

IRSN

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Modeling hydrogen explosion in level 1 PSA

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Gaseous hydrogen in PWR

➤ Normal operation of the plant: hydrogen sources

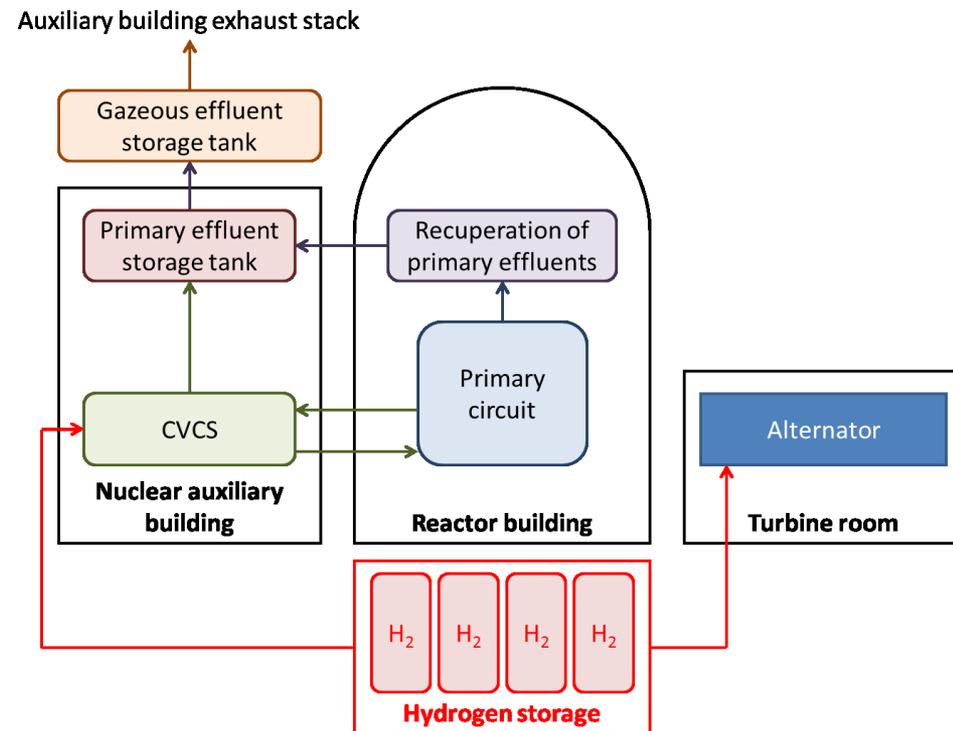
Physical properties

- High calorific heat
→ alternator cooling

Chemical properties

- Radiolysis effect: production of O_2 in main primary circuit
→ saturation of primary water with H_2 (CVCS)

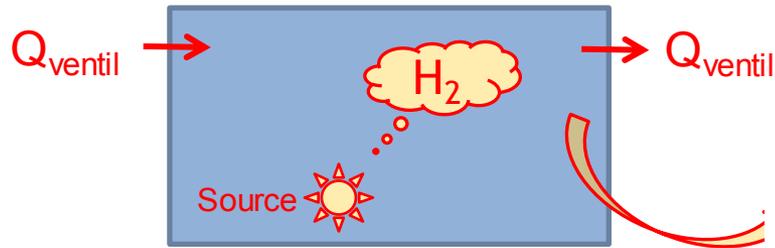
Constant production in the electrical batteries



Gaseous hydrogen in PWR

➤ Accumulation of hydrogen: simple modeling

■ Modeling assumption: homogeneous dispersion



Hydrogen concentration evolution:

$$C(t + dt) = C(t) + \frac{Q_{H_2} dt}{V} - \frac{Q_{ventil} C(t) dt}{V}$$

■ Without venting $\frac{dC}{dt} = \frac{Q_{H_2}}{V} \Rightarrow C(t) = \frac{Q_{H_2}}{V} t$

■ With venting

$$C(t) = \frac{Q_{H_2}}{Q_{ventil}} \cdot \left(1 - e^{-\frac{Q_{ventil}}{V} t}\right)$$

➤ Evaluation of Q_{H_2} ?

Gaseous hydrogen in PWR

➤ Hydrogen flowrate

Auxiliary nuclear building

Initiating event: leak (pipe, valve, etc...)

