FUNCTIONAL DESIGN REQUIREMENT

FOR A

CORE PROTECTION CALCULATOR

CEN-305-NP

Nuclear Power Systems
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## LEGAL NOTICE

## Abstract

This document provides a description of the Core Protection Calculator (CPC) System functional design. The scope of this functional description includes detailed specification of the reactor protection algorithms to be implemented in software and system requirements affecting the executive software and hardware design. The CPC System design bases are also presented.

System requirements are defined to assure that the hardware/software configuration is compatible with the reactor protection algorithms. Requirements are specified in the areas of input/output, protection program interaction, operator interface, and initialization.

Algorithm functional descriptions are provided for the protection software. The protection software consists of four distinct programs and a subroutine accessible to any of the four programs. Detailed algorithm descriptions are provided for each program and the subroutine. The algorithm equations are written in symbolic algebra. All variables are defined, and units are specified where applicable. To complete the algorithm descriptions, the output variables and required constants are listed for each program.

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## LIST OF ACRONYMS AND DEFINITIONS

| Name | Definition |
| --- | --- |
| ANO-2 | ARKANSAS NUCLEAR ONE - UNIT 2 |
| AOO | ANTICIPATED OPERATIONAL OCCURRENCE |
| CEA | CONTROL ELEMENT ASSEMBLY |
| CEAC | CONTROL ELEMENT ASSEMBLY CALCULATOR |
| CEDM | CONTROL ELEMENT DRIVE MECHANISM |
| CPC | CORE PROTECTION CALCULATOR |
| CRT | CATHODE RAY TUBE DISPLAY UNIT |
| DNBR | DEPARTURE FROM NUCLEATE BOILING RATIO |
| LPD | LOCAL POWER DENSITY |
| SONGS-2,3 | SAN ONOFRE NUCLEAR GENERATING STATION - UNITS 2, 3 |
| WSES-3 | WATERFORD STEAM AND ELECTRIC STATION - UNIT 3 |
| PVNGS-1,2,3 | PALO VERDE NUCLEAR GENERATING STATION - UNITS 1, 2, 3 |
| MAX(---) | MAXIMUM VALUE OF THE FOLLOWING |
| MIN(---) | MINIMUM VALUE OF THE FOLLOWING |
| RPC | REACTOR POWER CUTBACK |
| RSPT | REED SWITCH POSITION TRANSMITTER |
| SAFDL | SPECIFIED ACCEPTABLE FUEL DESIGN LIMITS |

# 1.0 INTRODUCTION

## 1.1 PURPOSE

The purpose of this document is to provide a description of the latest approved Core Protection Calculator (CPC) functional design. This document incorporates all the approved modifications made to CEN-147-(S)(Reference 1.4.1) as documented in References 1.4.2 thru 1.4.4 and as approved in References 1.4.5 thru 1.4.9. This document is for NRC information only as it contains information that has already been reviewed and approved by the NRC Staff. This document will serve as the base reference for future modifications and is intended to be updated as future modifications are approved and implemented.

## 1.2 SCOPE

The CPC design consists of three major components: executive software, application software, and hardware. This functional design requirements provides the following:

1) The reactor protection algorithms to be implemented as the application software and

2) Requirements on protection program interfaces, system interfaces, protection program timing, and system initialization.

Items (1) and (2) establish functional requirements affecting the three major CPC components.

1.3 APPLICABILITY

This document is a generic description of the CPC Functional Design Requirements. It is currently applicable to SONGS 2 (Cycle 2) and ANO-2 (Cycle 5). It is intended to be applicable to SONGS 3, WSES-3, and PVNGS 1,2, and 3 when this version of the functional design requirements is implemented and/or referenced at these plants.

1.4 REQUIRED REFERENCES

1.4.1 Functional Design Specification for a Core Protection Calculator, CEN-147(S)-NP, January 1981.

1.4.2 CPC/CEAC Software Modifications for Waterford 3, CEN-197(C)-NP, March 1982.

1.4.3 CPC/CEAC Software Modifications for System 80, LD-82-038-NP, March 1982.

1.4.4 CPC/CEAC Software Modification for San Onofre Nuclear Generating Station Units No. 2 and 3, CEN-281(S)-NP, July 1984.

1.4.5 Safety Evaluation Report related to operation of San Onofre Nuclear Generating Station, Unit 2 and 3, Docket Nos. 50-361 and 50-362, Southern California Edison Company, January 1982.

