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CORE COOLABILITY FOLLOWING LOSS-OF-HEAT SINK ACCIDENTS

by

Mohsen Khatib-Rahbar

Department of Nuclear Energy
Brookhaven National Laboratory
Upton, New York 11973

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Core Coolability Following Loss-of-Heat Sink Accidents*

Mohsen Khatib-Rahbar
Department of Nuclear Energy
Brookhaven National Laboratory
Upton, New York 11973

Most investigations of core meltdown scenarios in liquid metal fast breeder reactors (LMFBRs) have focused on accidents resulting from unprotected transients. In comparison, protected accidents which may lead to loss of core coolability and subsequent meltdown have received considerably less attention until recently [1,2,3].

The sequence of events leading to the protected loss-of-heat sink (LOHS) accident is among other things dependent on plant type and design. The situation is vastly different in pool-type LMFBRs as compared to the loop-type design; this is as a result of major differences in the primary system configuration, coolant inventory and the structural design.

The principal aim of the present paper is to address LOHS accidents in a loop-type LMFBR [4] in regard to physical sequences of events which could lead to loss-of-core coolability and subsequent meltdown.

There are three major phenomenological phases controlling the LOHS accident progression, consisting of:

1. HEAT-UP PHASE - occurs as a result of the LOHS leading to slow increase in system temperature as a result of the decay heat generated inside the core and deposition into the coolant and structural materials.

2. BOILING PHASE - results from the absence of heat sink. Due to the slow nature of the transient (assuming the structural integrity of the

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reactor vessel is maintained), sodium boiling is expected to occur at the location of lowest saturation temperature (lowest pressure) and propagate into the subassemblies. Stable low quality boiling will follow with heat flux well below the dryout heat flux limit [5].

3. DRYOUT/BOIL-OFF PHASE - occurring as a result of sodium boiling and evaporation in the reactor vessel leading to fuel pin uncovery. This situation must be sustained long enough such that clad failure eventually results.

During the heat-up and/or boil-off phase, the reactor vessel, vessel seals, guard vessel, and primary system piping and guard pipes are exposed to high sodium temperatures for several hours, resulting in temperature rises (over the nominal operating values) of about 500K at the inlet and 350K at the outlet regions, respectively. Consequently, structural failures as a result of thermal growth, and high temperature creep of the stress-bearing reactor vessel supports may occur that can lead to a loss-of-coolant inventory from the system and subsequent core uncovery and dryout. Meltown sequences follow core uncovery and pin dryout [1]. However, if core uncovery is precluded either as a result of vapor condensation, and/or heat removal through the primary system boundaries and the reactor cover head, due to thermal radiation at sufficiently low decay heat levels, core meltdown may be delayed or prevented. This mode of heat removal is not expected to be credible for designs such as the Clinch River Breeder Reactor (CRBR) where the pipes are well insulated. In other designs such as the German SNR-300, the thermal conductivity of the rock wool pipe insulating material increases with temperature, thus leading to increased heat losses through the walls [6].

The progression of LOHS accident is not significantly altered by operation of the primary pony motors (forced flow). In the absence of pony motors, natural convection resulting from the temperature differential between the cold and hot legs will continue, until isothermal conditions are reached.

Figure 1 shows the time sequence of a protected loss-of-heat sink accident occurring at the secondary side of the intermediate heat exchanger, assuming all of the primary pump pony motors are operational, as predicted by the SSC-L code [7].

It is seen that as a result of lower saturation temperature in the reactor upper plenum, sodium flashing starts in about 10 hours into the accident, nearly two hours prior to boiling in the reactor subassemblies.

Following boil-off in the upper plenum, (assuming perfect cover gas pressure control) the sodium inventory of the upper plenum is expected to deplete in about eight hours, thus leading to core uncovery.

Furthermore, stable low quality sodium boiling inside the subassemblies prevents film dryout until the sodium level drops below the top of the subassemblies. However, failure of cladding due to excessive fission gas pressure can occur prior to or during sodium boiling, leading to fission gas release into the coolant [1]. It is not expected that the fission gas release could cause voiding for a long enough time to have a significant impact or the pin coolability. Fuel pin toppling, slumping and meltdown processes will follow core uncovery as studied by Bari, et al.,[1].

