Chapter 3

PROGRAM MCP : POWER MEASUREMENT AND CALIBRATION

3.1 INTRODUCTION

The function of this program is to provide a precise value of the reactor power based on measurements. Many types of measurements will be taken into account here. We can divide them into two principal groups: thermal measurements and neutron measurements. These two groups will have to be harmonized together. In particular, the neutron measurements will be corrected, or as we say, "calibrated" by the thermal measurements. The fact that some measurements are more precise at high power than at low power (and vice versa), and that the time constants of the measurements vary on different scales will have to be taken into account. This can be due to the physical phenomena themselves, for example, the time required to remove heat from fuel, or to the measuring devices and the associated electronics. A Platinum detector responds faster to neutron flux changes than a Vanadium detector for example.

The module MCP (Power Measurement and Calibration) produces estimates of the logarithmic and linear powers for the total reactor power. It also provides individual zonal powers for the liquid zone controllers.

The program description that we will give here is quite simplified by comparison with the real version used in the control computers. In order to emphasize the essential elements of it, we eliminate from our discussion the detection and elimination of out of bound or irrational values of the measurements. These aspects would complicate needlessly our description of the algorithms.

3.2 THERMAL MEASUREMENTS

Two types of thermal measurements are treated by MCP. These are measurements provided by the reactor, and by the steam generators.

3.2.1 REACTOR

Three thermo-couple thermometers ("Resistive Temperature Detectors" or RTD) are located on each of the four inlet collectors. The average of these 12 values is made. In the same fashion, three RTD's are located on each of the four outlet collectors; they are configured in such a way as to give the temperature difference between an outlet collector and the corresponding inlet collector. The average of these 12 outlet RTD's is also computed. Using these two averages and the coolant pumps flow rates, it is easy to obtain the thermal power , in Fraction of Full Power (FPP) of the reactor, based on the RTD measurements. This value is labeled PTHRTD.

3.2.2 STEAM GENERATORS

The steam flow rate at each of the four steam generators, as well as the corresponding feedwater flow rat and feedwater temperature are read. The power at each of the steam generator is inferred from correlations using the enthalpy of water. The average of the four steam generator powers is calculated, and is labeled PTHGV, the thermal power of the steam generators.

3.3 NEUTRON MEASUREMENTS

Two types of neutron power are available and treated by MCP. The measurements come from neutron flux detectors. They are provided by the three ion chambers, and by the 28 Platinum detectors. We note here that the Vanadium detectors are not directly used for the total power of the core.

3.3.1 ION CHAMBERS

We note here that because of their inherent characteristics, the ion chambers provide logarithmic measurements of the power and of the power variation. This will have an effect on the way that the data coming from these detectors will be processed. We also keep in mind that these ion chambers are on the core periphery. The thermal neutron flux is quite low in this area. Consequently, the ion chambers only see a much reduced neutron density.

For information purposes only, the median of the linear value of the ion chambers is calculated. It is not used elsewhere in the actual control programs.

The median of the logarithmic variation of the ion chambers output is calculated (log rate). It is labeled TLOGI, and will be used in the CEP and EBA modules.

The median of the three logarithmic output of the ion chambers is also calculated, and is labeled PIULOG, the non calibrated ion chamber power.

3.3.2 PLATINUM DETECTORS

The signals of the 28 Platinum detectors are read in turn. As mentioned earlier, these 28 detectors constitute 14 assemblies, one per control zone, since they are grouped two by two. The average value of the two detectors in a given zone assembly is taken, which gives 14 values of non calibrated zonal powers, PIU_i , (i going from 1 to 14). We note that if the deviation between two detectors of a given zonal assembly j is greater than the maximum of [12.5% of PTH or 5% FP], then the highest of the two values replaces the average to become PIU_j. After this, the average of the 14 values PIU_i is calculated,

$$\mathrm{PLN} = \frac{1}{14}\sum_{i=1}^{14}\mathrm{PIU}_i \qquad (3.1)$$

The variable PLN is the non calibrated linear power of the reactor. We will use it later on.

3.4 CALIBRATED POWER CALCULATION

We now have at our disposal 4 different measurements of the total power of the reactor, PTHGV,PTHRTD,PIULOG,and PLN. For reactor control, we need to establish one thermal power (of rather limited use), a linear power estimate (in FPP) and a logarithmic power estimate (in decades). The linear power and logarithmic power are provided essentially by the neutron detectors with corrections added to take into account the thermal measurements.

