

**METHOD IMPLEMENTED BY THE IRSN
FOR THE EVALUATION OF UNCERTAINTIES
IN LEVEL 2 PSA**

SOME EXAMPLES

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11 General objectives for L2 PSA

During the last few years, the IRSN (as technical support of French Safety Authority) has developed a level 2 PSA for French 900 MWe PWRs with the following objectives :

- to contribute to reactors safety level assessment,
- to estimate the benefits of accident management procedures and guides to reactor safety,
- to provide more quantitative judgment elements about the advantages of any modifications to reactor design or operation,
- to acquire quantitative knowledge for emergency management teams and tools,
- to help in the definition of research and development programs in the severe accidents field.

L2 PSA for French 900 MWe PWR at IRSN

2000 - Preliminary version - power states of reactor

2003 - Version 1.1 - power states of reactor - (improved containment failure studies, uncertainties on release assessment)

2004-2005 - Review of EDF study in the framework of preparation of safety review at third decennial visit

2006 - Version 3 - power states of reactor and shut down states - modifications envisaged at third decennial visit

L2 PSA for French 1300 MWe PWR at IRSN

2005 - Specifications of the study

2006 - Beginning of studies

2009 - Preliminary version

2010 - Preparation of safety review before third decennial visit

1 Introduction

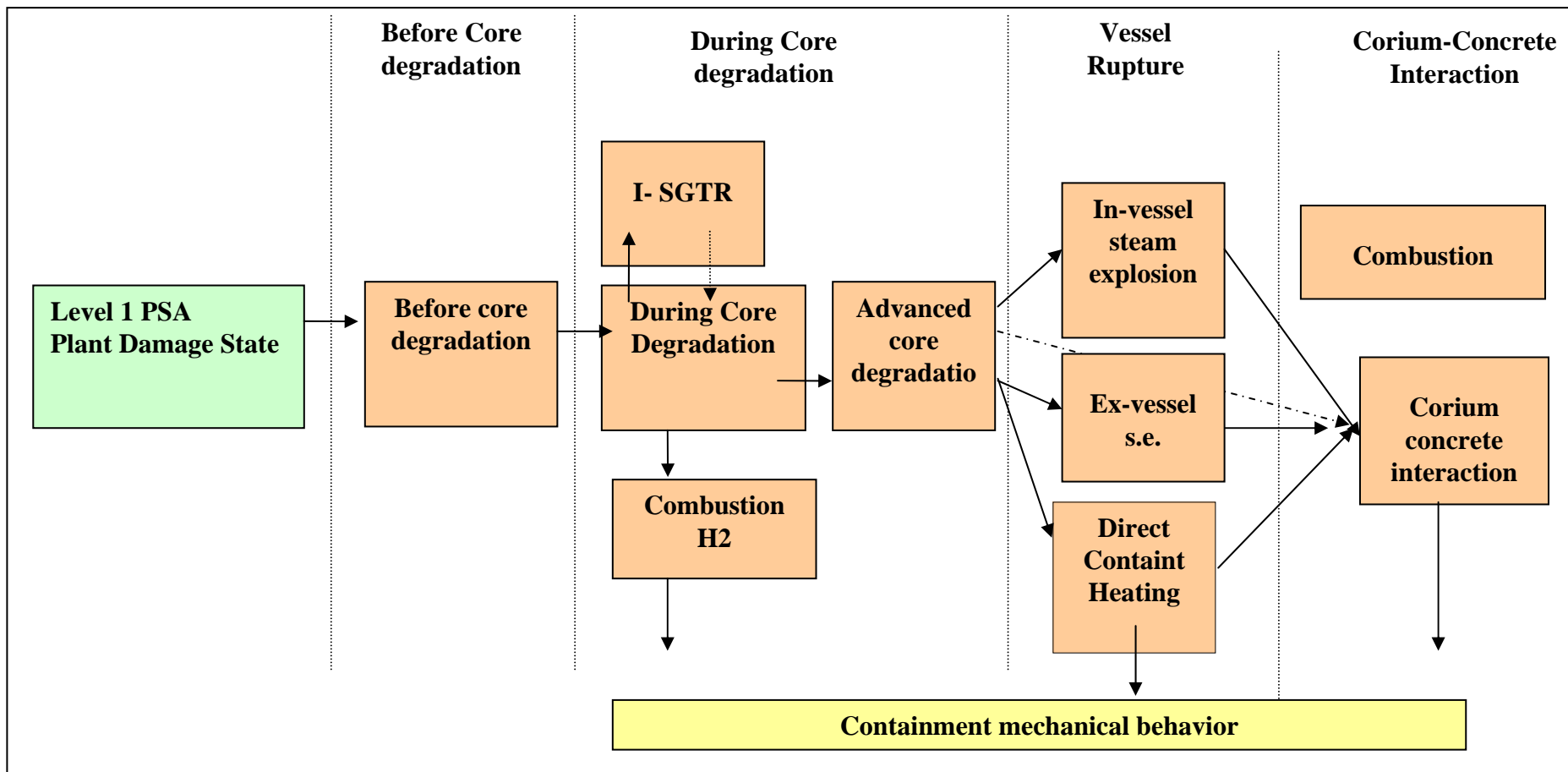
Uncertainties assessment in L2 PSA

- 1 - L1 PSA uncertainties : not propagated in L2 PSA
- 2 - Uncertainties (approximation) due to binning of level 1 sequences in PDS
→ effort is made to have a detailed interface (> 100 PDS)
- 3 - Uncertainties due to the definition of representative transient for each PDS
→ effort is made to have as many calculated transients as possible
- 4 - Uncertainties on the probabilities and instant of stochastic events (human actions, failure ...) → the level 2 PSA APET generates as many situations as possible - Human Actions are represented by a specific model - Only a dynamic approach could solve this issue.
- 5 - Uncertainties due to the binning of level 2 sequences in release categories
→ more than 1000 release categories are generated

6 - Uncertainties on physical phenomena

7 - Uncertainties on release assessment

2 Quantification of physical phenomena Method



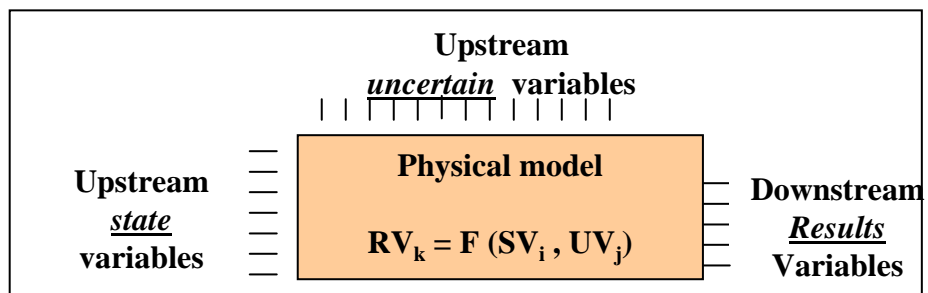
2 Quantification of physical phenomena Method

Physical models of APET must :

- Give a "best-estimate" evaluation of a physical phenomenon and of its consequences,
- Take into account uncertainties,
- Run fastly,
- Replace sophisticated codes used for severe accident with relative accuracy.

2 Quantification of physical phenomena Method

One general form :



