MODIFIED STATISTICAL

COMBINATION OF UNCERTAINTIES

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ABSTRACT

Modified Statistical Combination of Uncertainties

This report describes changes to the methodology for statistically combining uncertainties used to determine the LSSS and LCO overall uncertainty factors for C-E's digital monitoring and protection systems. The resultant overall uncertainty factors using the Modified Statistical Combination of Uncertainties (SCU) Program are determined and applied such that the Core Operating Limit Supervisory System (COLSS) Power Operating Limit (POL) and the Core Protection Calculator System (CPCS) DNBR and Local Power Density (LPD) calculations are conservative to at least a 95/95 probability/confidence level. The changes do not impact either the manner in which COLSS aids the operator in maintaining operating margin to limits on linear heat rate (LHR) and DNB or the manner in which the CPCS responds to transients and provides the low DNBR and LPD trips. Therefore the changes do not impact transient analysis assumptions or results and do not involve changes to Technical Specifications.

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DEFINITION OF ABBREVIATIONS

ASI	Axial Shape Index
BERR1-4	CPC Overall Uncertainty Factors
BPPCC	Boundary Point Power Correlation Coefficient
C-E	Combustion Engineering, Inc.
CEA	Control Element Assembly
CETOP-D	CE Thermal-Hydraulic Design Code
CHF	Critical Heat Flux
CIP	CPC Improvement Program
CPC	Core Protection Calculator
CPCS	Core Protection Calculator System
COLSS	Core Operating Limit Supervisory System
DNB	Departure from Nucleate Boiling
DNBOPM	DNB Overpower Margin
DNBR	DNB Ratio
EPOL	COLSS DNBR Overall Uncertainty Factor
FLAIR	CE Neutronics Simulator
Fq	3-Dimensional Peaking Factor
Fxy	Planar Radial Peaking Factor
HID-1	High Impact Design Spacer Grid (Type 1)
LCO	Limiting Condition for Operation
LHR	Linear Heat Rate
LPD	Local Power Density
LSSS	Limiting Safety System Settings
NRC	Nuclear Regulatory Commission
pdf	Probability Density Function
POL	Power Operating Limit
PVNGS	Palo Verde Nuclear Generating Station
RCS	Reactor Coolant System
RPS	Reactor Protection System
RSF	Rod Shadowing Factor
SAM	Shape Annealing Matrix
SCU	Statistical Combination of Uncertainties
UNCERT	COLSS LHR Uncertainty Factor

1.0 INTRODUCTION

1.1 Purpose

The purpose of this report is to describe changes to the methodology for statistically combining uncertainties associated with the LCO and LSSS setpoints for CE's digital monitoring and protection systems. These changes are designed to improve plant operating performance and flexibility and reduce the incidence of unnecessary reactor trips by reducing the overall uncertainty factors applied in the COLSS and CPCS. Rigorous, statistically justified methods are used to establish the resultant uncertainty factors. The Core Operating Limit Supervisory System (COLSS) aids the operator in monitoring the Limiting Conditions for Operation (LCO) based on DNBR margin, Linear Heat Rate (LHR) margin, Axial Shape Index (ASI) and core power. The Core Protection Calculator System (CPCS) within the Reactor Protection System (RPS) initiates the reactor trips based on low DNBR and high Local Power Density (LPD). Overall uncertainty factors are determined and applied for both the COLSS and CPCS such that the COLSS Power Operating Limits (POL) and the CPCS DNBR and LPD calculations are conservative to at least a 95/95 probability/confidence level. The Modified Statistical Combination of Uncertainties Program resulting from the methodology changes described in this report has been developed in such a way that this level of conservatism is maintained.

1.2 Background

1.2.1 Protection and Monitoring Systems

The functions and interactions of the protection and monitoring systems, LCO's and LSSS's, and COLSS and CPCS are described in previous PVNGS SCU reports such as References 1 and 2 and in current COLSS and CPCS Reports such as

(1)

References 3, 4, and 5. The changes to the Statistical Combination of Uncertainties (SCU) methodology described in this report do not impact the functions of these systems.

