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IRSN / PSN-RES / SAG

Severe accident mitigation strategy for the generation II PWRs in France – some outcomes of the on-going periodic safety review of the French 1300 MWe PWR series

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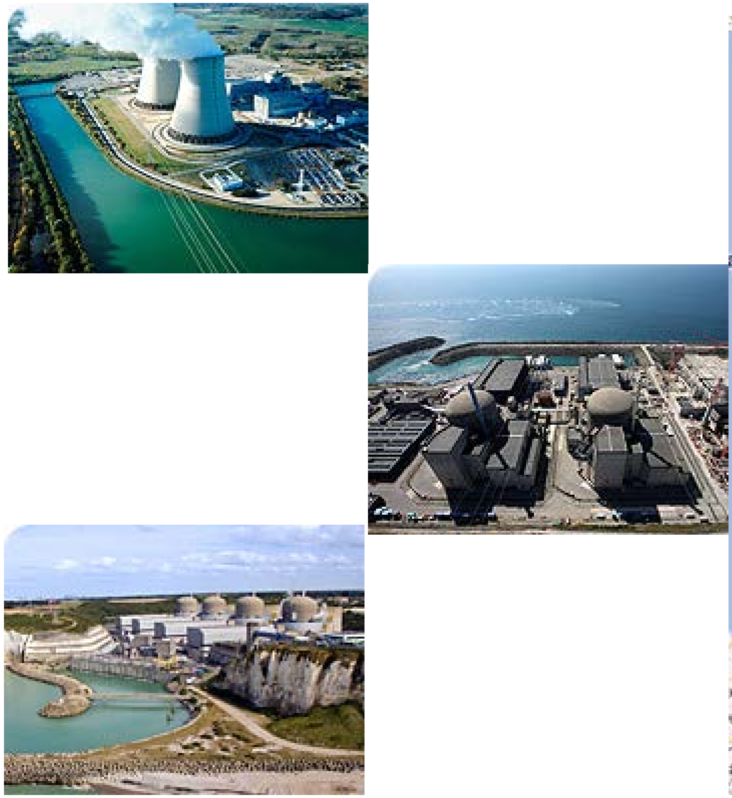
CONTEXT: French Periodic Safety Reviews

The French electrical utility EDF is operating a fleet of 58 standarized PWRs

3 series of 900 MWe (34 reactors), 1300 MWe (20 reactors) and 1450 MWe (4 reactors)



CONTEXT: French Periodic Safety Reviews

French regulatory framework:

Periodic Safety Reviews (PSRs)
every 10 years for the whole series considered

The 3rd PSR for the 1300 MWe PWRs is presently on-going

Their 3rd ten-yearly outage is planed from 2015 to 2021

CONTEXT: French Periodic Safety Reviews

Core melting accidents (severe accidents) were not included in the initial design of the Gen II PWRs

NEVERTHELESS

All French PWRs include already severe accident management equipment as a result of previous reviews such as (non limited list)

- PARs
  Passive Autocatalytic Hydrogen Recombiners
- EFCVS
  Emergency Filtered Containment Venting System
- Severe accident instrumentation

CONTEXT: French Periodic Safety Reviews

EDF has produced a severe accident safety standard for 1300 MWe reactors including the safety requirements

containing

The approach and safety objectives
(severe accident prevention and mitigation)

The studies necessary to demonstrate compliance with the objectives

The current practical provisions and their design basis

The requirements applied to equipment used during severe accident

CONTEXT: French Periodic Safety Reviews

The EDF severe accident safety standard has been analyzed by IRSN

keeping in mind that

Severe accident frequencies and radiological consequences should be as low as reasonably practicable

The robustness of equipment used for severe accident management should be ensured

Severe accident management strategies should be as safe as possible (radiological consequences should be as low as reasonably practicable)

Severe accident frequencies and consequences

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Severe accident frequencies and radiological consequences should be as low as reasonably practicable

The robustness of equipment used for severe accident management should be ensured

Severe accident management strategies should be as safe as possible (radiological consequences should be as low as reasonably practicable)

IRSN level 2 probabilistic safety assessment (L2 PSA) was used to compare the assumptions of the EDF L2 PSA

A simplified reassessment of the EDF results was then performed by IRSN taking into account lessons learned from this review

Severe accident frequencies and consequences

Then, to review the plant modifications and to identify some additional issues for plant safety enhancement

