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12.1 CORE PROTECTION CALCULATORS (CPC)

Learning Objectives:

1. State the purpose of the Core Protection Calculators (CPC).
2. Explain how the Departure From Nucleate Boiling Ratio (DNBR) and the Local Power Density (LPD) limits are calculated by the CPCs.

12.1.1 Introduction

The purpose of the CPCs is to generate trip signals based upon LPD and DNBR which prevents these limits from being exceeded during Anticipated Operational Occurrences (AOOs). The CPC is a digital computer that calculates a conservative value of plant LPD and DNBR. A CPC is installed in each of the four reactor protection (RPS) channels and the trips that are generated by the calculators must satisfy the required two out of four RPS trip logic.

12.1.2 CPC Inputs

In order to provide protection for DNBR and LPD, the CPCs must be supplied with inputs that affect these limits. DNBR is a function of RCS pressure, RCS flow, RCS temperature, reactor power, and flux distribution. While LPD is a function of total power and power distribution.

12.1.2.1 Reactor Power

The reactor power input is supplied from two sources. Those sources are loop temperatures and excore linear power. Hot leg (T_h) temperature and cold leg (T_c) temperature are inputs into the calculation of ΔT power ($\Delta T = T_h - T_c$). ΔT power provides an accurate indication of true plant power when the unit is being operated at steady state. The highest of either ΔT power or excore linear power is supplied to the calculations of DNBR and LPD.

The output of the three excore linear power detectors is supplied to the CPC, but because these detectors sense leakage neutrons several corrections are required before an accurate power signal is available. These corrections are discussed in Section 12.1.3.1.

12.1.2.2 Reactor Coolant Temperatures

Hot leg temperature and cold leg temperature is supplied to the CPCs for the calculation of ΔT power, correction of the excore detector signal, and as the temperature input into the DNBR calculation. Temperatures are sensed by well mounted resistance temperature detectors (RTDs).

12.1.2.3 Pressurizer Pressure

A pressurizer pressure transmitter supplies the DNBR calculation with the necessary pressure input.

12.1.2.4 Reactor Coolant System Flow

Reactor coolant system flow is not an input to the CPC, instead flow is calculated from the speed inputs of the four reactor coolant pumps (RCPs). The flow of the RCS is verified during testing.

12.1.2.5 Control Element Assembly (CEA) Positions

CEA positions for the twenty CEAs located in the associated CPC core quadrant are used to correct the excore linear power input signals and the power distribution calculations. These CEAs are called target CEAs. In addition to the target CEA positions, each control element assembly calculator (CEAC) modifies the power distribution calculations for CEA misalignments. Table 12.1-1 below summarizes the CPC inputs.

Each input is monitored for proper input range. Should an input be out of range, a sensor failure alarm will result.

Table 12.1-1 CPC Inputs

Input Signal	Range	Number Per CPC
RCP Speed	20-100% of Rated Speed	4 - 1/RCP
Cold Leg Temperature	465°F-615°F	2 - 1/Loop
Hot Leg Temperature	525°F-675°F	2 - 1/Loop
Pressurizer Pressure	1500 – 2500 psia	1
Excore Linear Power	0 - 200%	3 - one per detector
CEA Position	0 - 150 inches	20
CEA Penalty	1 - 4	2 - 1/CEAC