1.2.2   Current SCU Program

References 6, 7, and 8 are the latest references for the currently approved SCU methodology. The methods documented in these SONGS references are similar to those used for System 80 (i.e. PVNGS Cycle 1) as documented in References 1, 2 and 11. As part of the CPC Improvement Program, several modifications were made to simplify the SCU analysis process. These modifications are documented in Reference 9. NRC approval of the CIP related modifications was provided in Reference 10. The changes to the SCU methodology for the Modified SCU program are presented in this report based on the current SCU program described in these references.

The uncertainties involved in the SCU methodology are divided into two categories. The first category, referred to as "system parameter" uncertainties, includes engineering factors, CHF correlation uncertainties and TORC code modeling uncertainties. The uncertainties in this group are statistically combined to generate a DNBR probability density function (pdf). The 95/95 probability/confidence level tolerance limit of this function has been used as the DNBR limit in COLSS and CPCS thus accounting for the uncertainties in this category.

The second category, referred to as "state parameter" uncertainties, includes measured state parameter, COLSS and CPC algorithm, radial peaking factor measurement, simulator model, computer processing and startup measurement uncertainties. The state parameter, algorithm and startup

measurement uncertainties are stochastically simulated to generate a state parameter pdf. The 95/95 probability/confidence level of this function is then root-sum-squared with the other uncertainties to determine the CPC and COLSS overall uncertainty factors, hence accounting for the uncertainties in this group. The uncertainty analysis which determines these overall uncertainty factors in the heretofore approved SCU program is illustrated in Figure 1-1.

Even though uncertainties within each part are combined statistically and a 95/95 probability/confidence level is generated for each group, the resultant uncertainties of the two groups are effectively combined in a deterministic manner due to separate application in the DNBR limit and the overall uncertainty factors. Tables 1-1 and 1-2 list the uncertainties included in the system parameter and the state parameter categories, respectively. These uncertainties are defined and described further in References 6, 7, and 8.

In the current SCU methodology, power measurement uncertainties are applied separately from the system and state parameter uncertainty factors. COLSS normally uses secondary calorimetric power as the standard and therefore the power measurement uncertainty for COLSS consists of the secondary calorimetric uncertainty. The CPC neutron flux power measurement uncertainty factor is calculated by a deterministic combination of the secondary calorimetric uncertainty, a calibration allowance, and the neutron flux power synthesis uncertainty. The CPC thermal power measurement uncertainty factor is calculated by a deterministic combination of the secondary calorimetric uncertainty, a calibration allowance, and a thermal power transient offset, if needed.

Figure 1-2 is a schematic of what will henceforth be referred to as the "current SCU" program.

1.3   Modified SCU Program

This document describes the changes to the current SCU program designed to improve plant operating performance and flexibility and reduce the incidence of unnecessary reactor trips by reducing excess conservatism in the DNBR overall uncertainty factors for COLSS and CPCS. The reduction in overall uncertainty factors results primarily from [

] In addition, minor changes have been made in the statistical treatment of several components and the methodology has been developed so that the overall uncertainty factors can be calculated and applied in discrete regions of core burnup, power, and axial shape index (ASI). The changes made to the SCU program are the following:

1. [

]

2. [

]

3. [

]

4. [

]

5. Develop the methodology for determining and implementing Burnup, ASI, and Power dependent uncertainty factors in COLSS and CPCS.

These changes are described in more detail in Section 2.0. The SCU program with all these modifications will henceforth be referred to as the "Modified SCU" program. Figure 1-3 provides a schematic of the Modified SCU program.