2 types of model

- response surfaces
- grid of results

2 Quantification of physical phenomena

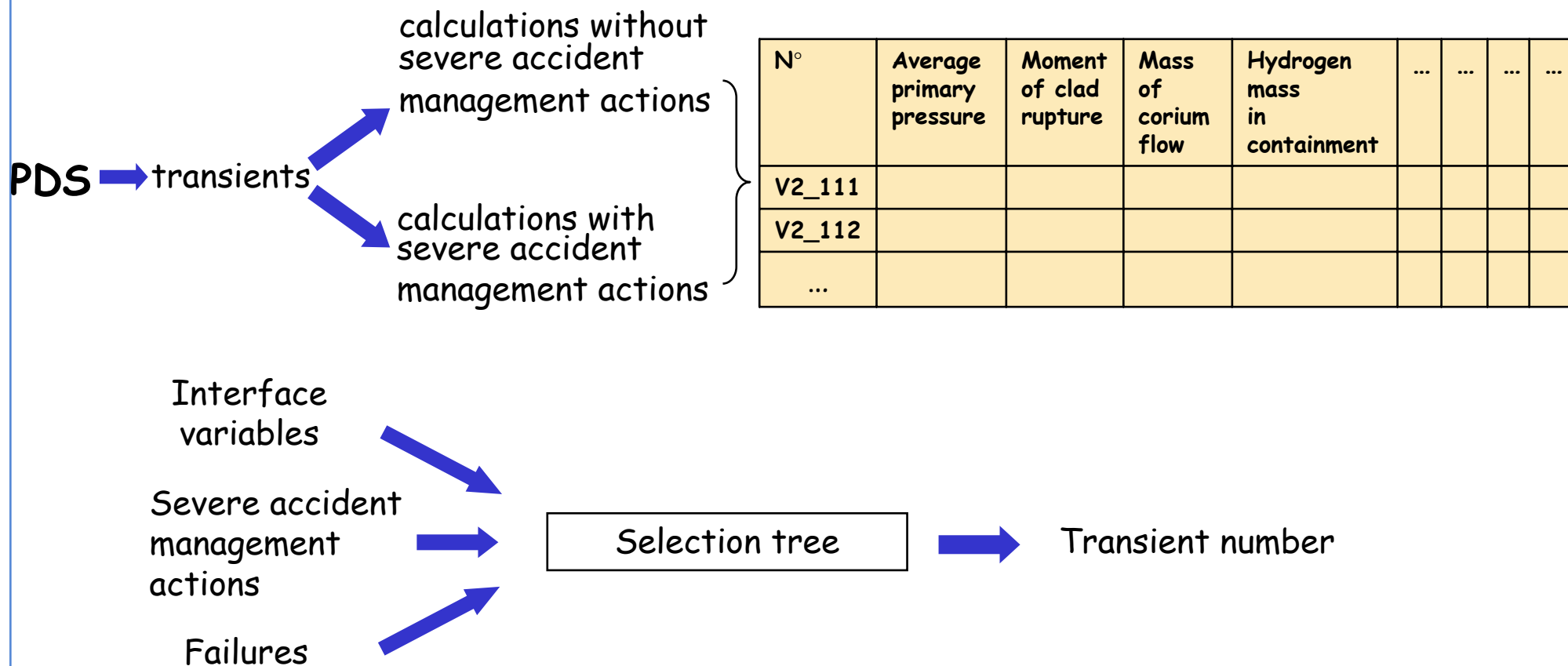
22 Example 1 - Core degradation

- ❑ Aim : to describe accident progression from beginning of core degradation to appearance of a corium flow in the lower head
- ❑ Tools : SIPA simulator with CATHARE 2 for transients (from initiating event to beginning of core uncovering) - ASTEC V0.4 after core dewatering.
- ❑ Method : a grid of results is used according to 2 stages
 - 1/ for each considered scenario (depending on systems availability, human actions, residual power...), the APET has to choose a representative transient ; the choice is done according to the identification variables values by a selection tree
 - 2/ ASTEC calculation results used for accident progression evaluation are then extracted from the grid for the selected transient

2 Quantification of physical phenomena

22 Example 1 - Core degradation

Use of ASTEC calculations : grid of results + selection tree



2 Quantification of physical phenomena

22 Example 1 - Core degradation

Many physical information are extracted from ASTEC calculations and are used in APET

Residual power at beginning of core degradation	Water temperature in lower head
Delay before beginning core dewatering	Sump temperature at vessel rupture
Moment of total core dewatering	Oxidation fraction of zirconium at vessel rupture
Moment of application of severe accident guide	Melted core composition before corium flow
Moment of clad rupture	Melted core composition after corium flow
Moments of corium flow toward lower head	Moment of core flooding
Moment of vessel rupture	Pressure at flooding
Average primary pressure	Mass of melted core at flooding moment
Primary pressure at vessel rupture	Available water mass in accumulators
Containment pressure at vessel rupture	Minimum flow for evacuation of residual power by evaporation
Fraction of melt core at corium flow toward lower head	Maximum possible hydrogen combustion peak during core degradation
Mass of corium flow	Burnt hydrogen mass in case of ignition by recombiners
Mass of melted core at vessel rupture	First moment of possible ignition by recombiners
Water mass in lower head	Hydrogen mass in containment at vessel rupture if no combustion has occurred
Vessel temperature in upper plenum	Hydrogen burned mass at first possible ignition by recombiners

To maintain a quite simple model, uncertainties are only assigned to results which are supposed to have a major impact on safety issues

□ Uncertainty on hydrogen mass in containment at vessel rupture

High uncertainties because :