12.1.3 CPC Software (Figure 12.1-1)

12.1.3.1 Excore Linear Power Corrections

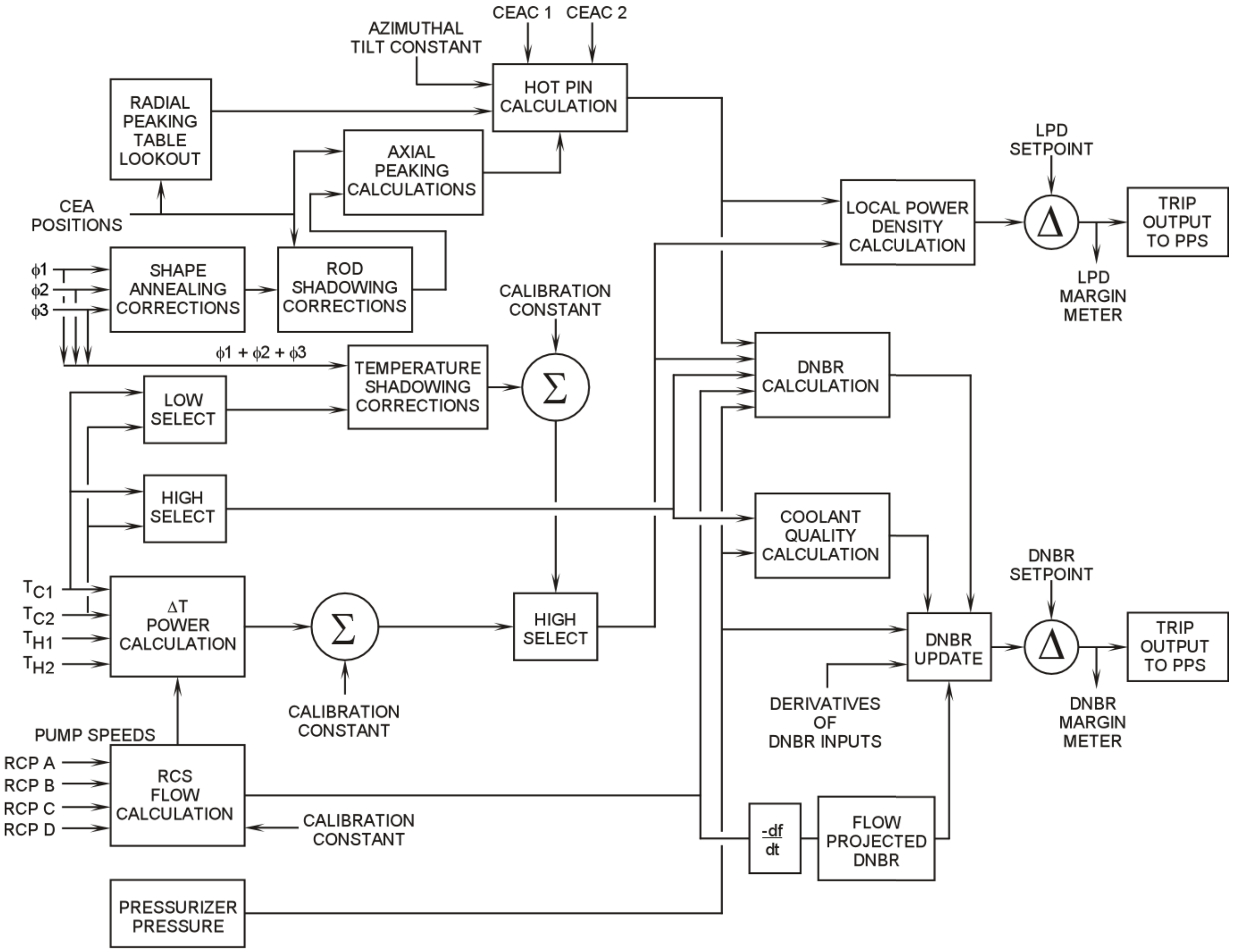

Figure 12.1-1 CPC Software Block Diagram

The first correction that is applied to the excore signal is called the shape annealing factor. Each excore linear channel consists of three detectors located parallel to the axis of the core. The upper detector monitors leakage neutrons from the top 1/3 of the core, the middle detector senses neutrons from the center 1/3 of the core, and the bottom detector detects neutrons from the bottom one third 1/3 of the core. In theory, the use of three detectors should yield an accurate indication of the core's axial power distribution. However, each of the detectors can sense neutrons from all parts of the core and the ability of the detectors to accurately reflect axial power distribution is impaired.

During power range testing, different axial power distributions are created by inducing an axial xenon transient. The incore instrumentation system is used to gather power distribution data which is compared with the excore detector output. Shape annealing factors result from the incore to excore correlation and are input into the CPC software as addressable constants. Addressable constants are program variables that can be changed. These shape annealing constants restore the accuracy of the excore detector flux distribution indication.