1.4   Summary of Results

The methodology of the Modified SCU program will generate overall uncertainty factors such that the COLSS Power Operating Limit (POL) and CPCS DNBR and LPD calculations are conservative to at least a 95/95 probability/confidence level. The changes to the SCU methodology described in this report do not impact either the manner in which COLSS aids the operator in maintaining operating margin to limits on linear heat rate (LHR) and DNB or the manner in which the CPCS responds to transients and provides the low DNBR and high LPD trips. Therefore, the changes do not impact transient analysis assumptions or results and do not involve changes to Technical Specifications.

In Section 3.0, the Modified SCU program methodology has been applied to PVNGS using typical models and input data and results in DNBR overall uncertainty factors of [   ] for COLSS and [   ] for CPCS.

Table 1-1

Uncertainties Included in the System Parameter SCU

Core inlet flow distribution [1]

Engineering factor on enthalpy rise

Systematic fuel rod pitch

Systematic fuel clad O.D.

Engineering factor on heat flux

CE-1 CHF correlation (Including cross validation
uncertainty)

TORC code uncertainty

Fuel rod bow penalty [2]

HID-1 grid penalty [2]

(1) Core inlet flow distribution uncertainty[　　　　　　　　　　　　　　　]
    for System 80 plants

(2) [　　　　　　　　　　　　　　　]

Table 1-2

General Categories of Uncertainties Included in State Parameter SCU

Measured State Parameter Uncertainties

Algorithm Uncertainties

Startup Measurement Uncertainties

Radial Peaking Factor Measurement Uncertainty

Computer Processing Uncertainties

Simulator Model Uncertainties

Rod Bow Penalty on Fxy

FIGURE 1-1
COLSS AND CPCS UNCERTAINTY ANALYSIS
FOR CURRENT SCU

FIGURE 1-2
CURRENT SCU PROGRAM SCHEMATIC

FIGURE 1-3
MODIFIED SCU PROGRAM SCHEMATIC

2.0   METHODS

2.1   INTRODUCTION

The current SCU program is described in References 6, 7, and 8
with CPC Improvement Program modifications described in Reference
9. The following sections describe the changes made to the SCU
methodology in the Modified SCU program. Section 3.0 will
provide a typical DNBR overall uncertainty factor calculation
using the Modified SCU program.

The changes to the SCU methodology primarily impact the treatment
of system parameters, secondary calorimetric power measurement,
and neutron flux power synthesis uncertainties as described in
Sections 2.2, 2.3, and 2.4, respectively. Section 2.5 presents
other minor methodology changes.

2.2   SYSTEM PARAMETER SCU METHODOLOGY

The uncertainties considered in the system parameter SCU include
engineering factors, CHF correlation uncertainties and TORC code
modeling uncertainties. In the current system parameter SCU
analysis, described in Reference 6, these uncertainties are
combined statistically to arrive at the DNBR limit. The Modified
SCU methodology [

                                    ] Thus the DNBR overall
uncertainty factors for COLSS and CPC [

                                                            ]

(11)

The individual uncertainties that are combined in the system parameter SCU are as follows:

a)   Core inlet flow distribution [1]
b)   Engineering factor on enthalpy rise
c)   Systematic fuel rod pitch
d)   Systematic fuel rod diameter
e)   Engineering factor on heat flux
f)   CE-1 CHF correlation
g)   CE-1 CHF correlation cross validation penalty (5% increase in CHF correlation standard deviation)
h)   T-H code uncertainty penalty (5%, equal to two standard deviations)

These uncertainties are statistically combined to yield the DNBR probability density function (pdf).

In the current SCU analysis the 95/95 probability/confidence limit of this DNBR pdf is deterministically combined with the fuel rod bow and the HID-1 grid penalties to determine the minimum DNBR limit to be applied in COLSS and CPC. This DNBR limit is then used in the state parameter SCU stochastic simulation to determine the COLSS and CPCS DNBR overall uncertainty factors. This limit is also used in the on-line COLSS DNBR power operating limit calculation and as the CPCS DNBR trip setpoint.