IRSN identified the containment failure modes that contribute the most to the global risk using a risk metric based on the product (accident frequency) x (consequence amplitude)

(without giving too much importance to the figures themselves)

(accident frequency)
obtained from the
IRSN reassessment
work of EDF L2 PSA

(consequence amplitude)
1000 (large early releases)
100 (other non acceptable releases)
10 (late filtered releases)

Severe accident frequencies and consequences

Risk of containment bypass by induced steam generator tube rupture (accident of core melt without reactor coolant system depressurization) is one of the dominant risks (due to the high station black-out frequency as initiating event)

Two modifications are planned by EDF

1. To anticipate the pressurizer valves opening in the operators procedures
2. To modify the pressurizer valves pilot to guaranty that the valves stay in open position even if there is not any more power supply

IRSN has considered these two modifications relevant

The complementary safety review performed after the Fukushima accident has confirmed the importance of this issue

Severe accident frequencies and consequences

The L2 PSA results (EDF, IRSN) show the interest to provide an additional electrical supply of some containment isolation valves to improve the reliability of the containment isolation in case of station black out

This modification is planned by EDF for all reactors

Interest was confirmed during complementary safety review performed after the Fukushima accident

Robustness of equipment used for severe accident management

EDF severe accident safety standard has been analyzed by IRSN

keeping in mind that

Severe accident frequencies and radiological consequences
should be as low as reasonably practicable

The robustness of equipment used for severe accident management should be ensured

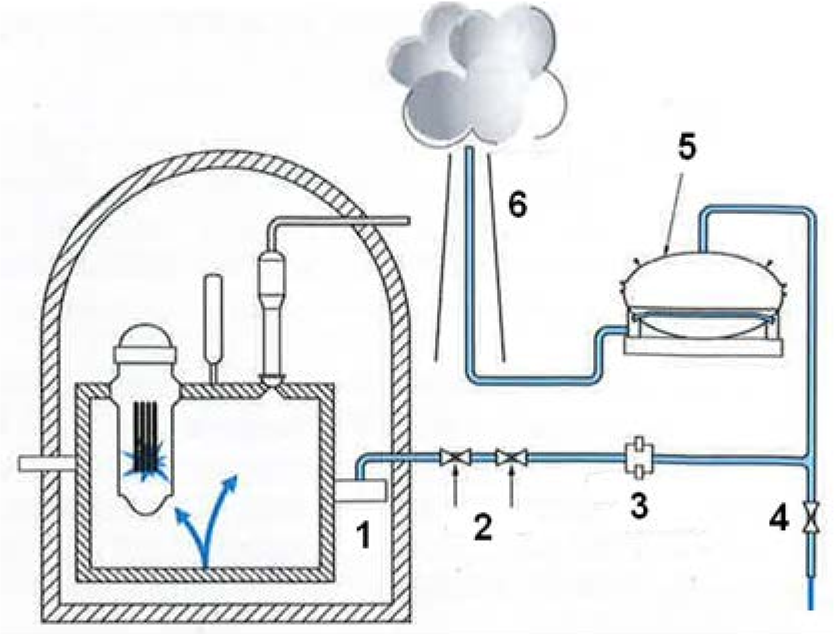
Severe accident management strategies should be as safe as possible (radiological consequences should be as low as reasonably practicable)

IRSN has reviewed the list of equipment
and the EDF requirements for each equipment
associated to severe accident management

Robustness of equipment used for severe accident management

Behavior of equipment in severe accident (P, T, radiation, ...), protection against internal and external events and also reliability. One example

French EFCVS opening is performed by means of 2 isolation manual valves in series. In other countries, the opening of EFCV is either redundant or diversified (manual or motorized valves, rupture disks...)



EDF was asked to perform
a feasibility study
of the French EFCVS
opening redondancy
or diversification

Management of the water in the reactor cavity

EDF severe accident safety standard has been analyzed by IRSN

keeping in mind that

Severe accident frequencies and radiological consequences should be as low as reasonably practicable

