Impact of safety relevant severe accident R&D topics and uncertainties on the mitigation features selection

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1. Background and Goal of the present work

After the Fukushima accidents, most nuclear countries have launched reassessment of the safety margins towards extreme events and severe situations. The first lessons learned have already oriented the design measures towards the robustness of the defence in depth approach. Nevertheless in the field of severe accidents, in spite of R&D performed for several decades, some major issues remain incompletely resolved due to phenomenological uncertainties. Some of them could challenge the trend of the safety objectives after Fukushima to practically eliminate the early and large radiological releases, should a core melt occur

The safety enhancement can naturally apply to the new reactors at the design stage. Ensuring the containment integrity against severe accidents phenomena without cliff-edge effects at short and long terms, may request the implementation of robust mitigation features

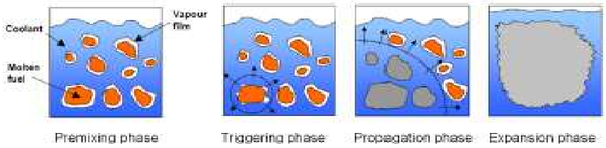
The assessment , here-after, of some R&D open issues aims at promoting , for new plants, the selection of mitigation features which overcome with still significant uncertainties ,in order to comply with a robustness requirement .

By pursuing safety related R&D, it is important to reach a consensus regarding uncertainties; it will support the justification of the extent of the efficiency of technical solutions, in particular those implemented at the operating plants .Nevertheless, as long as R&D issues are not closed, the safety objectives of the new reactors and selected mitigation features should be used as reference for operating plants in particular in the frame of Plant Life Extension.

2. Assessment of some R&D open issues which impact the selection of mitigation features

2.1. Ex-vessel steam explosion

It is acknowledged that the underlying physical phenomena related to flooding of pouring corium are not fully understood and significant uncertainties remain. Despite the significant progress made in OECD/SERENA program, high scattering of steam explosion code results have been outlined with high difference between prototypic corium and stimulant (aluminia) experimental results. An improvement of numerical modelling of the jet fragmentation with local conditions is one of the key R&D identified to improve the code robustness and reduce results differences. The high explosion strengths (peak, impulse) can be sensitive to non symmetrical corium release from the vessel, and 3 D calculations (with MC3D code, IDEMO code developed in Europe) must take into account also non vertical corium jet. New R&D intends to investigate oxidation rate effects on voiding (in particular for metallic streams) and impact on solidification of prototypical corium which can be sufficiently strong to reduce at the reactor scale an energetic steam explosion risk.

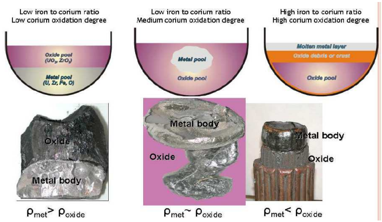


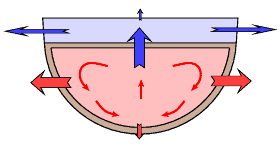
By inducing reactor pit displacement or failure, significant vessel uplift with reactor cooling system displacement with concrete missile or containment penetration failure, ex-vessel steam explosion is one of the phenomena which could lead to an early containment failure according to the state of the present uncertainties of impulse calculations.
To prevent that, a dry reactor pit before vessel failure and corium spreading before flooding enable to justify a safe mitigation approach.

2.2. In-vessel corium retention for high power PWR

One important input data to justify the in-vessel retention by outside vessel cooling is the enhancement of the Critical Heat Flux on the outside surface to remove the heat corium flux, in particular at the top metal layer above the oxide corium in the vessel lower head (focusing effect).Many experiments are on-going to master the optimization. It is mainly the uncertainties related to the thickness of the top metal layer and the highest heat flux which could challenge the vessel integrity.

The OECD MASCA experimental program has identified physicochemical phenomena which could lead to different layering of oxide/metal corium stratification according to mass fraction of steel and oxidation level of corium.