In the Modified SCU methodology, the system parameter uncertainties are combined in the same way to determine the DNBR pdf. However, [

]

[1]   Core inlet flow distribution uncertainty [
      ] for System 80 plants.

(12)

[

]

This modification to the SCU program is consistent with statistical methods approved in the current SCU program. [

]

are chosen such that the COLSS DNBR POL and CPCS DNBR calculations are conservative at a 95/95 probability/confidence level.

2.3   SECONDARY CALORIMETRIC POWER MEASUREMENT UNCERTAINTY METHODOLOGY

Both COLSS and CPC use Secondary Calorimetric power as a measure of true core power for their LHR/LPD and DNBR calculations. The calculation of Secondary Calorimetric power has an uncertainty associated with it. Currently, this uncertainty is calculated statistically as described in Reference 7 and applied deterministically in both COLSS and CPC. The Modified SCU methodology will apply this uncertainty [

]

The Secondary Calorimetric power measurement uncertainty (ECAL) is core power dependent. Figure 2-1 shows a typical example of the uncertainty as a function of power. In the current SCU program, this uncertainty is applied as [   ] directly on the core power used in the COLSS and on the thermal and neutron flux power used in CPC. This uncertainty is implemented [   ] in both COLSS and CPC.

In the Modified SCU methodology, the Secondary Calorimetric power measurement uncertainty will be represented by [

] The DNBR overall uncertainty analysis will statistically [

] The method of application of this uncertainty will remain deterministic, unchanged from the current methodology, [

]

The Modified SCU approach is consistent with statistical methods approved in the current SCU program. Application of this uncertainty [   ] will continue to assure conservative DNBR POL calculations by COLSS and DNBR calculations by CPCS to at least a 95/95 probability/confidence level.

2.4   CPC NEUTRON FLUX POWER SYNTHESIS UNCERTAINTY METHODOLOGY

The CPC Neutron Flux Power calculation based on ex-core detector signals includes a neutron flux power measurement uncertainty. One component of this uncertainty is the power synthesis uncertainty. The current SCU method for determining and applying this uncertainty is described in Reference 7. The Modified SCU methodology will [

]

In the current SCU analysis, a pdf of the power synthesis uncertainty is produced at the same time that the DNBR uncertainty factor is determined. The 95/95 probability/confidence tolerance limit of the pdf is applied [
] in the CPC Neutron Flux Power calculation.

(14)

In the Modified SCU analysis, the power synthesis uncertainty will be applied [

]

The Modified SCU program approach is consistent with statistical methods approved in the current SCU program. Application of this uncertainty [   ] will continue to assure a conservative DNBR calculation by CPCS at a 95/95 probability/confidence level.

2.5   OTHER MODIFICATIONS TO SCU METHODOLOGY

The Modified SCU methodology includes several minor changes to the techniques of determining and applying uncertainty components. These changes, described in the following section, are consistent with statistical methods approved in the current SCU program and retain conservatism in the resultant uncertainty factors to at least a 95/95 probability/confidence level.

2.5.1   RADIAL PEAKING FACTOR MEASUREMENT UNCERTAINTY APPLICATION

Both COLSS and CPC use Radial Peaking factors (Fxy's) that are verified, and adjusted if necessary, during startup testing. The Fxy measurement which is used for this verification has an uncertainty associated with it.

In the current SCU analysis, the Fxy measurement uncertainty is combined with other uncertainty components [
]

(15)

In the Modified SCU methodology the Fxy uncertainty will be
[.] Thus the
Fxy uncertainty will be [

                              .] This modification involves only a
change in the statistical combination technique for this
particular uncertainty component.

2.5.2   APPLICATION OF UNCERTAINTY FACTORS AS A FUNCTION OF
         BURNUP, ASI, AND POWER

The COLSS and CPC overall uncertainty factors calculated in the
SCU analysis typically vary as a function of power level, cycle
burnup, and Axial Shape Index (ASI). In the current SCU
methodology, limiting values of these uncertainty factors are
chosen and applied for all conditions.