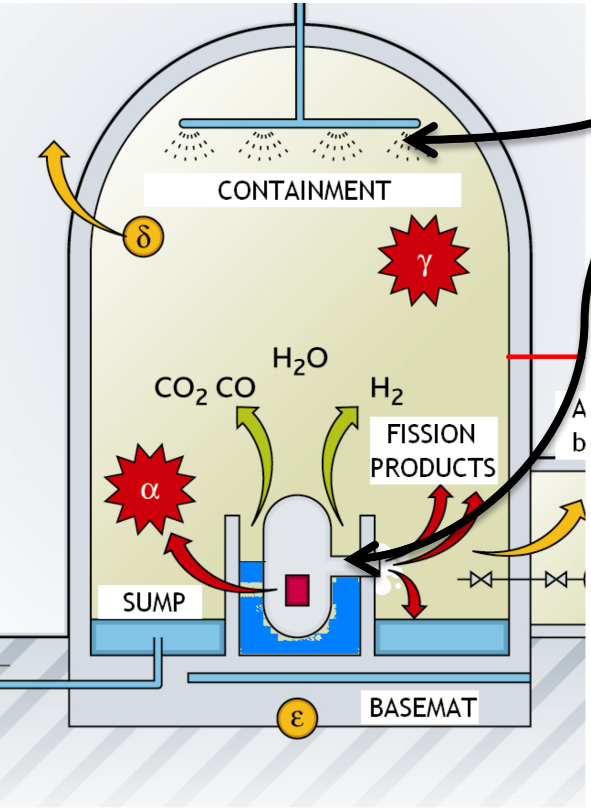
The robustness of equipment used for severe accident management should be ensured

Severe accident management strategies should be as safe as possible (radiological consequences should be as low as reasonably practicable)

As an example, management of the water in the reactor cavity (compartment of the reactor containing the reactor vessel) during a severe accident has been analyzed by IRSN

Management of the water in the reactor cavity

For French PWRs
there is water entering into the reactor cavity
IF INTERNAL CONTAINMENT SPRAY IS FUNCTIONING



Passive complete reactor cavity flooding possible within 1.5 to 2.5 hours of spray system functioning.

DOES THIS WATER REALLY HAVE A BENEFICIAL EFFECT ON THE REACTOR SAFETY during a core melting accident?

Management of the water in the reactor cavity

What are the beneficial impacts?

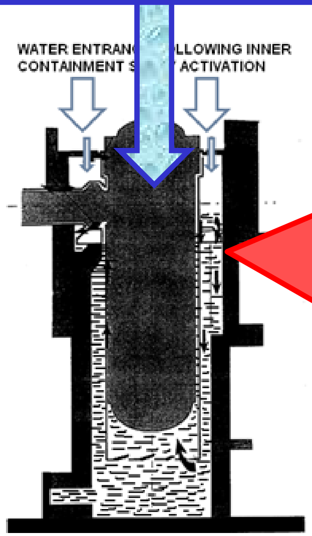
COOLING the molten core INSIDE the vessel?

IT REQUIRES BOTH

Water injection into the vessel

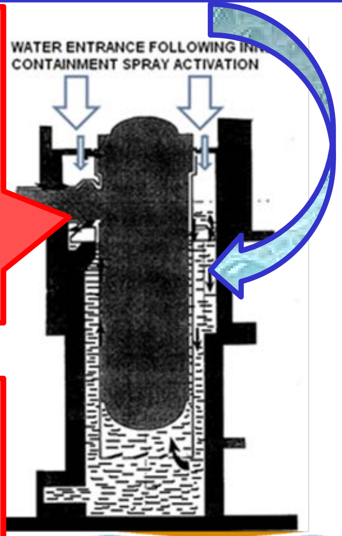
AND

A fully flooded reactor cavity



BUT if the core is melting, it is probably because there is no water injection into vessel

A fully reactor cavity flooding needs hours



Both conditions difficult to reach with a passive reactor cavity flooding following containment spray activation

Management of the water in the reactor cavity

What are the beneficial impacts?

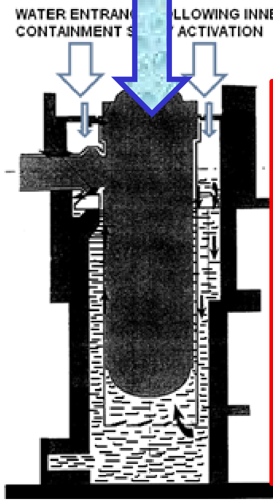
COOLING the molten core INSIDE the vessel?