1.4.6 Safety Evaluation Report Related to the Operation of Waterford Steam Electric Station Unit No. 3, Docket No. 50-382, Louisiana Power and Light Company, July 1981.

1.4.7 Safety Evaluation Report Related to the Operation of Palo Verde Nuclear Generating Station, Units 1, 2 and 3, Docket Nos. STN-50-528, STN 50-529, and STN 50-530, Arizona Public Service Company, October 1984.

1.4.8 Safety Evaluation Related to Amendment No. 32 to NPF-10 and Amendment No. 21 to NPF-15 for San Onofre Nuclear Generating Station, Units 2 and 3, Docket Nos. 50-361 and 50-362, Southern California Edison Company, March 1985.

1.4.9 Safety Evaluation Related to Amendment No. 66 of Facility Operating License No. NPF-6, Arkansas Power & Light Company, Arkansas Nuclear One Unit 2, Docket No. 50-368, May 1985.

## 2.0 CPC DESIGN BASIS

The low DNBR and high local power density trips, (1) assure that the specified acceptable fuel design limits on departure from nucleate boiling and centerline fuel melting are not exceeded during Anticipated Operational Occurrences (AOO), and (2) assist the Engineered Safety Features System in limiting the consequences of certain postulated accidents.

### 2.1 SPECIFIED FUEL DESIGN LIMITS

The fuel design limits used to define the subject trip system settings are:

a. The DNBR in the limiting coolant channel in the core shall not be less than the ratio where there is at least a 95% probability, with 95% confidence, that DNB is avoided.

b. The peak linear heat rate, in the limiting fuel pin in the core, shall not be greater than that value corresponding to the centerline fuel melting temperature.

### 2.2 ANTICIPATED OPERATIONAL OCCURRENCES (AOOs)

Anticipated operational occurrences are defined in Appendix A of 10 CFR 50 (General Design Criteria for Nuclear Power Plants) as: "...those conditions of normal operation which are expected to occur one or more times during the life of the nuclear power unit...".

The anticipated operational occurrences that were used to determine the design requirements for the above trip functions are as follows:

A. Uncontrolled Axial Xenon Oscillations.

B. Insertion or withdrawal of full-length or part-length CEA groups,[1] including:

   1. uncontrolled sequential withdrawal of CEA groups from critical conditions,
   2. out-of-sequence insertion or withdrawal of a single CEA group from critical conditions,
   3. malpositioning of the part-length CEA groups,
   4. excessive insertion of full length CEA groups.

C. Insertion or withdrawal of full-length CEA subgroups[2] including:

   1. uncontrolled insertion or withdrawal of a single CEA subgroup from critical conditions,
   2. dropping of a single CEA subgroup,
   3. static misalignment of CEA subgroups comprising a designated CEA group.

D. Insertion or withdrawal of a single full-length or part-length CEA[3] including:

   1. uncontrolled insertion or withdrawal of a single CEA from critical conditions,
   2. a single dropped full or part-length CEA,

---

(1) A CEA group is any combination of one or more CEA subgroups which are operated and positioned as a unit.

(2) A CEA subgroup is any one set of four or five symmetrical CEAs.

(3) A CEA is a complement of poison rods connected to the same extension shaft and driven by the same drive mechanism.

3. a single CEA sticking, with the remainder of the CEAs in that group moving,
4. a statically misaligned CEA.

E. Excess heat removal due to secondary system malfunctions including:

1. excess feedwater flow,
2. excess steam flow caused by inadvertent opening of turbine bypass valves,
3. excess steam flow due to inadvertent opening of turbine control valves,
4. decrease in feedwater enthalpy.

F. Change of forced reactor coolant flow including simultaneous loss of electrical power to all reactor coolant pumps at 100% power.

G. Inadvertent depressurization of the reactor coolant system including actuation of full spray flow without proper performance of any pressurizer heaters.

H. Decrease in heat transfer capability between the secondary and reactor coolant systems including:

1. complete loss of main feedwater flow,
2. loss of external load.

I. Complete loss of AC power to the station auxiliaries.

J. Uncontrolled boron dilution.

K. Asymmetric steam generator transients due to instantaneous closure of one MSIV.

## 2.3 POSTULATED ACCIDENTS

The postulated accidents that are used to determine the design requirements for the subject trips are as follows:

a. Reactor coolant pump shaft seizure,
b. Steam generator tube rupture.

