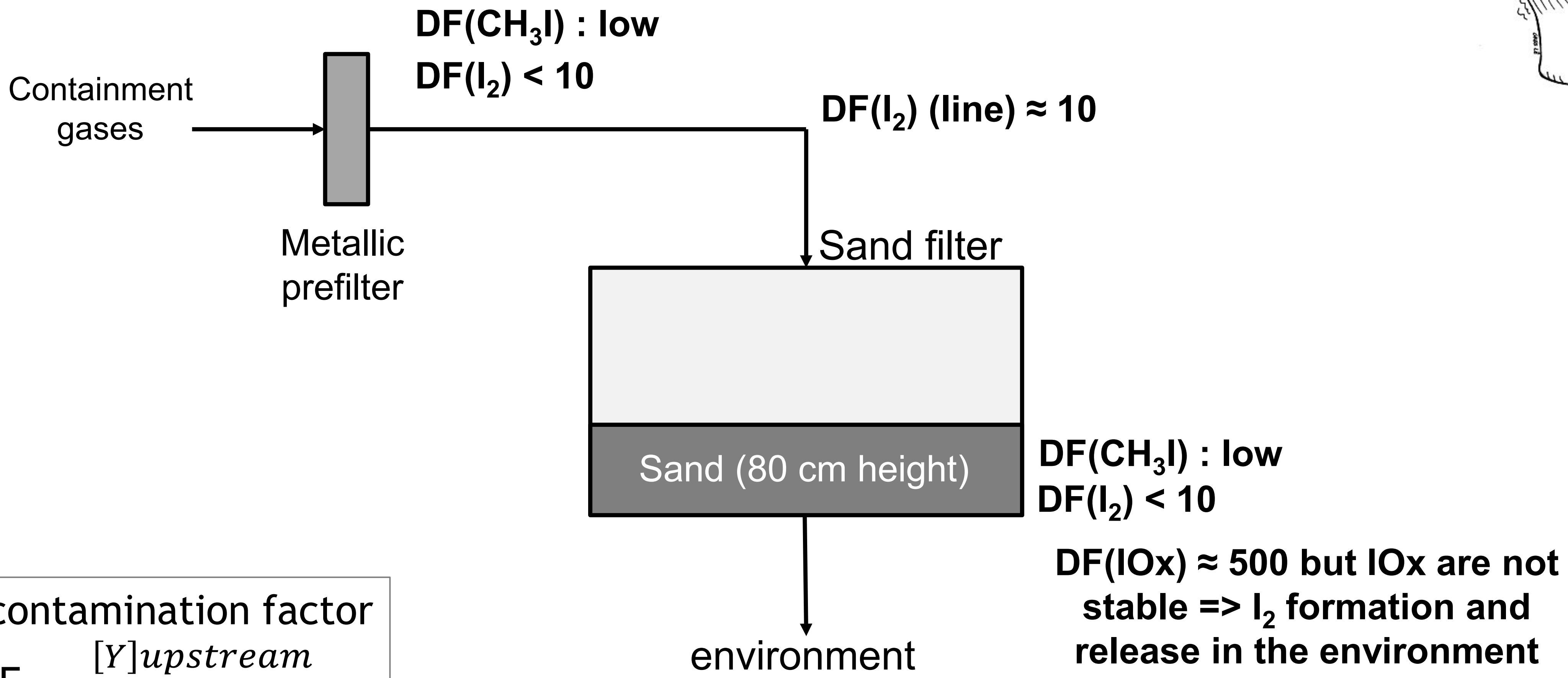
Influence of silver on iodine volatility



- 900 MWe reactors are equipped with Silver-Indium-Cadmium control rods
  => Solid particle of Ag in the water sump.
- Ag is know to react with Iodine and then limit the I2 release from sump to containment atmosphere
- PHEBUS FPT-1 have shown silver oxide is located on the outer shell of the particles, other experiments have shown a limitation of iodine trapping by silver particles
- Limitation of silver interaction capability on an outer shell of particles
- Taken into account these recent results outlines the necessity to have a basic pH in sump even if silver is expected to be released during the accident

Filtered containment venting system



Decontamination factor

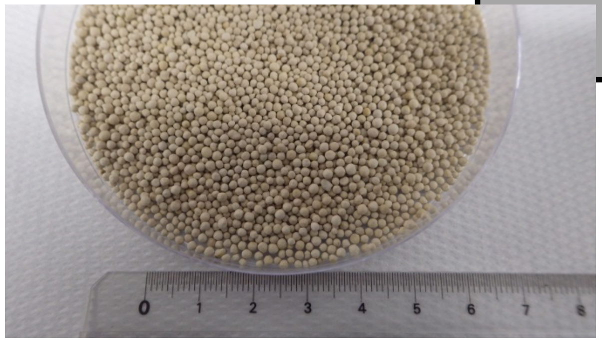
$$DF = \frac{[Y]upstream}{[Y]downstream}$$

Mitigation of the fission products releases: improvement of FCVS efficiency

New insights are available to improve gaseous iodine species trap, thanks to recent experiments (French domestic program)

Silver containing zeolite (35% Ag) mixed with sand (4 cm height, 80-140°C)

Air + iodine



$DF(CH_3I) > 10$

$DF(I_2) > DF(CH_3I)$ is expected (for higher sand height)

Metal Organics Framework (MOF) loaded with I_2 (120°C, 20% RH)

Air

No iodine release

The irreversible and efficient capture of I_2 and CH_3I by new material has been demonstrated at the laboratory scale

These results have to be taken into account by the utility to design modifications on existing FCVS systems

Conclusion

- IRSN safety assessment on severe accident is supported by R&D programs covering the main issues on SA management and consequences. The results are valorized in ASTEC code.
- Available R&D on MCCI has been used to review EDF strategy for corium stabilization. Uncertainties on MCCI concerning siliceous concrete are still important. The starting OECD project ROSAU conduced by ANL will address the remaining questions.
- Concerning FP releases, new knowledge led to recommendations in order to alkalize sumps and improve FCVS efficiency. Nevertheless there is still open issues on iodine chemistry, such as mid and long term releases. This is why IRSN propose a new OECD program called ESTER.