Chapter 3

THE REACTOR MODEL

The DNRR model uses the point kinetics to obtain neutron power with time. To avoid solving the neutron diffusion equation, we assume that the neutron flux shape is known from available experimental data. The radial flux shape is assumed to be the same along the core height. As we can see later, it is not necessary to know the radial flux in detail, but only the maximum to average ratio, k_r, called the *radial peaking factor*. The axial flux shape, $\varphi(z)$, is also assumed to be the same at any radial point. Usually, $\varphi(z)$ is the cosine function, but it may be distorted. The radial peaking factor and the axial flux shape are given in Appendices A and B.

The dynamic reactivity presented in the point kinetics equations is a time-dependent function of all control elements' reactivity and reactivity feedback due to poisoning of fission products and changing core temperature.

Generally, the reactivity of all control elements is a function of their positions in core with time. Their moving speed is strictly limited due to safety considerations. In order to have fast transients, we assume that this reactivity can be changed at any rate.

Xenon-135 is the most significant contributor to the poison feedback because of its enormous thermal neutron absorption cross section and its relatively large fission yield. However, it has nearly no effect for short-term transients. For long-term transients, its build-up can introduce a small amount of negative reactivity, easily obtained from solving the build-up equations of iodine-135 and xenon-135.

The reactivity feedback due to change in core temperature is a function of fuel and moderator temperatures with time. It is the first reason why we need to solve the thermal hydraulic equations. The second reason is from the safety point of view. The point kinetics could give any neutron power without any limits. However, for fuel and, especially, for cladding materials, there exist some finite temperature levels which, if exceeded will lead to fuel damage and probably consequential release of fission products from the fuel into the environment.

A one-dimensional model for thermal hydraulics will be used. Thus, the reactor core is subdivided into a number of axial planes along which the radial heat transfer in an average fuel assembly will be considered. For hydrodynamics, the core, the chimney and

the pool are also be subdivided into a number of regions along the flow direction. Conservation of mass, momentum and energy in lumped form is applied to write the equations for mass (M), flow (W) and enthalpy (H) within each region. All water properties, averaged in a region, are calculated at the hydrostatic pressure (P) obtained from the equation of state.

Fig. 3.1. shows the hydraulic network of the reactor heat transfer system. Thus, the heat generated in the fuel is transferred through the cladding to the coolant flow in the core (symbolized as 000). The heated water from the core comes into the chimney (as 100), then flows from the chimney to the upper open pool (as 200). From this, if the pump is working, a fixed flow (G) determined by pump capacity goes out to the cooling system (as 400). The same pump flow (G) with known inlet temperature (T_{in}) comes from the cooling system (as 500) into the lower pool. Generally, heat transfer can also take place at the chimney tube wall between the fluid flows inside and surrounding the chimney. Finally, from the lower pool the coolant flow enters the core. The coolant circulation is maintained by natural convection. That is, light hot water in the core and chimney flows up while dense cold water outside the core and chimney flows down. The cooling system keeps the pool water temperature as low as possible to avoid boiling in the core.

Since the lumped form of the conservation equations is to be applied, the hydraulic network of the in-pool heat transfer system is represented by a series of interconnected nodes to form a node-link circuit as shown in fig. 3.2. The mass and energy equations are averaged over the volume. The pressure is determined by the equation of state as a function of mass and energy of the volume. The flow is driven by pressure differences. Therefore, the momentum equation is applied between the points of known pressures, i.e., between volumes. Volumes are represented by nodes, flow paths are represented by links. The node centre locations define the positions at which the pressure will be evaluated and are important for correct flow calculations. The links are chosen to have constant across area.

In our model, first, the core is represented by a number of average channels, as if all fuel channels had the same radial power factor $k_r = 1$. Thermal hydraulic equations solved for this to obtain all node and link parameters. These parameters are adequate to

calculate the temperature reactivity feedback for the point kinetics. They are, though, the average values, but for the core only. For all of remaining nodes outside the core, they are the same as in the case of the actual core. Then, using known properties of the lower pool node as inlet to the core and of the chimney as outlet from the core, we can proceed to calculate any core channel (with any k_r). At this time, only core nodes and links are considered. The dashed lines, shown in fig. 3.2., from the calculated channel, chosen as the hottest one, to these boundary nodes are intentional because the flows do not change the properties of the boundary nodes. The hottest channel calculations are necessary to have the maximum temperature and heat flux for safety reasons.