The CPC's are designed to provide a reactor trip when required for the above anticipated operational occurrences and postulated accidents when initiated from a power level greater than the CPC operating bypass power setpoint.

## 2.4 ADDITIONAL BASES FOR TRIP SETPOINTS

The subject trip systems in conjunction with the remaining Reactor Protective Systems (RPS) must be capable of providing protection for the design basis events given in Section 2.2, provided that at the initiation of these occurrences the Nuclear Steam Supply System (NSSS), its systems, components and parameters are maintained within operating limits and limiting conditions for operation (OL and LCO).

### 2.4.1 <u>Relationship Between Monitoring and Protection Systems</u>

The designs of the monitoring and protective systems are integrated with the plant technical specifications (in which operating limits and limiting conditions for operation are specified) to assure that all safety requirements are satisfied. The plant monitoring systems, protection systems and technical specifications thus complement each other. Protection systems provide automatic action to place the plant in a safe condition should an abnormal event occur. The technical specifications set forth the allowable regions and modes of operation on plant systems, components and parameters.

The monitoring systems (meters, displays, and systems such as COLSS) assist the operating personnel in enforcing the technical specification requirements. Making use of the monitoring systems, protection system and technical specifications in the manner described above will assure that if, (1) the operating personnel maintain all protective systems settings at or within allowable values, (2) the operating personnel maintain actual plant conditions within the appropriate limiting conditions for operation, and (3) equipment other than that causing an abnormal event or degraded by such an event operates as designed, then all anticipated operational occurrences or postulated accidents will result in acceptable consequences.

### 2.4.2 CPC Timing

The limiting event with respect to CPC timing requirements is that event which results in the most rapid approach to the DNBR safety limit. It is this event which determines the limiting CPC time response for the low DNBR trip.

[ ]

## 3.0 SYSTEM REQUIREMENTS

The following sections describe the system elements required for performance of the CPC protection function. Section 3.1 describes the input and output signals that must be provided to the CPC protection programs. The structure and interaction of the CPC protection algorithms is described in Sections 3.2 through 3.4. These sections provide information regarding the structure of the protection software, execution frequency of each protection program, sampling rates for input parameters, and communication among protection programs. Section 3.5 describes the necessary provisions for operator interaction with the CPC System. The requirements for initialization of the CPC algorithms are specified in Section 3.6. Interlocks and permissives required for the system are described in Section 3.7. Requirements related to hardware and software qualification are defined in Reference 1.5.2.

### 3.1 INPUTS AND OUTPUTS

Table 3-1 lists the CPC process input signals for each channel. Figure 3-1 is a system diagram that shows the allocation of input signals to each channel. Each CPC channel is required to have appropriate signal processing to provide four digital words accessible to the FLOW program (refer to Section 4.1). Each digital word must represent a value that is inversely proportional to the speed of one of the four reactor coolant pumps.

The temperature, pressure, excore detector, and CEA position inputs shall be analog signals proportional to the value of the respective measured process variable. The accuracy requirements in Table 3-1 establish the maximum allowable uncertainty introduced by the conversion of input signals to internal binary format. The accuracy requirements given in Table 3-1 are based on the total uncertainties attributable to the following:

## Table 3-1

## CPC Process Input Signals

| Signal | Number per CPC Channel | Description | Representative Range | Signal Type | Accuracy Required |
|---|---|---|---|---|---|
| Reactor Coolant Pump Speed | 4 | Reactor coolant pump shaft speed | [ ] | | |
| Cold Leg Temperature | 2 | Temperature in primary coolant cold legs, 1 of the 2 for each steam generator | 465°F -615°F | analog | ±1.0°F |
| Hot Leg Temperature | 2 | Temperature in primary coolant hot legs 1 and 2 | 525°F -675°F | analog | ±1.0°F |
| Pressure | 1 | Pressurizer pressure | 1500-2500 psia | analog | ±6.00 psia |
| Ex-Core Neutron Flux | 3 | Excore neutron detector signals | 0-200% | analog | ±0.5% |
| Deviation Penalty Factor | 2 | CEA deviation penalty factor from CEACs | [ ] | | |
| CEA Position | 23 | Target CEA position | 0-100% withdrawal | analog | [ ] |

[ ]

FIGURE 3-1: CPC I/O CONFIGURATION FOR ANO-2

1) loading effects
2) reference voltage supply regulation
3) electrical noise
4) linearity
5) A/D converter power supply sensitivity
6) quantization.

