DEBRIS BED COOLING

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INTRODUCTION

A debris bed as a mixture of fuel debris submerged in a pool of water was formed as a result of the Three Miles Island core damage accident. In a fast reactor accident the debris bed can exist in a pool of liquid sodium coolant.

Since the decay of the fission products could evaporate the water or the sodium, it becomes of paramount importance to continue cooling these debris beds in the case of an accident, whenever possible. If cooled, remelting of the fuel debris can be avoided.

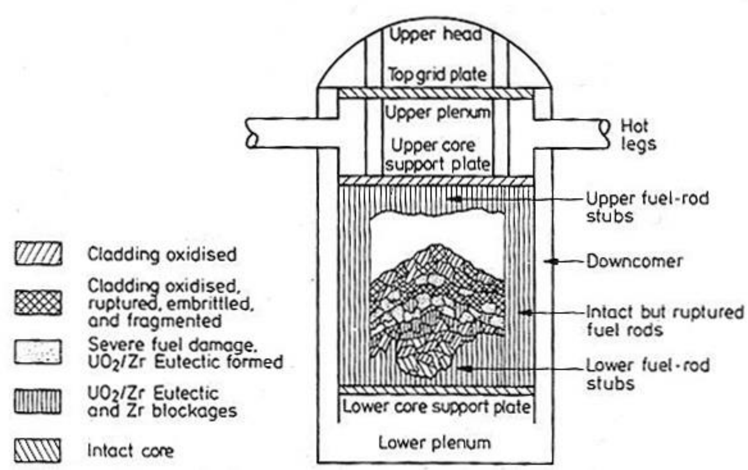

Figure 1. Debris bed resulting from the core damage in the Three Miles Island accident.

The cooling of the debris beds is a complex process and is affected by many factors including the composition of the debris and their particle size.

It also depends on the dimensions of the bed, the operating pressure, the coolant availability and the method of access to the debris bed. Different situations present themselves, demanding different approaches to their cooling.

SHALLOW BED “CHIMNEYS” COOLING

In the case of the existence of a shallow bed of immersed particles at the bottom of the containment, “chimneys” form much like in the case of those forming in rice when cooking. The formed steam escapes through the chimneys. The liquid is pulled through capillary action through the particulates layer in between the chimneys.

This efficient method of cooling can only exist under a very limited set of conditions.

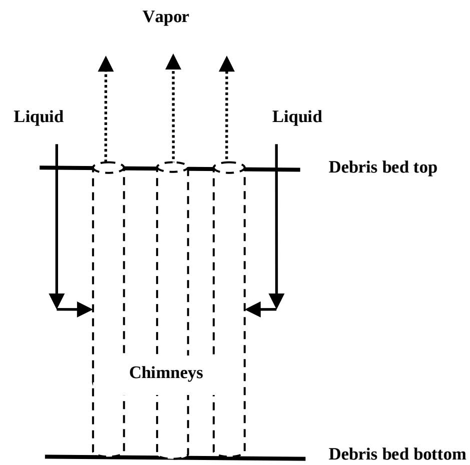

Figure 2. Debris bed chimneys cooling.

CLOSED DEEP BEDS COOLING

In this case the cooling liquid enters from the top of the debris bed. It trickles down the debris bed and cools it. It generates vapor which escapes from the top of the bed.

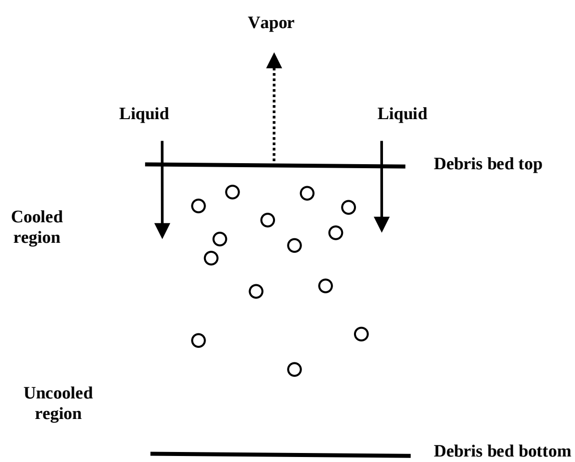

Figure 3. Closed bed debris bed cooling.

The situation causes a flooding phenomenon with the generated vapor countering the flow of the liquid and resulting in only the top of the bed being effectively cooled; a case of steam-binding.

Without cooling, the bottom part of the debris bed would overheat. The overheating of the bottom of the bed is more severe the smaller the particle sizes in the bed. Drying out of the bottom may occur, followed by melting and fusing of the particles, limiting the cooling capability.