Physical modeling:

- Energy conservation
- Perfect gas
- Isentropic expansion

Hydrogen flowrate

$$Q_{H_2} = S \cdot \rho_s \cdot \left(\frac{P}{P_s}\right)^{\frac{1}{\gamma}} \sqrt{\frac{2\gamma}{\gamma-1} \left(1 - \left(\frac{P}{P_s}\right)^{\frac{\gamma-1}{\gamma}}\right)}$$

γ : Laplace coefficient

\dots_s : characteristics of H_2 storage tank

Electrical building (batteries)

Initiating event: loss of venting system

Physical modeling:

- Faraday's law
- Penalization to take into account aging or temperature effects (Arrhenius law)

Hydrogen flowrate

$$Q_{H_2} = 0,42 \cdot 10^{-3} \cdot I \cdot C \cdot N$$

I (A/Ah) : applied current

C (Ah) : capacity of the battery

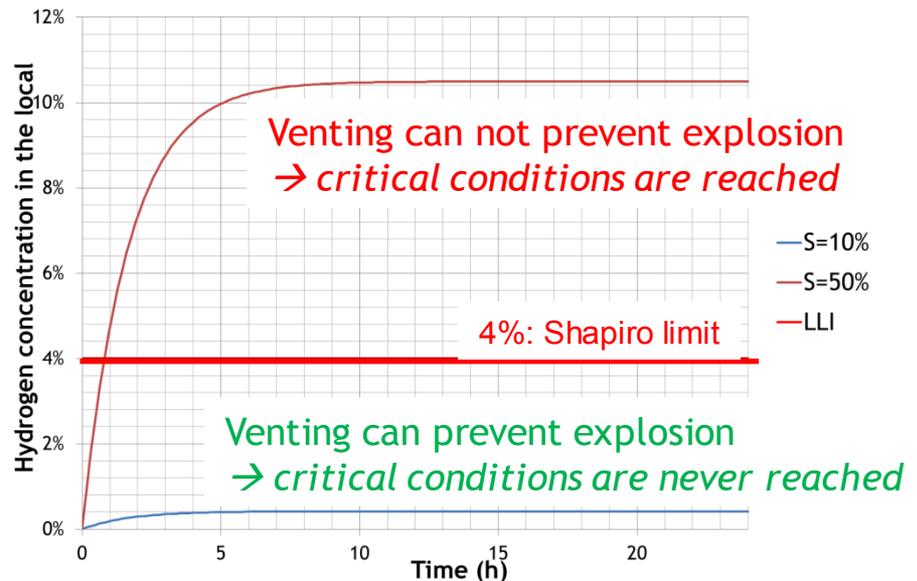
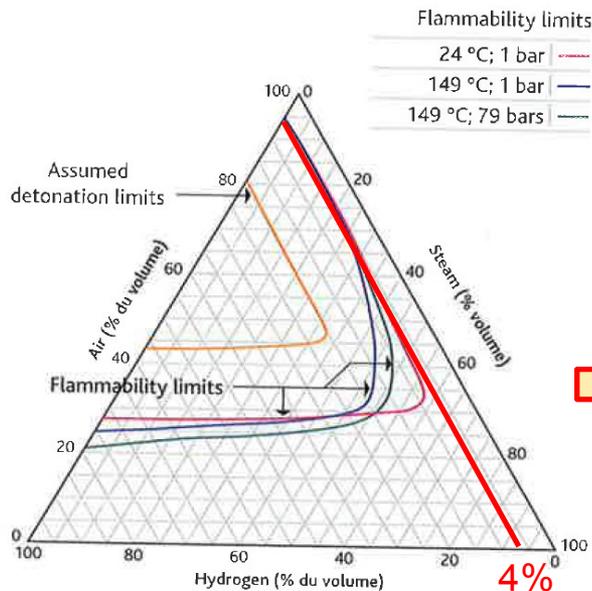
N : number of elements in the battery