A digital word shall be received from each of two CEA calculators (Ref. 1.5.3). Each digital word shall contain CEA deviation penalty factors for the DNBR and LPD calculations. Application of the deviation penalty factors is described in Sections 4.2 and 4.4.

The output signals for each CPC channel are listed in Table 3-2. The two trip outputs are required to be input to the Plant Protection System for use as DNBR and LPD trip signals. Either the Reactor Power Cutback flag or the DNBR pretrip or the LPD pretrip outputs shall initiate CEA Withdrawal Prohibit (CWP) signals within the Plant Protection System. All five contact outputs must actuate operator alarms. The analog outputs for DNBR margin, LPD margin, and neutron flux power are required to drive analog meters that are monitored by the operator. The analog output for core coolant mass flow rate is required for comparison of CPC calculated flow to measured flow during startup testing.

In addition to the input and output capabilities discussed above, a device is required to allow the operator to modify a limited set of constant parameters and to interrogate a broad set of parameters within the software. The operator interface is described in more detail in Section 3.5.

## 3.2 PROGRAM STRUCTURE

The CPC design bases require that the system calculate conservative, but relatively accurate, values of DNBR and peak linear heat rate. However the algorithms required to achieve sufficiently

Table 3-2

CPC Output Signals

| Signal | Type | Range |
|---|---|---|
| Low DNBR Trip | Contact Output | |
| Low DNBR Pretrip | Contact Output | |
| High LPD Trip | Contact Output | |
| High LPD Pretrip | Contact Output | |
| Sensor Failure | Contact Output | |
| CEA Withdrawal Prohibit | Contact Output | |
| DNBR Margin | Analog | |
| LPD Margin | Analog | |
| Calibrated Neutron Flux Power | Analog | |
| Core Coolant Mass Flow Rate | Analog | |

detailed calculations cannot be executed rapidly enough to provide protection for those design basis events with the most rapid approach to the specified acceptable fuel design limits. In order to achieve a system time response sufficient to accommodate the limiting design basis events additional dynamic calculations of DNBR and peak linear heat rate are required. The dynamic calculations must provide conservative estimates of DNBR and peak linear heat rate based on changes in the process variables between successive detailed calculations of DNBR and peak linear heat rate. The dynamic calculations must be separated into two programs because adjustments in DNBR based on core coolant mass flow rate must be computed more frequently than adjustments based on the other process variables. The detailed calculations of DNBR and peak linear heat rate must also be separated into two programs. The grouping of the detailed calculations must be such that the execution interval of each program reflects the time interval over which the dynamic adjustments to the parameters, calculated in that program, are valid.

The resultant protection software shall consist of four interdependent programs and one subroutine that is accessible to all four programs:

1) Coolant Mass Flow Program (FLOW),
2) DNBR and Power Density Update Program (UPDATE),
3) Power Distribution Program (POWER),
4) Static DNBR and Power Density Program (STATIC),
5) Trip Sequence Subroutine (TRIPSEQ).

The FLOW program shall compute the primary coolant mass flow rate and a projected DNBR based on the time derivative of core coolant mass flow rate. In addition the FLOW program shall service the digital-to-analog converters for analog outputs.

The UPDATE program shall perform the following major computations:

1) Calibrated neutron flux power,
2) Total thermal power,
3) Core average heat flux,
4) Hot pin heat flux distribution,
5) DNBR and quality margin updates for changes in input parameters,
6) Peak local power density,

The major computations executed in POWER shall include the following:

1) Axial shape index (ASI) dependent flow projection constant and DNBR operating limit,
2) Core average axial power distribution,
3) Pseudo hot pin axial power distribution,
4) Three dimensional power peak,
5) Average of the hot channel power distribution.

STATIC shall compute static DNBR, static hot channel quality, and average enthalpy at the core inlet and outlet.

In TRIPSEQ, minimum DNBR, quality margin, and peak local power density shall be compared to their respective pretrip and trip setpoints. Whenever a setpoint is violated, the appropriate contact output shall be actuated. In addition, trips shall be initiated for core conditions outside the analyzed operating space, low reactor coolant pump speed, hot leg saturation, or internal processor faults including:

1) Fixed point divide fault (division by zero or quotient overflow),
2) Floating point arithmetic fault (overflow or underflow),
3) Memory parity error,

4) Illegal machine instruction,

5) Failure to meet the timing requirements of Section 3.3.

