Chapter 5

PROGRAM CBL: LIQUID ZONE CONTROL

5.1 INTRODUCTION

The aim of the CBL program is to fix the level of each of the 14 liquid zone controllers (LZC). The LZC constitute the most solicited devices to reduce the power error on the one hand, and the discrepancies between the individual control zone powers on the other hand. Because of the ongoing perturbations acting on the core, the 14 LZC continually change levels. The CBL module is the sole responsible of these changes. It thus acts directly and at all times on the LZC, and is thus the most "active" of all control programs.

5.2 LIQUID ZONE CONTROLLERS

We can think of a LZC, in a very simplified model, as a cylindrical vertical tank, called an assembly, containing light water. Part of this water is removed continuously, and new water is added by a piping system. The flow rate is regulated by a valve. When this valve is at an opening such that the incoming flow is equal to the outgoing flow, the water level is the constant in the LZC. This valve opening giving this equilibrium is called the "bias". The CBL module calculates the required valve opening (more exactly, the valve closure) around this bias value.

The top part of the LZC is covered with Helium gas, not of air. Generally speaking, air is not admissible in the core, because of neutron activation, and of the accelerated corrosion rates of the zircalloy structures that would result. There is thus a pressure control for the Helium gas of the LZC. The level measurement is taken, or inferred from this pressure system.

The opening and closure of the water admitting valve of the LZC is measured in fraction of full opening, FPO. Note that the signal sent to these valves is one of closure, not opening. The levels of the LZC are measure in fractions of full level, FPN.

In a CANDU-6 reactor, we find fourteen zone controllers, one per control zone. There are longer LZC, in the core periphery, and shorter LZC closer to the center of the core. It takes about 60 seconds to empty or fill a long LZC, and about 36 seconds for a short LZC.

The light water making up the useful part a LZC is a strong absorber of neutrons compared to the heavy water of the moderator embedding the LZC assemblies. When the LZC is emptied, there is less absorbant in the core, which make the reactor slightly super critical. Conversely, when the LZC fills up, the absorbers in the core increase, which makes the reactor slightly sub-critical. Generally speaking, the 14 LZC are worth about 5 mk of reactivity, when going from full to empty.

5.3 GLOBAL CONTROL AND DIFFERENTIAL CONTROL

The CBL module acts in two ways on the LZCs. First, it displaces the levels of each LZC by the same amount in order to maintain the power of the reactor at the demanded value. This is called global control. CBL also acts differently on the individual levels, in order to reduce the discrepancies between the control zones powers and levels. This constitutes the differential control.

5.4 SLOW AND FAST PART OF CBL

CBL is also divided into a fast part and a slow part. Generally speaking, the fast part takes care of the global control, and determines the desired valve position. The slow part of CBL takes care of determining the differential terms in the LZC control, and also calculates many of the parameters that are used in the fast part.

5.5 LEVEL RELATED CALCULATIONS

CBL starts by reading the levels of each LZC individually; these are the NIV_i variables.

From these 14 values, the Average Zone Level (NMBL), is calculated by dividing by 14 the sum of the the individual zonal levels; the individual volumes of the LZC is not taken into account. This value of NMBL plays an important role in many of the other control algorithms (CBC, CBS...).

Then the fourteen spatial zonal control activation factors, α_{TLi} are obtained from the graph of Figure 5.1. These factors determine the weight to give to the zonal powers in differential control.

The inferior and superior limits of valve openings are determined by the two functions shown on Figure 5.2. These limits are used to prevent filling up or emptying completely the LZC, which would cause subsequent difficulties in the operation of the LZC system.

Finally, the fourteen zone level deviations are calculated by the expression

$$\mathrm{ENIV}_i = \mathrm{NMBL} - \mathrm{NIV}_i$$

5.6 POWER RELATED CALCULATIONS

5.6.1 DIFFERENTIAL CONTROL

The fourteen calibrated zonal powers,PZC_i provided by MCP are read. The average calibrated zonal power is then calculated by the formula

$$\mathrm{PZCM} = \frac{\sum_{i=1}^{14} \alpha_{TLi}\mathrm{PZC}_i}{\sum_{i=1}^{14} \alpha_{TLi}}$$

Because of the α_{TLi} factors, the levels that are too high or too low do not contribute much to PZCM. The 14 zonal power deviations, DPZ_i, can now be evaluated by the 14 expressions,

$$\mathrm{DPZ}_i = \mathrm{PZC}_i - \mathrm{PZCM}$$

Using the calibrated thermal power of the reactor, PTHRTD, also calculated in MCP, we can calculate the global factor of activation of spatial control, α_{TP}, whose graph is shown on Figure 5.3. Recalling MCP, the neutron power switches to Platinum detectors above 15% FP, and to ion chambers below 5% FP. Since ion chambers do not give any information about spatial power distribution (ie zonal powers), differential control starts to be "cut" as power approaches 15%, power at which ion chambers start to contribute.

