Multinational Design Evaluation Programme (MDEP)
Common Position
CP-VVERWG-02

VVER Working Group

Common Position Addressing Ex-vessel Corium Stabilization in Core Catcher

Participation

Regulators involved in the MDEP working group discussions:	HAEA (Hungary), AERB (India), NNSA (CPR), Rostechnadzor (RF), NDK (Turkey), STUK (Finland)
Regulators which support the present report	HAEA (Hungary), AERB (India), NNSA (CPR), Rostechnadzor (RF), NDK (Turkey), STUK (Finland)
Compatible with existing IAEA related documents:	Yes

Introduction

Representatives of the regulatory bodies of Finland, Hungary, China, India, Turkey and Russia on the basis of national requirements in the field of severe accidents and design data of the AES-91, AES-92 and AES-2006 agreed on the need to develop a common position regarding the criteria/conditions for reliable ex-vessel corium stabilization in the core catcher. These criteria could be recommendatory in-addition to the existing requirements of national regulators.

Background

All new VVER designs (AES-91, AES-92 and AES-2006) are equipped with a device dedicated for corium localization and cooling in case reactor vessel failure and to prevent containment failure and environmental release due to core melt and concrete interactions. It is a crucible type device, initially containing a volume-distributed sacrificial material. The incoming corium interacts with the sacrificial material, forming a melt that extends through the volume from the centre to the cooled outer surface of the core catcher [1].

Cooling of corium in the core catcher is provided due to water boiling in the shaft surrounding the vessel of the corium catcher. Generated steam comes to the upper part of the containment where it is condensed. Condensate flows down to the containment sump and then from sump to the shaft surrounding the core catcher. Thus, the closed cooling circuit is provided.

Additional cooling of the corium is provided due to water delivery on the surface of the corium in the corium catcher. This water can be delivered by passive way through the valves with melting plugs (AES-2006 only) or by operator from the inspection shaft (both AES-91 and AES-2006 designs).

The national regulatory requirements of member countries regarding the core catcher are of general nature. It could be explained by the fact that core catcher is a new element in the VVER technology, and by the fact that the regulatory requirements are not given for the detailed technical solutions applied in different types of reactors (typically for countries operating different reactor types such as PWR, BWR, VVER). In all member countries, it is expected that in case of ex-vessel stage of severe accident core catcher should ensure:

- sufficient cooling of the melt;
- subcriticality of melt;
- restriction of FP release from the core catcher;
- restriction of the hydrogen release.

Taking into account the complexity of the physical and chemical processes in core catcher the representatives of regulatory authorities discussed the possibility to agree a more detailed criteria (conditions) for justification of reliable melt stabilization in the core catcher.

Although there are many issues that are connected to the core catcher, this Common Position cover only those issues (phenomena) that can affect corium stabilization and those that require some specific properties of the corium and corium stabilization process.

Common Position addressing ex-vessel corium stabilization in the core catcher

The representatives of the regulatory authorities Finland, Hungary, China, India, Turkey and Russia agreed that the following criteria (conditions) should be considered under the review of the justification of successful melt stabilization in the core catcher:

Selection of the representative scenario for the melt stabilization issue

When choosing representative scenarios, the following aspects that can worsen the stabilization of the melt in the core catcher should be taken into account.

Energy of the corium entering in the core catcher. The energy of the fuel melt entering the core catcher determines the intensity of its of its impact on the walls of the core catcher. The higher the level of residual energy release in the melt, the stronger the impact of the melt on the walls of the core catcher vessel will be. Thus, in this respect, the most unfavourable scenario will be the scenario with the earliest melt-through of the reactor pressure vessel, since in this case the residual energy in the melt will be maximal. Usually it is LBLOCA combined with blackout. When assessing the thermal impact of the melt on the wall of the core catcher vessel the heat from all exothermic reactions possible during the interaction of the melt with the sacrificial material, and also other exothermic reactions such as water-metal oxidation, should be taken into account.

The duration of the corium release from the reactor vessel to the core catcher.

Two aspects related to the duration of the melt transfer from the reactor vessel to the core catcher should be taken into account:

a) the release of the melt must be completed before water is supplied to the surface of the melt[1], thus, the scenario with maximal duration of the melt release should be identified and analysed. For this scenario, it should be demonstrated that water delivery on the surface of the melt through passive valves located in the wall of the core catcher will not occur until the melt release from the reactor vessel will be completed.

b) the melt has a significant radiation impact on the thermal shields, located above the core catcher during transport from the reactor vessel to the core catcher and from the surface of the melt in the core catcher until this surface will be flooded with water, thus for scenario with the longest melt release time, the state of the thermal shields and the structures protected by them should be analysed and confirmed that the thermal shields successfully perform their function.

The analyses of the bounding scenario should cover all phases of the accident and phenomena relevant for corium behaviour in the core catcher, and consider for possible operator actions.

Initial characteristics of the melt entering in the core catcher

Usually, when analysing the corium behaviour in the core catcher, characteristics of the melt entering the core catcher (it’s temperature and composition) are assumed to be the same as characteristics of the melt leaving the reactor vessel. However, during the process of melt flow from the reactor vessel to the core catcher the melt characteristics could change: the melt cools down, additional components can be mixed with it due to the melting of the structures over which the melt flows. This can change (worsen) the condition for interaction of the corium with sacrificial material, and it results on slowing down of gravitational inversion. In safety analyses, this aspect should be taken into account, at least on the basis of sensitivity analysis.