## 3.3 PROGRAM TIMING AND INPUT SAMPLING RATES

Execution of the four programs described in Section 3.2 shall be scheduled on a priority basis. The execution frequency of each protection program shall be fixed, based on the required CPC time response. In addition, the more frequently executed programs shall be assigned higher priority. The required execution frequencies of the four protection programs are specified in Table 3-3. The Trip Sequence shall be called by FLOW and UPDATE. Sampling of the input signals shall be initiated within the protection programs. Therefore the sampling rate for a given input is the same as the execution frequency of the program that reads that input parameter.

## 3.4 PROGRAM INTERFACES

Communication among the protection programs must be controlled to ensure that the output of a program is based on a consistent set of inputs. Therefore it is necessary to ensure that the input to a program is not changed until after execution of that program is complete. One method of controlling communication between programs is to assign exclusive input and output buffers to each program. The output of a program is made available to other programs through its output buffer. The output buffer is updated only when execution of the program is complete. The executive must be prohibited from interrupting a protection program while it is reading input from the output buffer of another protection program. In addition, no protection program may be interrupted while it is transferring data to its output buffer or while the Trip Sequence Subroutine is being executed.

Table 3-3

Program Execution Intervals and Input Sampling Rates

| Program | Inputs Sampled | Execution/Sampling Interval* | Remarks |
|---|---|---|---|

## 3.5 OPERATOR INTERFACE

The reactor operator shall be informed of the status of a CPC channel by three mechanisms:

1) The system generates alarms to alert the operator to abnormal events,
2) The operator interrogates the system to determine the current value of a particular parameter,
3) The operator reads one of three meters driven by the CPC analog output.

### 3.5.1 Alarms and Annunciators

Each channel must generate unique alarms for each of the following events:

1) Failure of a sensor,
2) Failure of the CPC channel,
3) Failure of a CEAC.

Indication of an alarm shall be visual. The executive should prohibit removal of the alarm indication unless the condition causing the alarm no longer exists. The alarm signals also must actuate the plant annunciator.

### 3.5.2 Displays and Indicators

Each channel must have an input/output device that allows interrogation by the operator. The device must enable the operator to initiate display of the significant parameters stored by the CPC programs, including system inputs, addressable constants and selected calculated variables. All parameters to be displayed are listed in Appendix A.

The three analog meters shall provide the operator with a continuous indication of the DNBR margin, LPD margin, and calibrated neutron flux power calculated by each CPC channel. The three meters shall be calibrated in engineering units over the following ranges:

1) DNBR Margin - 0-10,
2) LPD Margin - 0-25 kw/ft,
3) calibrated neutron flux power - 0-200%.

### 3.5.3 Operator Input

The operator must have the capability to change a limited set of program constants, called addressable constants, via the input/output device. Modification of addressable constants shall be permitted only when a manual interlock has been activated. In addition means, shall be provided to prevent modification of any constants not designated "addressable". The required addressable constants are listed in Table 3-4.

A means shall be provided for automated reentry of addressable constants, via floppy disc, whose values are not expected to change or whose values are expected to change very infrequently during the fuel cycle. Those constants are designated as Type II in Table 3-4. All other addressable constants are designated as Type I.

### 3.5.4 Failed Sensor Stack

[ ]

Table 3-4

Addressable Constants

| Symbol | Definition | Range |
| --- | --- | --- |

Table 3-4 (Cont'd.)

Addressable Constants

| Symbol | Definition | Range |
| --- | --- | --- |

Note: A validity check must be implemented to reject values outside the indicated range for each constant.

Table 3-5

Failed Sensor IDs

| Sensor ID | Sensor Name | Sensor ID | Sensor Name |
|---|---|---|---|

Table 3-5 (Cont'd.)

Failed Sensor IDs

NOTES:

[ ]

### 3.5.5 Tripped CPC Channel Snapshot

When a trip signal is generated in a CPC channel, a snapshot of CPC variables required for display shall be transmitted to a buffer which shall be accessible by using a teletype. [

] Changing the constant from 1 to 0 could be used to clear the buffer.

[ ]

## 3.6 INITIALIZATION

The CPC System must be capable of initializing to steady state operation for any allowable plant operating condition. Initialization must be complete within five (5) minutes of initial CPC System startup or of restart following a channel failure or in-test condition. Until initialization of a channel is complete, all trip outputs must be set in the tripped state.

