Functional Design Requirements for a Core Protection Calculator System for APR1400

Revision 1

Non-Proprietary

March 2017

REVISION HISTORY

Revision	Date	Page	Description
0	August 2014	All	First issue
1	March 2017	6	In accordance with the response to RAI 50-7911 Question 07.02-1, Rev.01, the description of figure identification to all channels was added.
		ix, 12, 14	In accordance with the response to RAI 435-8541 Question 07.02-16, the functional block diagram of CPCS was added.

ABSTRACT

This document provides a description of a Core Protection Calculator System (CPCS) functional design. The scope of this document includes detailed specifications 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 six distinct programs. Detailed algorithm descriptions are provided for each program. 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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ACRONYMS AND ABBREVIATIONS

AOO	anticipated operational occurrence
APR1400	Advanced Power Reactor 1400
ASGT	asymmetric steam generator transient
CEA	control element assembly
CEAC	control element assembly calculator
CEDM	control element drive mechanism
CMI	CEA motion inhibit
CPC	core protection calculator
CPCS	core protection calculator system
CPP	CEA position processor
CRC	cyclic redundancy check
CRT	cathode ray tube display unit
CWP	CEA withdrawal prohibit
DNBR	departure from nucleate boiling ratio
ESFAS	engineered safety features actuation system
I/O	input/output
IPS	information processing system
LPD	local power density
LPLDT	low pressure and low DNBR trip
MAX(---)	maximum value of the following
MIN(---)	minimum value of the following
MSIV	main steam isolation valve
MTP	maintenance and test panel
OM	operator's module
PSR	part-strength rod (part-strength cea)
RPC	reactor power cutback
RSPT	reed switch position transmitter
SAFDL	specified acceptable fuel design limits
SKN 3&4	Shinkori Units 3&4
VOPT	variable overpower trip

1. INTRODUCTION

1.1 Purpose

The purpose of this document is to provide a description of the Core Protection Calculator System (CPCS) Algorithm functional design with Common Qualified (Common Q) platform. When implemented with the appropriate data base and addressable constants, the Functional Design Requirements described in this document will meet the design bases for CPCS given in Section 2.

1.2 Scope

The CPCS design consists of three major components: executive software, application software, and hardware.

This functional design requirements document provided here includes the following:

1) A description of the reactor protection algorithms to be implemented as the application software;

2) The requirements for protection program interfaces, system interfaces, protection program timing, and system initialization;

3) A description of the Control Element Assembly (CEA) Penalty Factor Algorithm to be implemented in the Core Protection Calculator System of the Reactor Protection System;

4) A description of algorithms to initiate alarms in the event of CEA sensor failure and CEA deviation;

5) A description of a diagnostic failed sensor data stack.

Items (1) through (5) establish the functional requirements affecting the three major CPCS components.

1.3 Applicability

This document is a generic description of CPCS Functional Design Requirements. This document is prepared based on Ref. 1.4.1.

It is currently applicable to Advanced Power Reactor 1400 (APR1400).

1.4 Required References

1.4.1 KNF-S34ICD-08005, "Functional Design Requirements for a Core Protection Calculator System for Shinkori Nuclear Power Plant Units 3&4," Rev. 1, KNF, September 2010.

2. CPCS DESIGN BASIS

Low Departure from Nucleate Boiling Ratio (DNBR) and high local power density trips, (1) assure that the Specified Acceptable Fuel Design Limits (SAFDL) on departure from nucleate boiling and centerline fuel melting are not exceeded during Anticipated Operational Occurrences (AOO), and (2) assist the Engineered Safety Features Actuation System (ESFAS) in limiting the consequences of certain postulated accidents.

CPC shall meet additional design bases via auxiliary trip functions. These auxiliary trip functions are:

- Variable Overpower Trip (VOPT) which provides protection for sudden power increases.

- Asymmetric Steam Generator Transient (ASGT) trip which provides protection for instantaneous closure of the Main Steam Isolation Valves (MSIVs) to a single steam generator.

- Low Pressure and Low DNBR Trip (LPLDT) which provides protection for Reactor Coolant System (RCS) inventory decrease events.

- Range trip on several parameters which assures the core conditions are within the analyzed operating space.

- Pump trip which precludes operation with less than two reactor coolant pumps running.

- Hot leg saturation trip which precludes operation with substantial voiding in the hot leg fluid.

- Internal processor failure trip which provides a trip signal whenever the CPC is in test, initialization, or when an internal processor fault is detected.

- Low reactor coolant pump shaft speed trip which generates a trip when the Reactor Coolant Pump (RCP) shaft speed is below a certain value.

These auxiliary trip functions can also aid in meeting the above primary design bases.

The function of Control Element Assembly Calculator (CEAC) is to scan all CEA positions and, based on any single CEA deviation detected within a CEA subgroup, to calculate the individual CEA position-related penalty factors needed to ensure that the CPCs calculate conservative approximations for the actual core peak Local Power Density (LPD) and DNBR during single CEA-related AOOs which require CPCS protection. The CEAC must also be capable of detecting a reactor power cutback event.

2.1 Specified Accept able 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 be maintained such that 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 be maintained such that centerline fuel melting is avoided.

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 CEA groups[(1)], including:

1. uncontrolled sequential withdrawal of CEA groups from critical conditions,

2. out-of-sequence insertion or withdrawal of CEA groups from critical conditions.

C. Insertion or withdrawal of CEA subgroups[(2)] including:

1. uncontrolled insertion or withdrawal of a CEA subgroup from critical conditions,

2. dropping of a CEA subgroup,

3. misalignment of CEA subgroups comprising a designated CEA group.

D. Insertion or withdrawal of a single CEA[(3)] including:

1. uncontrolled insertion or withdrawal of a single CEA, from critical conditions,

2. a dropped CEA,

3. movement of a single CEA sticking with the remainder of the CEAs in that group,

4. a statically misaligned CEA.

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

1. excessive feedwater flow,

2. excessive steam flow caused by inadvertent opening of turbine bypass valves or an atmospheric dump valve,

3. excessive steam flow due to inadvertent opening of turbine control valves (governor 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 heater.

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(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.

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.

L. Letdown line break outside containment.

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,

c. Steam line break outside containment.

The CPC's are designed to provide a reactor trip when required for the above AOO 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 Protection 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 Limiting Conditions for Operation (LCO).

2.4.1 Relationship between Monitoring and Protection Systems

The designs of monitoring and protective systems are integrated with the plant technical specifications (in which operating limits and limiting conditions for operation are specified) to ensure 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 ensure that if, (1) the operating personnel maintain all protection 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 Specified Acceptable Fuel Design Limits on DNBR and LPD. The CPC incorporates dynamic filters and correction algorithms to accommodate sensor response characteristics, total CPC system time delay and NSSS dynamic response. The total CPC system time delay and NSSS dynamic response consist of:

τ_1 - the CPC sampling and processing time,

τ_2 - the RPS trip logic and trip breaker delay time,

τ_3 - the Control Element Drive Mechanism Control System (CEDMCS) holding coil decay time,

$\tau 4$ - the time for the CEAs to insert to the point which terminates the DNBR decrease, and

τ_5 - The fuel centerline temperature time constant.

The Limiting Conditions for Operation (LCO) and the dynamic algorithms in the CPC provide adequate margin to accommodate the total system time delay during transient conditions.

3. 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 CPC protection algorithms is described in Sections 3.2 through 3.4. These sections provide information regarding the structure of protection software, the 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 CPC algorithms are specified in Section 3.6. Interlocks and permissives required for the system are described in Section 3.7.

All figures provided in this document are identical for all channels or divisions. If a figure provided is not identical for all channels or divisions, a note is provided in the figure to indicate the difference.

3.1 Inputs and Outputs

Table 3-1 lists the CPC process input signals for each channel and the CEAC process input signal for each CEAC/CPP. 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 that can be 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:

1) loading effects

2) reference voltage supply regulation

3) electrical noise

4) linearity

5) A/D converter power supply sensitivity

6) quantization.

Table 3-1 CPC/CEAC Process Input Signals

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Signal	Number per CPC Channel	Description	Representative Range	Signal Type	Accuracy Required
Reactor Coolant Pump Speed	4	Reactor coolant pump shaft speed	10-100% of rated speed	Digital	
Cold Leg Temperature	2	Temperature in primary coolant cold legs, 1 of 2 for each steam generator	230-330°C (446-626°F)	Analog	
Hot Leg Temperature	2	Temperature in primary coolant hot legs 1 and 2	250-350°C (482-662°F)	Analog	
Pressure	1	Pressurizer pressure	105-175kg/cm^{2}A (1500-2500psia)	Analog	
Ex-Core Neutron Flux	3	Excore neutron detector signals	0-200% power	Analog	
Deviation Penalty Factor	2	CEA deviation penalty factor form CEACs	1.0-8.0	Digital	
CEA Position	23	Target CEA position	0-100% withdrawal (0-381cm)	Analog	
CEA Position	93/ CEAC	CEA position from CEA position processor (CPP)	0-100% withdrawal (0-381cm)	Analog	

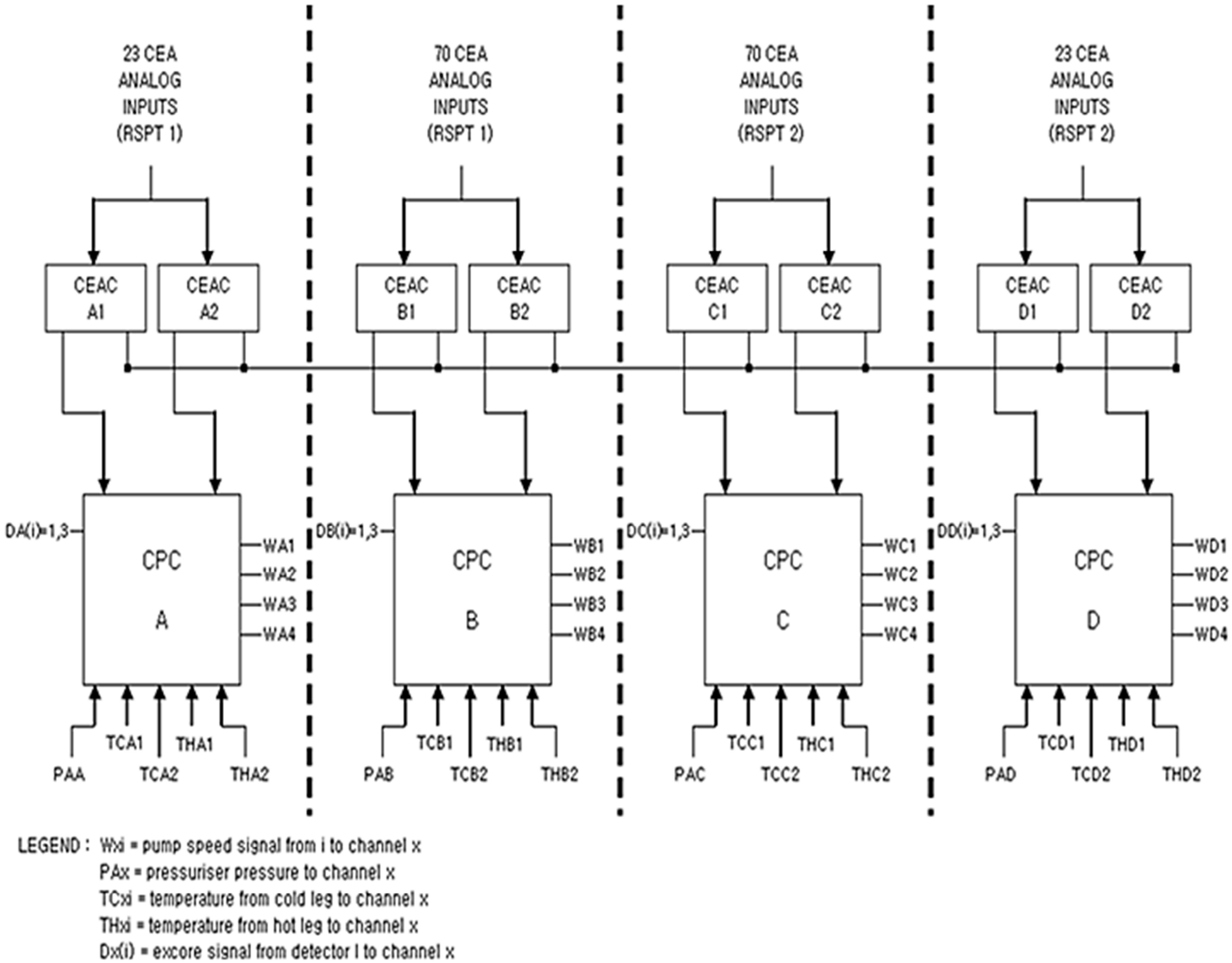

Figure 3-1 Common-Q CPCS I/O Configuration (For a 93 CEA Plant)

A digital word shall be received from each of two CEA calculators. 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 4.2.4 and 4.2.4.3.

The CEA Position Processor (CPP) shall receive each analog core axial CEA position measurement signal which originates from one of two Reed Switch Position Transmitter (RSPTs) associated with each CEA. Each CEA position is measured by two redundant and independent RSPTs which transmit analog signals to two redundant and independent CEAC/CPPs per each CPC channel.

The output signals for each CPC channel are listed in Table 3-2. The DNBR and LPD trip outputs are required to be input to the Plant Protection System for use as DNBR and LPD trip signals. The CEA Withdrawal Prohibit (CWP) signal will be processed in the Plant Protection System (PPS) so as to produce a CWP to the Control Element Drive Mechanism Control System (CEDMCS) if any two or more of the four CPCS indicate a CWP condition. CWP is initiated by the CPCS on:

- Low DNBR Pretrip
- High LPD Pretrip
- CEA Group Out of Sequence
- Subgroup deviation alarm
- CEA deviation or Reactor Power Cutback input from the channel CEACs

All six contact outputs must actuate operator alarms. The analog outputs for DNBR margin, LPD margin, core coolant mass flow rate and neutron flux power are required to drive analog meters that are monitored by the operator.