- hydrogen in-vessel generation is a complex phenomenon
- combustions can occur before vessel rupture
- burnt hydrogen mass at each combustion before vessel rupture cannot be quantified
- recombiners efficiency depends on hydrogen distribution in containment

mean value	ASTEC value with combustion at the time of first ignition by recombiners
lower boundary	null if the mixture (vapor-hydrogen) is flammable at least once during degradation of core, and half of the mean value otherwise
upper boundary	evaluated according to the containment atmosphere composition; corresponds to the hydrogen mass necessary to reach the limit of recombiners ignition criteria (criteria are based on H2PAR, KALI H2 and AECL experiments)

2 Quantification of physical phenomena

22 Example 1 - Core degradation

□ **Uncertainty on total mass of relocated corium in lower head**

The calculated relocated mass strongly depends on the numerical meshing

The relocated mass is sampled between two ASTEC results :

- the mass of relocated corium (MIN)
- the total melt core mass (MAX)

Experts considered an exponential distribution between these boundaries.

The sampled value is then transmitted to advanced core degradation model and direct containment heating model.

2 Quantification of physical phenomena

22 Example 2 - Delay before vessel rupture

A specific code has been developed for evaluation of delay before vessel rupture after corium flow in the vessel.

Based on results obtained with this code, a response surface has been established for the APET.