Initialization shall be considered to be complete when the following criteria are satisfied:

[ ]

Table 3-[illegible]
Variables for CPC Channel Trip Snapshot

| Symbol | Definition | Units |
| --- | --- | --- |

Table 3-6 (Cont'd.)

Variables for CPC Channel Trip Snapshot

| Symbol | Definition | Units |
| --- | --- | --- |

Table 3-6 (Cont'd.)

Variables for CPC Channel Trip Snapshot

| Symbol | Definition | Units |
| --- | --- | --- |

[ ]

## 3.7 INTERLOCKS AND PERMISSIVES

A means is required to bypass the trip and pretrip contact outputs for a CPC channel when reactor power indicated by the corresponding Plant Protection System (PPS) linear power channel is less than $10^{-4}$ percent. In addition, means shall be provided to adjust the bypass setpoint up to at least 1% power to allow bypass of all CPC channels during low power physics testing. In either case, the bypass shall be implemented such that it must be manually initiated at the input/output device for each CPC channel. A means, such as a key switch, must be provided to prevent initiation of the bypass by unauthorized personnel. The bypass must be automatically removed from each CPC channel when the respective PPS linear power channel indicates that reactor power is greater than the bypass setpoint.

## 4.0 ALGORITHM DESCRIPTION

This section includes detailed description of the functions to be performed by the CPC protection algorithms. For each of the five programs described below, the sequence of computations required is described in sufficient detail to allow the software designer to specify the coding of the protection algorithms. To further assist the software designer, a functional block diagram, showing the information flow among and within the CPC algorithms, is included in Appendix B.

## 4.1 PRIMARY COOLANT MASS FLOW

[ ]

### 4.1.1 Algorithm Input

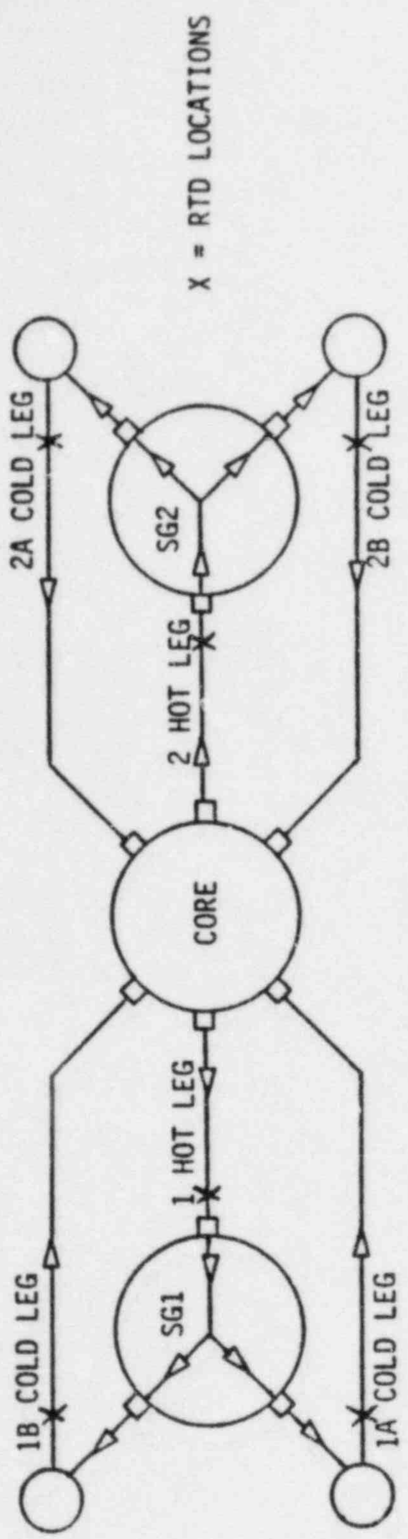
The FLOW algorithm requires the following process parameters from other CPC programs:

[ ]

4.1.2 Flow Resistances

Specific volumes for the primary coolant are computed from a curve fit of specific volume versus temperature and pressure.

