SAN ONOFRE UNITS 2 AND 3

DOCKETS 50-361 AND 50-362

CEN-148 (S)-NP

FUNCTIONAL DESIGN SPECIFICATION
FOR A
CONTROL ELEMENT ASSEMBLY CALCULATOR

RESPONSE TO NRC QUESTIONS

221.18 AND 221.20

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This document describes the San Onofre Units 2 and 3 CEAC functional design. Included in this design are changes to current ANO-2 Cycle 1 CEAC functional design. These changes are indicated by vertical bars in the right margins. The pages involved are 7,9,10,13 ,18,26,27,30-33,43,61.

ABSTRACT

This document provides a description of the CEA Calculator (CEAC) and CEA Penalty Factor Algorithm functional design to be implemented in the DNBR/LPD Calculator System of the Reactor Protection System. The scope of this functional description includes detailed specification of the CEAC Penalty Factor Algorithm, which is a component of the CPC/CEAC software.

Two CEACs are provided in the DNBR/LPD Calculator System. Each CEAC receives all of the CEA positions and calculates two penalty factors based on the severity of CEA deviation within a subgroup. These two penalty factors are transmitted to the CPCs to be included in the DNBR and LPD calculations. Detailed algorithm descriptions are provided. The algorithm equations are written in symbolic algebra. All variables are defined, and units are specified where applicable. In addition, the 16-bit output buffer, which transmits the penalty factors to the CPCs, is defined.

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LIST OF ACRONYMS AND DEFINITIONS

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

1.0 INTRODUCTION

1.1 PURPOSE

The purpose of this document is

1. To specify a CEA Calculator (CEAC) functional design and functional interface that meet the design bases given in Section 2.0, when implemented with quality assured data constants,

2. To serve as a quality assured interface document between the C-E engineering groups responsible for specification of the CEAC functional design and those responsible for implementation of the CEAC design for the C-E NSSS identified in Section 1.3, and,

3. To provide a quality assured record of the CPC design for reference by C-E design groups that are not directly responsible for the CEAC design, but require knowledge of the design specification for related tasks.

1.2 SCOPE

This functional description provides the following:

1. The CEA Penalty Factor Algorithm to be implemented in the DNBR/LPD Calculator System of the Reactor Protection System

2. Algorithms to initiate alarms for CEA sensor failure and CEA deviation

3. A diagnostic failed sensor data stack

4. Requirements on CEAC/CPC interfaces, system interfaces, and system initialization.

1.3 APPLICABILITY

This document is a generic description of the CEAC functional design. It is considered to be applicable to the ANO-2, SONGS-2, and SONGS-3.

2.0 CEAC DESIGN BASIS

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).

2.1 SPECIFIED FUEL DESIGN LIMITS

The fuel design limits used to define the low DNBR and LPD trip settings to ensure the following Specified Acceptable Fuel Design Limits (SAFDLs) are not exceeded are:

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

b. The peak LPD in the limiting fuel pin in the core shall not be greater than that value corresponding to the minimum temperature which would initiate centerline fuel melting.

2.2 ANTICIPATED OPERATIONAL OCCURRENCES (AOOs)

Anticipated operational occurrences are defined in Appendix A of 10CFR50 (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 AOOs accommodated by the CPCs using the CEAC-generated penalty factors are the following:

a. The insertion or withdrawal of a single full-length or part-length CEA including:

1. Uncontrolled insertion or withdrawal of a single CEA;

2. A single dropped full or part-length CEA;

3. A single CEA sticking, with the remainder of the CEAs in that subgroup moving;

4. A statically misaligned full or part-length CEA.

3.0 FUNCTIONAL DESIGN AND COMPUTER DESIGN REQUIREMENTS

3.1 CEA CALCULATOR PENALTY FACTOR ALGORITHM FUNCTIONAL REQUIREMENT

The CPC determination of the planar radial peaking factors at any given axial node is done by a table look-up routine. This table look-up routine utilizes a precalculated table of values for the planar radial peaking factor associated with those CEA groups that are inserted or withdrawn in a normal sequence into the axial node of interest. The normal sequence of group insertion or withdrawal is the prescribed plant technical specification sequence. To account for the increased radial peaking that would result from conditions other than normal, CEA position-related penalty factors are then applied. These penalty factors are multiplicative factors applied to the look-up value to increase the planar radials for the effects of CEA groups being inserted or withdrawn out of normal sequence and for excessive misalignment of subgroups from the group position. The penalty factors associated with the CEA group and subgroup AOOs are calculated within the CPCs. The CEA Calculator (CEAC) accommodates the single CEA deviation-related AOOs.

The single CEA deviation-related penalty factors calculated by the CEAC will accommodate changes in the local power density (LPD) and DNBR. The DNBR and LPD penalty factors calculated in the CEACs accommodate changes in the core axial and radial shapes and the core power not perceived in the CPCs during single CEA deviation events.

