5.5.2 Mass Quality and Void Fraction Distribution

Boiling in the flow channels changes the moderating properties of the fluid and hence the reactivity and this, in turn, will change the heat flux. Consequently it is necessary to perform simultaneous neutronics and multiphase flow calculations in order to properly establish the heat flux and two-phase flow conditions in the boiling region. Perhaps it is most illustrative to consider approaching the solution iteratively starting with the heat flux distribution that would occur in the absence of boiling (see section 5.2) as sketched with the solid line in the top graph of figure 1. This would imply a coolant temperature given by the solid line to the left of the boiling location in the second graph. It will be assumed that when this reaches the saturated vapor temperature at the prevailing coolant pressure, boiling begins and the temperature thereafter remains at the saturated vapor temperature (since the pressure decreases with elevation due to a combination of hydrostatic pressure drop and frictional pressure drop the saturated vapor temperature may drop a little as sketched in figure 1). For the present it will be assumed that the critical heat flux (CHF) (see section 6.5.2) is not reached in the reactor core; otherwise the temperature would begin to rise substantially as sketched by the dashed line in the second graph of figure 1.

The next step is to integrate the heat flux using equation 2, section 5.3, to obtain the mass quality as a function of elevation as sketched in the third graph of figure 1; note that the mass quality, $\mathcal{X}$, will begin at zero at the point where boiling begins and that the slope of the line beyond that point will vary like the heat flux, $\mathcal{Q}$. The next step is to deduce the void fraction, α, of the two-phase flow knowing the mass quality, $\mathcal{X}$. This is a more complex step for, as discussed in section 6.2.1, the relation between α and $\mathcal{X}$ involves the velocities of the two phases and these may be quite different. The calculation of the void fraction is necessary since the void fraction changes the moderating properties of the two-phase coolant. The local reactivity will decline as α increases as discussed in section 7.1.2 and will therefore take the qualitative form sketched in the lowest graph of figure 1.

However this change in the reactivity means that the heat flux will be different from that which was assumed at the start of the calculation. Therefore the second iteration needs to begin with a revised heat flux determined using the new, corrected reactivity. This will result in a decreased heat flux above the location of boiling initiation and the previous series of steps then need to be repeated multiple times until a converged state is reached.

It should be noted that the two-phase flow also alters the heat transfer coefficient, h, governing the heat flux from the fuel rods to the coolant. Under these conditions the functional relation between the Nusselt number, Nu, and the Reynolds and Prandtl numbers will change and this, in turn, will change the temperatures in the fuel rod. This complication also needs to be factored into the above calculation.

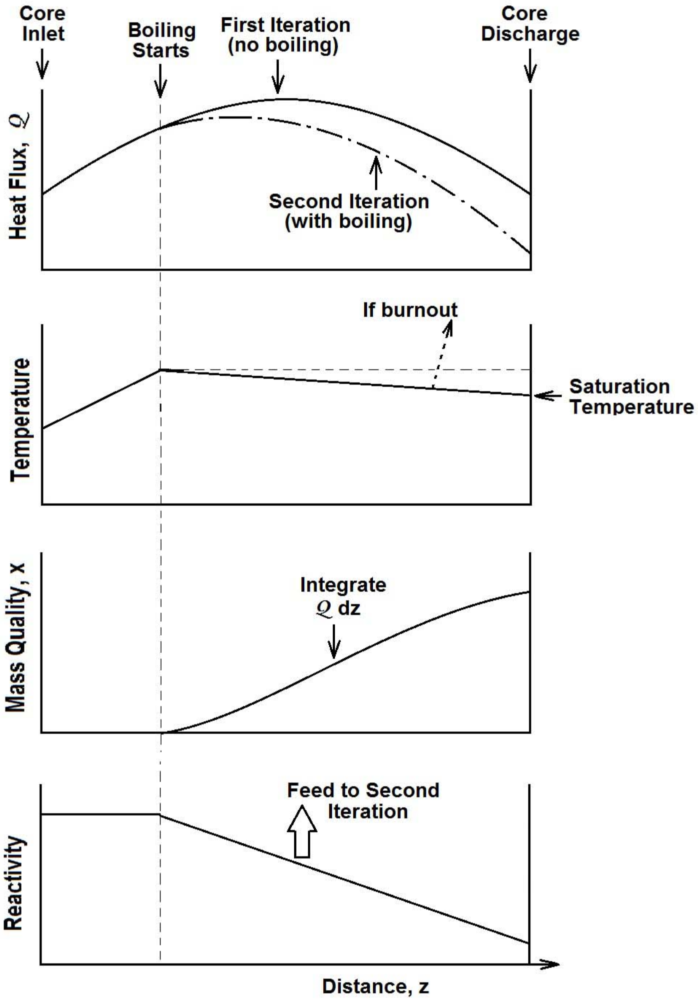

Figure 1: Schematic relation between the heat flux, $\mathcal{Q}$, as a function of elevation within the core of a boiling water reactor (top graph) and the coolant temperature, mass quality and reactivity.