IT REQUIRES BOTH

Water injection into the vessel

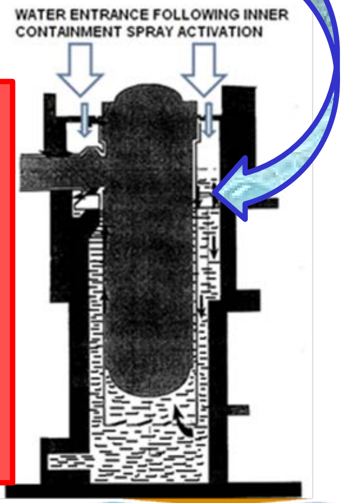
AND

A fully flooded reactor cavity



Even if both conditions fulfilled

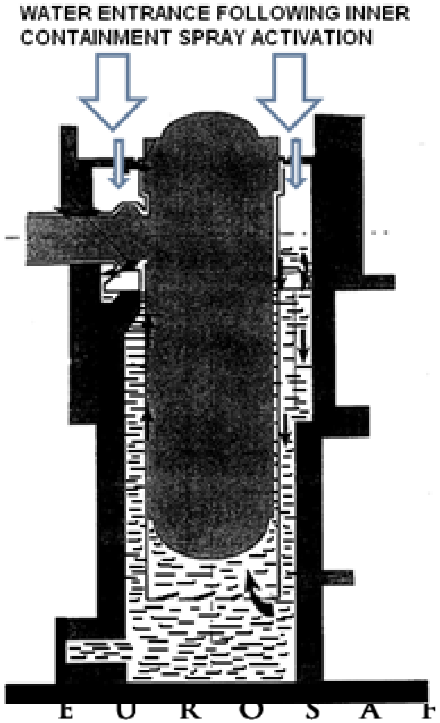
The vessel lower head failure
MAY BE INEVITABLE
with a high decay heat level and a large corium melt relocated in the vessel lower head, i.e. for accidents leading to a fast core melting



Management of the water in the reactor cavity

What are the beneficial impacts?

COOLING the molten core INSIDE the vessel?



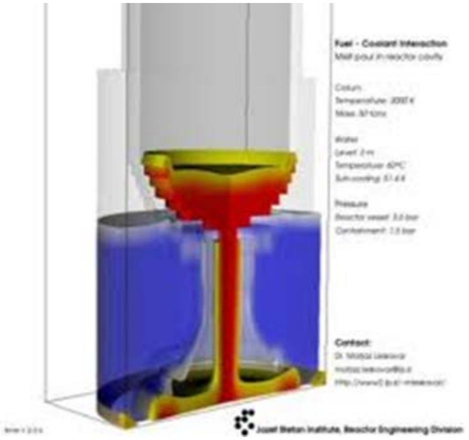
If there is no water injection into the vessel

The vessel lower head failure
is INEVITABLE
even with a flooded reactor cavity
(either passively following spray activation or voluntarily using dedicated systems)

Management of the water in the reactor cavity

What are the beneficial impacts?

IN CASE OF VESSEL LOWER HEAD FAILURE



COOLING the molten core OUTSIDE the vessel?

There is presently NO DEMONSTRATION that a large mass of molten core flooded with water can be cooled inside the reactor cavity and/or spread all over the bottom area of the reactor cavity
(risk of local melt accumulation)

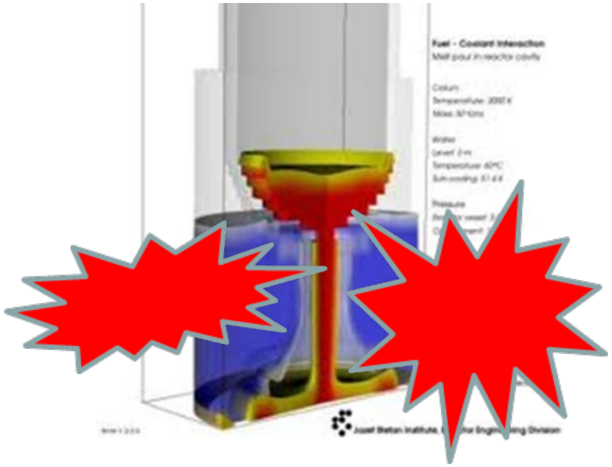
Management of the water in the reactor cavity

What are the negative impacts?