The output signals for each CEAC are listed in Table 3-3. The CEAC shall calculate the CEA deviation penalty factors based on CEA position sensor input data obtained from each of the RSPTs and send the CEA deviation penalty factors to CPC. The CEACs shall also transmit "Target" CEA position from RSPT1 CEA position in their respective core quadrants to the CPC Channels A and B, and from RSPT2 CEA position to the CPC channels C and D.

Each CEAC shall generate CPC input signals for CEA Deviation Alarm flag, Reactor Power Cutback flag, Big Penalty Factor flag and CEA Fail flag.

The two contact outputs must actuate operator alarms. The 32 bit digital-word outputs for DNBR and LPD penalty factors are transmitted to the CPC as floating point numbers. The other flags (including CEA Deviation Alarm flag, Reactor Power Cutback flag, Big Penalty Factor flag and CEA Fail flag) are packed (one bit per flag) and transmitted to the CPC as an integer number.

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

Table 3-2 CPC Output Signals

Signal	Type	Range
Low DNBR Trip	Contact Output	0, 1 (logical)
Low DNBR Pretrip	Contact Output	0, 1 (logical)
High LPD Trip	Contact Output	0, 1 (logical)
High LPD Pretrip	Contact Output	0, 1 (logical)
CEA Withdrawal Prohibit	Contact Output	0, 1 (logical)

Table 3-3 CEAC Output Signals

Signal	Type	Range
DNBR Penalty Factor	Digital	1.0-8.0 [2)]
LPD Penalty Factor	Digital	1.0-8.0 [2)]
CEA Deviation Alarm flag	Digital [1)]	0, 1 (logical)
Reactor Power Cutback flag	Digital [1)]	0, 1 (logical)
Big Penalty Factor flag indicating CASE2 Deviation	Digital [1)]	0, 1 (logical)
CEAC Fail flag	Digital [1)]	0, 1 (logical)
Sensor Fail Alarm	Digital	0, 1 (logical)
CEA Deviation Alarm	Digital	0, 1 (logical)

Note :

1) Part of 32-bit penalty factor flags word.

2) Real number as floating point (32-bit).

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 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 detailed calculations of DNBR and peak linear heat rate must also be separated into different programs. The grouping of 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 six interdependent 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 Program (TRIPSEQ),

6) CEAC Penalty Factor Program.

The five programs are executed in the CPC Processor Subrack. The last program is executed in the CEAC Processor Subrack. Figure 3.2 shows the functional block diagram of CPCS.

The FLOW program shall compute the primary coolant mass flow rate and DNBR margin. The DNBR margin is transmitted to the Information Processing System (IPS).

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 at the node of minimum DNBR, updated for changes in input parameters,

6) Peak local power density,

7) Asymmetric Steam Generator Transient (ASGT) trip,

8) Variable Overpower Trip (VOPT),

9) Low Pressure and Low DNBR Trip (LPLDT).

The major computations executed in POWER shall include the following:

1) Core average axial power distribution,

2) Pseudo hot pin axial power distribution,

3) Three dimensional power peaking factor,

4) Average of the hot channel power distribution.

STATIC shall compute static DNBR, static hot channel quality, maximum hot leg temperature including uncertainties and the saturation temperature of water, 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, less than two reactor coolant pumps running, hot leg saturation, VOPT, ASGT, LPLDT, or internal processor faults including:

1) Failure of the Random Access Memory(RAM) test self-diagnostics,

2) Failure of the Cyclic Redundancy Check (CRC) checks on the application Programmable Read Only Memory (PROM),

3) Illegal machine instruction,

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

The CEAC Penalty Factor Algorithm has been designed:

1) To recognize the initiation of a reactor power cutback event.

2) To calculate a deviation (difference in position) amongst the CEAs in each subgroup.

3) To recognize excessive CEA deviation within a subgroup, and to identify each occurrence as a single CEA withdrawal, single CEA insertion, or multiple CEA deviations within a subgroup and communicate this recognition to the CPCs.

4) To calculate and/or look up a penalty factor for LPD, and a penalty factor for DNBR based on the type of deviation event, the magnitude of the deviation, the CEA subgroup with the deviation, the CEA configuration, and the elapsed time since the start of the deviation. The LPD and DNBR penalty factors shall be selected as the maximum of LPD and DNBR penalty factors calculated for each subgroup.

5) To determine the status of CEAC sensor fail alarm and CEA deviation alarm.

6) To check some conditions under which CEAC (or upstream hardware) failure should be indicated to the CPCs.

7) To provide diagnostic information on CEA sensor failures, and on the causes of CEAC penalty factors.

8) To provide an indicator to CPCs of the scale used in determining the penalty factors transmitted.

9) To support CEA CRT display software by sending appropriate parameters used for the display.

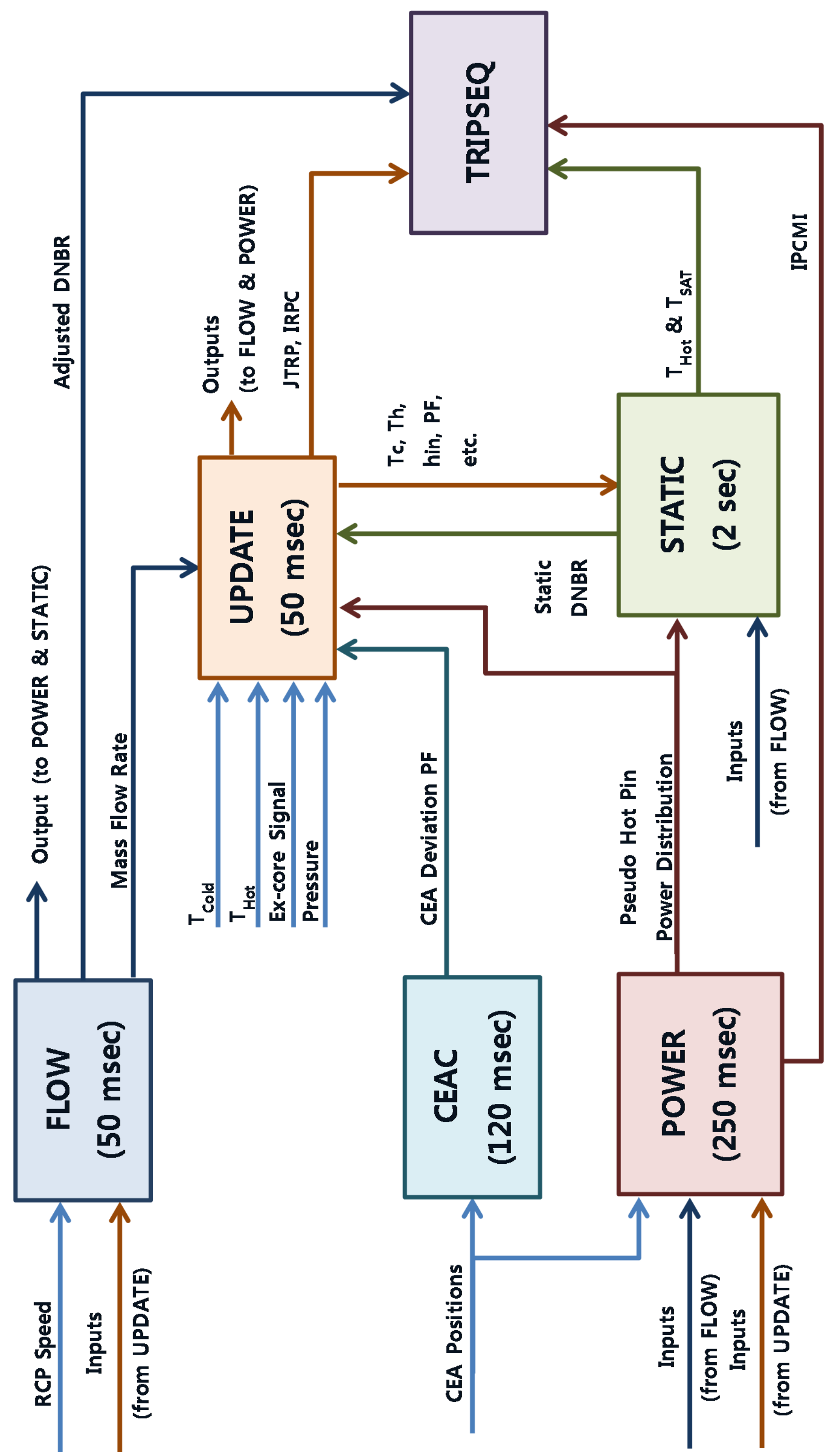

Figure 3.2 Functional Block Diagram of CPCS

3.3 Program Timing and Input Sampling Rates

Execution of the six programs described in Section 3.2 shall be scheduled on a priority basis. The execution frequency of each protection program shall be fixed, based upon the required CPC time response. In addition, more frequently executed programs shall be assigned higher priority. The required execution frequencies of six protection programs are specified in Table 3-4. The software shall insure that the functional programs (FLOW, UPDATE, POWER, STATIC, TRIPSEQ, and CEAC) are consistently executed on the schedule specified in Table 3-4. Any failure to execute the CPC programs on the specified schedule will result in a channel trip on Low DNBR and High LPD. In case of CEAC PF, failure to execute on the specified schedule will result in CEAC Fail in the associated CEAC.

The existing (legacy) CPCS executes FLOW every 50 milliseconds and UPDATE every 100 milliseconds. If a trip condition is generated by either of these programs, the TRIPSEQ program is called. TRIPSEQ generates the necessary trip outputs. The Common Q CPCS platform does not support such a “TRIPSEQ call” function. Therefore, the FLOW, UPDATE, and TRIPSEQ programs are to be executed in the same Control Module (CONTRM), every 50 milliseconds, in the order FLOW-UPDATE-TRIPSEQ. By executing these programs in the order specified, the system response time is improved, while replicating the order of execution of the legacy CPCS. That is, UPDATE will be executed with the most recent data from FLOW. Executing TRIPSEQ immediately after FLOW and UPDATE in the same program CONTRM improves response time, since any trip generated by FLOW or UPDATE will be processed immediately by TRIPSEQ.

Sampling of the input signals is initiated at the beginning of protection programs. Therefore the sampling rate for a given input is the same as the execution frequency of the program that reads the input parameter.

Target CEA position input to the CPC channel is an exception to the preceding rule. Target CEA position shall be updated by the CEA Position Processors and transmitted to the CPC channel via the CEAC every 200 milliseconds. This effectively delays the transmission of Target CEA positions to the CPC POWER program, where it is used. In order to compensate for this delay, the POWER program, which is executed every 1.0 seconds in the legacy CPCS, will have its execution frequency (cycle time) changed to 250 milliseconds.

Table 3-4 Program Execution Intervals and Input Sampling Rates

Program/ Processor	Inputs used	Execution Interval	Remarks (Note 1)
FLOW(CPC)	RCP Shaft Speed	50 msec	Input signal processing must update input value at least once per 50ms for speeds above 70% of rated pump speed. FLOW to be combined with UPDATE and TRIPSEQ, and executed every 50 ms, in the order FLOW-UPDATE-TRIPSEQ
UPDATE (CPC)	Cold Leg Temperatures Hot Leg Temperatures RCS Pressure CEA Deviation Penalty Factors Excore Detector Signals	50 msec	CEA Deviation PFs must be updated by CEACs at least once per 100 ms. UPDATE to be combined with FLOW and TRIPSEQ, and executed every 50 ms, in the order FLOW-UPDATE-TRIPSEQ
POWER(CPC)	CEA Positions	250 msec	
STATIC(CPC)	None	2 sec	
TRIP SEQUENCE (TRIPSEQ)	STATIC, POWER, FLOW and UPDATE programs	50 msec	TRIPSEQ to be combined with FLOW and UPDATE and executed every 50 ms, in the order FLOW-UPDATE-TRIPSEQ (TRIPSEQ is executed immediately following FLOW execution in the legacy CPCs)
CEAC(CEAC1)	CEA Positions from CPPs	120 msec	CEAC1 uses RSPT-1 on each CEA. Produces CEA deviation penalty factors
		200 msec	Provides target CEA position to CPC
CEAC(CEAC2)	CEA Positions from CPPs	120 msec	CEAC2 uses RSPT-2 on each CEA. Produces CEA deviation penalty factors
		200 msec	Provides target CEA position to CPC

Note 1: Input processing for all inputs will be performed preceding execution of the algorithms. Inputs other than CEA positions shall be read directly from the CPC AI modules. CEA position is processed by the CPPs and transmitted to the CEACs for penalty factor generation and to the CPC via the CEAC to CPC SL for Target CEA position processing.

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 data to a program is not changed until after the acquisition of all inputs to a program is complete. The CPC operating system will be prohibited from interrupting a protection program while it is reading input from the output of another protection program, or shall include provisions to assure that input data to one program from another is from a single execution cycle.

3.5 Operator Interfaces

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 using Operator's Module (OM or Maintenance and Test Panel (MTP) to determine the current value of a particular parameter,

3) The operator reads some information driven by the IPS (Information Processing System).

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

1) The system generates alarms to alert the operator to CEA sensor failures or excessive CEA deviation.

2) The CEA Position Display (CEAPD) Monitor displays the position of individual CEAs arranged into subgroups and control groups utilizing a bar graph representation, the floating point values of two penalty factors, and a flag to indicate the cause of any output.

3) The CPC/CEAC OM or MTP can be used to display CEAC inputs, and selected intermediate variables.

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.