FIGURE 4-1: Schematic of Primary System Showing Approximate Location of Temperature Sensors



4.1.3 Core Flow Calculation

4.1.4 Flow Projection

4.1.5 FLOW Output

The following quantities are transferred to the output buffer of the Primary Coolant Mass Flow Algorithm for use by other programs:

| Variable Name | Description | Destination |
| --- | --- | --- |

| Variable Name | Description | Destination |
| --- | --- | --- |

4.1.6 FLOW Constants

The constants required for the data base of the Primary Coolant Mass Flow Program are summarized below. The constants will be provided by the design implementation group. All other flow constants will be provided by the functional design group.

4.2 DNBR AND POWER DENSITY UPDATE

4.2.1 Input to UPDATE

The UPDATE program requires the following process parameters from other CPC programs:

Each CPC channel monitors two cold leg temperature signals (from diagonally opposite cold legs), two hot leg temperature signals, one primary pressure signal, and three excore neutron flux detectors. The raw signals are first checked for range and then scaled appropriately. [

]

4.2.2 Temperature Compensation

[ ]

4.2.3 Neutron Flux Power

4.2.4 CEAC Penalty Factors

The DNBR and LPD penalty factors for control element assembly (CEA) deviation are transmitted to each CPC from two Control Element Assembly Calculators (CEAC). The values from the two CEACs are compared and conservative values are chosen based upon the operational state of the CEACs. If an alarm situation exists, a visual indication is produced at the CPC input/output device.

4.2.5 Heat Flux Compensation

FIGURE 4-1A

Power Dependent Uncertainty Bias Program

[ ]

### 4.2.6 Update of DNBR Penalty for Asymmetric Steam Generator Transients

FIGURE 4-2: Penalty Components for [ ] [ ]

[ ]

## 4.2.7 Update of DNBR and Quality Margin

4.2.8 <u>Compensated Local Power Density</u>

The value of core average power used to compute local power density is biased to accommodate uncertainties and limited to a minimum value.

[ ]

[ ]

4.2.9 UPDATE Outputs

The following quantities are transferred to the output buffer of the DNBR and Power Density update program for use by other programs:

| Variable Name | Description | Destination |
| --- | --- | --- |

[ ]

4.2.10 UPDATE Constants

The constants required for the DNBR and Power Density Update are listed below. The following constants will be provided by the design implementation group:

The remaining constants listed below will be provided by the functional design group.

[ ]

4.3 POWER DISTRIBUTION ALGORITHM

The purpose of the power distribution is to compute the core average axial power distribution, pseudo hot pin power distribution, and the three dimensional power peak from the excore detector signals and target CEA positions. [ ]

4.3.1 POWER Input

The power distribution algorithm requires the following process parameter inputs from other CPC programs:

[ ]

TABLE 4-1

Correspondence of Index i(=1,12) to CEA Groups

4.3.2 Subgroup Deviation Penalty Factor

[ ]

4.3.3 Planar Radial Peaking Factors and CEA Shadowing Factors

[ ]

FIGURE 4-3

Sample Planar Radial or Shadowing Factor Lookup Table

FIGURE 4-4 [ ]

[ ]

FIGURE 4-5 [ ]

[ ]

FIGURE 4-6 [ ]

[ ]

[ ]

4.3.4 Out of Sequence Conditions

[ ]

[ ]

4.3.5 Excore Signal Normalization

[ ]

4.3.6 Power Distribution Synthesis

TABLE 4-2

Core Spline Regions

| Region | Non-Zero Spline Function |
| --- | --- |
| [ | ] |

4.3.7 ASI-Dependent Parameters

### 4.3.8 Pseudo Hot Pin Power Distribution

The pseudo hot pin relative axial power distribution is calculated using the relative axial power distribution calculated in Section 4.3.6 and the adjusted planar radial peaking factors.

4.3.9 Base Core Coolant Mass Flow Rate

The base core coolant mass flow rate is computed for use in the

4.3.10 POWER Output

| Variable Name | Description | Destination |
| --- | --- | --- |

### 4.3.11 POWER Constants

The constants required for the data base of the Power Distribution Program are listed below. Values of the constants $C_{1C}$, and $C_{2C}$, will be provided by the design implementation group. Values of the remaining constants will be provided by the functional design group.

## 4.4 STATIC DNBR AND POWER DENSITY

The purpose of the Static DNBR and Power Density Program is to compute the static values of DNBR, hot channel quality, primary thermal power and maximum hot leg temperature. In addition, this program establishes static values of the process variables that, in turn, constitute the baseline conditions for the DNBR update.