IN CASE OF VESSEL LOWER HEAD FAILURE

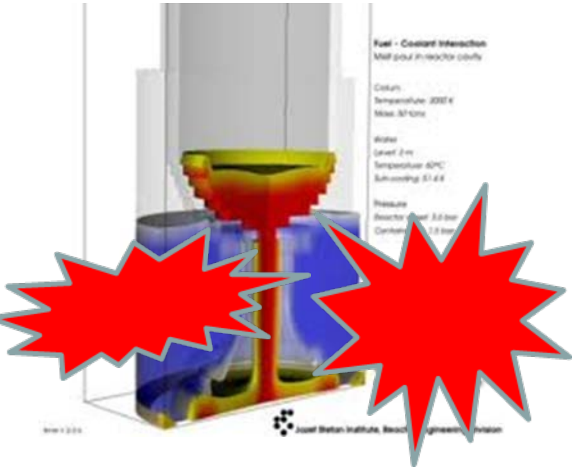
During molten core release into water

Possible EXPLOSION in the reactor cavity due to ENERGETIC fuel coolant interactions called “steam explosion”



Management of the water in the reactor cavity

In case of a steam explosion in the reactor cavity



What are the consequences of the explosion on the whole 1300 MWe PWRs reactor safety?

on the reactor containment tightness?

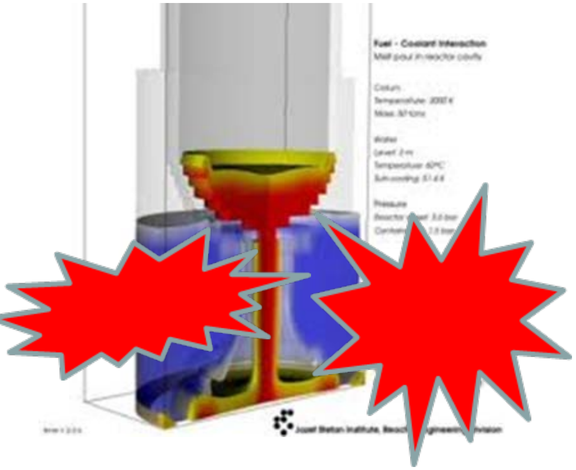
on the reactor SA management possibilities?

It depends on the status of the internal structures and equipment in the containment after the explosion

Results of calculations raised questions about potential consequences, for example on heavy equipment and containment penetrations tightness and showed a potential for equipment dysfunctions (if not destruction)

Management of the water in the reactor cavity

In case of a steam explosion in the reactor cavity



QUESTIONS ALWAYS REMAIN because the status of internal structures and equipment in the containment after the explosion is evaluated by means of calculations subjected to LARGE UNCERTAINTIES

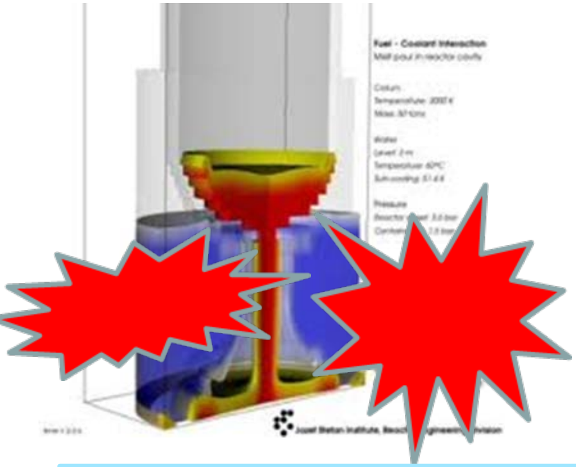
All these issues show that the possibility of an intense steam explosion in the reactor cavity threats the efficiency of accident management in addition to a possible containment tightness damage

Management of the water in the reactor cavity

The effective risk associated to a steam explosion
after vessel lower head failure with a flooded reactor cavity
is still a topic of debate

IRSN has deemed that solutions
able to avoid possibility of energetic phenomena
must be preferred because
it eliminates a risk of an early containment failure
(large early radioactive release)
or additional equipment damage
that can threat the long term accident management

Management of the water in the reactor cavity



Solutions able to avoid possibility of energetic phenomena must be preferred

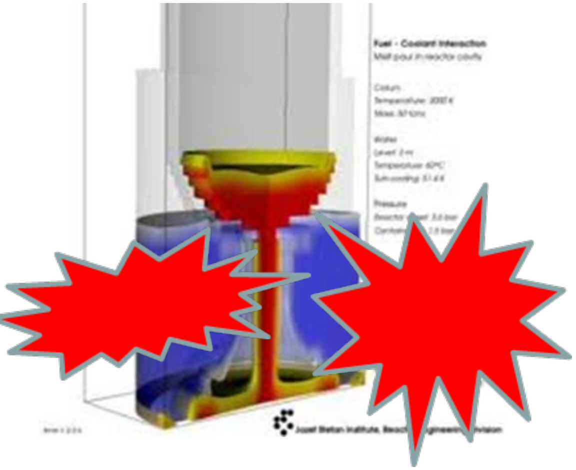
High pressure core melt ejection in the reactor cavity prevented by means of voluntary primary circuit depressurization