CEACs must generate unique alarms for each of the following events:

1) Failure of a sensor,

2) CEA deviation.

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 Display and Indicator

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.

Both CEACs shall be linked to a single CEA Position Display for the purposes of displaying individual CEA position information. The connection between the data link and each individual CEAC shall be made via an appropriate isolation device. A manual selection switch shall be utilized to determine which of the two CEACs the Display Generator will utilize in generating a CEA position display. The CEA Position Display consists of a CRT Video Monitor and a Display Generator. The CEA Position Display shall display the position of individual CEAs arranged into subgroups by control groups utilizing a bar graph representation. The CEAs and subgroups assigned to each control group shall be recorded above the bar graphs. The CRT shall provide an indication of CEA deviation which allows the deviating CEAs to be identified as well as the magnitude of deviation.

Each CEAC shall provide diagnostic information to the operator via the operator's module or a terminal. The three types of diagnostic information to be provided are:

1. Failed sensor stack,

2. A "snapshot" or listing of CEA positions, penalty factors, and time of occurrence of the deviation,

3. A flag indicating the cause of any alarm.

A CEAC fail indication is transmitted to CPCs under the following conditions:

1. More than a pre-set number of sensors are indicated failed,

2. More than a pre-set number of subgroups contain excessive deviation (excessive deviations are counted by core quadrant),

3. Initialization and in-test mode,

4. CEAC hardware failure,

5. CEAC memory unprotected,

6. Watchdog timer timeout.

3.5.3 Operator Input

The operator shall be able to change addressable constants using the OM or MTP. 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 3-5.

A means shall be provided for automated reentry of addressable constants 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 3-5. All other addressable constants are designated as Type I.

3.5.4 Failed Sensor Stack

The failed sensor stack display pages shall include the date, time, and failure mode of at least the last

twenty sensor failures. There shall be separate failed sensor stacks for each of the processor subracks (CPC, CEAC 1, and CEAC 2). The CPC Failed Sensor Stack shall include separate entries for each of the following conditions:

- Out of Range High. This denotes an input value beyond the process input range limit.

- Out of Range Low. This denotes an input value beyond the process input range limit

- Channel Read Error. This denotes a failure to read a process input from both redundant AI module inputs. This will most likely result from a sensor failure which exceeds the AI module range limits. It may also be due to failures in both redundant AI module channels.

- Sensor Recovered. This denotes that the input sensor has returned to the normal range of operation.

For each of the above conditions the sensor point ID and Tag Name shall be provided, along with the nature of the failure (High, Low, Read Error, Recover), and the time of the event.

Table 3-5 CPCS Addressable Constants

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Table 3-5 CPCS Addressable Constants (Cont'd.)

Each CEAC Failed Sensor Stack shall include separate entries for each of the following conditions:

- Out of Range High: This denotes an input value beyond the process input range limit.

- Out of Range Low: This denotes an input value beyond the process input range limit.

- Rate of Change Failure: This denotes an excessive rate of change of CEA position sensor (RSPT) position. This is indicative of a sensor failure. The rate of change failure condition will latch until the “clear rate failure” icon is depressed. This is necessary in order to prevent resetting of the failure condition as soon as the position stops changing.

- Channel Read Error: This denotes a failure to read a process input from the AI modules in both subracks in the affected channel. This will most likely result from a sensor failure which exceeds the AI module range limits. It may also be due to AI module or channel failure.

- Sensor Recovered. This denotes that the input sensor has returned to the normal range of operation.

For each of the above conditions the sensor point ID and Tag Name shall be provided, along with the nature of the failure (High, Low, Rate, Read Error, Restore), and the time of the event.

3.5.5 CPC and CEAC Trip Buffer Displays

The default CPC trip buffer/CEAC snapshot display shall be the display of the most recent data. It shall also be possible to select the previous two trip buffer displays processed by the CPC Aux Processor/CEAC Processor. In the event of a Low DNBR or High LPD channel trip, the CPC trip buffer will be frozen at the time of trip, and the previous two displays will depict the buffer report data from two 50 millisecond CPC execution cycles immediately preceding the trip.

Similarly, the CEAC snapshot will be frozen on each of the following conditions:

- CEAC DBAND violation (CEA Deviation beyond deadband limits)

- Case 2 Deviation (multiple deviations in a subgroup)

- CEAC Fail caused by excessive number of failures in a core quadrant

- CEAC Failure caused by an excessive number of deviations in a core quadrant

When a snapshot is frozen, the current snapshot will depict data at the time of the freezing. The previous two CEAC displays will depict the CEAC snapshot data for two 120 millisecond execution cycles immediately preceding the violation.

The CPC Trip Buffer display page shall include a “Print CPC trip buffer” icon. Each CEAC display page shall contain a similar “Print CEAC Snapshot” icon.

Depressing the CPC Trip Buffer, CEAC 1 snapshot, or CEAC 2 snapshot print icons will cause a printout of the entire associated Trip buffer/CEAC snapshot. The printed trip buffer shall include the time of day and date, point ID, tag name, and the present and preceding two sets of values from two previous execution cycles.

Trip Buffer Clear:

It shall be possible to clear a latched trip buffer/CEAC snapshot from the trip buffer display screen. There

shall be separate icons for “Clear CPC Trip Buffer”, "Clear CEAC 1 Snapshot”, and "Clear CEAC 2 Snapshot” on the trip buffer menu screen. Clearing the trip buffer shall require placing the Function Enable (FE) switch to the “enable” position. Clearing a latched trip buffer will reset the CPC BUFFTRP addressable constant to 0, or the CEAC BUFFSNAP addressable constant to zero, as appropriate.

Table 3-6 shows the CPC parameters monitored by the CPC Trip Buffer and Table 3-7 depicts the same information for the CEAC snapshot. This is the minimum set needed to provide useful information in attempting to determine the cause of a trip. Table 3-6a shows the default set of 30 RDB values. These RDB values may be changed during the generation of a new RDB as desired by the specific plant implementation.

Table 3-6 Variables for CPC Channel Trip Snapshot (Typical)

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Table 3-6 Variables for CPC Channel Trip Snapshot (Typical) (Cont'd)

TS

Table 3-6 Variables for CPC Channel Trip Snapshot (Typical) (Cont'd.)

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Table 3-6 Variables for CPC Channel Trip Snapshot (Typical) (Cont'd.)

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Table 3-6a Default 30 PIDs

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Table 3-6a Default 30 PIDs (Cont'd)

TS

Table 3-7 Variables for CEAC Snapshot (Typical)

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3.6 Initialization

The CPC System must be capable of initializing to steady state operation for any allowable plant operating condition. The CPCS channel shall complete initialization within eight minutes of initial system startup. Initial system startup is defined as applying power to all of the equipment in a CPCS channel.

The CPC processor initialization shall be complete within five (5) minutes of resetting the CPC 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:

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The CEAC has no required initialization time. However, the CEAC processor initialization should be complete within five minutes of resetting a CEAC processor module. Until initialization of a CEAC as defined in Section 4.6.1.5 is complete, the CEAC Failure flag shall be set.

During initialization, the calculated penalty factors shall approach the steady state value from the conservative direction. Initialization shall be considered to be complete after at least five executions of the CEAC initialization program have occurred.

3.6.1 Initial Constants

The CPCS algorithm uses past values or values calculated from other subroutines. During the first execution of the program, these data shall be pre-defined. There are two types of data which require pre-defined values.

a) The first type is the data in the CPC Initialized Storage. The Initialized Storage contains the assumed past values used following a CPC restart in calculations where the current values of some variables

depend on these past values. An example of this type of data is the past values of the cold leg temperature used in the compensated cold leg temperature calculation.

b) The second type of data is the initial values of variables in the CPC program output buffers. The output buffers store the values of variables calculated in one program, which are used in another program. All output buffer locations are initialized, whether there is a clear need or not.

Table 3-8 lists the initial values of CPC variables in the CPC Initialized Storage. These values are chosen such that:

1. The values of DNBR and LPD calculated by the CPCS approach steady state from the conservative direction.

2. All digital filters are initially assumed to be at steady state.

3. Reactor Power Cutback (RPC) is not in effect.

4. Initialization time is minimized.

Table 3-9 contains the initial values of the variables in CPC program output buffers. The values of these variables are chosen as follows:

1. If the data are used in a higher priority program (i.e., one that executes more frequently) or in the TRIP SEQUENCE subroutine, the values are chosen such that the CPC calculated values of DNBR and LPD approach steady state from the conservative direction. An example of this type of data is the DNBR operating limit calculated in UPDATE, but used in TRIPSEQ.

2. If the value is used only in a lower priority program (one that executes less frequently), a value of zero is chosen, since output will be calculated before the lower priority program executes. An example is the heat flux calculated in UPDATE and used in STATIC.

3. The values are in English engineering units. For plants using metric, the values should be converted accordingly.

Table 3-8 CPC Initialized Storage (TYPICAL)

Variable	Program	Description	Value(Units)	Notes
$M_1 – M_7$	FLOW	Normalized mass flow rate in legs 1-6 and in core (M_7)	All 0.0 (fraction of design)	1
M_C	FLOW	Calibrated, normalized core coolant mass flow rate	0.0 (fraction of design)	1
K_{P0}	UPDATE	Past value of number of pumps running	-1	2
$F_{HTI2}(t)_p$,$F_{HTI2}(t\text{-}\Delta t)_p$, $F_{HTI1}(t\text{-}\Delta t)_p$ thru $F_{HTI1}(t\text{-}3\Delta t)_p$, $F_{CLI2}(t)_p$,$F_{CLI2}(t\text{-}\Delta t)_p$, $F_{CLI1}(t\text{-}\Delta t)_p$ thru $F_{CLI1}(t\text{-}3\Delta t)_p$	UPDATE	Past values of intermediate variables used in compensated power calculations	All 135 (% of design)	1
$L_{PDI2}(t)_p$, $L_{PDI2}(t\text{-}\Delta t)_p$ $L_{PDI1}(t\text{-}\Delta t)_p$ thru $L_{PDI1}(t\text{-}3\Delta t)_p$	UPDATE	Past values of intermediate variables used in compensated LPD calculations	All 400 (% of design)	1
PF_{1P}, PF_{2P}, PF_{L1P}, PF_{L2P}	UPDATE	Past values of DNBR and LPD penalty factors from CEACs 1 and 2	All 1.0	3
$B_{DYN}(t)_p$, $B_{DYN}(t\text{-}\Delta t)_p$	UPDATE	Past values of dynamic thermal power	0.0 (% of design)	4
$T_{C1}(t)_P$ thru $T_{C1}(t\text{-}7\Delta t)_p$	UPDATE	Past values of TC1	615 (°F)	5
$T_{C2}(t)_P$ thru $T_{C2}(t\text{-}7\Delta t)_p$	UPDATE	Past values of TC2	615 (°F)	5
$T_{cf1}(t)_p$, $T_{cf1}(t\text{-}\Delta t)_p$ $T_{cf2}(t)_p$, $T_{cf2}(t\text{-}\Delta t)_p$	UPDATE	Past values of cold leg temperature compensated for increasing Tcold	615 (°F)	1
$T_{cs1}(t)_p$, $T_{cs1}(t\text{-}\Delta t)_p$ $T_{cs2}(t)_p$, $T_{cs2}(t\text{-}\Delta t)_p$	UPDATE	Past values of cold leg temperature compensated for decreasing Tcold	465 (°F)	1

Table 3-8 CPC Initialized Storage (Cont'd)

Variable	Program	Description	Value(Units)	Notes
$T_{havg}(t)_p$, $T_{havg}(t-\Delta t)_p$	UPDATE	Average hot leg temperature	525 (°F)	1
$\Delta T_L(t)_p$, $\Delta T_L(t-\Delta t)_p$	UPDATE	Lagged cold leg temperature difference	0 (°F)	7
$\Delta T_1(t-\Delta t)_p$ thru $\Delta T_1(t-3\Delta t)_p$	UPDATE	Past values of cold leg temperature differences	0 (°F)	7
$\Delta T_{COMP1}(t)_p$ thru $\Delta T_{COMP1}(t-5\Delta t)_p$	UPDATE	Past values of compensated cold leg temperature differences	0 (°F)	7
I_{RPC}	UPDATE	Reactor Power Cutback Flag	0	9
I_{PFCB1P}, I_{PFCB2P}	UPDATE	Previous cycle RPC flag from CEAC1 and CEAC2	0	9
I_{CB1}, I_{CB2}	UPDATE	RPC event marker for CEAC1 and CEAC2	0	9
t_{CBP}	UPDATE	Elapsed time from the initiation of the RPC	0(seconds)	9
$FOLLOW_p$	UPDATE	Past value of VOPT variable (rate limited maximum of auctioneered power)	110 (%)	7
N_{PASSp}	UPDATE	UPDATE execution count	---	10
PF_{SGP}	POWER	The past value of subgroup deviation penalty factor	1.0	8
IDIR	POWER	Flag to indicate direction from which the detector response will approach the low power limit band	0	6
$\bar{M}(t - \Delta t)$	POWER	Long-term average core coolant mass flow rate	1.0 (fraction)	7
F_{R1}– F_{R20}	POWER	Radial peaking factors	1.55	9
F_1– F_{20}	POWER	CEA shadowing factors	1.0	9

Table 3-8 CPC Initial Storage (Cont'd)

Variable	Program	Description	Value(Units)	Notes
IP_{CMI}	POWER	Incipient CEA penalty flag	1.0	11
IRPC	CEAC	Reactor power cutback flag	0	9
$ND_{p}i$	CEAC	Last execution cycle flag of cutback group i with dropped CEA (i=1,3)	0	9

Notes for Table 3-8

1. Provides for approach to DNBR and LPD steady state values from a conservative direction.

2. Assumes that pump-dependent variables are calculated for all possible pump configurations.

3. Permits CPC restart with one CEAC failed or in-test without penalizing the CPC. Consistent with Tech Spec permitting plant operation with one CEAC out of service.