Gaseous hydrogen in PWR

➤ Explosion

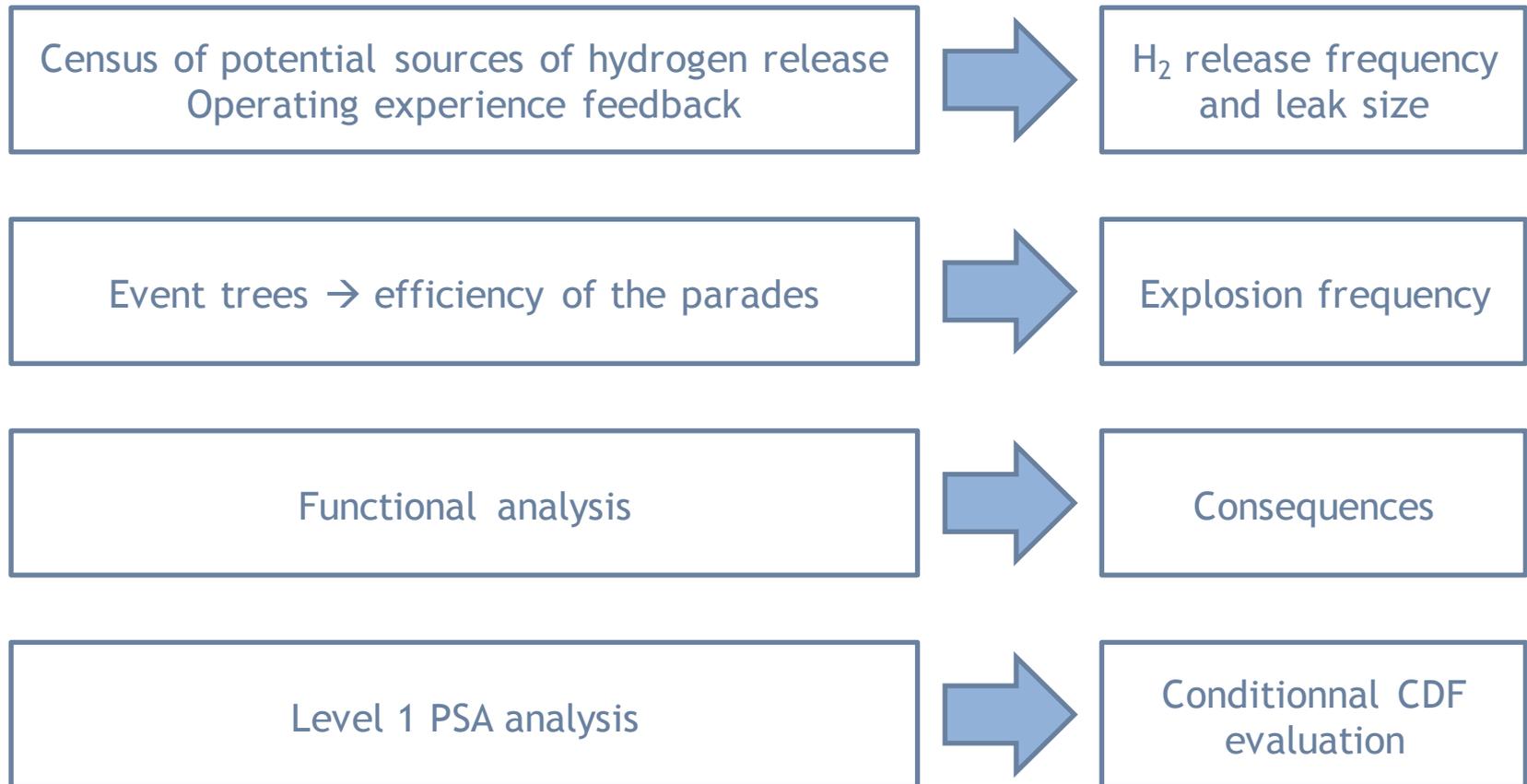
Based on the hydrogen flowrate and local properties (volume, venting flowrate, etc...), the hydrogen concentration is calculated and compared to the Shapiro limits

Typical results in auxiliary nuclear building:



General overview of the PSA

➤ Four successive steps



General overview of the strategy

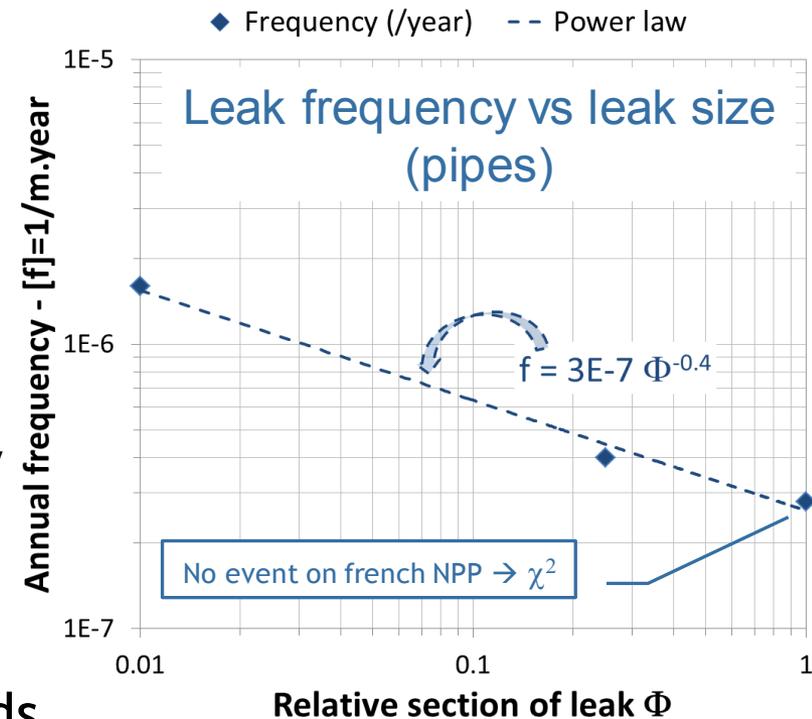
➤ Step 1: H₂ release frequency and leak size

■ Frequency evaluation: IRSN used only the national OEF

■ Difficulty: the events reports rarely mention the break size

- **Singularities:** an arbitrary size of $eD/4$ has been retained
- **Pipes:** three categories have been defined (1%, 25%, 100%), and the affectation of an event to a category has been decided on the basis of experts judgements

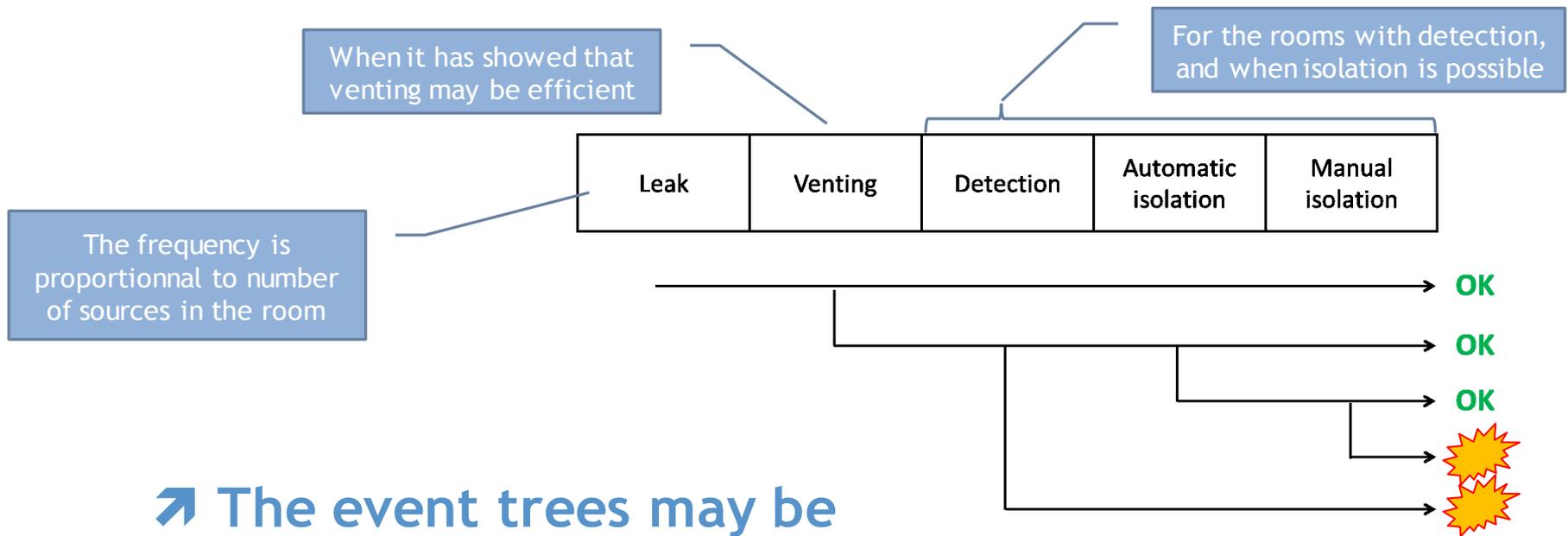
■ Some more sophisticated methods may be found in the littérature (Bayesian approach...)