The fourteen spatial command activation factors are then given by

$$\alpha_{Ti} = \alpha_{TP} * \alpha_{TLi}$$

Finally, the fourteen differential valve opening signals are obtained by the formula

$$\mathrm{DLIFTS}_i = \alpha_{Ti} * \mathrm{KT} * \mathrm{DPZ}_i + (1 - \alpha_{Ti}) * \mathrm{KH} * \mathrm{ENIV}_i + \mathrm{KL} * \mathrm{ENIV}_i$$

with the gains

- KT=3
- KH=0.006
- KL=0.001

thus, the DLIFTS_i includes a power alignment term, and terms for zonal level alignment. Normally, because of the gains, the power alignment terms dominate the level alignment terms.

5.6.2 GLOBAL CONTROL

The global component of the valve opening signal is essentially composed of the product of a gain KP (kp=31) and of the power error ERPU, calculated in the CEP module:

$$\mathrm{BLIF} = \mathrm{KP} * \mathrm{ERPU}$$

This term will be applied to each zones, which will make all LZC move by the same fraction of opening.

5.7 VALVE CLOSURE

Finally, the fourteen opening signals of the LZCs can be calculated:

$$\mathrm{RLIF}_i = \mathrm{BLIF} + \mathrm{DLIFTS}_i$$

However, if a reactor stepback is occurring, or if the reactor is shutdown by either of SDS1 or SDS2, the RLIF_i will be automatically set to 0.15, independently of the preceding formula. This will cause a slow fill-up of the LZC to 95%.

The RLIF_i will then be limited by the RLIF_{Min} and the RLIF_{Max} values, before being used in the calculation for the closure signal to the LZC valves,

$$\mathrm{YVZ}_i = (1 - \mathrm{BIAS}_i - \mathrm{RLIF}_i) * 100$$

This completes our description of the CBL module.