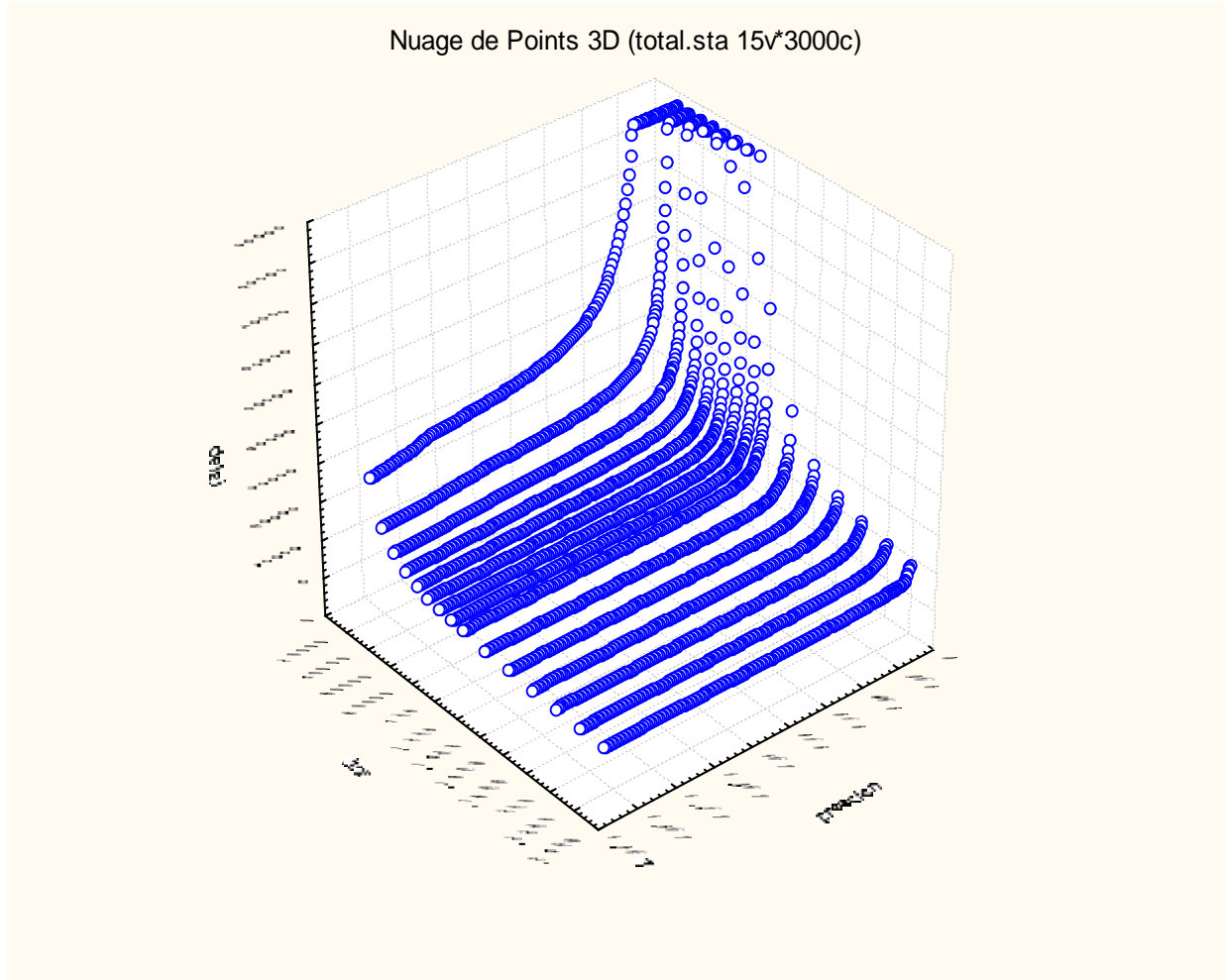
2 Quantification of physical phenomena

22 Example 2 - Delay before vessel rupture

Uncertain parameters	Mean Value	Uncertainty
The so-called "tunnel effect" observed at TMI2 (part of the corium which flows inside tunnel of crust without interacting with the water)	0.75	[0.5 - 1.]
Density of corium (oxide) kg/m ³	6000	[5000;7000]
Conductivity of corium (oxide) W/mK	3.3	[2.3 ; 4.3]
Dilatability of corium (oxide) K ⁻¹	1 10 ⁻⁴	[0.5;1.5]1.10 ⁻⁴
Viscosity of corium (oxide) Kg/m/s	4 10 ⁻³	[2.; 6]1.10 ⁻³
Specific heat of corium (oxide) J/K/kg	600	[450 ; 750]
Density of corium (metallic) kg/m ³	6000	[5000;7000]
State variables		
Primary pressure at the first corium flow towards the lower head		
Total mass of relocated corium		
Corium composition at the first corium flow towards the lower head		
Mass of water		
Time of the first corium flow towards the lower head		

2 Quantification of physical phenomena