4. Engineering judgment. Assumes steady-state (i.e., no dynamic component of thermal power) at initialization.

5. Lower temperature conservative for flux power calculation; higher temperature conservative for DNBR calculation.

6. Engineering judgment. Either value of IDIR (0 or 1) is appropriate.

7. Value permits quicker initialization.

8. Engineering judgment. Assumes no subgroup deviation during initialization.

9. Assume reactor power cutback is not functional, all relevant control parameters are set to inhibit the function. Radial peaking factors and CEA shadowing factors should always be the All-Rods-Out values.

10. Set to the larger of (60* PFDTME/DTB) and (NPASMX) throughout initialization.

11. Set to 1 to be consistent with CCIP plants.

Table 3-9 Initial Values of Output Buffer

Variable	Program	Definition	Value (units)	Notes
K_p	FLOW	Number of reactor coolant pumps running	0	1
M_c	FLOW	Calibrated, normalized core coolant mass flow rate	0.0 (fraction of design)	1
M_5, M_6	FLOW	Normalized steam generator coolant mass flow rates	Both 0.0 (fraction)	1
X_1	FLOW	FLOW adjusted DNBR	0.0	1
F_2	FLOW	Pump dependent adjustment factor	0.0	1
V_c	FLOW	Normalized average cold leg specific volume	0.0	1
X_2	UPDATE	Updated DNBR	0.0	2
I_{RPC}	UPDATE	Reactor power cutback flag	0	2
L_{PDT}	UPDATE	Compensated peak LPD	400.0 (% of design)	2
QM_{min}	UPDATE	Minimum, updated quality margin	-0.01	2
D_{RAW1}, D_{RAW2}, D_{RAW3}	UPDATE	Raw Excore neutron flux detector values	All 0	1
T_{cavg}	UPDATE	Average cold leg temperature	615 (°F)	2
T_{havg}	UPDATE	Average hot leg temperature	675 (°F)	2
T_F	UPDATE	Temperature shadowing factor	0.0	1
$\phi_{CALC}(t)$	UPDATE	Maximum compensated core average heat flux	0.0 (% of rated)	1
T_{CMAX}	UPDATE	Maximum compensated cold leg temperature	0.0(°F)	1
h_{in}	UPDATE	Core inlet enthalpy	0.0 (BTU/lbm)	1
h_f	UPDATE	Liquid enthalpy at saturation	0.0 (BTU/lbm)	1
h_{fg}	UPDATE	Latent heat of vaporization	0.0 (BTU/lbm)	1
PF	UPDATE	CEA Deviation penalty factor for DNBR	0.0	1
T_{c1},T_{c2}	UPDATE	Scaled cold leg temperatures	Both 615(°F)	2
T_{h1},T_{h2}	UPDATE	Scaled hot leg temperatures	Both 675(°F)	2

Table 3-9 Initial Values of Output Buffer (Cont'd)

Variable	Program	Definition	Value (units)	Notes
J_{TRP}	UPDATE	Auxiliary trip flag	1	2
P	UPDATE	Corrected pressurizer pressure	1500 (psia)	2
CEA_{DEV}	UPDATE	Flag showing CEA deviation alarm	1	1
P_{NOR}	POWER	Flux power normalization factor corrected for shape annealing and CEA shadowing	130.0 (%)	4
PKMX	POWER	Maximum peaking factor	5.0	4
IP_{CMI}	POWER	Incipient CEA penalty flag	0	2
PD_i	POWER	Relative power in axial node i of the pseudo hot pin (i=1,20)	For i=1,10 -all 0.2 for i=11,20 -all 3.8	5
PD_{AVG}	POWER	Average of the hot channel power distribution	5.0	4
MC_{ST}	STATIC	STATIC core coolant mass flow rate	1.3 (fraction of design)	7
P_{ST}	STATIC	STATIC primary coolant system pressure	2500 (psia)	6
$P1_{ST}$	STATIC	STATIC one pin radial peak	1.0	7
ϕ_{CALCST}	STATIC	STATIC compensated core average power (heat flux)	10.0 (% of rated)	7
X_{ST}	STATIC	Hot channel quality at node of minimum DNBR	.50	6
C_{PIN1}, C_{PIN2}	STATIC	Enthalpy-temperature ratios for cold legs	Both 0.96 (BTU/lbm-°F)	2,8
C_{POUT1}, C_{POUT2}	STATIC	Enthalpy-temperature ratios for hot legs	Both 1.10 (BTU/lbm-°F)	2,9
T_{SAT}	STATIC	Saturation temperature of water	525 (°F)	2
T_{hmax}	STATIC	Maximum hot leg temperature with uncertainties	675 (°F)	2
$q''_{LOCALST}$	STATIC	Hot pin heat flux at node of minimum DNBR	0.0(10^6 BTU/hr-ft^2)	2

Table 3-9 Initial Values of Output Buffer (Cont'd)

Variable	Program	Definition	Value (units)	Notes
F_{KST}	STATIC	F-correction factor at node of minimum DNBR	0.0	2
G'_{4ST}	STATIC	Hot channel max flux at node of minimum DNBR	2.60 (10^6 lbm/hr-ft^2)	7
Dh_{ST}	STATIC	Hot channel enthalpy rise to node of DNBR	300 (BTU/lbm)	6
PF_{ST}	STATIC	CEA deviation penalty factor for DNBR	1.0	7
XY,LNX	STATIC	Intermediate variables from STATIC DNBR calculation	Both 0.0	6
XXY	STATIC	Intermediate variables from STATIC DNBR calculations	1.0	7
$DNBR_{ST}$	STATIC	Static DNBR	1.00	2

Notes for Table 3-9

1. Variables are used only in lower priority programs or variables recalculated before Trip Sequence executes. Any value acceptable.
2. Variables are used in higher priority programs or variables not recalculated before Trip Sequence executes. Conservative values provided.
3. Not used.
4. Value based on engineering judgment.
5. Any values are acceptable since values will be recalculated before CPC initializes. Values provided will force the hot pin ASI to equal –0.9.
6. Any value is acceptable if either F_{KST} equals 0.0 or $q''_{LOCALST}$ equals 0.0.
7. Any value except 0.0 is acceptable, if either F_{KST} equals 0.0 or $q''_{LOCALST}$ equals 0.0.
8. The ratio at 465 °F and 1500 psia.
9. The ratio of saturated liquid at 2500 psia

3.7 Interlocks and Permissives

The CPCS operating bypass under 10^{-4} percent power shall be implemented in the Plant Protection System (PPS) channel. The bypass must be automatically removed from each PPS channel when the PPS neutron flux signal power indicates that reactor power is greater than the bypass setpoint.

4. ALGORITHM DESCRIPTION

This section includes a detailed description of the functions to be performed by the CPCS protection algorithms. For each of the six 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.

4.1 Primary Coolant Mass Flow

The purpose of the Primary Coolant Mass Flow Algorithm is to compute a normalized flow rate in each leg of the primary coolant system and in the reactor core, and to compute an adjusted value of DNBR based on the number of RCPs running.

4.1.1 FLOW Algorithm Inputs

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

FROM UPDATE:

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FROM POWER:

None.

FROM STATIC:

None.

Normalized mass flow rates in each leg of the primary coolant system are computed from the speeds of the four reactor coolant pumps (RCP), the specific volume of the primary coolant and a correction based on hot leg temperature. The normalization of the flow rates is based on a reference cold leg specific volume and rated pump speed. Raw input values indicative of pump speed are obtained from the Reactor Coolant Pump Shaft Speed Sensors (RCPSSS). These raw input values vary inversely with the rotational speed of the RCP shaft. In the event of a loss of input pulses from the RCPSSSS (e.g. sheared-shaft), the RCP pump speed approaches infinite value.

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TS

Two pump-dependent constants are selected to adjust the DNBR and LPD for conditions with less than four pumps running:

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TS

4.1.2 Specific Volumes

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

TS

As is apparent in Equations 4.1-6 through 4.1-8 a single curve fit with a single set of coefficients is used to compute the specific volume corresponding to each temperature and pressure. The temperatures and

pressure above are computed from raw input values sampled in the UPDATE Program.

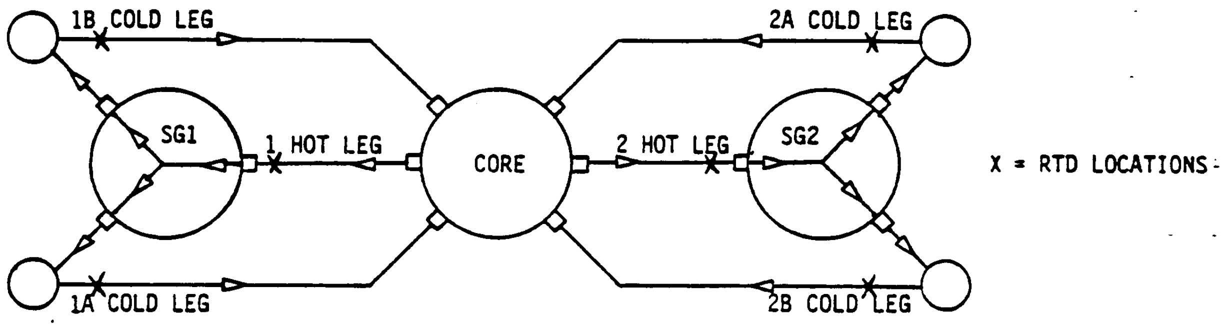

Figure 4-1 Schematic of Typical Primary System Showing Approximate Location of Temperature Sensors

4.1.3 Core Flow Calculation

The normalized mass flow rate for each leg of the primary coolant system pump is computed from

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The hot leg and core mass flow rates are then computed by,

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TS

4.1.4 DNBR Calculation

The DNBR value calculated in UPDATE is adjusted for the pump dependent uncertainty.

TS

4.1.5 FLOW Outputs

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

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TS

4.1.6 FLOW Constants

The constants required for the data base of the Primary Coolant Mass Flow Program are summarized below.

TS

4.2 DNBR and POWER DENSITY UPDATE

The purpose of the DNBR and Power Density Update Algorithm ("UPDATE") is to compute an updated value of DNBR, quality margin, and local power density based on temperature, pressure, core power, flow, and power distribution. Also computed are neutron flux power, thermal power, hot pin axial shape index, hot pin heat flux, the one-pin integrated radial peaking factor, Asymmetric Steam Generator Transient (ASGT) trip and Variable Overpower Trip (VOPT).

First Execution Cycle

The CEAC penalty factor timer is set during the first cycle of initialization as follows:

Set N_{PASS} to the larger of $60 \cdot PF_{DTME}/DTB$ or N_{PASMX} throughout the CPC initialization period. This assures that any penalty factors that are appropriate at the end of initialization will be applied without delay.

Where

TS

The auxiliary trip flag is initialized as follows:

$J_{TRP} = 0$

for each execution of UPDATE.

4.2.1 UPDATE Algorithm Inputs

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

FROM FLOW:

TS

FROM POWER:

TS

TS

FROM STATIC:

TS

FROM CEAC$_i$ (I = 1,2):

TS

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

out of range, a maximum or minimum value is assigned, and a sensor failure alarm is initiated.

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For two CPC channels, i = 1 denotes the temperature in cold leg 1A, and i = 2 denotes the temperature in cold leg 2B. For the other two CPC channels, i = 1 denotes the temperature in cold leg 1B, and i = 2 denotes the temperature in cold leg 2A (see Fig. 4-1).

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Each CEACi, (i=1 or 2), sends to the CPC the DNBR penalty factor, PF_i, (called PF_{DNBR} in the CEAC algorithm), the LPD penalty factor, PF_{Li}, (called PF_{LPD} in the CEAC algorithm) and the status flag, $FLAG_{CEACi}$. The status flag is set up as follows (1 bit for each flag):

Most Significant Bit Least Significant Bit

IFAILi	I_{CASE2i}	I_{PFCBi}	$CEACi_D$

where:

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4.2.2 Temperature Compensation

The cold leg temperatures are dynamically compensated for effects of the sensor time constant, transport delays, and the plenum mixing time constant. This is accomplished through the use of digital algorithms that use the previous measured cold leg temperatures and dynamically compensated cold leg temperatures. Each cold leg temperature is compensated by two separate digital algorithms - one optimized for increasing temperature and one optimized for decreasing temperature.

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4.2.3 Neutron Flux Power

Calibrated neutron flux power is calculated from:

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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). (See Section 4.2.1.) 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.

In addition to a status flag from each CEAC, the addressable constant C_{INOP} is used to indicate to the CPC the status of the CEACs and to specify the DNBR and LPD penalty factors to be used. C_{INOP} has four allowable values, which are:

0 - Both CEACs are considered operable. Use DNBR and LPD penalty factors determined by the CEACs and auctioneer for maximum values except during the period immediately following the imposition of a non-zero penalty factor from the CEACs.

1 - CEAC1 is considered inoperable. Use the last good DNBR and LPD penalty factors from CEAC1. Auctioneer with penalty factors from CEAC2 for maximum values.

2 - CEAC2 is considered inoperable. Use the last good DNBR and LPD penalty factors from CEAC2. Auctioneer with penalty factors from CEAC1 for maximum values.

3 - Both CEACs are considered inoperable. Use the pre-determined DNBR and LPD penalty factors. For certain situations involving failure of CEA position sensors and/or CEACs the plant technical specifications will require that the addressable "CEAC/RSPT Inoperable" flag be set equal to 3.

4.2.4.1 Determination of RPC Status

If $IFAIL_1 \neq 1$ and $C_{INOP} \neq 1$ or 3, then the reactor power cutback (RPC) flag status is determined as follows:

If the RPC flag from the CEAC1 changes from 0 to 1, the CPC RPC flag is set.