ONCE-THROUGH MULTILAYEREDCOOLING

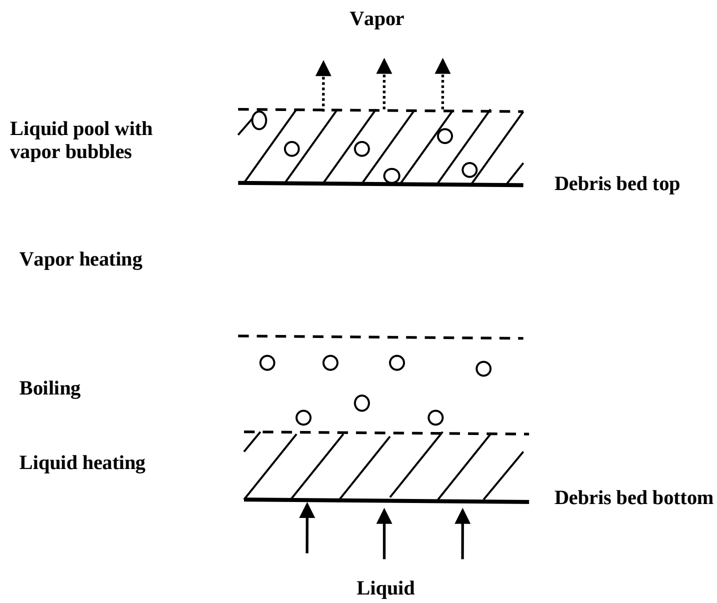

Figure 4. Multilayered once-through debris bed cooling.

This is the best possible situation where the cooling liquid reaches the bottom of the bed and flows upwards through it through the action of forced and natural convection, much like what occurs in a steam boiler.

The natural convection would be caused by the differential in density of the fluid within and outside the debris bed.

The debris bed could be the subject of a pressure drop within the primary system that would drive the flow.

The decay heat generated within the fission products would bring the fluid coolant to its boiling point generating vapor bubbles. As the fluid moves through the bed, it is totally converted into vapor. At this stage, the temperature rises rapidly up the bed.

If the circulation is insufficient, or the debris bed is too thick, the particles at the bottom of the bed could rise to a high enough temperature so that they fuse together, eventually obstructing the upward flow.

EXPERIMENTAL OBSERVATIONS

The debris bed cooling efficiency is dependent on the particles size. In the case of deep debris beds cooling, at atmospheric pressure, for a 1 m deep bed with particles 4 mm in diameter, a heat dissipation rate of 750 kW/m^3 is achievable. On the other hand, if the particle size is 0.1 mm in diameter, the heat dissipation rate falls dramatically to the 20 kW/m^3 level.

A typical debris bed can have a decay heat power generation rate from the fission products of 1 MW/m^3 about 3 hr after an accident. This is the time at which, should cooling of the core fails, the core would melt down in a PWR accident. This bed could be dissipated in a bed 0.5 m in thickness if the particle size is larger than 2 mm in diameter.

In the case of a sodium-cooled system, the higher fuel rating and the associated higher decay heating from the fission products is balanced by the higher latent heat of vaporization of Na compared with H_2O.

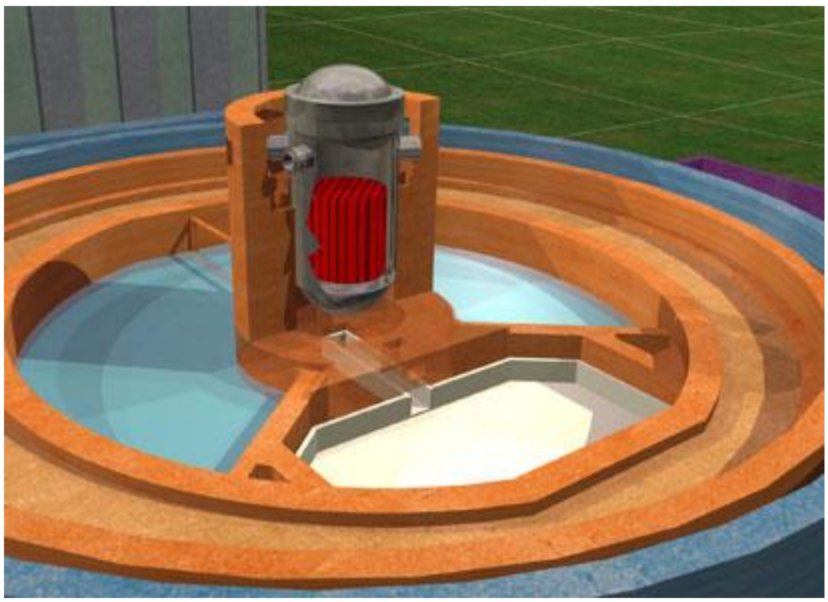

Figure 5. Corium and debris bed cooling system in the Evolutionary PWR, EPWR.
Source: Areva.

The real difficulty here is that the size of the particles varies as the accident progresses, and it is difficult to predict their sizes. Thus the worst case scenario must be envisioned by providing a method of spreading the bed into a well cooled pool in the case of an accident.

This provision is used in the newer Evolutionary PWR, EPWR design by the French Company Areva, where the corium material is spread into a well confined shallow pool that would cool itself passively through radiative cooling to the atmosphere.

EXERCISE

1. Compare the levels of heat generation for debris beds having the following particles diameter sizes:
a) 4 mm,
b) 0.1 mm.