22 Example 2 - Delay before vessel rupture



The APET model has to calculate delay before foundation penetration after vessel rupture and flow of corium into the reactor pit.

Construction of the model is based on CORCON code results.

“State” variables are

- the residual power,
- the mass of corium in vessel pit (which depends partly on ejected corium mass in containment at vessel rupture by DCH or ex-vessel steam explosion),
- the non-oxidized zirconium mass
- the steel mass

2 Quantification of physical phenomena

23 Example 2 - Delay before foundation penetration

Response surface methodology has been followed without success and grids of results are used in APET.

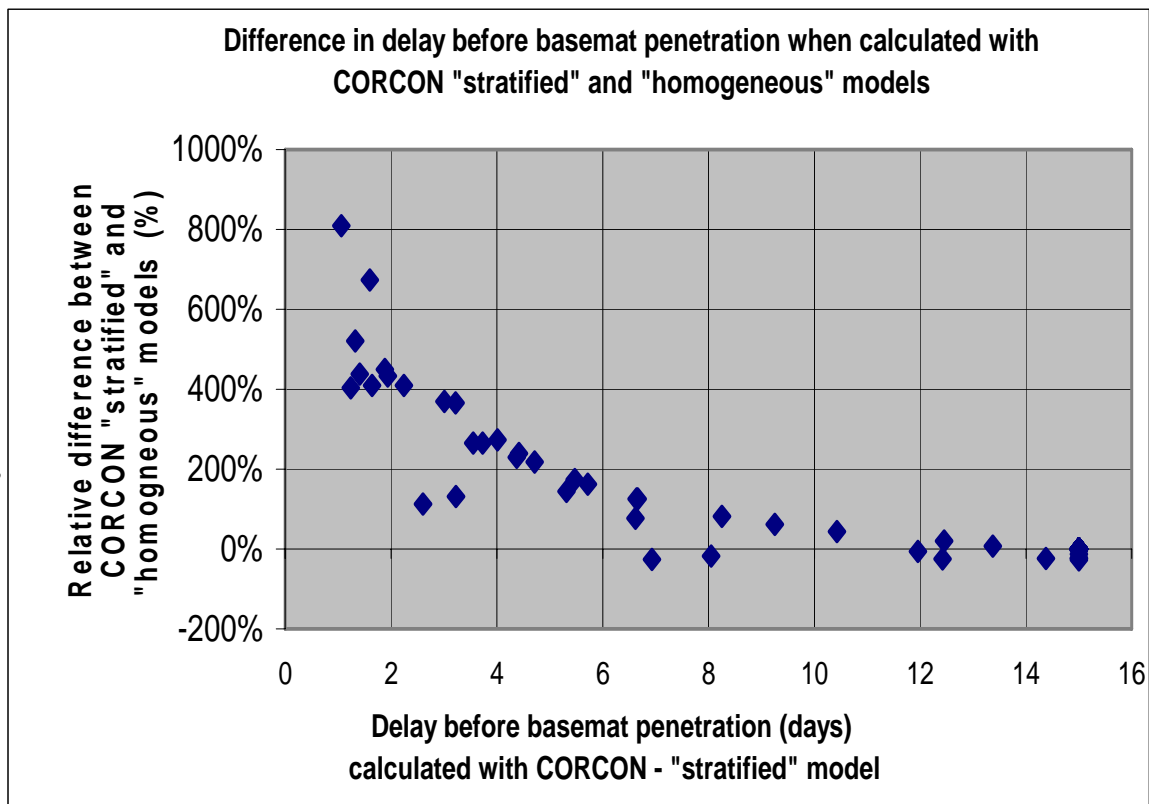
In complement, an analysis of physical models of CORCON code was performed in collaboration with CEA. This analysis has confirmed the lack of knowledge on MCCI phenomena and the high level of uncertainties on CORCON predictions.