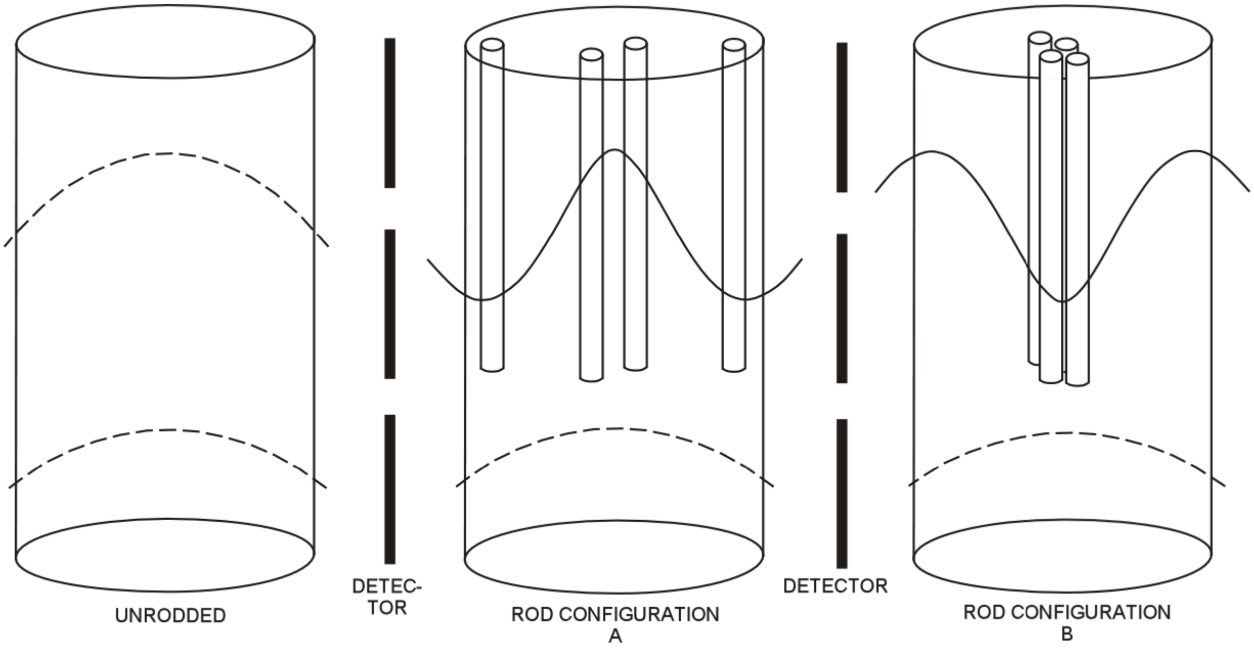

Figure 12.1-2 Rod Shadowing Examples

The second excore correction is called rod shadowing and corrects the output of the detectors for changes in power distribution due to CEA insertion. For example, deeply inserted CEAs in the center of the core forces power to the peripheral assemblies while rods inserted at the core periphery has the opposite effect. As illustrated in Figure 12.1-2, changes in individual detector outputs occur because of the different rod patterns. Target CEA positions are supplied to the rod shadowing calculation and compensates for excore detector output changes caused by rod position changes. After the excore signal is corrected for shape annealing and rod shadowing, it is supplied to the axial peaking calculation section of the CPC software.

The next excore correction is necessary because a change in water temperature in the reactor vessel affects the leakage of neutrons from the core. Leakage is inversely proportional to temperature; therefore, as temperature decreases, detector output decreases. This could cause indicated power to be less than actual power. The effect is called temperature shadowing. The minimum T_c is used for this temperature shadowing correction because the vessel flow path places T_c water between the core and the detectors.

The final correction that is applied to the excore signal is the calibration addressable constant which is used to ensure that CPC power is in agreement with the power that is calculated by secondary heat balance (calorimetric power). Temperature shadowing and calibration corrections are applied to the total excore power signal before it is sent to the program section that high selects either excore or ΔT power for use in the calculation of LPD and DNBR.

12.1.3.2 ΔT Power

Core power based upon the difference in hot and cold leg temperatures is called ΔT power. The temperature inputs are combined with coolant mass flow rate to determine the core enthalpy rise. This energy rise is calibrated to secondary heat balance power by an addressable constant and is dynamically compensated by changes in average

Th. The output of the ΔT power is sent to the high selection program section which is discussed above.

12.1.3.3 Power Distribution Calculations

Localized concentrations of heat flux are of prime importance in the calculation of LPD and DNBR. If the designer can assure that the worst case localized hot spots do not exceed these specified limits, then no local spot in the core will violate limits. Hot spots are characterized as areas of high heat generation and of low heat removal. The latter condition is caused by increased resistance to heat transfer and reductions in flow areas.