The single CEA position-related penalty factors calculated by the CEAC must be such that a conservative approximation to the peak local power density and minimum DNBR is obtained in the CPCs during individual CEA-related AOOs. To satisfy this requirement the following specific functional requirements, as a minimum, must be satisfied.

3.1.1 Requirements for Accommodation of Defined Single CEA-Related AOOs

The CEA Penalty Factors generated by the CEAC for use in the CPC trip functions must be designed to accommodate the individual CEA-related AOOs described in Section 2.2. The bases for this requirement are:

1. Criteria 25 and 29 of 10CFR50 Appendix A, "General Design Criteria for Nuclear Power Plants."

2. Regulatory Guide 1.70.

3.1.2 Inputs and Outputs

The CEACs shall each receive analog core axial CEA position measurement signals which originate from one of two Reed Switch Position Transmitters (RSPTs) associated with each CEA. Each CEA position is measured by two redundant independent RSPTs which transmit analog signals to two redundant independent CEACs (refer to Figure 3-1 for ANO-2). The resolution requirements on the CEAC measurement of CEA position shall be such that (excluding process signal error) CEA position shall be determined to within [ ]

The RSPT consists of a series of magnetically actuated reed switches spaced at intervals along the RSPT assembly and wired with precision resistors in a voltage divider network. The RSPT is affixed adjacent to the Control Element Drive Mechanism (CEDM) pressure housing and CEA extension shaft. A magnet attached to the CEA extension shaft actuates the adjacent reed switches, causing a voltage signal proportional to the CEA position to be transmitted for each CEA. The two RSPTs are isolated both electrically and physically from each other. The CEAC input signal derived from the RSPT output has a range of 5 to 10 volts corresponding to 0 to 150 inches of CEA travel, or 0% to 100% withdrawal.

FIGURE 3-1

CEA CALCULATOR INPUT INTERFACE DIAGRAM FOR ANO-2

The CEAC shall calculate the CEA Penalty Factors based on CEA position sensor input data obtained from each of the RSPTs (refer to Figure 3-1 for ANO-2 Cycle 1). The components of the CEA Penalty Factors are determined from the following data:

1. A static penalty factor component calculated as a function of deviation magnitude within a subgroup;

2. A dynamic Xenon penalty factor component calculated as a function of elapsed time during which excess deviation exists in the subgroup.

3. A correction constant for the Xenon component.

The output signals for each CEAC are listed in Table 3-1.

The two contact outputs must actuate operator alarms. The five digital-word outputs form the 16-bit output buffer which transmits the CEA penalty factors to the CPCs. The CEAC Failure Flag indicates the quantity of failed sensors or the quantity of deviating CEAs per core quadrant exceed limiting pre-set numbers. Actuation of the CEAC Failure Flag is described in more detail in Section 3.4.1. The Scale Flag indicates the range of the penalty factors, and is described in more detail in Section 3.4.3.

3.2 PROGRAM STRUCTURE

The CEAC design bases require that the calculator be capable of detecting CEA deviation, calculating the CEA penalty factors, and indicating by alarm and indicator flag CEA deviation, CEAC failure, and sensor out-of-range failures. In addition, the CEAC will provide diagnostic information on CEA sensor failures. Therefore, the CEAC Penalty Factor Algorithm shall calculate or determine the following quantities:

Table 3-1

CEAC Output Signals

Signal	Type	Range
CEAC Failure Flag	Digital Word[1]	
Packed DNBR Penalty Factor (minus 1.0)	Digital Word[1]	
Multiple CEA Deviations in Subgroup Flag	Digital Word[1]	
Packed LPD Penalty Factor (minus 1.0)	Digital Word[1]	
Scale Flag	Digital Word[1]	
Sensor out-of-range Alarm	Contact Output	
CEA Deviation Alarm	Contact Output	

1. Part of 16-bit output buffer.
2. See Section 3.4.

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

2. 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.

3. 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 the LPD and DNBR penalty factors calculated for each subgroup. The maximum penalty factors minus one will be transmitted to the CPCs as part of the output of the CEAC.

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

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

6. To provide diagnostic information on CEA sensor failures, and on the causes of a CEAC penalty factor.

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

8. To support CEA CRT display software by calculating parameters used for the display.

3.3 PROGRAM TIMING AND INPUT SAMPLING RATES

The CEAC Penalty Factor Algorithm software is designed for the purposes of providing, for existing CEA configurations, an on-line real-time determination of the single CEA deviation related DNBR and LPD penalty factors to be applied in the CPC determination of the hot pin heat flux distribution, the adjusted compensated core average power, and the local power density. The algorithm required for this purpose is time oriented, with a calculation scheduling rate and update period that is compatible with overall CEAC/CPC system response requirements. The execution period is the maximum time in seconds from the time CEA RSPT sensors are scanned to the time the CEAC calculated outputs are updated with new information from that input scan and calculation. The calculations shall be scheduled in such a manner that the update requirements are met.