3.4.1 THERMAL POWER

The thermal power will be a mixture of measurements coming from the steam generators,PTHGV, and from the reactor, PTHRTD. This mixture will take into account the fact that the measurements from the steam generators are excellent when the power is higher than 80% FP, and less reliable when lower than 60%. However, when the power is lower than 60%, no fuel channels will be boiling, and the value provided by PTHRTD will be excellent, in part because of the limited application range of the correlations used in the calculation of PTHRTD.

We thus define a function, α_T, which is shown on figure 3.1. We note that the power PLN from the neutron measurements is used to define the power axis. The thermal power of the core is then defined in the following way:

$$\text{PTH} = (1 - \alpha_T)\text{PTHRTD} + \alpha_T\text{PTHGV} \tag{3.2}$$

The interpretation of PTH is then:

- when $\text{PLN} > 0.8$, $\text{PTH} = \text{PTHGV}$
- when $\text{PLN} < 0.6$, $\text{PTH} = \text{PTHRTD}$
- when $0.6 < \text{PLN} < 0.8$, PTH is a linear combination of PTHGV and PTHRTD.

This value of PTH will be used in the calculation of the acceptable deviation of the readings of the detectors belonging to given zones, in the calibration factor for neutron power, and will be used in the module CEP.

3.5 NEUTRON POWER

3.5.1 LINEAR POWER

The idea here is to modify the non calibrated linear power, PLN, with a correction from the thermal measurements. There are two types of thermal power, one coming from the reactor, PTHRTD, and one coming from the steam generators, PTHGV. There is a delay of about 20 seconds between a Platinum detector response, and the response of the RTD's, and a delay of 28 seconds between the platinum detector response and the response of the measurements at the steam generators. This is due to the transport time in the primary loops. If these different power measurements are to be compared together, as if they were all simultaneous, we use linear filters. The variable PLN is passed through a filter of a 20 second time constant, which gives the variable PLN20. PLN is also passed in a 28 second filter, which gives PLN28. A linear combination of these two is taken,

$$\text{PDAF} = (1 - \alpha_T)\text{PLN28} + \alpha_T\text{PLN20} \tag{3.3}$$

The variable PDAF should behave somewhat like thermal power. The calibration factor is obtained by taking the difference between PTH and PDAF,

$$\text{ADA} = \text{PTH} - \text{PDAF} \tag{3.4}$$

and after passing ADA in a 180 second filter, to eliminate noise, we obtain the "linear power calibration factor",

$$\text{FCPLN} = \text{ADA}^{F180} \tag{3.5}$$

(we also limit the value of ADA, hence of FCPLN, between -0.08 and +0.2 FPP) Finally, we obtain the calibrated linear power, PLNCA, with the expression

$$\text{PLNCA} = \text{PLN} + \text{FCPLN} \tag{3.6}$$

The calibrated linear power will be used in the calculation of the calibrated logarithmic power, and in the CEP, Reactor Setback and Reactor Stepback modules.

3.5.2 LOGARITHMIC POWER

The first step in the calculation of the reactor logarithmic power consists in calculating the calibrated power of the ion chambers. The ion chambers, on the boundary of the core are not as affected as the Platinum detectors by the release of energy in the fuel. Because of this, the designer has considered that a fixed delay of 25 seconds would represent adequately the average time that it take from the moment it is measured in the core to the moment the corresponding thermal power is measured at the steam generators. The logarithmic power of the ion chambers is transformed into a linear power by exponentiation, and then filtered with a time constant of 25 seconds:

$$\text{PIUF25} = (10^{\text{PIULOG}})^{\text{F25}} \tag{3.7}$$

The ratio between the thermal power and this new power is given by

$$\text{KI} = \text{PTH}/\text{PIUF25} \tag{3.8}$$

A ratio is used because of the logarithms which will be taken later on. The KI variable is filtered with a time constant of 180 seconds, to remove noise as before,

$$\text{KIF} = \text{KI}^{\text{F180}} \tag{3.9}$$

The ion chamber power calibration factor is obtained by taking the base 10 logarithm of KIF,