### 4.4.1 Inputs

This program requires the following process parameters:

### 4.4.2 Upgrade Power Distribution Data for Static DNBR Calculation

4.4.3 Saturation Properties and Pressure Dependent Terms

The saturated fluid properties are obtained from the following polynomials.

4.4.4 <u>Calculation of Inlet Coolant Mass Flux and Region-Dependent Parameters</u>

The core and hot assembly inlet conditions are calculated as follows.

4.4.5 Calculation of Linear Heat Distributions

### 4.4.6 Computation of Core/Hot-Assembly Fluid Properties

The calculations described in this section result in the enthalpy, mass flux, cross-flow and pressure drop axial distributions, for both the core region and hot-assembly channels. The hot-assembly distributions will be used in subsequent calculations. (Section 4.4.7)

The properties at each node depend on the properties of the upstream and downstream nodes. The method of solution is a

[ ]

## 4.4.7 Calculation of Buffer/Hot-Channel Fluid Profiles

The calculations described in this section result in the enthalpy and mass flux distributions for the buffer and the hot channels. The hot channel distributions will be used subsequently in the critical heat flux calculations.

As in the preceeding section, the properties at each node depend on the properties at both the upstream and downstream nodes. Again the method of solution is by [ ]. The technique is summarized below:

[ ]

### 4.4.8 Computation of Hot Channel Quality and Flow Profiles

The [ ] hot channel enthalpy and mass flux profiles are [ ] to generate the [ ] quality and mass flux profiles.

## 4.4.9 Hot Channel Heat Flux Distributions

The calculations described in this section result in the hot-channel critical heat flux and actual local heat flux distributions.

## 4.4.10 Correction Factors for Non-Uniform Heating

The correction factors for non-uniform heating are calculated from:

4.4.11 Calculation of Static DNBR

The DNB ratio at each hot-channel node is given by the following:

4.4.12 Static Thermal Power

The enthalpy in both hot legs and both cold legs is computed from the measured temperatures and pressures. If the average hot leg temperature is at its lower range limit,

### 4.4.13 Definition of Volume Functions

The preceeding calculations make use of the VOLUME functions* defined in this section. The independent variables in these functions are pressure (P) and local specific enthalpy (h). The three specific volumes resulting from these calculations are:

4.4.14 Definition of Friction Factor Function

4.4.15 STATIC Outputs

The following variables are written to the Static DNBR and Power Density Program output buffer for use by other programs:

| Variable Name | Definition | Destination |
| --- | --- | --- |

### 4.4.16 STATIC Constants

The constants required for the Static DNBR and Power Density Program are given below. These constants will be provided by the functional design group. However, the design implementation group must verify that the constant .

4.5 TRIP SEQUENCE ALGORITHM

The purpose of the Trip Sequence Algorithm is to issue trip outputs (contact output (C.O.) = logical "1") when computed variables within the program structure violate predetermined setpoint values; otherwise reset outputs (contact output (C.O.) = logical "0") are generated. [ ]

4.5.1 Input to the Trip Sequence Algorithm

The trip sequence algorithm requires the following process parameters from other CPC algorithms:

[ ]

## 4.5.2 DNBR/Quality Trip

First, determine the minimum, calculated value of DNBR and compensate for any uncertainty in calculation:

[ ]

If DNBR Trip or Pre-Trip limits are violated, or if Quality Margin Trip or Pre-trip limits are violated, issue a DNBR Trip or Pre-Trip signal:

[ ]

4.5.3 LPD Trip

If Local Power Density Trip or Pre-Trip limits are violated, issue a Local Power Density Trip or Pre-Trip signal:

4.5.4 Auxiliary Trips

4.5.5 CWP Signal

4.5.6 Trip Sequence Constants

The following constants, required for the Trip Sequence, will be provided by the functional design group:

[ ]

APPENDIX A

Parameters to be Displayed by
CPC I/O Device

Appendix A

Parameters to be Displayed by CPC I/O Device

| Symbol | Section Reference | Units of Displayed Value |
| --- | --- | --- |

Appendix A (Continued)

| Symbol | Section Reference | Units of Displayed Value |
| --- | --- | --- |

Appendix A (Continued)

| Symbol | Section Reference | Units of Displayed Value |
| --- | --- | --- |

Appendix A (Continued)

| Symbol | Section Reference | Units of Displayed Value |
| --- | --- | --- |

| Symbol | Section Reference | Units of Displayed Value |
|---|---|---|

APPENDIX B

CPC Functional Block Diagram