Present assessment of the progression of LOHS accident shows that the timing of significant events leading to fuel pin dryout is considerably longer than previously estimated [1]. However, loss-of-coolant inventory as a result of sodium vaporization and/or leaks through thermally-induced ruptures can strongly influence the accident progression towards core melt. Therefore, a complete failure modes and effects analysis of the reactor vessel and associated seals and structural components is warranted for a more realistic evaluation of the LOHS accidents for loop-type LMFBRs.

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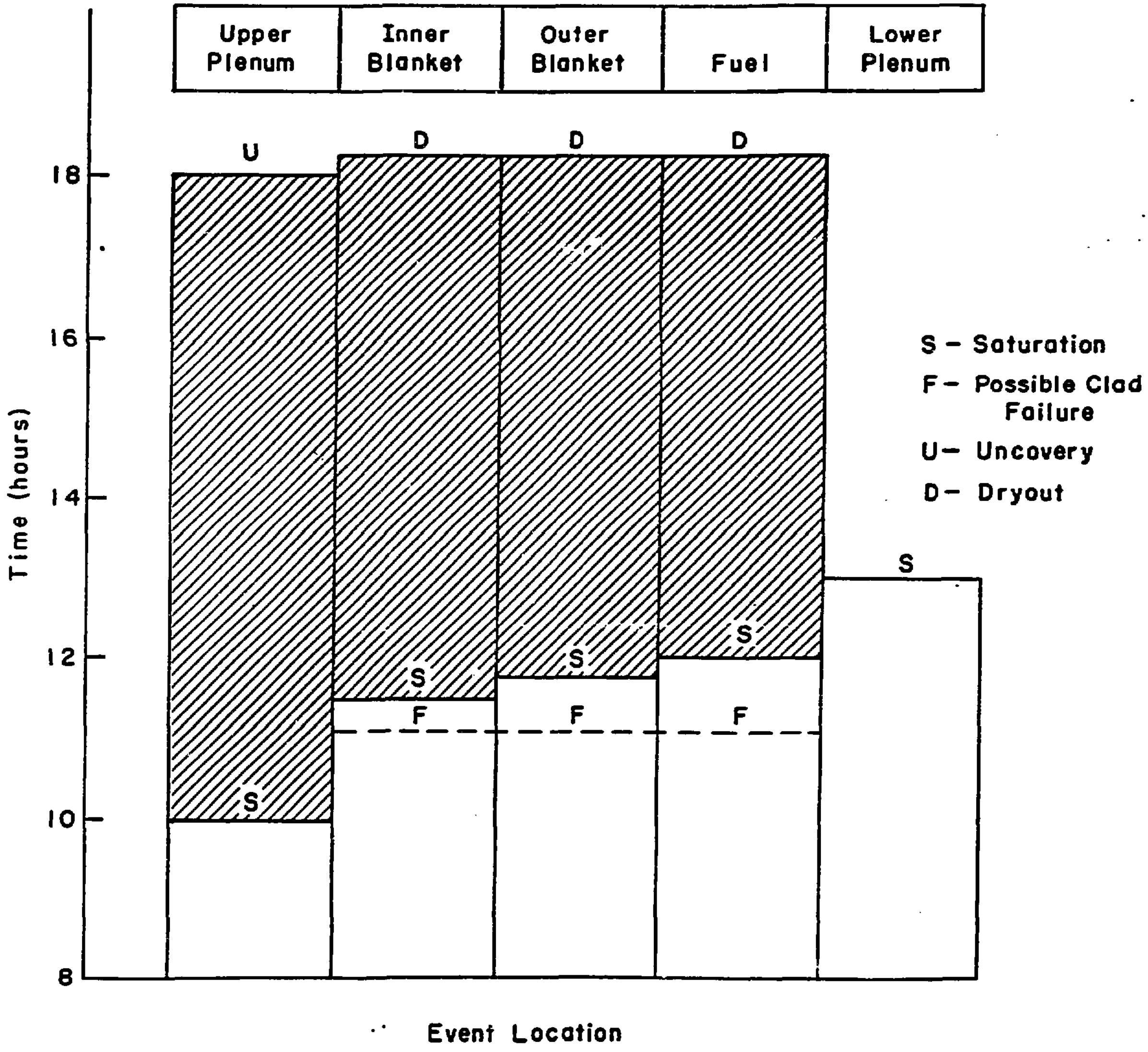

Figure 1 - Accident Progression Following Protected LOHS