Recent investigations let think that the heat partitioning from the final configuration of corium stratification in the lower determined with a thermodynamic equilibrium model with database to establish the corium partition could be questionable and not representative of the highest thermal flux.

New models development with new experiments are planned to address the kinetics of corium layering, the kinetics of oxidation, with realistic mass and heat transfer through the crust between layers, to determine the focusing effect in transient conditions during corium relocation and not only in steady-state conditions.

Unless to be able to justify the implementation of a reliable early in-vessel re-flooding to complement outside vessel cooling, it appears that the vessel failure risk cannot be negligible for high power PWR (around 1000MW and above) by taking into account the present R&D results .

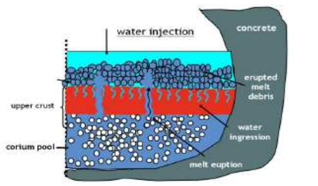
To overcome with drawbacks, in particular the vessel failure and uncertainties associated with released corium fragmentation in the pit and expected high steam explosion loads due to confined pit geometry the choice for new plants, of a robust ex-vessel corium retention (core-catcher) is a safer mitigation approach.

2.3. Ex-vessel corium stabilization by only top flooding

The top flooding of corium during corium/concrete interaction is the simplest containment failure mitigation, especially for operating plants. Related cooling mechanisms as water ingression, corium ejection due to gas production (in particular during the interaction with limestone concrete) have been studied in the OECD-MCCI program, but without a demonstration of the cooling efficiency.

New experimental tests with prototypic corium will have to complete the investigations of the interplay of the different cooling mechanisms and provide data for model development .These investigation will have also to assess the relevance of crust formation due to scale effect and provide data of its mechanical strength. Even some partial cooling can be justified the main uncertainties are related to the depth of the base-mat ablation, knowing that the fraction of mixed concrete with corium can have adverse effects according to the cooling mechanism.

For new plant, to comply with radiological safety objectives with margins, the formation of concrete cracks with risk of radiological leaks can be prevented implementation of a robust core-catcher can ensure containment leak-tightness without risk to melt-trough any bottom liner.



The last step of demonstration of such cooling mode which will be able to impact the back-fitting of operating plant but also future reactors will depend on new experimental approach addressing scale effect and modes of corium water interaction.

2.4. Qualification of mitigation features under harsh severe accident environmental conditions

One lesson learnt from Fukushima accidents is related to the behaviour of structures and systems under harsh environmental conditions, which deserve a comprehensive assessment .In particular the leaks, which occur likely due to very high temperatures, have impacted the pressure in the vessels, the efficiency to bring water into the vessel, the pathways of hydrogen and fission products releases from the Daichi containments.

The development of specific new technology to cope with a severe accident takes into account the validation under severe accident environmental conditions to justify there efficiency:

it is the case of enhanced AREVA's containment filtered venting system which allow to gain a significant factor on the filtration of aerosols, elemental and organic iodines, it is also the case of the resistant passive hydrogen recombiners with high efficient catalyst design and high depletion rate.

But the resistance under harsh severe accident temperature, pressure, radiation should be justified for all equipments and structures participating in maintaining the confinement.

A severe accident qualification should apply in particular to the selected instrumentation which will be used for decision making in a timely many during a severe accident or used to monitor the performance of mitigation measures by indicating correct information..

3. Conclusions and Acknowledgements

To be able to justify the safety enhancement against severe accidents, it is a wise approach to select robust mitigation features which do not involve phenomena (as ex-vessel steam explosion) which do not have a solid and definitive backing from R&D, knowing that many years may be necessary to close the issue without a full guarantee about the results of on-going R&D .A defence in depth approach must be adopted for new plants which can should also remain a reference for improvements implemented in operating plants. We can think that the international impact of Fukushima accidents will accelerate problem solving capabilities and will provide the opportunity to share a common of R&D needs and progress in the field of beyond design events.

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