$$\text{FCLGCI} = log_{10}(\text{KIF}) \tag{3.10}$$

and finally, the calibrated ion chamber logarithmic power becomes

$$\text{LGCII} = \text{PIULOG} + \text{FCLGCI} \tag{3.11}$$

We mentioned elsewhere that the Platinum detector readings are reliable at high power, and much less reliable at low power, because of the long time constants of their response. On the other hand, the ion chambers are reliable over a very large scale of power, going from 10^-7 to more than 1.0 FPP. But the ion chambers do not provide readings coming from all parts of the core, which would be preferable, especially at high power. In order to take this in effect, the calibrated logarithmic power will be a combination of the logarithm of the calibrated linear power, and of the calibrated logarithmic power of the ion chambers,

$$\text{PLGCA} = \alpha_P \cdot log_{10}(\text{PLNCA}) + (1 - \alpha_P)\text{LGCII} \tag{3.12}$$

where α_P is shown on the graph of Figure 3.2. From this graph, we see that

- when PTHRTD < 0.05FPP , PLGCA comes from the ion chambers
- when PTHRTD > 0.15FPP , PLGCA comes from the Platinum detectors

- when $0.05 < \text{PTHRTD} < 0.15$, PLGCA is a linear combination of the two types of detectors

We note that the calibrated logarithmic power plays a fundamental role in the power error calculation, as well as in the control of the liquid zone controllers. An explanation for this is that during transients, the dynamical behavior of the flux and the power is essentially dominated by exponentials. For example, such exponentials appear in point kinetics. The logarithmic derivative of the power should then vary slowly, and the control of the reactor will be simplified if it is based on such values.

3.6 INTERACTIONS WITH THE FLU PROGRAM

This module MCP sends the 14 values of the non calibrated zonal power to the flux mapping module FLU. These are the 14 PIU_i values, filtered with a time constant of 325 seconds to reflect the time response of the Vanadium detectors that are used in FLU,

$$\text{PIUF}_i = \text{PIU}_i^{\text{F325}} \tag{3.13}$$

The FLU module will return 14 "differential calibration factors", ADI_i, which will be filtered with a time constant of 180 (again to eliminate noise) and thus become the zonal calibration factors, FCZ_i,

$$\text{FCZ}_i = \text{ADI}_i^{\text{F180}} \tag{3.14}$$

and the calibrated power of each zone is then

$$\text{PZC}_i = \text{PIU}_i + \text{FCZ}_i + \text{FCPLN} \tag{3.15}$$

It is interesting to take the average of the 14 PZC_i. When we will examine the FLU module, we will see that the ADI_i are such that they sum to zero. Therefore, we will also have for the FCZ_i,

$$\sum_{i=1}^{14} \text{FCZ}_i = 0 \tag{3.16}$$

Taking the average of the 14 calibrated zonal powers,

$$\begin{aligned} \frac{1}{14}\sum_{i=1}^{14}\mathrm{PZC}_i &= \frac{1}{14}\sum_{i=1}^{14}\mathrm{PIU}_i + \frac{1}{14}\sum_{i=1}^{14}\mathrm{FCZ}_i + \frac{1}{14}\sum_{i=1}^{14}\mathrm{FCPLN} \\ &= \mathrm{PLN} + \mathrm{FCPLN} \\ &= \mathrm{PLNCA} \end{aligned}$$

We thus have established the important result that the calibrated zonal powers are consistent with the calibrated linear power when the reactor is stable, this is to say when nothing has been happening for a sufficiently long time to permit the filtered values of the variables to be constant and equal to the variables themselves.