To simplify the model elaboration and considering the result of the assessment of CORCON models, it has been considered that uncertainties could be assessed by the difference between results obtained with CORCON for two modeling of the corium configuration (homogeneous or stratified with metallic and oxidized layers).

2 Quantification of physical phenomena

23 Example 2 - Delay before foundation penetration

Results conduct to a very high level of uncertainties for calculations of delay before foundation penetration



Reduction of uncertainties on MCCI calculations will remain an objective for next versions of the study.

3 Quantification of releases

31 Method

Two main requirements for releases evaluation in IRSN level 2 PSA

- Best-estimate evaluation with quantification of uncertainties
- Definition of detailed Release Categories (more than 1000 RC can be generated)

Releases evaluation

- Inventory of uncertain parameters and definition of their distribution law
- A simplified model can estimate atmospheric releases for each RC and for any values of uncertain parameters

3 Quantification of releases

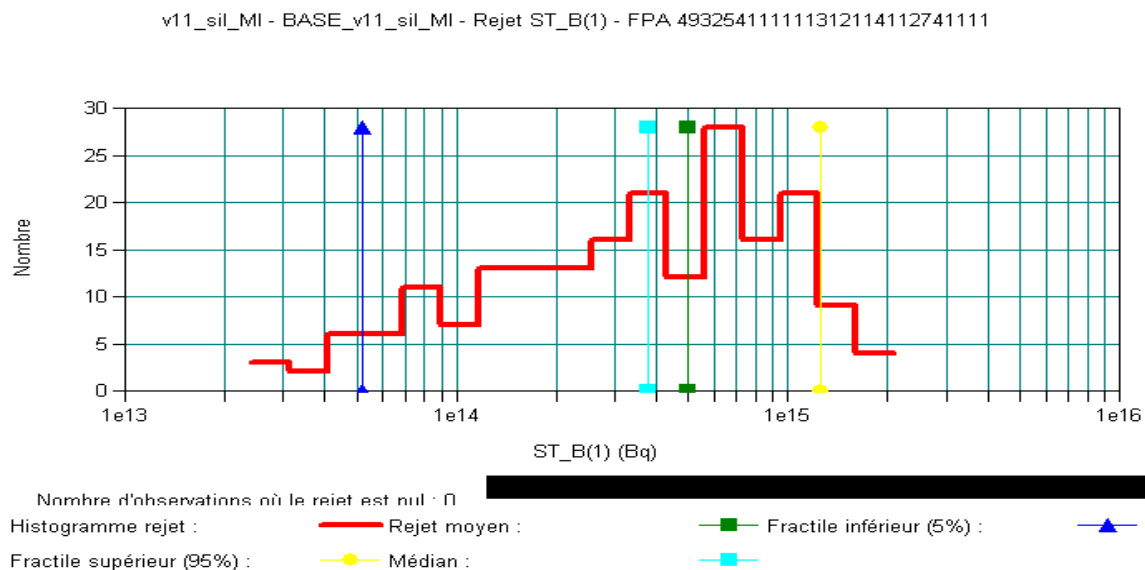
31 Method

Example of uncertain parameters

- Coefficient multiplying the containment size break
- Mass of noble gases emitted during core melt
- Mass of aerosols emitted during core melt
- Mass of volatile molecular iodine emitted in the containment during core melt
- Aerosols retention coefficient inside the RCS
- Aerosols retention coefficient inside the secondary system
- Resuspension coefficient of the aerosols deposited on the containment walls
- Coefficient characterizing the adsorption speed law of molecular iodine on the painted surfaces of the containment
- Coefficient characterizing the conversion of molecular iodine into organic iodine when adsorbed on the painted surfaces of the containment
- Coefficient concerning iodine separation between liquid and gaseous phases in case of a liquid leakage
- Coefficient of in vessel aerosols resuspension / revolatilization
- Duration of core degradation phase