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The RPC flag timer is initiated if it is not already started.

If the RPC flag from the CEAC1 changes from 1 to 0, the CPC RPC event marker is reset.

TS

If $IFAIL_2$ is not set and CINOP < 2, then the CPC RPC flag status is determined as follows:

If the RPC flag from the CEAC2 changes from 0 to 1, the CPC RPC flag is set.

TS

The CPC RPC flag timer should be initiated if it is not already started.

If the RPC flag from the CEAC2 changes from 1 to 0, the CPC RPC event marker should be reset.

TS

TS

If both CEACs are operable, i.e., $IFAIL_1$ = 0 and $IFAIL_2$ = 0 and C_{INOP} = 0, it's necessary to verify that both the RPC event markers (I_{CB1} and I_{CB2}) are set after the CPC RPC flag timer count is equal to or greater than T_{BOTH}. If not, the CPC RPC flag should be cleared. Also the CPC RPC flag should be cleared if it has been set for more than the addressable maximum period.

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The base CEA DNBR and LPD deviation penalty factors are determined by the logic described below.

4.2.4.2 CEAC Failure Check

The CEAC inputs are tested to determine whether both CEACs are operable, i.e., not in test or failed. If either one is failed, a sensor failure alarm should be issued and the appropriate flag set. This test is

executed for all values of C_{INOP}. Thus,

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4.2.4.3 Penalty Factor Calculation for Two Operable CEACs

If both CEACs are operable, the Case 2 type deviation flags are checked. If the Case 2 type deviation flag = 1, the corresponding DNBR and LPD penalty factors are set to the larger of the CEAC computed penalty factor and the pre-set Case 2 type deviation penalty factor values. If both CEACs are operable, the corresponding DNBR and LPD penalty factors from both CEACs are greater than 1.0, and the larger penalty factor from the two CEAC is used in the computation. If both the DNBR and LPD penalty factors from one CEAC are 1.0, a time delay is introduced before the larger penalty factor is selected. At the same time, the difference between the penalty factors from the two CEACs is checked and a sensor failure alarm is initiated if the difference exceeds a threshold for a significant time period. The DNBR and LPD penalty factors from both CEACs are saved for the next UPDATE execution.

Initial conditions should be set prior to decoding the penalty factors from the CEACs.

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TS

If either the DNBR or the LPD penalty factor from either CEAC is greater than one, then the CEA deviation flag should be set; otherwise the penalty factor delay counter should be set to zero.

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At this point either $CEACi_D$ is set or PF_i, or PF_{Li} is greater than one, indicating a CEA deviation is detected by the CEACi. The corresponding DNBR and LPD penalty factors from the two CEACs are compared.

The following logic are executed (eqs 4.2-16H to 4.2-16J; note eqs 4.2-16F & 4.2-16G are not used):

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The penalty factors from the two CEACs are tested. If only one CEAC sends penalty factor(s) larger than one, the penalty factor application is delayed.

TS

then the sensor failure alarm should be issued, the appropriate sensor failure indication set and the time counter increased:

TS

TS

4.2.4.4 Penalty Factor Calculation for One or Two Inoperable CEACs.

If one CEAC is off-line or inoperable (failed or in test) and the other CEAC is on-line and operable, (i.e., $JINOP_3$ is 1 or 2 while C_{INOP} is set to zero, or C_{INOP} is one while $JINOP_3$ is one or C_{INOP} is two while $JINOP_3$ is two), the CPC uses the larger of the penalty factor from the operable CEAC and the previously stored penalty factor from the failed CEAC. If a Case 2 type deviation is indicated, then the larger of the computed penalty factor and the pre-set Case 2 type deviation penalty factor is chosen. The penalty factors from the operable CEAC are saved. The DNBR penalty factor is also tested for CEA deviation alarm only and the alarm flag is set if necessary.

$PF_o = 1.0$ (4.2-17A)

$PF_{oL} = 1.0$

If CEAC1 is failed (or in test) or C_{INOP} is equal to one and CEAC2 is operable, the DNBR and LPD penalty factors are determined in the following manner:

TS

TS

TS

and skip to section 4.2.4.5.

If both CEACs become inoperable while C_{INOP} is set to less than three, the CPC issues the sensor failure alarm, sets the appropriate failed sensor indications and selects the penalty factors based on time delay logic. During the time delay interval the larger of the latest previous penalty factors are used. After the time delay the pre-selected penalty factors are used.

TS

TS

If C_{INOP} equals three, predetermined values are used for the DNBR and LPD penalty factors. In addition, checks are made of the status of the CEAC inputs. If either CEAC or both CEACs are failed or in-test, then the sensor failure alarm is issued.

TS

4.2.4.5 Total Penalty Factor Calculation

The total DNBR and LPD penalty factors are calculated as follows:

TS

TS

If the reactor power cutback flag is set, the off-line calculated RPC penalty factors are used.

TS

4.2.5 Heat Flux Compensation

Total thermal power is computed as the sum of a dynamic component and a static component as follows:

TS

TS

TS

The CPC uncorrected core average power is determined as the maximum of the total thermal power and the calibrated neutron flux power. Both the calibrated neutron flux power and the calibrated total thermal power are compensated by uncertainty bias terms and are limited to values no less than ϕ_{min} in determining the corrected values of neutron flux power and total thermal power.

TS

The power dependent uncertainty bias is calculated. Figure 4-1A illustrates the algorithm graphically.

The slopes, C_{PERRT} and C_{PERRN}, of the power related bias are calculated in the first execution cycle of UPDATE during initialization.

TS

Figure 4-1A Power Dependent Uncertainty Bias Program

TS

TS

TS

TS

The corrected neutron flux power is compensated for fuel dynamics by a digital filter. The core average heat flux is selected as the maximum compensated thermal power and compensated neutron flux power values.

TS

Core average heat flux is multiplied by the pseudo hot pin power distribution to yield a hot pin heat flux distribution

TS

TS

The hot pin axial shape index is calculated from the synthesized hot pin heat flux distribution.

TS

4.2.6 Asymmetric Steam Generator Transient Trip Function

An ASGT trip is computed based on the temperature difference between opposing cold legs. This algorithm provides automatic protective action in the event of certain asymmetric steam generator transients, e.g. a closure of a single main steam isolation valve (MSIV).

The previous temperature differences are retained for use in calculating the compensated cold leg temperature difference.

TS

TS

The temperature difference is calculated and filtered to eliminate the steady state error component. Its absolute value is then calculated:

TS

The cold leg temperature difference is compensated for effects of the sensor time constant and then is adjusted by the addition of the absolute value of the steady state difference.

TS

Add in steady state error

TS

The cold leg temperature difference trip setpoint bias, corresponding to the current power level, is calculated. Figure 4-2 illustrates the basis for the following calculation.

TS

TS

TS

Figure 4-2 Cold Leg Temperature Difference Trip Setpoint Bias vs. Power Level

4.2.7 Update of DNBR and Quality Margin

The integrated one pin radial peak is calculated from the average of the hot pin power distribution and the azimuthal tilt allowance.

TS

It can be determined from the current values of cold leg temperature, primary pressure, hot pin ASI, and one pin radial peak whether the plant is within the wide band operating space.

TS

TS

The following fluid properties are calculated based on the core inlet temperature and/or pressure: the core inlet enthalpy, the liquid enthalpy at saturation, and the latent heat of vaporization

TS

The updated quality at the node of minimum DNBR is calculated as follows:

TS

TS

The F-correction factor is calculated for this execution of the UPDATE program.

TS

The hot channel heat flux is calculated for this execution of the UPDATE program.

TS

TS

The updated minimum DNBR is calculated as follows:

TS

TS

The updated quality margin is calculated:

TS

4.2.8 Compensated Local Power Density

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

TS

TS

Local power density is compensated for power change.

TS

TS

The compensated local power density is multiplied by uncertainty factors to obtain the value to be used in the trip decision.

TS

TS

4.2.9 Variable Overpower Trip Function (VOPT)

The VOPT is based on auctioneered power from excore detector signals, temperature shadowing corrected excore detector signals, neutron flux power and thermal power. A variable, FOLLOW, is calculated which follows changes in the auctioneered power within rate limits. FOLLOW cannot be changed from its previous value by more than an amount depending on the data base rate limits and the computing interval. The VOPT setpoint is computed by adding a fixed power bias, ΔSP_V, to the variable FOLLOW. The VOPT setpoint is limited by a minimum allowable value, SP_{VMIN}, and a maximum allowable value, SP_{VMAX}.

The raw neutron flux power and the temperature corrected neutron flux power are calculated by,

TS

TS

4.2.10 Low Pressure and Low DNBR Trip Function (LPLDT)

The low pressure and low DNBR trip (LPLDT) is based on the updated DNBR and the primary pressure. If the updated DNBR is lower than LDNBR and the primary pressure is lower than LPRES, then the LPLD trip is set. This algorithm provides automatic protective action for the RCS inventory decrease events such as Steam Generator Tube Rupture (SGTR) and Letdown Line Break (LDLB) events.

TS

TS

4.2.11 UPDATE Outputs

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

TS

h_{fg}	Latent heat of vaporization (BTU/lbm)	STATIC
PF	CEA deviation penalty factor for DNBR	STATIC
I_{RPC}	Reactor power cutback flag	POWER, TRIP SEQUENCE
CEA_{DEV}	Flag for CEA deviation from either CEAC	TRIP SEQUENCE
T_{C1}, T_{C2}	Scaled cold leg temperature, °F	FLOW, STATIC
T_{h1}, T_{h2}	Scaled hot leg temperature, °F	STATIC
J_{TRP}	Auxiliary trip flag	TRIP SEQUENCE
P	Corrected pressurizer pressure, psia	FLOW, STATIC

4.2.12 UPDATE Constants

TS

TS

TS

TS

TS

4.3 POWER Distribution Algorithm

The purpose of the power distribution algorithm 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. The excore detector signals, CEA positions, and the temperature shadowing factor are also used to compute a power normalization factor required for calculation of calibrated neutron flux power in UPDATE. Finally, the long-term average core flow rate is computed to provide a stable display to the operator.

4.3.1 POWER Algorithm Inputs

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

FROM FLOW:

TS

FROM UPDATE:

TS

FROM STATIC:

TS

The raw target CEA position values must first be converted to target CEA positions in units of percent withdrawal. The scaled values are then reordered according to the Control Element Drive Mechanism (CEDM) CEA group assignments and compared to upper and lower sensor range limits. If the scaled value for any target CEA is outside the limits, a sensor failure alarm is initiated.

Raw values are converted to target CEA positions in percent withdrawal by an appropriate sensor calibration function. Symbolically,

TS

initiates a sensor failure alarm. Otherwise the sensor failure alarm is reset.

TS

The target CEA positions are considered to be CEA subgroup positions. Each CEA subgroup is assigned to one of 12 CEA groups, including a maximum of eight regulating CEA groups, a maximum of two Group P CEA groups, and a maximum of two shutdown CEA groups. The parameters S_i, i = 1, N_{SG}, are ordered according to CEA group assignments. That is, the positions of the subgroups assigned to regulating CEA groups 1 through 8 must be given in the order of their respective group numbers followed by the positions of subgroups assigned to CEA Group P1, CEA Group P2, shutdown CEA group A, and shutdown CEA group B, respectively.

Given this ordering of Si, CEA group positions are defined by the following algorithm:

TS

Table 4-1 Correspondence of Index i(=1,12) to CEA Groups

i	CEA Group
1	Regulating Group 1
2	Regulating Group 2
3	Regulating Group 3
4	Regulating Group 4
5	Regulating Group 5
6	Regulating Group 6
7	Regulating Group 7
8	Regulating Group 8
9	Group P1
10	Group P2
11	Shutdown Group A
12	Shutdown Group B

4.3.2 Subgroup Deviation Penalty Factor

When C_{INOP} is less than three each CEA subgroup position is compared to its respective group position to determine whether the subgroup deviates excessively from the group position computed above. If a subgroup position and the corresponding group position are not within the deadbands at the top or bottom of the core, and if that subgroup deviates from its group position, the magnitude of the deviation is calculated. If the magnitude of the deviation is greater than the CMI threshold, the IP_{CMI} flag is set. If the magnitude of the deviation is greater than allowed for a CEA subgroup deviation, a penalty factor, PF_{SG}, is applied to the planar radial peaking factors. The allowed deviation for CMI activation is less than the allowed deviation for application of the subgroup deviation penalty factor. In the case of a reactor power cutback, the subgroup deviation penalty factor calculated from the last execution of the POWER program will be used.

TS

It should be determined if the CEA group has one or fewer subgroups. If it does, the CEA group i subgroup deviation penalty factor is set to 1.0 and the subgroup deviation is set to 0.0.

TS

It should be determined if the group position is within the CEA deadband at the top of the core. If it is, the CEA group i subgroup deviation penalty factor should be set to 1.0 and the subgroup deviation set to 0.0. TS

TS

If CEA group i has more than one subgroup, it should be determined if all the subgroups in that group are within the deadband at the bottom of the core. If so, the CEA group i subgroup deviation penalty factor should be set to 1.0 and the subgroup deviation set to 0.0.

TS

If none of the three conditions above are true the subgroup deviation and subgroup deviation penalty factor for CEA group i should be set as follows:

TS

If the magnitude of the subgroup deviation exceeds the CMI threshold, the IP_{CMI} flag should be set.