Examples are lack of mixing, enrichments of pellets at the maximum values, low gap conductivity, and flow reductions caused by fuel rod bow. The conditions change slowly and can be lumped together as an engineering penalty factor. A conservative engineering factor is assumed in the CPC algorithms.

Heat generation, is a dynamic factor and cannot be assigned a conservative value. Heat generation is a function of the flux in the localized area and for the CPC calculation is broken down into its radial and axial components. Radial flux distribution is a function of control rod position; therefore, radial peaking factors can be pre-calculated and programmed into a software table. Once these values have been established, the CPC needs only the input of control rod position to determine radial peaks. The input of control rod position comes from the twenty CEAs located in the core quadrant associated with a particular CPC. The CEAs are called target CEAs. From the target CEA inputs, the radial peaking program looks up the appropriate peaking factor in the pre-programmed table. From the table look up, the radial peaking factor is supplied to the hot pin calculation.

The axial component of flux distribution is derived from the corrected output of the three excore linear power range detectors. The axial flux distribution is also supplied to the hot pin calculation.

In addition to the inputs of radial and axial flux distribution, the hot pin calculation receives an azimuthal tilt addressable constant and the penalty factors from the CEACs. The azimuthal tilt constant is used to correct the hot pin calculation for steady state radial tilts.

The inputs from the CEACs correct the hot pin calculation for CEA misalignments between core quadrants. The hot pin selects the highest (worst case) penalty factor. The output of the hot pin program section is routed to the calculation of LPD and DNBR.

12.1.3.4 RCS Flow Calculations

The RCS flow rate is calculated by converting the pump speed input signals to a volumetric flow rate. The volumetric flow rate is corrected for system pressure losses and converted to a mass flow rate by considering fluid properties that are pressure and temperature dependent. Addressable calibration constants are used to insure that the calculated value of flow is in agreement with values measured during plant testing. Mass flow rate is sent to the calculation of ΔT Power, to the DNBR calculation, and a derivative of flow (negative values only) is used to update the DNBR calculation.

12.1.3.5 Reactor Coolant System Pressure

A pressurizer pressure transmitter supplies the pressure input to the DNBR and DNBR update calculations.

12.1.3.6 DNBR Calculation

The DNBR calculation is performed by manipulating the inputs of the following parameters:

1. Hot pin calculation,
2. Power (high selected ΔT or excore).
3. Maximum Tc,
4. RCS flow and
5. Pressurizer pressure.

A value of DNBR is calculated. This value is called the static DNBR and is calculated every two seconds. The output of the static DNBR calculation is supplied to the DNBR update calculation.

12.1.3.7 DNBR Update Calculation

The DNBR update calculation is performed every 100 milliseconds by considering the derivatives of the inputs to the static DNBR, and DNBR projections based on flow and coolant quality.

The derivatives are used to update the DNBR calculation based upon changes in these parameters that have occurred since the last calculation of DNBR. The factors (partial derivatives) that are used are a function of the values of a set of process variables. These variables are:

1. Cold leg temperature,
2. RCS pressure,
3. Axial shape index (ASI) and
4. The radial peaking factor.

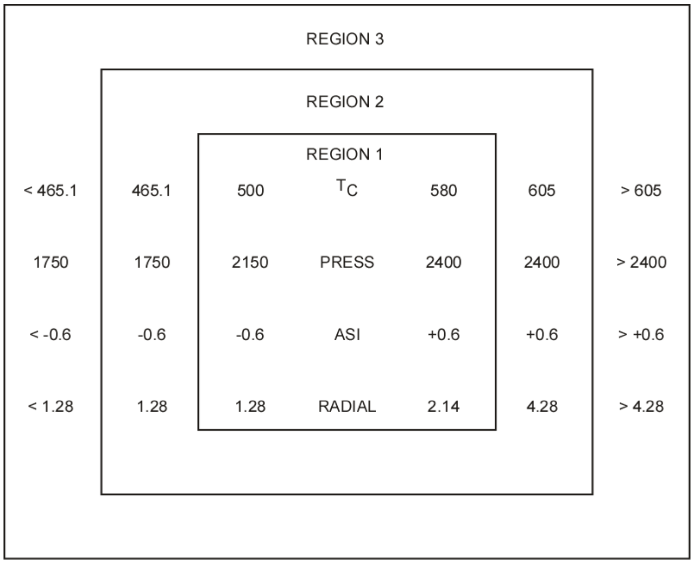

Figure 12.1-3 DNBR Update Program

As illustrated in Figure 12.1-3, these factors are combined into three separate regions with region 1 being defined as normal operation. Crossing from region 1 to region 2 results in the use of a larger value of derivatives that reduce DNBR. Likewise, moving from region 2 to region 3 results in even larger values being used. If the parameters exceed region 3, a DNBR trip results.