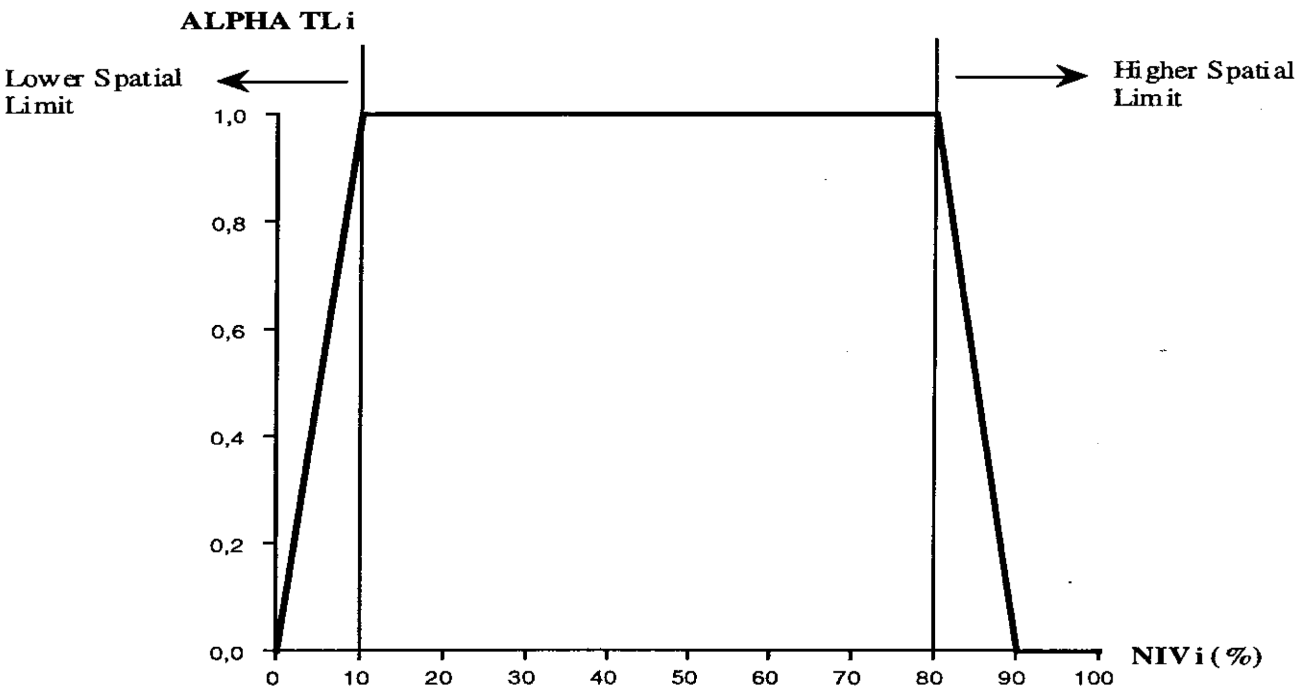

Figure 5.1: α_{TL} : Spatial Control Activation Factors

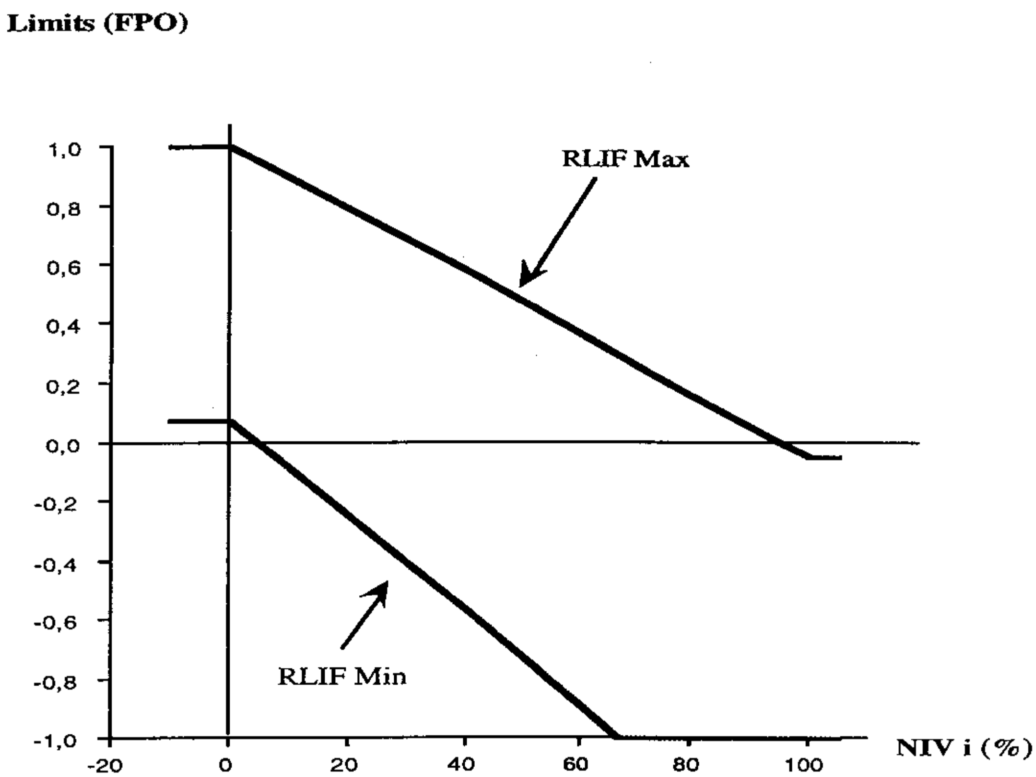

Figure 5.2: Inferior and Superior Limits on LZC Valve Opening Demand

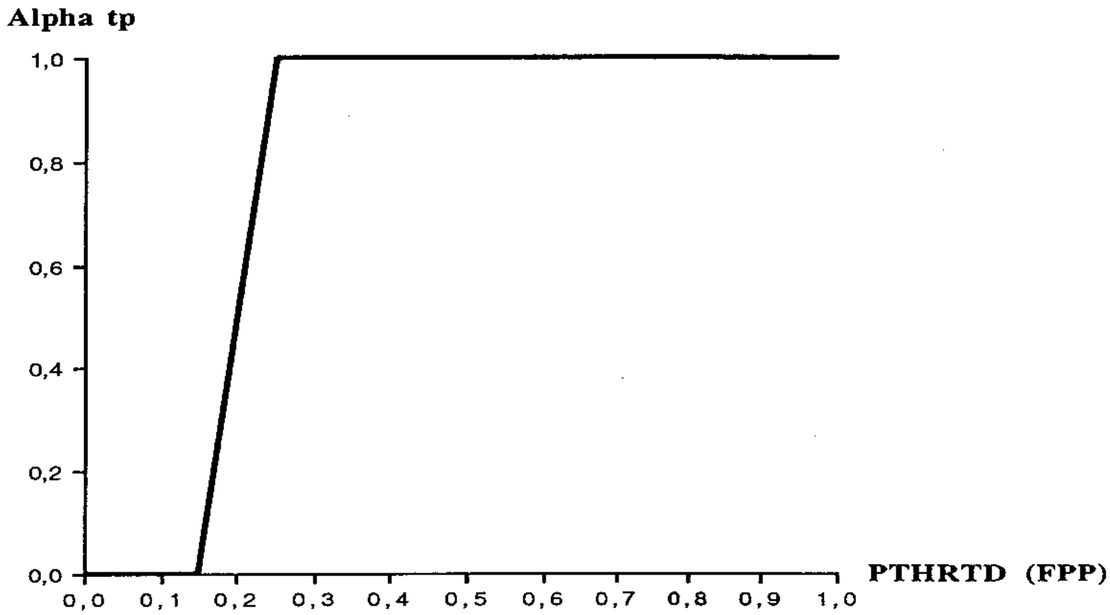

Figure 5.3: α_{TP} : Spatial Control Global Factor