TS

The subgroup deviation penalty factor should be calculated from the individual group i subgroup deviation penalty factors as follows:

TS

TS

4.3.3 Planar Radial Peaking Factors and CEA Shadowing Factors

If the reactor power cutback flag is set, the planar radial peaking factors and CEA shadowing factors calculation should be skipped and then continue on to Equation 4.3-14. The planar radial peaking factors and CEA shadowing factors remain the same as those calculated in the last execution of the POWER program. If the reactor power cutback flag is not set, the CEA group positions G_i are used to determine planar radial peaking factors and CEA shadowing factors for each of 20 axial nodes in the reactor core. The algorithm first determines which CEA groups are present at a given axial node. Then the planar radial peaking factor and CEA shadowing factor for that node are selected from the two constant arrays that are arranged to be consistent with the table format in Figure 4-3. Each planar radial peaking factor or CEA shadowing factor selected is adjusted by an addressable constant multiplier. There are five multipliers for planar radial peaking factors and four multipliers for CEA shadowing factors. Each multiplier applies to a particular region of the table in Figure 4-3 as shown in Figure 4-4. The planar radial peaking factors and rod shadowing factors are not applied for the shutdown groups unless a shutdown CEA is inserted more than the deadband constant at the top of the core.

A correction factor that is dependent upon CEA configuration and the value of the normalized core inlet moderator density is applied to the planar radial peaking factors.

TS

TS

The cold leg density deviations, D_{HI} and D_{LO} are calculated first. $K_{DEN,0}$ is initialized to a non-positive value.

TS

		No Group P, or Shutdown Groups	Group P (G9 or G10)	Shutdown Groups (G11 or G12)
		J = 1	J = 2	J = NCOL = 3
Unrodded	In = 1	M = 1	M = 2	M = 3
G_{NREG}	In = 2	M = 4	M = 5	M = 6
G_{NREG} + G_{NREG-1}	In = 3	M = 7	M = 8	M = 9
G_{NREG} + G_{NREG-1} + G_{NREG-2}	In = 4	M = 10	M = 11	M = 12
…	…	…	…	…
G_{NREG} thru G_1	In = N_{REG}+1	M = NCOL - N_{REG} + J		

Figure 4-3 Sample Planar Radial or Shadowing Factor Lookup Table for 1 Group

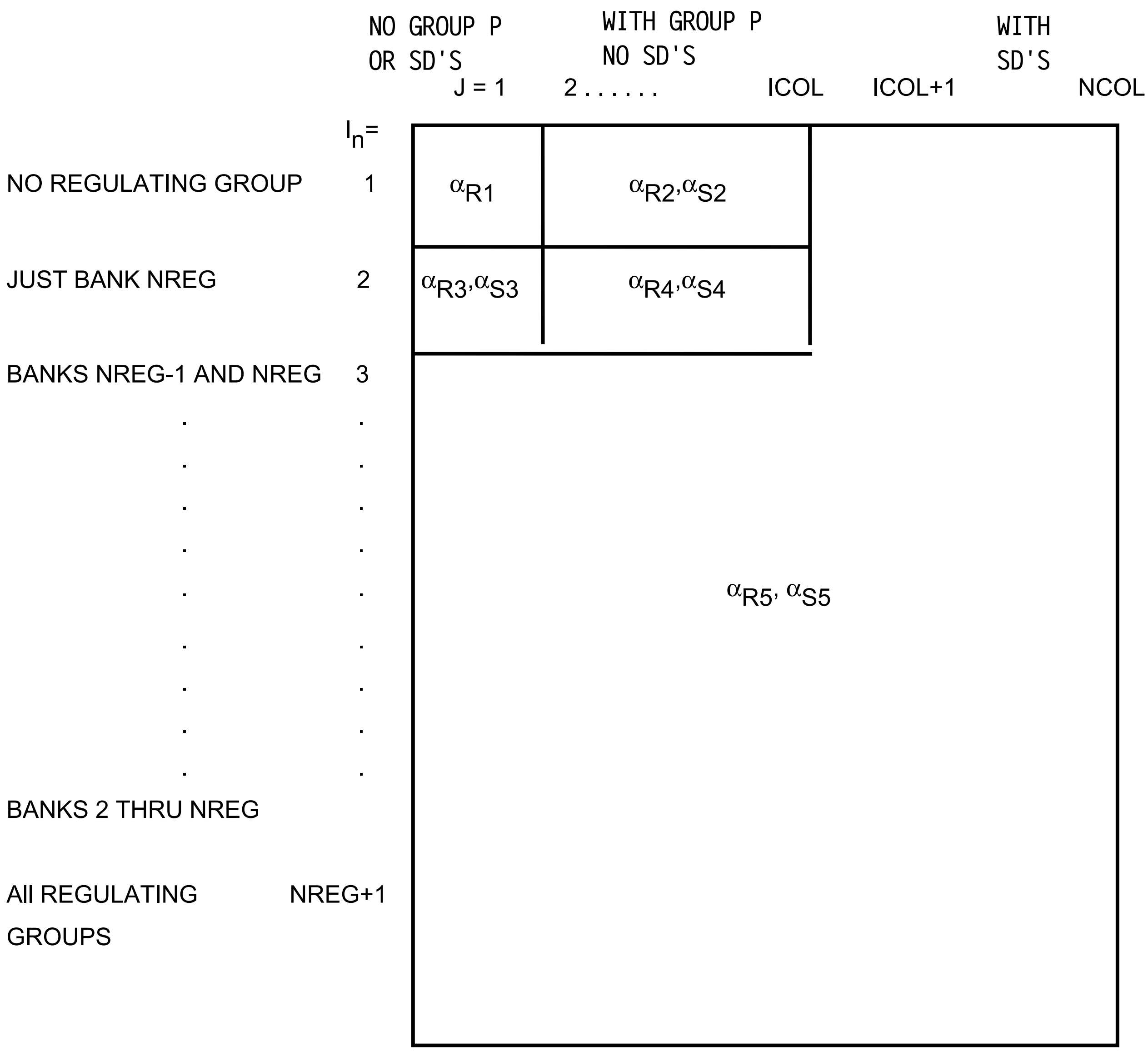

Figure 4-4 Partition for Application of Addressable Multipliers for Planar Radials (α_{Ri}) and Rod Shadowing (α_{Si}) factors.

TS

For each axial node n=(1,20), a column index J is computed first.

TS

TS

Next a row index I_n is computed for axial node n. This index is determined sequentially starting at the bottom axial node (n=1) building each row index based on the previous row index.

Prior to determining the row index for the first axial node

TS

(1) For plants using full-length Group P CEAs instead of PLRs, L_{PLR} will be set to 100%.

If the comparison is performed for all the values of i up to $i=N_{REG}$ without assigning I_n,

TS

Next, column and row indices are used to compute an index m for constant arrays in which precalculated planar radial peaking factors and CEA shadowing factors are stored.

TS

The indices J and I_n are used to select addressable constant multipliers for adjusting the planar radial peaking factor and CEA shadowing factor at axial node n. (see Figure 4.4).

TS

TS

TS

Each of the four ranges of values in S_{LP} are shown by Figures 4-6a through 4-6d.

The CEA shadowing factor and planar radial peaking factor at axial node n are given by

TS

Average CEA shadowing factors, $\overline{R}$, are determined for each detector segment dependent on CEA insertion in the region of the detector segment. This can be expressed formally as

TS

The X_{ij} are determined by a core volume weighted average. Thus, for the 20 node three detector system used, the general equation becomes:

TS

		NO GROUP P OR SD'S J = 1	WITH GROUP P NO SD'S 2.............................. NCOL-1	WITH SD'S
NO REG GROUPS	1	$K_{DEN,n} = 1$	$K_{DEN,n} = 2$	
JUST BANK NREG	2	$K_{DEN,n} = 3$	$K_{DEN,n} = 4$	
BANKS NREG-1, NREG	3	$K_{DEN,n} = 5$	$K_{DEN,n} = 6$	
• • • • • • • • • • •		$K_{DEN,n} = (2*I_n)-1$	$K_{DEN,n} = 2 * I_n$	
		If $K_{DEN,n} >$ 17, set $K_{DEN,n} = 17$		$K_{DEN,n} = 17$
BANKS 2 thru NREG	NREG			
ALL REG GROUPS	NREG+1			

Figure 4-5 Partition for Application of Density Slope Table Indices (K_{DEN}) at Each Axial Node 'n'

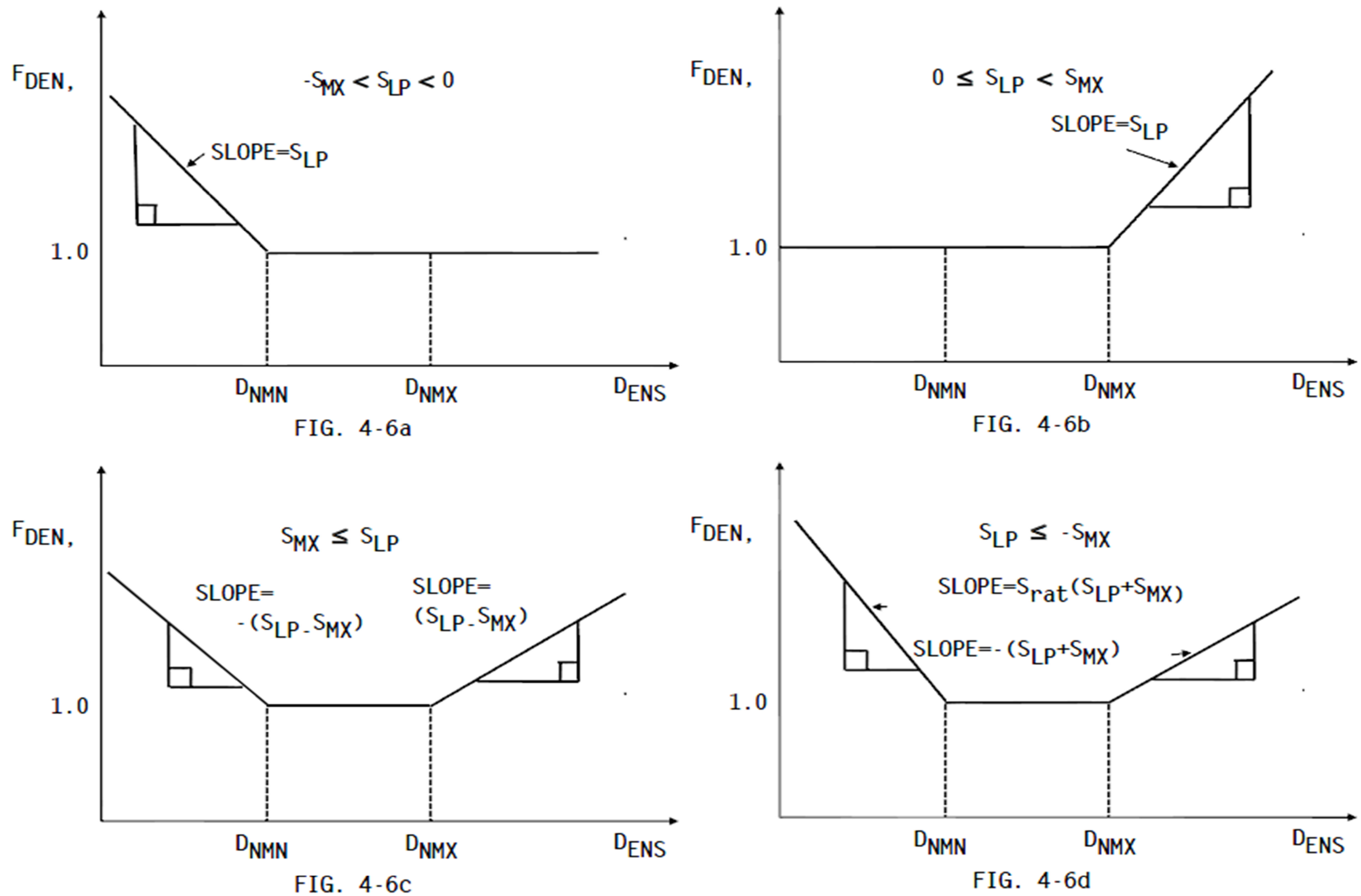

Figure 4-6 Normalized Core Inlet Moderate Densities

4.3.4 Out-of-Sequence Conditions

The selection of CEA shadowing factors and planar radial peaking factors implicitly assumes that regulating CEAs are moved in sequence outside of the CEA deadbands and that Group P CEAs are not inserted beyond the prescribed limit in the core. A check is made to verify these assumptions unless the RPC flag is set indicating a cutback is in progress. If either assumption is invalidated, a penalty factor is applied to the planar radial peaking factor at each axial node. Additionally, a check is made to set the CEA Motion Inhibit flag. If the Group P CEAs are inserted beyond the allowed insertion [1], the IP_{CMI} flag is set. If the CEA groups are out-of-sequence beyond the allowed limit, the IP_{CMI} flag is set.

TS

(1) For plants using full-length CEAs instead of PLRs, B_4C and IP_{CMI} flag tests do not apply. L_{B4C} and PLR_{CMI} will be set to the lower range limit.

TS

4.3.5 Excore Signal Normalization

The raw unnormalized element response of the three element excore detector string is designated as D_{rawi} where i designates one of the three excore detector elements. The normalization proceeds as follows:

1) The total unnormalized response is determined:

TS

TS

.2) To preserve the integrity of the calculations at very low power, a test is performed to select the normalizing procedure. If the total response is below a preset minimum, a preselected set of normalized responses is introduced to provide a conservative power shape and avoid the possibility of either division by zero or an excessively noisy signal.

TS

Note that i = l, 2, 3 denotes the signals from upper, middle, and lower excore detectors, respectively.

3) The relative power level, corrected for rod shadowing and temperature shadowing, is generated and used to adjust the detector response level but not the distribution.

TS

TS

4.3.6 Power Distribution Synthesis

A shape annealing correction is applied to the adjusted normalized segment responses to yield segment responses which approximate those responses that would be obtained had the detectors been placed at the core periphery. The calculation is performed as follows:

TS

TS

The neutron flux power normalization factor corrected for shape annealing and CEA shadowing is then calculated to be consistent with usage in the DNBR and Power Density Update Program.