General overview of the strategy

➤ Step 2: explosion frequency

- For every room with H₂ pipes, an event tree is constructed
 - Unacceptable consequence: accumulation of hydrogen over 4% in volume
→ *venting system is not necessarily efficient, as mentioned above*



➤ The event trees may be simpler in some rooms!

General overview of the strategy

➤ Steps 3 and 4: functional analysis and CDF evaluation

- This step is probably the most challenging of the study

- The consequences on the material are difficult to evaluate

- IRSN approach is simplified: when an explosion takes place all the materials are considered to be lost

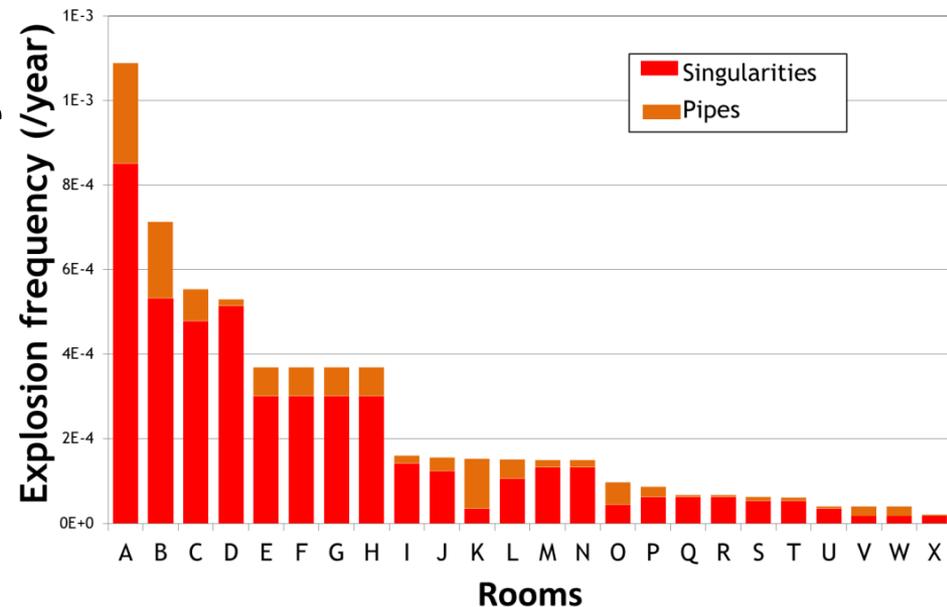
- In some cases, the explosion induces an « initiating event » (from the « internal event level 1 PSA » point of view)
- Some of the parades taken into account for this event may also be lost
- IRSN analysis has been limited to one room, where the consequences have been estimated to be the more severe

➤ This step should be improved in the future IRSN studies

General overview of the strategy

➤ Some results

- Pipes contribution to the risk of explosion is not negligible (~40% in the IRSN study)
- A clear classification of the rooms regarding the risk of explosion may be obtained
- The evaluations of the induced CDF have to be consolidated



Conclusion and IRSN perspectives

- The analysis performed by IRSN has been used for the expertise of the similar EDF study that has been realized for the 4th decennial visit of the 900 MWe NPP
 - Despite some differences in the underlying hypotheses, the classification of the different rooms (regarding H₂ explosion risk) appears to be particularly robust
- This analysis is a great interest to evaluate the contribution of the different rooms to the risk of core melting induced by an H₂ explosion
- IRSN considers that this analysis may be used to prioritize the control that should be performed on the venting system, room by room

Conclusion and IRSN perspectives

- Future perspectives: this analysis will be performed again for the 1300 MWe NPP
 - Some improvements are expected in the quantification of the leak frequencies
- An important effort will be devoted to the evaluation of the explosion consequences
 - In particular, the possibility of hydrogen dispersion in the rooms adjacent to the « source » will be investigated
 - The assumption of « homogeneous dilution » in the room will be questioned