3 Quantification of releases

32 Example 1



Example of distribution law for noble gases releases before vessel breach

Uncertainties have been taken into account on the containment leakage rate to express the loss of information regarding this rate, while binning level 2 PSA sequences into release categories

As shown above, these uncertainties have a strong impact on the extent of the release distribution law of any species

3 Quantification of releases

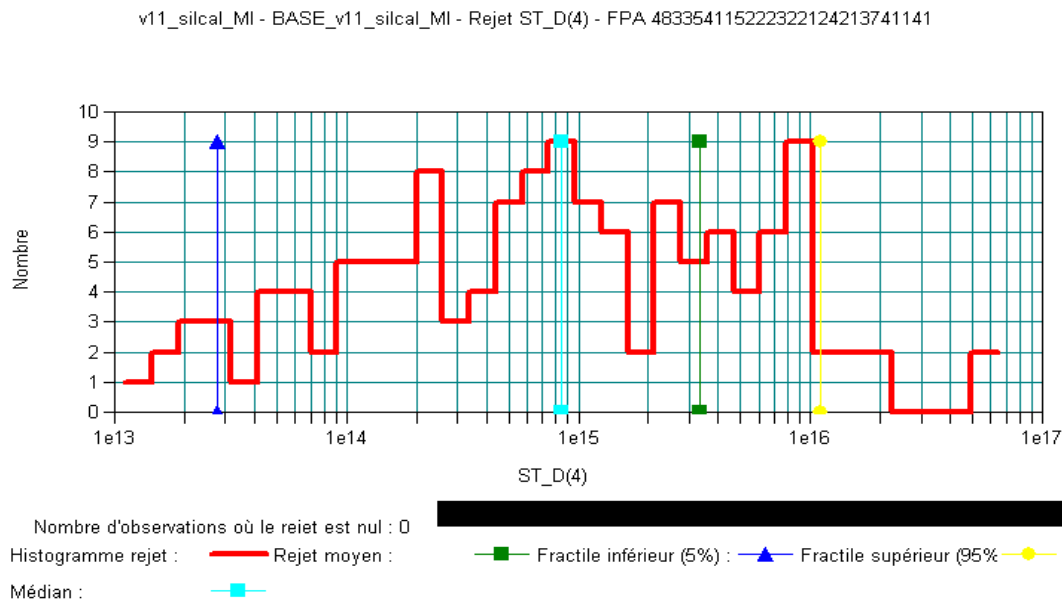
32 Example 1

In the case of the previous example, epistemic uncertainties on noble gases behaviour are quite negligible in comparison with the loss of information on containment leakage rate due to binning of level 2 PSA sequences

⇒ An objective of the forthcoming level 2 PSA should be the reduction of uncertainties by improvement of the methodology, to make uncertainties due to binning of level 2 PSA sequences one order of magnitude below epistemic uncertainties

3 Quantification of releases

33 Example 2



Example of distribution law for organic iodine releases in case of containment venting

Very large dispersion mainly due to the uncertainties on :

- emission of volatile form in the containment
- conversion of molecular iodine into organic iodine on the painted surfaces

⇒ improvement of knowledge on iodine behaviour remains an R&D priority

4 Conclusion and perspective

In the IRSN methodology, effort is made to minimize uncertainties due to binning of sequences by a large number of calculated transients.

Physical models of APET include uncertainties evaluation. This evaluation is obtained by code calculation and is completed by experts judgment in some cases (hydrogen production in case of reflooding, hydrogen mass in containment at vessel rupture, reflooding efficiency, corium melted mass in vessel at vessel rupture time ...).

For release assessment, uncertainties come in some cases from a lack of knowledge (organic iodine production for example) and also from binning effect (containment leak size).

An objective for next version of level 2 PSA (with a best-estimate approach) should be to keep uncertainties due to binning of sequences one order of magnitude below uncertainties due to lack of knowledge.