Hydrogen explosion in the containment prevented and mitigated by means of PARs

Flooding the reactor cavity does not prevent a steam explosion

Management of the water in the reactor cavity

In case of steam explosion in the reactor cavity



Solutions able to avoid possibility of energetic phenomena must be preferred

Steam explosion is PRACTICALLY ELIMINATED
if water is not available to contact the molten pool

A severe accident management strategy avoiding a steam explosion in the reactor cavity could be obtained
by avoiding water in the reactor cavity before the vessel failure
and by promoting corium cooling after vessel failure
(for instance by promoting corium spreading followed by water injection on the corium)

Conclusions

The 3rd PSR of the French 1300 MWe PWRs series includes the reactors upgrades to increase their robustness in the case of a severe accident

Their analysis is based on both deterministic and probabilistic approaches

The utility L2 PSA review by IRSN has confirmed the benefits of some modifications proposed by EDF (additional electrical supply of the containment isolation valves, new electrical command of reactor coolant system depressurization safety valves…)

It helps also identifying some risks that can still be reduced by mitigation measures or better understood through R&D efforts

Conclusions

The optimization of severe accident management
strategies remains an area were progress is expected
as shown by the management of the water
in the reactor cavity

This is an example where the optimal strategy
is not so easy to define

IRSN has concluded that solutions able to avoid possibility
of energetic phenomena must be preferred because
it eliminates a risk of an early containment failure
(large early radioactive release)
or additional equipment damage that can threat
the long term accident management

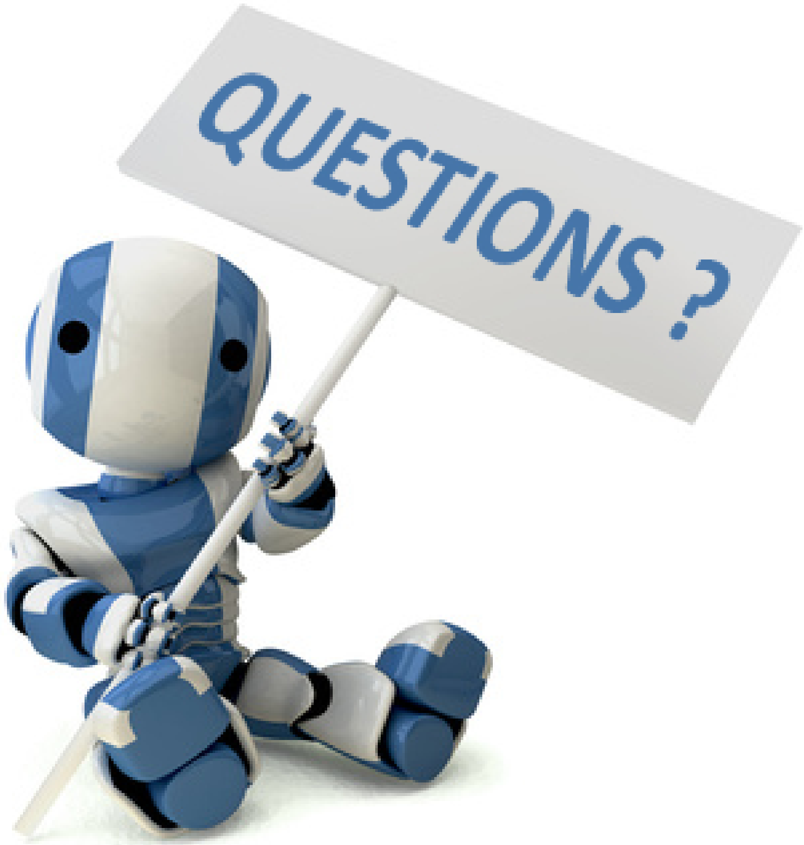
Conclusions

For on-going and future activities
the robustness of equipment
to be used in severe accident conditions
has a major interest

It concerns the behavior of equipment in severe accident conditions (pressure, temperature, radiation, ...)
their protection against internal and external events
and also their reliability

The interest of a diversification or redundancy of the French ECVS opening is one example among many others


Thank you!


QUESTIONS ?