There are two CEAC System update periods:

1. The [ ] Update Period

   The update period consists of a periodic fixed [ ] scheduling rate. The CEAC Penalty Factor Program outputs shall be updated [ ].

2. The [ ] Update Period

   This update consists of a fixed algorithm scheduling rate [ ] The CEAC Penalty Factor Program calculated output to a CRT bar graph display showing individual CEA positions arranged in subgroups and groups shall be updated [ ]

The tolerance on the execution periods [ ]

3.4 PROGRAM INTERFACES

Communications with the CPCs must be rapid and simple. In addition, the output to the CPCs must not change until after execution of the CEACs has been completed. This is accomplished by a 16-bit output buffer which transmits data to each CPC. This output buffer shall have a memory location, and the 16 bits shall be assigned in the following manner:

[ ]

3.4.1 CEAC Failure Flag

A CEAC failure flag shall be transmitted to the CPCs as part of the 16-bit output buffer. This flag shall be set true when either or both of the following conditions occur:

[ ]

The CEAC Penalty Factor Program shall perform sensor out-of-range validity checks on the raw RSPT sensor input data and initiate a sensor-out-of-range alarm when out of range conditions are detected. Analog signals outside the acceptable operating range represent failure of the RSPT. If this check indicates sensor in-range, a [ ] is then performed. If either of these checks fail, the sensor fail flag is set.

In addition, the CEAC failure flag should be set for internal processor faults including fixed point divide faults, floating point arithmetic fault, memory parity errors, illegal machine instruction, or failure to meet the timing requirements of Section 3.3.

3.4.2 Case 2 Deviation Flag

A Case 2 deviation (or large penalty factor) flag shall be transmitted to the CPCs as part of the 16-bit output buffer. This flag shall be set true when either or both of the following conditions occur:

[ ]

The CEAC Penalty Factor Program shall check for indications of [ ]

3.4.3 Scaling Flag

After the DNBR and LPD penalty factors have been calculated, each penalty factor is prepared for packing into the 16-bit output buffer [ ]

[ ]

3.4.4 CEAC Off-Line Storage and Reloading

To accommodate events where reloading of the CEAC Penalty Factor Algorithm program is required because of software and/or hardware failures, a means shall be provided to permit rapid reloading of the CEAC software from a suitable off-line mass storage device (one per CEAC). The off-line storage device shall be utilized for normal CEAC start-up loading but not during normal CEAC operation.

3.5 OPERATOR INTERFACE

The reactor operator shall be informed of the status of the CEACs by three mechanisms:

1. The calculators generate alarms to alert the operator to CEA sensor failure or excessive CEA deviation.

2. The CRT Video Monitor displays the position of the individual CEAs arranged into subgroups and control groups utilizing a bar graph representation, the floating point values of the two penalty factors, and a flag to indicate the cause of any alarms.

3. The CPC/CEAC operator's module provides CEAC inputs, selected intermediate variables, and outputs.

3.5.1 Alarms and Annunciators

A CEA deviation alarm (including Case 2 type deviations) and a failed sensor alarm shall be provided to the Plant Annunciator System (audible and visual) and to the CPC/CEAC operator's module. Removal of the alarm indication should be prohibited unless the condition causing the alarm no longer exists.

3.5.2 Displays and Indicators

Both CEACs shall be linked to a single CRT Display Generator 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 (as defined in IEEE Std. 279-1971). 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 (Figure 3-1) consists of a CRT Video Monitor and a Display Generator.

The CRT Video Monitor shall display the position of the 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 the deviation.

Provisions shall also be made to allow the operator to obtain a digital position read out in units of inches from the bottom of the core by addressing the particular point I.D. of the CEA on the operator's module. Certain CEAC intermediate variables and outputs (including the LPD and DNBR penalty factors and the packed penalty factor word to be transmitted to the CPCs) shall be available through the operator's module.

Each CEAC shall provide diagnostic information to the operator via the operator's module or a teletype. 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.

Each CEAC performs sensor input out-of-range checks [

]

Table 3-2

Example of Failed Sensor Arrays

[ ]

This information can be retrieved through the operator's module or a teletype. The failed sensor stack should be saved through auto-restarts.

A "snapshot" of CEA positions, penalty factors, and time of deviation occurrence is initiated by 1) a CEAC penalty factor greater than one, 2) the large PF flag, 3) a CEAC failure caused

Changing the constant from 1 to 0 could be used to clear the buffer. This information can be retrieved through a teletype. The CEAC snapshot should be saved through auto-restarts.