TS

.

For further improvement of the accuracy of the synthesis, minor adjustments to the detector responses are made using correction factors based on the power normalization factor, PT, and the total response after

shape annealing, PSUM. Adjustments are made first to the middle element and then to the upper and lower elements.

TS

The middle detector response needs no further correction. One of the following corrections are applied to the upper and lower detector responses: TS

TS

The final values of the adjusted detector response are then assigned to the power vector to be used in calculating spline amplitudes.

TS

The power vector needed to calculate the spline function amplitudes requires the generation of boundary point power values for both the top of the core, B_1, and the bottom of the core, B_5, based on the average power in the end regions. The correlations are empirically, based on four addressable constants, B_{PPCC1} through B_{PPCC4}, and the minimum permitted boundary point powers. The boundary point powers are calculated as follows:

TS

TS

The synthesis of the axial power shape involves the selection of a set of spline functions and the determination of their amplitudes. The selection of the functions is determined by the gross power shape of the core as indicated by the values of the P_i'''. The general form of the functions is fixed so that the selection involves only break point locations that permit pre-calculation of a set of inverse matrices. This module selects one of these matrices via the selection of the index k. The listed tests are performed in order. Once any test has been satisfied, the testing stops with the value of k determined on that test.

TS

TS

The index value, k, is then available for use in determining spline amplitudes.

The spline amplitudes are computed by performing the matrix multiplication

TS

The values of the elements of $\underline{\underline{H}}^{-1}$ have been precalculated and are stored in array HC for each value of the index, k. The expression used to evaluate this equation is thus dependent on the storage order. The equation to be used for actual evaluation is

TS

Once the amplitudes of the spline functions have been determined the axial power shape is determined as follows:

TS

The obvious methods of evaluating equation 4.3-68A are either to evaluate $\mu_j(Z_i)$ each time it is needed or to precalculate and save $\mu_j(Z_i)$ for each of the 7 functions at each of 20 nodes for each of the eight values of the index k. These two methods are unsuitable in that the former requires excessive execution time and the latter requires excessive storage. The CPC uses an alternate approach to evaluate equation 4.3-68A. This approach, described as follows, uses precalculated values and takes advantage of the similarities introduced by the choice of the spline functions.

There are always four regions in the core which have different sets of non-zero spline functions as shown in Table 4-2. Thus in region I1, spline functions I1 through I1+3 are always used, although the portion of the core covered will vary. Therefore,

TS

Table 4-2 Core Spline Regions

Region	Non-Zero Spline Function
1	1, 2, 3, 4
2	2, 3, 4, 5
3	3, 4, 5, 6
4	4, 5, 6, 7

For each of the four spline function regions (I1 = 1, 2, 3, 4) the constant location indices are determined starting with I1 = 1.

TS

Once the indices have been found, the axial power is given by

TS

For all four spline function regions repeat the evaluation of Equations 4.3-70 through 4.3-73 are repeated,

TS

When all four regions have been processed the axial power is checked to assure that the synthesis did not introduce any spurious negative power values.

TS

4.3.7 ASI-Dependent Parameters

The core average axial shape index ASI is computed from FZBOT and FZTOP. The ASI is used to determine the power peaking adjustment factors.

TS

The power peaking adjustment factors are initialized

TS

4.3.8 Pseudo Hot Pin Power Distribution

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

TS

The pseudo hot pin axial shape index (PQASI) is calculated for display to the operator.

TS

At low powers, when the flag IDIR equals 1, the pseudo hot pin relative axial power distribution is recalculated based on a precalculated relative axial power distribution. TS

TS

The maximum peaking factor is then selected and the average of the hot pin power distribution is computed.

TS

4.3.9 Base Core Coolant Mass Flow Rate

The base core coolant mass flow rate $\bar{M}(t)$ is computed for information only.

TS

4.3.10 POWER Outputs

The following values are transferred to the Power Distribution Program output buffer for use by other programs:

TS

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.

TS

TS

TS

TS

TS

4.4 STATIC DNBR and POWER DENSITY

The purpose of the Static DNBR and Power Density Program ("STATIC") 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 STATIC Algorithm Inputs

This program requires the following process parameters:

From FLOW: TS

From UPDATE: TS

From POWER: TS

4.4.2 Upgrade Power Distribution Data for Static DNBR Calculation

Due to the order of execution of the CPC subroutines, the hot pin heat flux distribution, axial shape index, and integral power and the integrated radial peaking factor are re-computed to ensure the most current

values are available for the static DNBR calculation.

TS

4.4.3 Saturation Properties and Pressure Dependent Terms

The saturated fluid properties are obtained from the following polynomials.

TS

TS

The VOLUME and FRICFAC functions involve a number of terms which depend only on pressure. Since the functions will be evaluated repeatedly, each time using the same value of pressure, the pressure dependent terms are defined separately.

The following are used by the VOLUME function:

TS

TS

4.4.4 Calculation of Inlet Coolant Mass Flux and Region-Dependent Parameters

The channel 1 and channel 2 inlet conditions are calculated as follows.

TS

TS

4.4.5 Calculation of Linear Heat Distributions

Four 10-element linear heat distributions are computed for the four modeling channels. The 20-element hot pin axial heat flux distribution is combined with the integrated one pin radial peak, and collapsed to 10-element distributions, as follows:

TS

TS

TS

4.4.6 Computation of Core/Hot-Assembly Fluid Properties for Channels 1 and 2

The calculations described in this section result in the enthalpy, mass flux, cross-flow and pressure drop axial distributions, for channel 1 and channel 2. 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 prediction/ correction scheme. The technique is summarized below:

At each of the 10 nodes (j=1,2...10) the following calculations are performed:

- Prediction of mass fluxes at node j
- Prediction of enthalpies at node j+1.
- Prediction of specific volumes and friction factors at node j+1
- Prediction of cross-flow at node j+1
- Calculation of corrected cross flow at node j
- Calculation of corrected mass-fluxes at node j
- Calculation of corrected enthalpies at node j+1
- Calculation of cross-flow resistance at node j+1
- Update state variables (i.e. calculation of "past values" to be used in next pass through nodal loop).

The calculations involved in each of the above steps are defined below.

First, state variables are initialized.

TS

TS

The fluid properties at each of the 10 nodes are predicted and then the corrected property values calculated.

For j=1,2...10 (Beginnings of "j-loop")

Mass fluxes at node j are predicted:

TS

:

TS

TS

Corrected enthalpies at node j+1 are calculated:

TS

Cross flow resistance at node j+1 is calculated, after first replacing. CIJ with CIJ_{NEXT}:

TS

TS

Increment j. “j – loop” terminates at this point.

Mass fluxes and pressure drop at 11th node are computed:

TS

The variables used in the above equations are defined below.

(a) Variables saved for subsequent calculations:

TS

.

(b) Intermediate variables:

TS

TS

(c) Constants:

TS

TS

4.4.7 Calculation of Buffer/Hot-Channel Fluid Properties for Channels 3 and 4

The calculations described in this section result in the enthalpy and mass flux distributions for channel 3 and channel 4. The hot channel distributions (channel 4) will be subsequently used in the critical heat flux calculations.

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

At each node j (j=2...11):

- The hot-channel mass flux, enthalpy, specific volume, friction factor and pressure drop at node j are predicted.

- Cross-flows at node j are calculated.

- Corrected axial flows at node j are calculated.

- State variables are updated (i.e. set up for next pass).

Specifically, the calculations proceed as follows:

First, state variables are initialized:

TS

The fluid properties at each of the 11 nodes are predicted and then the corrected property values are calculated.

The required fluid properties are computed at each node:

For j=2,3...11 <u>(Beginning of "j-loop")</u>

The hot channel mass flux, enthalpy, and other fluid properties at node j are predicted:

TS

The cross flow and turbulent interchange are calculated.

TS

The corrected flows and enthalpies at node j are calculated:

TS

The next pass is set up:

TS

TS

4.4.8 Computation of Hot Channel Quality and Flow Profiles

The 11-node hot channel enthalpy and mass flux profiles are extrapolated to generate the 21-node quality and mass flux profiles.

TS

TS

4.4.9 Hot Channel Heat Flux Distributions

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

TS

This distribution is normalized so that the integrated heat is the same as for the 20-node distribution. The latter is given by:

TS

4.4.10 Correction Factors for Non-Uniform Heating

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

TS

.

4.4.11 Calculation of Static DNBR

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

TS

The minimum is selected and adjustment terms applied.

TS

TS

Finally, the STATIC DNBR is limited to a range of 0.0 - 10.0.

TS

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, the cold leg temperatures are limited to a value somewhat above their lower range limit to preclude calculation of artificially high thermal powers. That is,

TS

The pressure dependent coefficients used to determine the enthalpy-temperature ratios are calculated:

TS

The enthalpy-temperature ratios for the cold legs are calculated:

TS

The enthalpy-temperature ratios for the hot legs are calculated:

TS

The maximum value of hot leg temperature is selected for use in the hot leg saturation trip.

TS

4.4.13 Definition of Volume Functions

The preceding 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:

TS

First the local quality, X, is calculated

TS

Then,

TS

TS

4.4.14 Definition of Friction Factor Function

The proceeding calculations make use of the FRICFAC function defined in this section. FRICFAC is a function of five variables and is defined as

TS

Specifically the calculation proceeds as follows:

TS

These three quantities are calculated below.

Calculation of single phase friction factor:

First, the local quality, viscosity and Reynold's number are calculated.

TS

Next, an approximation is made to $(R_E)^{-0.2}$:

TS

Calculation of subcooled boiling friction factor multiplier:

The required thermodynamic properties are calculated:

TS

Now the film and Jens-Lottus temperature drops are calculated:

TS

Then the subcooled boiling friction factor multiplier is calculated as follows:

TS

TS

TS

If $P_{BRK1} < P_{ST} \leq P_{BRK2}$

TS

If $P_{ST} > P_{BRK2}$

TS

TS

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:

TS

TS

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 X_{LIM} is adequate to prevent overflow.

TS

TS

TS

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. Also, core conditions outside the analyzed parameter space, less than two reactor coolant pumps running, an ASGT, a rapid power rise or the CPC in an other than normal operating mode will cause a trip output to be issued.

4.5.1 TRIP SEQUENCE Algorithm Inputs

The TRIP SEQUENCE algorithm requires the following process parameters from other CPC algorithms:

From FLOW:

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From UPDATE:

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From POWER:

TS

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From STATIC:

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4.5.2 DNBR/Quality Trip

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

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4.5.3 LPD Trip

If Local Power Density Trip or Pre-trip limits are violated, a Local Power Density Trip or Pre-trip signal is issued:

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TS

4.5.4 Auxiliary Trips

An auxiliary trip is initiated in response to any of a number of conditions by setting both the DNBR and LPD trip contact outputs. The conditions are as follows:

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a. Core conditions are outside the analyzed operating space

b. Less than two Reactor Coolant Pumps are running

c. A hot leg temperature has reached saturated liquid condition

d. Cold leg temperature difference has exceeded the limit TS

e. A VOP Trip flag has been set TS

f. A low pressure and low DNBR Trip flag has been set TS

g. The CPC is not set in the normal operating mode

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h. An internal processor fault has been detected, including:

1. Fixed point divide fault (division by zero or quotient overflow),

2. Floating point arithmetic fault (overflow),

3. Illegal machine instruction,

4. Failure to meet the timing requirements of Section 3.3,

For any of these conditions an operating condition trip signal is issued:

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4.5.5 CWP Signal

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4.5.6 TRIP SEQUENCE Constants

The following constants are required for the TRIP SEQUENCE.

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4.6 CEAC ALGORITHM

The function of the CEAC is to scan all CEA positions and, based on any single CEA deviation detected within a CEA subgroup, to calculate the single CEA position-related penalty factors necessary to ensure that the CPCs calculate conservative approximations to the actual core peak Local Power Density(LPD) and Departure from Nucleate Boiling Ratio (DNBR) during single CEA-related Anticipated Operational Occurrences (AOOs) which require CPCS protection. The CEAC must also be capable of detecting a reactor power cutback event.

This section includes a detailed description of the functions to be performed by the CEAC Program. For the program described below, the sequence of computations required is described in sufficient detail to allow the software designer to specify the coding of the protection program.

The penalty factor algorithm produces two penalty factors, one for DNBR and one for LPD. These penalty factors are found by taking the largest DNBR penalty factor and the largest LPD penalty factor calculated for any subgroup. The penalty factors on the subgroup level are formed by combining a static DNBR penalty factor component with a dynamic Xenon penalty factor component, and by combining a static LPD penalty factor component with a dynamic Xenon penalty factor component.

The static DNBR and static LPD penalty factor components are calculated as a function of deviation magnitude within a subgroup. The constants which define this dependence are looked up as a function of the deviation type, subgroup containing the deviation, and an index identifying the configuration of CEA groups. The dynamic Xenon penalty factor component is calculated as a function of elapsed time during which excess deviation exists in the subgroup. The Xenon constants are also looked up as a function of the deviation type, the subgroup containing the deviation, and the configuration index.

CEA position signals are read in and processed to screen out false signals, and the status of the sensor fail alarm is determined. CEAC recognizes the initiation of a reactor power cutback event based on the assumption of the preselected reactor power cutback that CEAs are dropping or reach the bottom of the core. The deviation magnitude, deviation type, subgroup position, group position, and configuration index are calculated next. The status of the CEA deviation alarm is determined. The constants for the penalty factor component equations are looked up and the penalty factors are calculated. Finally, the CEAC packs the status flags and sends them to the CPC along with the DNBR and LPD penalty factors. In addition, the CEAC maintains a stack of failed sensor information.