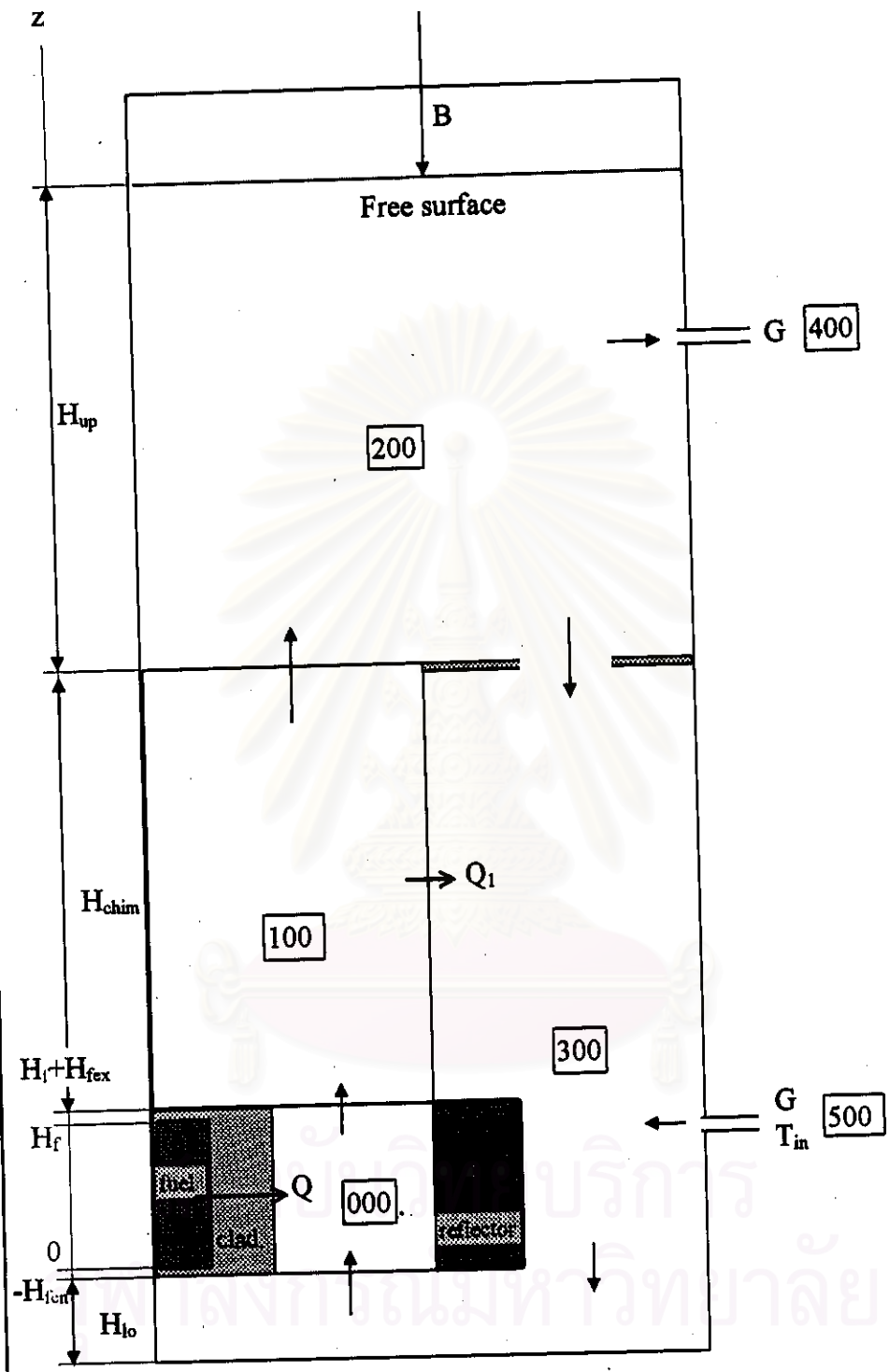

Fig. 3.1. Overall heat transfer system model of the DNRR

000 - core
100 - chimney
200 - upper pool
300 - lower pool
400 - to heat exchange
500 - from pump of primary loop

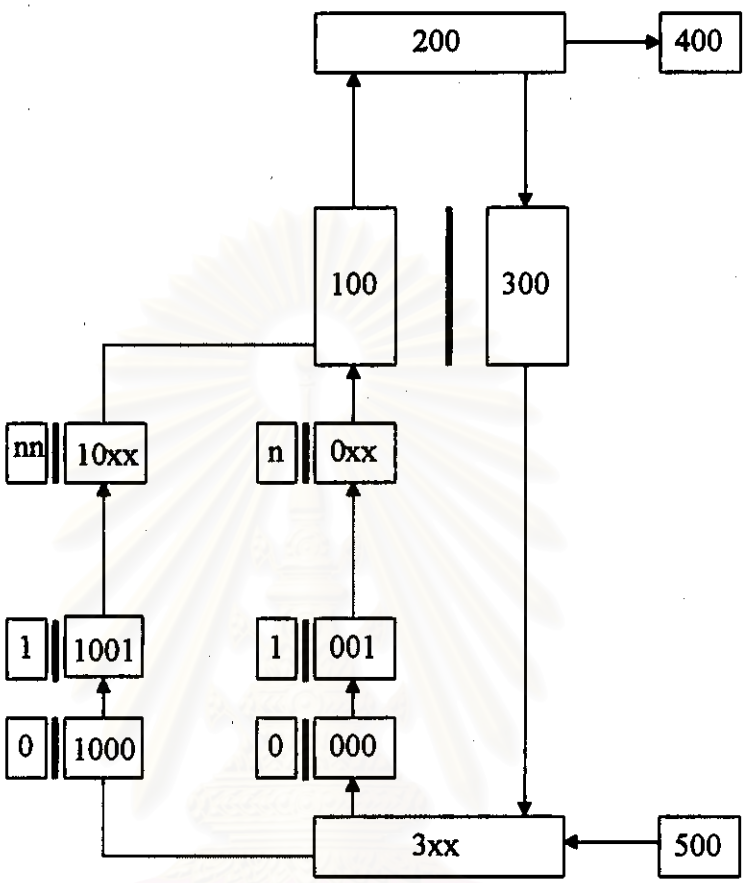

Fig. 3.2. Node-link diagram: in-pool circuit of the DNRR

0xx - core nodes
1xx - chimney nodes
200 - upper pool node
3xx - lower pool nodes
400 - to heat exchanger
500 - from primary loop pump
0-n - fuel sections

1000-10nn - hot channel nodes
0-nn - hot channel fuel sections