Because RCS flow has a drastic effect on DNBR, the effect of a negative rate of change of flow on DNBR is calculated every 50 milliseconds and supplied to the DNBR update calculation.

The final input into the DNBR update program is coolant quality. The coolant quality calculation accounts for changes in DNBR caused by unstable flow which results from boiling.

The updated value of DNBR is compared with the DNBR limit and a margin to trip is determined. This margin is displayed on a meter on the control board. If the margin reaches the pretrip set point a pretrip alarm results and if the margin decreases to zero a DNBR trip signal is generated.

12.1.3.8 LPD Calculation

The LPD calculation is used to generate a reactor trip signal before center line fuel melting limits are exceeded. This calculation receives inputs from the hot pin calculation and the highest of either excore power or ΔT power. The output of the LPD calculation is compared with the LPD limit. As in the DNBR trip routine, LPD margin is displayed, compared with the pretrip set point, and generates a LPD trip if the LPD margin drops to zero.

12.1.4 CPC Auxiliary Trips

The following will cause DNBR and LPD trips to be generated:

1. Internal computer processor faults,
2. Less than 4 RCPs running,
3. Operations in excess of region 3 parameters,
   or
4. ΔTc >17°F (asymmetric steam generators)

The auxiliary trip due to faults is installed to ensure that the CPC is functioning correctly and accurately calculating DNBR and LPD. Operations with less than four reactor coolant pumps has not been analyzed and is prohibited.

Operation in region 3 represents the approach to the upper and lower sensor input ranges and values assumed in safety analysis. The final auxiliary trip provides protection against the large radial flux tilts that would result if one main steam isolation valve was closed. The program checks for deviations between loop A and B cold leg temperatures (ΔTc) and if the deviation exceeds 17°F, a reactor trip signal is generated.

12.1.5 Summary

The CPCs provide protection for LPD and DNBR during AOOs. The CPC is a digital microprocessor that receives LPD and DNBR sensitive inputs and accurately calculates the approach to these limits.