4.6.1 PENALTY FACTOR ALGORITHM

4.6.1.1 CEAC Algorithm Inputs

The inputs to the algorithm are a set of live CEA position signals received from the reed switch position transmitters. Each signal is processed to screen out false signals, i.e. each signal is checked for out-of-range and excessive rate-of-change. If a signal is far out-of-range, the sensor failed flag is set and the signal added to the sum of failed sensors.

The sensor failed flag and counter are initialized at the beginning of each execution of the CEAC.

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The raw CEA position signals are processed for out-of-range and excessive rate-of-change. The CEA position signals are read into an array consecutively by quadrant. This array is designated DATAB. The interpretation of these signals is aided by use of a second array, designated CONTAB, which provides information to the penalty factor algorithm on the organization of CEAs into subgroups. As an example of this organization, a typical assignment of CEAs and subgroups are presented in Tables 4-3 and 4-4. CONTAB, the CEAC data base array containing this information, shall be set up in the order of CEAs per subgroup. The subgroups shall be arranged in the following order:

1. On a group by group basis, the order of the elements in CONTAB shall be those CEAs for Regulating Group 1, those CEAs for Regulating Group 2, ..., those CEAs for Regulating Group N_{REG} (where N_{REG} is the total number of regulating groups), those CEAs for Group P, and those CEAs for the Shutdown Groups.

2. On a subgroup by subgroup basis, the ordering of the elements in CONTAB for each group shall be those CEAs in the first subgroup, those CEAs in the second subgroup, ..., those CEAs in the last subgroup in the group.

3. On an individual CEA basis, the order of the elements in CONTAB for each subgroup shall be:

    a. for those subgroups with 4 CEAs - the CEA in quadrant 1, the CEA in quadrant 2, the CEA in quadrant 3, and the CEA in quadrant 4.

    b. for that subgroup with 5 CEAs -the CEA in quadrant 1, ..., the CEA in quadrant 4, and the center CEA.

    c. for any subgroup with 2 CEAs - the ordering of the CEAs is arbitrary.

The array CONTAB is used to identify each CEA. This ID is used to select the CEA's position stored in the array DATAB.

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Each CEA position signal is checked for far out-of-range, excessive rate-of-change and slightly out-of-range. If the signal fails the far out-of-range or rate-of-change (CEA appears to have moved an unrealistic distance) test, the sensor failed flag is set to a value indicating the type of failure, the failed sensor total is increased by one, and the last stored acceptable position is used as the current position. If the signal is

only slightly out-of-range, the CEA position is adjusted to the upper or lower range limit. For position signals in range or slightly out-of-range, the current position is stored for use during the next execution. The signal is then converted to inches withdrawn.

Perform the far out-of-range check:

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and set sensor fail flag (FLAG = 1, Value indicating failure type (High or Low)) and increase failed sensor counter (I_{SF}).

If the sensor is not far out-of-range and was not out-of-range during the previous test, perform the rate-of-change check:

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and set sensor fail flag (FLAG = 1, Value indicating failure type (Rate-of-change)) and increase failed sensor counter (I_{SF}).

If the CEA sensor is not failed far out-of-range, perform the slightly out-of-range check:

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If no far out-of-range or rate-of-change failure exist for the current execution, CEAIN remains unchanged, and is then stored for the next execution.

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A means (CEAC Clear Rate Failure Icon) shall be provided to reset the correct CEA position after a rate-of-change error has cleared.

The variables and constants used in these equations are:

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After evaluating CEAIN and either storing the position for the next execution or substituting the last stored acceptable position, the raw position is converted to inches withdrawn and stored in an array of CEA positions.

TS

If the sensor fail flag is set (FLAG=1), set the sensor fail alarm. The above calculations are performed for the next CEA beginning with Equation 4.6-3.

Table 4-3 Typical Assignment of CEDMs to Subgroups (For a 93 CEA Plant)

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Table 4-4 Typical Assignments of Subgroups to Control Groups[(1)]

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4.6.1.1.1 Determination of Reactor Power Cutback (RPC)

During the occurrence of a reactor power cutback event, certain pre-selected CEA group(s) will be dropped to reduce the reactor power rapidly. The rate-of-change of the processed CEA positions is used to determine whether the CEAs are dropping. If one or more CEAs from the pre-selected RPC groups are dropping and no other CEAs are dropping, then the reactor power cutback flag will be set (IRPC=1). It will remain set only if all of the CEAs in the same RPC group and preceding RPC group(s) are dropping or are bottomed after a pre-determined time period. The flag will be reset if a non-RPC CEA is determined to be dropping, or automatically after a time interval equal to a preset value. A non-RPC CEA which is partially inserted or on the bottom more than TCBP seconds to the detection of a RPC event will not prevent the cutback flag from being set. The constants and variables used in this section of the program are:

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The processed CEA positions which are stored in array PPOS are arranged in order according to their regulating group assignments. They are rearranged in the order of the CEA numbers and stored in array CPOS for the RPC detection.

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For each execution of the CEAC, the dropping-rod counter and the CEA drop flags are initialized and the RPC timer increased if the RPC flag is set.

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To check for dropping CEA, the most recent CEA position is compared to its position ICYCLE execution cycles ago.

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If any of the cutback group drop flags are set, then the IRPC flag is set to indicate a possible RPC event. If any CEA drop flag is set, the RPC timer is started if not already started.

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If $t_{RPC} \geq$ TGROUP and any NDi ≠ 0 (i=1,3) the RPC, flag will remain set only if all the CEAs within the same RPC group and the preceding RPC group(s) are dropping or are bottomed; otherwise the RPC flag will be reset.
(4.6-12o)

Start from RPC group 3.

TS

Go to Eq.4.6-12x.

TS

TS

Go to Eq. 4.6-12x.

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4.6.1.2 Determination of Deviation

The processed CEA positions are manipulated primarily at the subgroup level to find deviation magnitude, deviation type, and overall group configuration. These quantities are found by first sorting the CEAs in the subgroup by height. The deviation magnitude is calculated from the difference between the most and least withdrawn CEAs in a given subgroup. If the deviation magnitude is equal to or greater than the deviation alarm setpoint, the deviation alarm flag is set. If the deviation magnitude falls outside deadband limits, the deviation type is determined; and flags are set which direct the CEAC to calculate the penalty factors. Subgroup and group positions are determined, and the CEA configuration is determined based on group position. If all deviations are removed, the deviation alarm flag is reset, and deviation indicator counters are set to zero. Array POINT, which designates the subgroup and group sizes, is used to control the interrogation of CEA positions. The CEA positions for the first subgroup are selected and sorted by height, i.e., in order of decreasing withdrawal. After determining the CEA deviation magnitude, deviation type, and deviation within the subgroup and group, the CEA positions for the second subgroup are selected and sorted. This process continues until all CEA positions have been interrogated. The variables used in this section of the program are:

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For each execution of the CEAC, initialize the following indices:

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As each CEA group is interrogated, the array location index (I) for the array POINT is increased, the number of subgroups in the CEA group is determined, and the group counter to indicate the group being interrogated is increased.

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The CEA positions in subgroup I_{SG} are sorted by height from most withdrawn to least withdrawn, and the deviation magnitude is then calculated. The CEA positions in this subgroup are identified as PPOS(J) to

PPOS(J + N_{CEA} - 1) with PPOS(J) being the position of the CEA in core quadrant 1, PPOS(J+1) the position of the CEA in core quadrant 2, PPOS(J+2) the position of the CEA in core quadrant 3, and PPOS(J+3) the position of the CEA in core quadrant 4. For the subgroup with the center CEA, PPOS(J+4) is the position of CEA #1 (or CEA #2 or CEA #3).

From the CEA positions in the subgroup, the following variables are determined:

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The deviation magnitude is compared to the deviation deadband, and the positions compared to the lowest and highest CEAs in each subgroup are compared to the core upper and lower deadbands. If the deviation magnitude and CEA positions fall within these deadbands, then the deviation type is set to zero. If the deviation magnitude and CEA positions fall outside these deadbands, then 1) additional checks are performed to determine deviation type, 2) the maximum deviation is selected, 3) the group with the largest deviation is recorded, and 4) the deviation alarm is set.

It’s necessary to check whether the deviation magnitude exceeds the deviation deadband or if the subgroup is entirely within the core upper or lower deadbands.

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If the most withdrawn CEA in the subgroup is the Center CEA(#1, or #2 or #3 if assigned as Center CEA),

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For each subgroup (I_{SG}), if CASE = +1 and the number of CEAs in the subgroup is not equal to 2 and the most withdrawn CEA in the subgroup is in core quadrant i, or if CASE = -1 and the least withdrawn CEA in the subgroup is in core quadrant i,

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The subgroup position is taken to be the bottom position, unless a CEA insertion deviation exists. In that case, the next-to-bottom position is selected as the subgroup position. The group position is determined by selecting the lowest position for subgroups in that group.

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If the subgroup index is not equal to zero, the above calculations are performed for the next subgroup (beginning with equation 4.6-14) in the CEA group being interrogated.

If the subgroup index is equal to zero, the group position is determined. The group position (GROUP(I_{GRP})) is determined by selecting the minimum of the subgroup positions (SUB_{GRP}) for the subgroups assigned to the group under interrogation. Then the group index is decreased by one.

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If the group index is not equal to zero, the above calculations are performed for the next CEA group to be interrogated (beginning with equation 4.6-13). If the group index equals zero, the CEA configuration index

is determined.

The CEA configuration index is determined based on group positions for the regulating and Group P banks. The CEA configuration index is required for determining the penalty factor components.

The CEA regulating group component for configuration index is determined (perform all logical comparisons listed below):

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set the CEA deviation alarm.

4.6.1.3 Determination of Penalty Factors

Each subgroup is checked for its deviation type, and two penalty factors are calculated for each subgroup whose deviation type is not 0 or 2. If the deviation type is 0, no penalties are required for that subgroup. If the deviation type is 2, a special large penalty factor flag is set and no penalty factors are calculated for that subgroup. Otherwise, the penalty factors are determined by combining a static penalty factor component with a time-dependent Xenon component.

The status of the restart flag and indications of CEA deviations are checked. If there are no deviations indicated, the restarting flag is reset.

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The CEAC fail flag (I_{FAIL} = 0) and the big penalty factor flag (I_{BIGPF} = 0) should be initialized.

The DNBR and LPD penalty factors for subgroup I_{SG} should be determined, where I_{SG} = 1 to SG_{TOT}, and SG_{TOT} is the total number of subgroups.

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Otherwise $P_{LPD}(I_{SG})$, $P_{DNBR}(I_{SG})$, and $t_{ELAPSE}(I_{SG})$ are defined as follows:

The variable LCASE is introduced to redefine the type of deviation with

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The time-dependent Xenon component is determined. The Xenon time dependence is applied by maintaining an elapsed time counter (t_{ELAPSE}) for each subgroup. The counter is started when excess deviation in the subgroup is first detected, is limited to a maximum value, and is reset to zero when the excess deviation is removed. The Xenon penalty factor component is found as a linear function of elapsed time. (Refer to Figure 4-7.)

If the initialization/restart flag is not set (I_{REST} = 0),

then

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The static LPD and DNBR penalty factor components are determined as a piecewise—linear function of deviation magnitude (refer to Figure 4-7). The elements of the penalty factor component plots are selected from data tables, which are based on CEA configuration and deviation type.

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The above calculations are performed for the next subgroup beginning with equation 4.6-33.

The maximum LPD and DNBR penalty factors are defined as

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The deviation counters are checked to determine if the failed sensor flag should be set.

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Figure 4-7 Penalty Factor Components

4.6.1.4 Packing of Penalty Factors for Transmittal to CPCs

The LPD and DNBR penalty factors are sent to the CPC as floating point numbers. The other flags are packed (one bit per flag) and transmitted to the CPC as an integer number, $FLAG_{CEAC}$.

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4.6.1.5 CEAC Initialization

During initialization of the CEAC after power-on, the CEAC restart flag is set

$$I_{REST} = 1 \tag{4.6-82}$$

The maximum Xenon component of the penalty factors will be applied for any deviations which exist at the time restart occurs. I_{REST} is set to zero for the first CEAC execution after a power-on during which no deviations exist.

The initial positions stored in the array LDATAB during the first CEAC execution after a power-on are determined in the following manner:

All raw CEA position signals are processed and checked for out-of-range conditions.

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4.6.1.6 CEAC Constants

The constants required for the CEAC are listed below. The following constants will be provided by the functional design group:

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*For I_{BOX}, I_{BOXC}, X_E, and X_{EC} the array indices i, j, k are generically defined as:

i = Configuration index with a range of 1 to $(N_{REG}+1)\cdot 2$

j = Case number with a range of 1 to 2

k = Subgroup index with a range of 1 to the total number of 4-CEA subgroups.

For LPD_{CON} and DNB_{CON} the array indices i,j are generically defined as:

i = an index with a range of 1 to 8 for determining the deviation magnitude breakpoint and penalty factor component.

j = an index with a range of 1 to the maximum value given in the I_{BOX} and I_{BOXC} arrays, which is used to select the DNBR and LPD penalty lookup table.

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APPENDIX A Parameters to be Displayed by CPC I/O Device

APPENDIX A Parameters to be Displayed by CPC I/O Device (Continued)

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APPENDIX A Parameters to be Displayed by CPC I/O Device (Continued)

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APPENDIX A Parameters to be Displayed by CPC I/O Device (Continued)

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APPENDIX A Parameters to be Displayed by CPC I/O Device (Continued)

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APPENDIX A Parameters to be Displayed by CPC I/O Device (Continued)

TS

APPENDIX A Parameters to be Displayed by CPC I/O Device (Continued)

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APPENDIX B Parameters to be Displayed by CEAC I/O Device **TS**