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

2. Initialization and in-test mode,

4. CEAC hardware failure,

5. CEAC memory unprotected.

3.5.3 Operator Input

The operator must have the capability to change a limited set of program constants, called addressable constants, via the input/output device. Modification of addressable constants shall be permitted only when a manual interlock has been activated. In addition means shall be provided to prevent modification of any constants not designated "addressable". The required addressable constants are limited to one constant for clearing the snapshot buffer (3.5.2) and one constant for rewriting the entire CRT display on command.

3.6 INITIALIZATION

The CEACs must be capable of initializing to steady state operation for any allowable plant operating condition. Initialization should be complete within 15 seconds of initial CEAC startup or of restart following a CEAC failure or in-test condition. Until initialization of a CEAC 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.

3.7 TESTING REQUIREMENTS

The CEAC shall be designed to perform periodic testing of the CEAC Penalty Factor Program upon operator demand.

The bases for this requirement are:

1. IEEE Std. 338-1971, "IEEE Trial Use Criteria for the Periodic Testing of Nuclear Power Generating Station Protection Systems."

2. Criteria 21 and 22 of 10CFR50 Appendix A," General Design Criteria for Nuclear Power Plants."

3. Regulatory Guide 1.22, "Periodic Testing of Protection System Actuation Functions."

The testing of the program shall be accomplished by disabling the input interface and simulating new inputs from a periodic testing data base. Selected outputs will then be checked against a corresponding expected value data base, and differences will be identified. During the time the CEAC is undergoing periodic testing a digital code shall be generated and transmitted to the CPCs to identify that the CEAC unit is in-test.

4.0 ALGORITHM DESCRIPTION

This section includes 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 [ ] The dynamic Xenon penalty factor component is calculated as a function of [ ]

CEA position signals are read in and processed to screen out false signals, and the status of the sensor fail alarm is determined. [ ].

[ ]

4.1 PENALTY FACTOR ALGORITHM

4.1.1 Algorithm Input

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 [ ]

[ ]

TABLE 4-1

Assignment of CEDMs to Subgroups for ANO-2**

Sub-Group No.	CEDM No.
1	2, 3, 4, 5
2	6, 7, 8, 9
3	10, 11, 12, 13
4	14, 16, 18, 20
5	15, 17, 19, 21
6	22, 23, 24, 25
7	26, 27, 28, 29
8	30, 32, 34, 36
9	31, 33, 35, 37
10	38, 40, 42, 44
11	39, 41, 43, 45
12	46, 47, 48, 49
13	50, 52, 54, 56
14	51, 53, 55, 57
15	58, 59, 60, 61
16	62, 64, 66, 68
17	63, 65, 67, 69
18	70, 73, 76, 79
19	71, 74, 77, 80
20	72, 75, 78, 81
*xx	*1

1. *CEDM No. 1 is to be capable of being assigned to any one of the 20 subgroups.
2. The assignment of CEDMs to subgroups as controlled by the CEDMCS is fixed for the life of the plant (except for CEDM #1)
3. For AP&L first fuel cycle, CEDM No. 1 is assigned to subgroup No. 12.

** This CEDM assignment will differ for other plants.

TABLE 4-2

Assignments of Subgroups to Control Groups for ANO-2
First Fuel Cycle**

CONTROL GROUPS*	ASSIGNMENT OF SUBGROUPS TO CONTROL GROUPS (Subgroup No.)
Regulating Group #6	12
Regulating Group #5	15
Regulating Group #4	3
Regulating Group #3	16, 17
Regulating Group #2	2, 19
Regulating Group #1	10, 11
Shutdown Group A	13, 14, 18, 20
Shutdown Group B	1, 4, 5, 8, 9
Part-Length Group	
P1	6
P2	7

Notes:

*Regulating Control Group #6 is the first to be inserted in-sequence and Group #1 is the last. Regulating Control Group #1 is the first to be withdrawn in-sequence and Group #6 is the last. The insertion/withdrawal sequence maintains 40% overlap of adjacent groups.

**This subgroup assignment will vary according to plant and fuel cycle.

4.1.2 Determination of Deviation

if DEV $\geq S_{ALARM}$

and if $(BOT-D_{UP}) < SX$

and if $(D_{DN}-TOPP) < SX$

then set the CEA deviation alarm.

Otherwise, the CEA deviation alarm is not set. The variables used in this section are

4.1.3 Determination of Penalty Factors

FIGURE 4-1:

PENALTY FACTOR COMPONENTS

[ ]

The LPD and DNBR penalty factors for each subgroup are determined by combining the static penalty factor component, the [ ] Xenon penalty factor component, and the appropriate Xenon correction constant. [

4.1.4 Packing of Penalty Factors for Transmittal to CPCs

The LPD and DNBR penalty factors are adjusted for packing into the penalty factor word. [

]

[ ]

4.1.5 CEAC Initialization

[ ]

4.1.6 CEAC Constants

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

ENCLOSURE 6