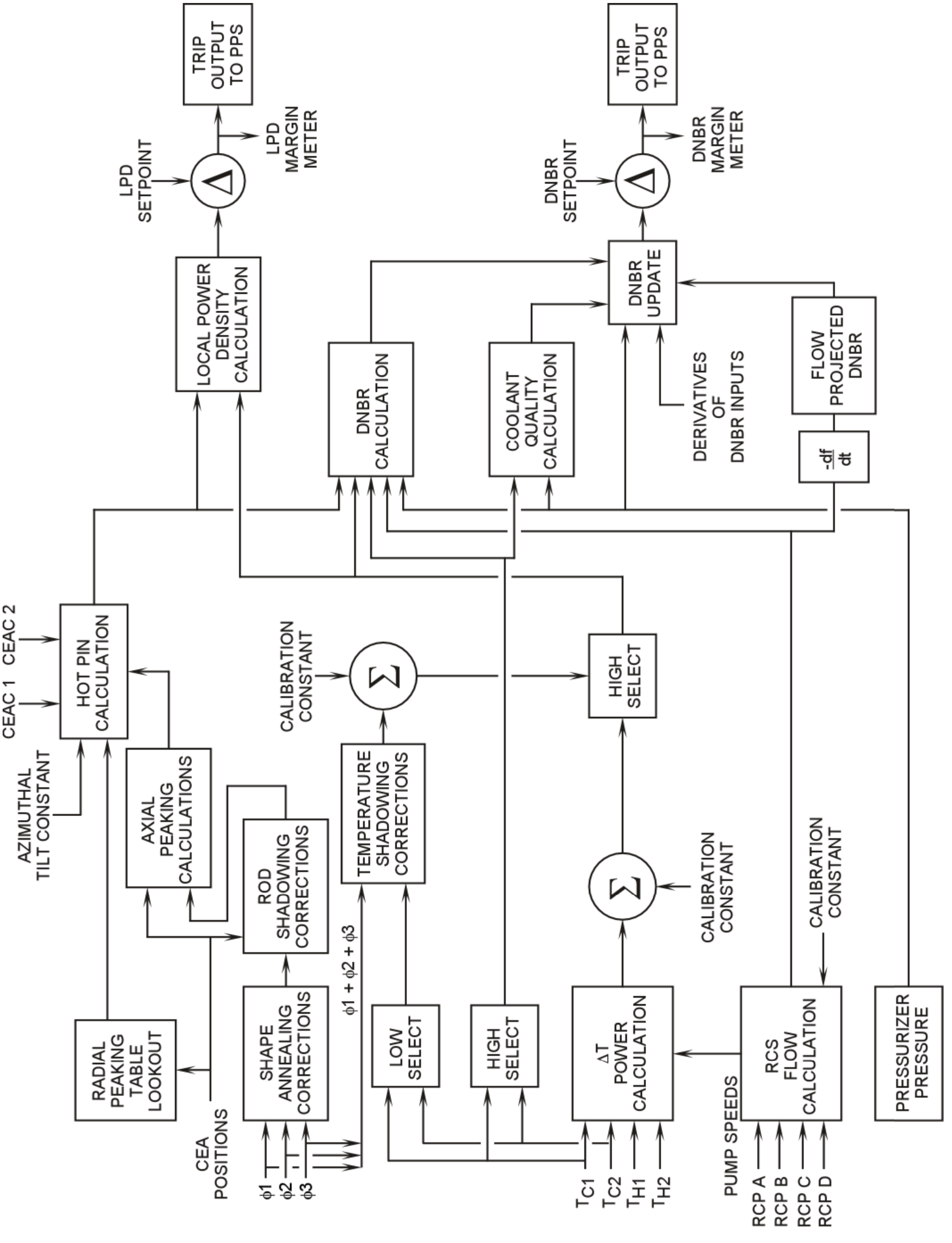

Figure 12.1-1 CPC Software Block Diagram

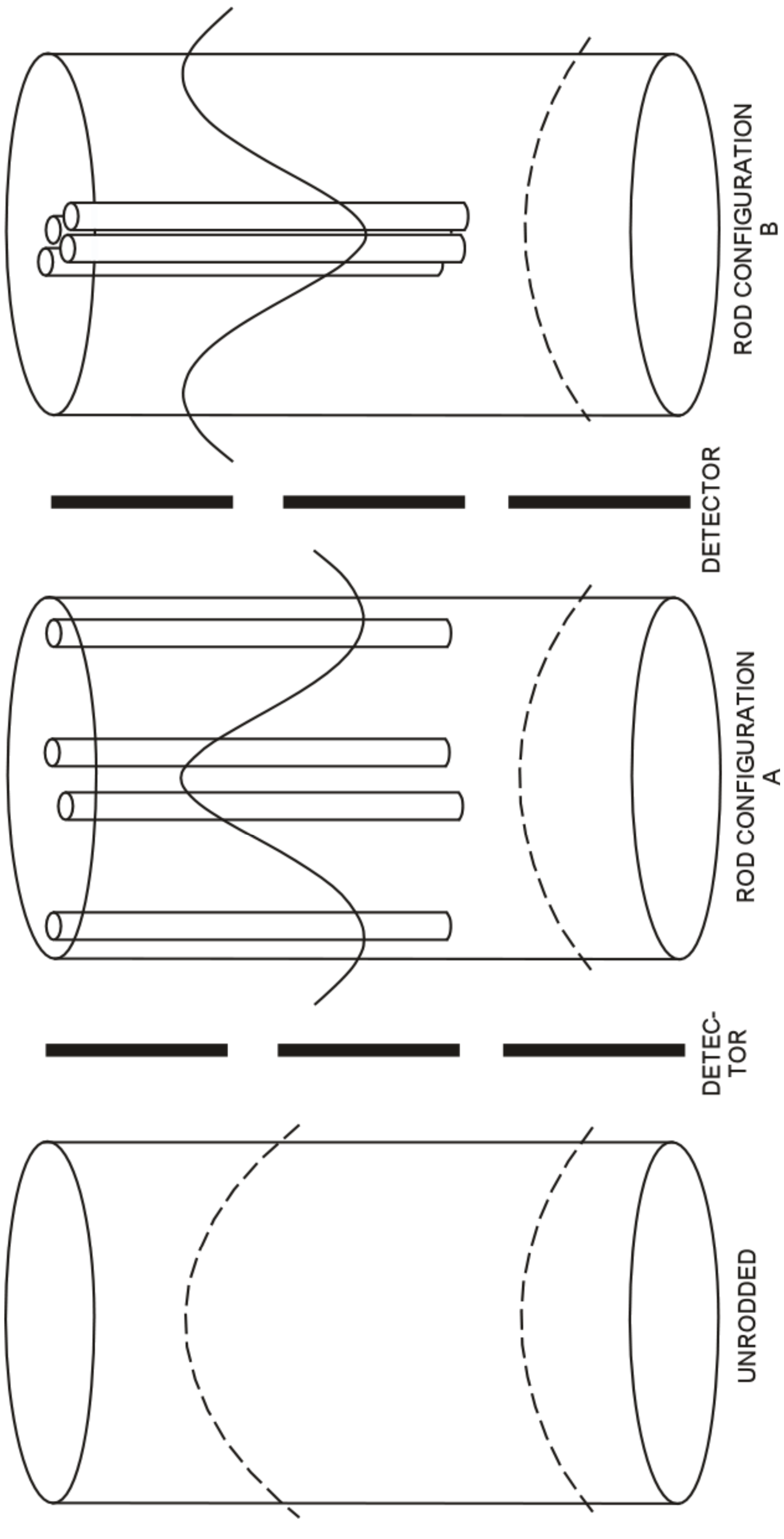