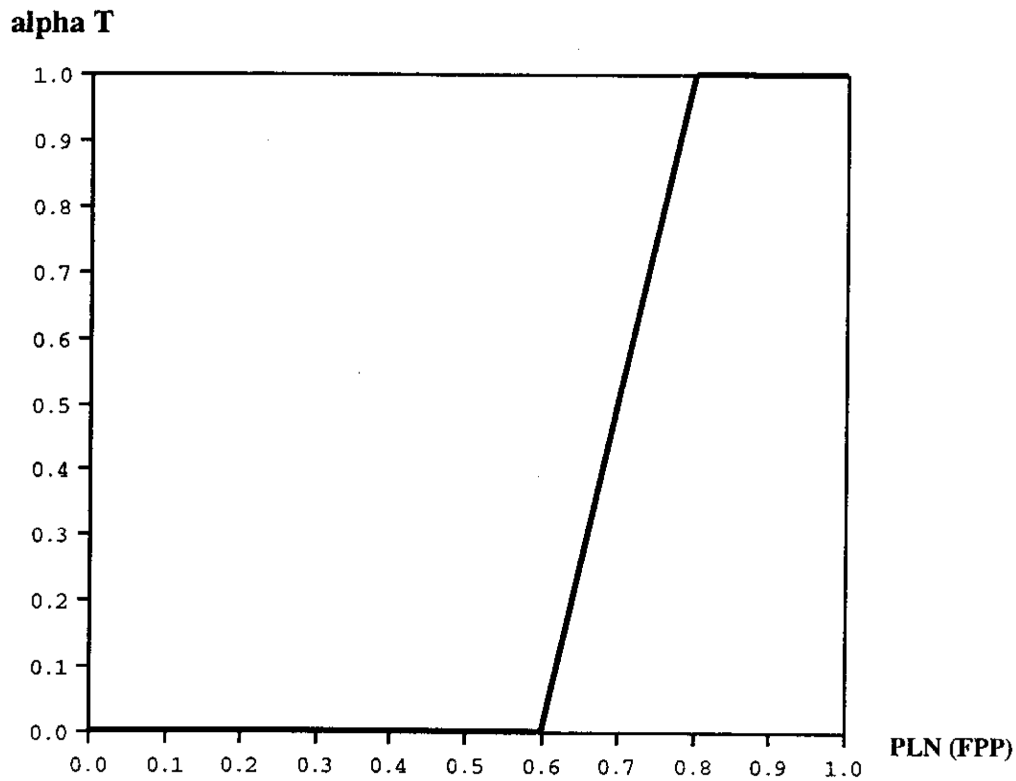

Figure 3.1: α_T versus PLN

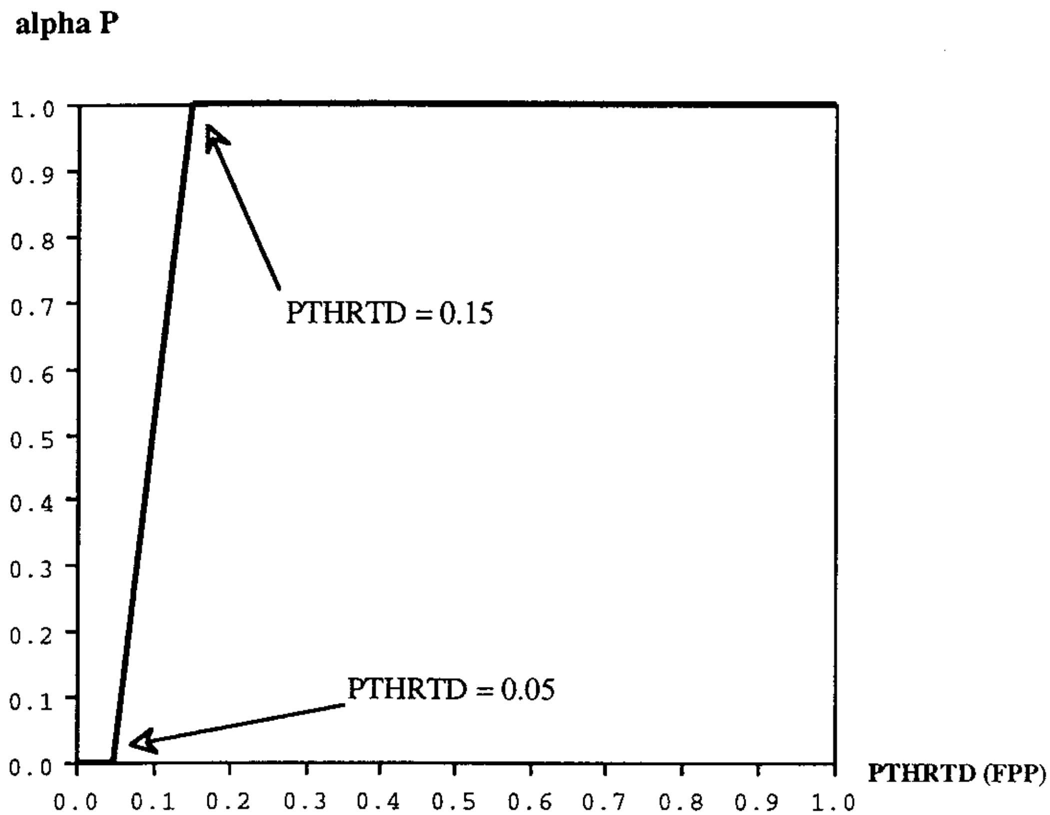

Figure 3.2: α_P versus PTHRTD