7.6.2 Loss-of-Coolant Accident: LWRs

The worst scenario leading to a LOCA envisages an instantaneous double-ended or guillotine break in the primary coolant piping in the cold leg between the primary containment vessel and the primary coolant pump. This would result in the rapid expulsion of reactor coolant into the primary containment, loss of coolant in the reactor core and rapid increase of the temperature of the core. This, in turn, might lead to a rapid increase in the pressure and temperature in the secondary containment; consequently the secondary containment must be designed to withstand these temperatures and pressures as well as potential complications that might follow (see below). Moreover, even though the loss of coolant in the core would result in shutdown of the chain reaction (see section 7.1.2), the decay heat could result in core meltdown unless the emergency core cooling systems were effective. Core meltdown might result in radioactive materials being released into the secondary containment and hence that secondary barrier needed to be designed to contain those radioactive materials.

The progress of a hypothetical LOCA and the steps taken to bring the accident under control can be divided into three phases, namely the blowdown phase, the refill phase and the reflood phase. During the first or blowdown phase the coolant is visualized as flashing to steam with two-phase flow proceeding through the primary cooling system and out through the guillotine break. Such multiphase flows are not easy to simulate with confidence and much effort has gone into developing computer codes for this purpose (see section 7.1.3) and into experimental validation of the results of those codes. These validation experiments needed to be conducted at large scale due to the uncertainty on how these multiphase flows scale (see, for example, Holowach *et al.* 2003, Grandjean 2007). In order to evaluate the behavior of the multiphase flow in a PWR LOCA, a large scale facility called the *Loss of Fluid Test Facility* (LOFT) was constructed at the Idaho National Laboratory. Advantage was also taken of a decommissioned reactor structure at Marviken, Sweden, in order to conduct additional blowdown tests mimicking a LOCA. For BWRs, General Electric conducted special full-scale blowdown tests at Norco in California. Key outcomes from these experiments were estimates of (a) the rate of steam and enthalpy ejection from the primary containment, a process that probably involved critical or choked flow through the effective orifice created by the break (b) the forces placed on the system by this flow in order to evaluate the possibility of further structural damage (c) the amount of heat removed from the core by this flow that, in turn, defines the role of the subsequent refill and reflood phases (some analyses assume, conservatively that no heat is removed).

About $10 - 20$ seconds after the start of the blowdown, the emergency core cooling system (ECCS) (described in section 7.4) begins operation and this marks the beginning of the second or refill phase. Accurate prediction of the complex two-phase flows generated by the injection and spray systems is essential to ensure that the accident can be brought under control. This relies on a combination of well-tested computational tools backed up by both small and large scale experiments. Using these tools predictions can be made of the development of the LOCA and its amelioration. An example of the information obtained is presented in figure 1 which shows how the maximum temperature in the cladding might change during the three phases of the accident using either conservative assumptions or best estimates.

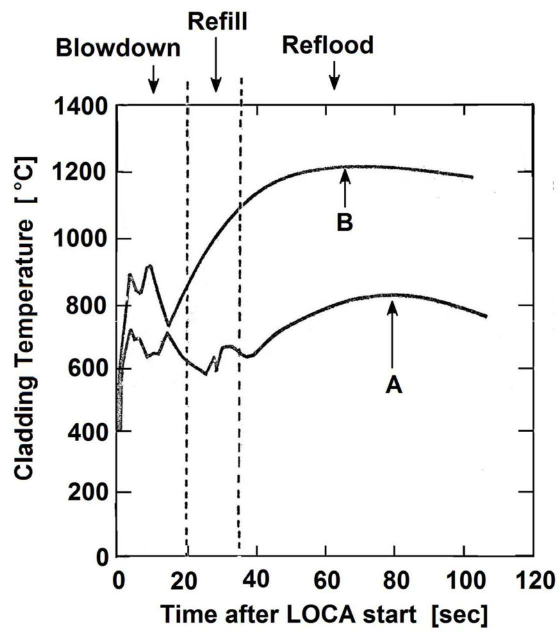

Figure 1: Estimated maximum temperature in the cladding during a postulated LOCA in a PWR as a function of time: (A) using realistic assumptions and (B) using conservative assumptions. Adapted from Hsu (1978).

By definition the refill stage ends when the liquid coolant level in the lower plenum rises to the bottom of the core; the last or reflood stage begins at this time. Reflood involves the quenching of the hot core as the liquid coolant rises within it (see, for example, Hochreiter and Riedle 1977). The liquid coolant may be coming from the spray and injection system above the core or from the injection below the core. In the former case quenching may be delayed as the water is entrained by the updraft of steam originating either in the core or in the lower plenum as a result of continuing flashing of the coolant. Such a *counter-current flooding condition* (CCFL) (see Brennen 2005) may delay quenching either throughout the core or only in the hotter central region of the core. Indeed a strong steam circulating flow is likely in which a steam/water droplet flow rises in a central column of the core and descends outside this central region. Other important differences can be manifest during reflood. For example, the *fast reflood* is defined as occurring when the liquid velocity exceeds the quench front velocity at the surface of the fuel rods (typically about

0.04 m/s) while a *slow reflood* involves coolant velocities less than the quench front velocity. Consequently, the two-phase flow conditions during reflood are unsteady, complex and three-dimensional and require substantial computational and experimental efforts in order to anticipate their progress.