Figure 12.1-2 Rod Shadowing Examples

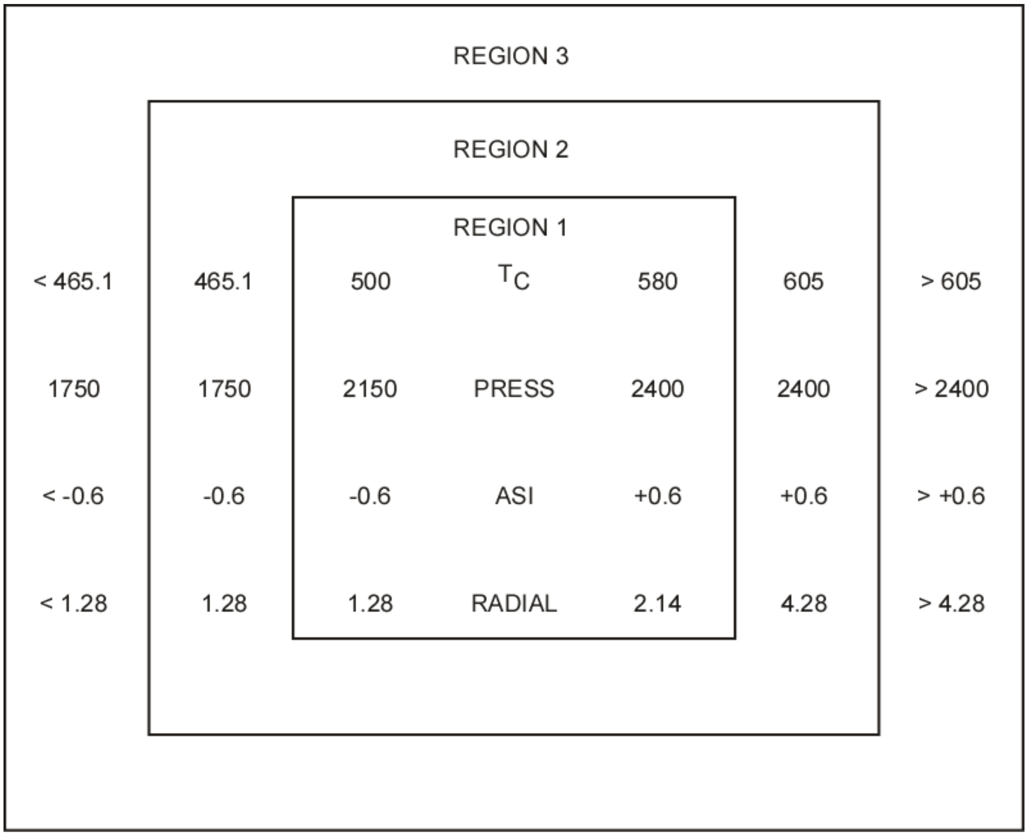

Figure 12.1-3 DNBR Update Program