5.1.4 Heat transfer to the coolant

It is appropriate at this juncture to give a brief summary of the heat transfer to the coolant in order to complete this review of the temperature distribution in the reactor core. In the notation of section 5.1.3, the heat flux, $\dot{q}$, from the fuel rod to the coolant per unit surface area of the fuel rod is given by $\mathcal{Q}/\mathcal{P}$ where $\mathcal{P}$ is the cross-sectional perimeter of the fuel rod. Though it is overly simplistic, the easiest way to relate the temperature differences in the coolant to this heat flux, is by defining a heat transfer coefficient, h, as

$$\dot{q} = \frac{\mathcal{Q}}{\mathcal{P}} = h(T_S - T_C) \tag{1}$$

where T_S and T_C are respectively the local temperature of the surface of the fuel cell and the local temperature of the coolant far from that surface. The coefficient, h, is, however, a complicated function of the transport properties of the coolant and of the coolant channel geometry. To express this function a dimensionless heat transfer coefficient known as the Nusselt number, Nu, is introduced, defined by hD_h/k_L where D_h is the *hydraulic diameter* of the coolant channel (see section 6.3.4) and k_L is the thermal conductivity of the coolant. The hydraulic diameter is 4 times the cross-sectional area of the channel divided by the perimeter of that cross-sectional area and applies to a range of cross-sectional geometries of the coolant channel. The other parameters needed are the *Reynolds number*, Re, of the channel flow defined by $Re = \rho_L U D_h/\mu_L$, where U is the volumetrically averaged coolant velocity, ρ_L and μ_L are the density and viscosity of the coolant and the *Prandtl number*, Pr, defined by $Pr = \mu_L c_p/k_L$, where c_p is the specific heat of the coolant. It transpires that Nu is a function of both Re and Pr; that functional relation changes depending on a number of factors including whether the Prandtl number is large or small and on whether the channel flow is laminar or turbulent. Commonly used correlations are of the form $Nu = CPr^{C_1}Re^{C_2}$ where C, C_1 and C_2 are *constants*. For details of these correlations the reader is referred to heat transfer texts (for example, Rohsenow and Hartnett 1973). For simplicity and illustrative purposes, it will be assumed that h is a known constant that, in the absence of boiling, is uniform throughout the reactor core. The case of boiling, either in a boiling water reactor or during an excursion in a normally non-boiling reactor, will be covered in a later section.

The next step is to subdivide the coolant flow through the reactor core into a volume flow rate, $\dot{V}$, associated with each individual fuel rod. As that flow proceeds through the core it receives heat from the fuel rod at a rate of $\mathcal{Q}dz$ for an elemental length, dz, of the rod. As a result, the temperature rise in the coolant over that length is dT where

$$\rho_L \dot{V} c_p \frac{dT}{dz} = \mathcal{Q} \tag{2}$$

In order to obtain the temperature distribution over the length of a coolant channel it is necessary to integrate the relation 2. To do so the variation of $\mathcal{Q}$

with z is needed. This is roughly proportional to the variation of the neutron flux with z. As seen in chapter 3 the neutron flux distribution also varies with the radial location, r, within the reactor core; it also depends on control factors such as the extent of the control rod insertion (section 3.7.4).