External cooling of the core catcher

External cooling of the core catcher is provided by boiling of water into the shaft surrounding the core catcher. It should be demonstrated that cooling of the outer surface of the core catcher vessel is sufficient and resulted on stable decrease of the melt temperature. The margin to the critical heat flux on the outer surface of the vessel of the core catcher should be sufficient to guarantee that no boiling crisis occurs, taking into account the significant uncertainties of the calculation.

When justifying adequate cooling of the external core catcher it should be demonstrated that sources of water (renewable or closed loop) are available.

[1] It is not applicable to the AES-91, AES-92 designs, where the water supply to the melt surface is not provided.

Cooling of the melt surface in the core catcher

Cooling the surface of the melt in the core catcher is provided for:

- to redistribute heat fluxes in the vessel of the core catcher and decrease heat flux on the vessel's wall;
- to reduce the heat flux from the melt surface on thermal shields and the structures protected by them;
- to reduce the release of fission products from the corium surface.

In order to achieve the above objectives, it is preferable to supply water to the surface of the melt as early as possible, however it should not be earlier than the release of the melt from the reactor vessel is completed and after the finishing the inversion of the melt in the core catcher. The duration of these processes should be determined basing on the results of experimental and analytical studies.

Structural integrity of the core catcher

A requisite for successful melt stabilization in the core catcher is maintaining the structural integrity of the load-bearing wall of the core catcher vessel. One of the phenomena that might threaten the structural integrity of the core catcher is the release of melt from the reactor pressure vessel (RPV) if the pressure in the RPV remains high at the time of melt release. Therefore, it should be justified that the maximum pressure at the moment of RPV failure is low enough so that the melt release does not cause damage to the core catcher vessel. The effective means to achieve this is ensuring primary circuit pressure reduction before the RPV failure, which also should be justified.

The AES-2006 core catcher has a double wall consisting of an outer wall and an inner wall. The space between the walls is filled with sacrificial material. The inner wall might be penetrated by the core melt during ex-vessel phase of the accident (this is taken into account in the design), but it is crucial that the outer wall maintains its structural integrity (does not rupture) even if there is contact between it and the core melt. In order to justify reliable melt retention in the core catcher, it should be demonstrated by strength analysis, that the minimum residual thickness of the outer wall is adequate to withstand all mechanical and thermal loads resulting from the accident even in case of interaction with core melt.

The start of the water delivery on the core melt might pose a risk of a steam explosion if the water delivery starts at a wrong time or with exaggerated flow rate. Therefore, the planned timing of core catcher flooding and the expected time of melt arrival and inversion in the core catcher should be carefully analysed to minimize the risk of steam explosion, the effects of which on core catcher integrity would be difficult to predict.

Restricting the release of fission products

One of the functions of the core catcher is to reduce the amount of radioactive materials released into the containment atmosphere and further into the environment. The release of fission products from the core melt is gradually reduced by water delivery on top of the melt. At a later stage of the accident when a deep layer of water is formed on top of the melt pool, and the boiling of the water in the core catcher stops, the fission products are retained in the water pool so that no significant releases from the corium occur. The capability to deliver adequate amount of water (with a chemical composition that supports the retention of fission products) should be demonstrated.

Minimizing radioactive releases should be accounted for in the selection of sacrificial materials. This is important because unintended release of gases due to chemical interactions between corium and sacrificial material in the core catcher might cause additional spreading of airborne radioactive substances into the containment. The core catcher analyses should demonstrate that the source term of radioactive releases can be effectively reduced by adequate and timely water delivery on top of the corium, and by final solidification of the corium.

Generation of Hydrogen and other Non-Condensable Gases:

The relocation of corium from the reactor pressure vessel to the core catcher leads to generation of non-condensable gases during the chemical reactions which take place in the core catcher. Non-condensable gases that are generated during this process mainly are hydrogen and oxygen. Hydrogen is potentially generated by metal (Zr, Steel) water reaction, radiolysis etc. during the interaction of corium with sacrificial material. Some top flooding experiments also indicated hydrogen generation and release during the interactions between water with the steel melt and un-oxidized zirconium. Oxygen is generated due to reduction of hematite (mineral form of iron oxide Fe_2O_3) which is part of sacrificial material of the core catcher. Some of the generated oxygen may get consumed with the un-oxidized melt which is relocated from the reactor pressure vessel. These gases eventually release in to the containment atmosphere and may increase the risk of combustion and pose a threat to the containment integrity. According to the design, the composition of the sacrificial material was selected so as to minimize the release of flammable gases. The analysis/experiments should demonstrate that the generation and release of gases are minimal considering all the possible accident scenarios and the phenomena in the core catcher. The uncertainties involved, if any, in the core catcher such as layer inversion and its timing, penetration of water through gaps or pores etc. should also be accounted. The heat that is liberated during these oxidation processes (metal water reaction, oxidation of Zr etc.) should also be accounted" with respect to melt stabilization process.

Final safe state of the corium catcher after severe accident

The state of a core catcher following severe accident could be accepted as a final safe state when the following conditions are provided:

- the core debris is solidified and its temperature is stable or decreasing,
- the heat from the core debris can be transferred into an external heat sink,
- the configuration of the core debris is well below criticality,
- the release of radioactive products from the core catcher into the containment is practically ended.

References

[1] Technical Report on Core Catcher. MDEP VVER TESG SA Member Countries.