The Modified SCU methodology will allow calculation and
application of these uncertainty factors over several burnup,
power, and ASI ranges. Choice of parameters and ranges will be
made on a cycle-by-cycle basis in order to optimize the
uncertainty factors for nominal full power operation throughout
the cycle, while retaining conservatism at a 95/95
probability/confidence level for all conditions.

FIGURE 2-1

SECONDARY CALORIMETRIC
POWER MEASUREMENT UNCERTAINTY
(SAMPLE PVNGS VALUES)

3.0 TYPICAL OVERALL UNCERTAINTY FACTOR CALCULATION

3.1 INTRODUCTION

The changes to the SCU Program described in Section 2.0 result in a Modified SCU methodology which can be applied to all C-E plants with digital monitoring and protection systems. The Modified SCU Program will be initially applied to PVNGS Unit 1 Cycle 2. Therefore, a calculation of COLSS and CPC DNBR overall uncertainty factors is presented here using typical PVNGS models and input data. This calculation will illustrate the application of the Modified SCU methodology and its results.

3.2 DNBR pdf

The System Parameter SCU methods used to determine the DNBR limit and pdf remain unchanged from that described in Reference 6. The uncertainties combined to derive this pdf are listed in Table 3-1 with typical values for PVNGS. The resultant pdf is shown in Figure 3-1.

As in the current SCU methodology, the DNBR limit for COLSS, CPC, and transient analyses is defined by the following equation:

$$DNBR \ limit = TL * P_{BOW} + P_{HID}$$

where

TL = 95/95 probability/confidence tolerance limit of DNBR pdf.

P_{BOW} = Rod Bow Penalty

P_{HID} = HID-1 Grid Penalty

[

] the DNBR limit
generated by this method is used in the on-line COLSS and CPC and
in the transient analyses.

The tolerance limit for the pdf shown in Figure 3-1 is 1.205.
Combining this with the rod bow penalty (1.75%) and the HID-1
grid penalty (0.01) yields a DNBR limit of 1.237.

3.3   SECONDARY CALORIMETRIC POWER MEASUREMENT UNCERTAINTY pdf

The secondary calorimetric power measurement uncertainty is
calculated from the uncertainties of the various measured
parameters used to calculate the secondary calorimetric power.
These components are listed in Table 3-2 with typical values for
PVNGS [   ]

3.4   COLSS DNBR OVERALL UNCERTAINTY FACTOR CALCULATION

The COLSS DNBR overall uncertainty analysis process using
Modified SCU is illustrated in Figure 3-2.

As in the current SCU Program (Reference 8), [

]

(19)

Table 3-3 lists the state parameter measurement uncertainty components [   ] in the COLSS overall uncertainty analysis, including typical ranges and uncertainty values for PVNGS. The uncertainty components [   ] are listed with typical PVNGS values in Table 3-4 and the remaining uncertainty components [   ] are presented in Table 3-5.

The COLSS DNBR overall uncertainty analysis using the typical PVNGS input values results in a DNBR overall uncertainty factor of [   ]

3.5   CPCS DNBR OVERALL UNCERTAINTY FACTOR CALCULATION

The CPC DNBR overall uncertainty analysis process is illustrated in Figure 3-3.

(20)

[
　　　　　　　　　　　　　　　　　　　　　　　　　　　　　]

As in the current SCU program (Reference 7), [

　　　　　　　　　　　　　　　　　]

[

　　　　　　　　　　　　　　　　　　　　　　　　　　　　　]

Table 3-6 lists the state parameter measurement uncertainty
components [   ] in the CPC overall uncertainty analysis,
including typical ranges and uncertainty values for PVNGS. The
uncertainty components [   ] are listed with typical
PVNGS values in Table 3-7 and the remaining uncertainty
components [   ] are presented in Table 3-8.

The CPC DNBR overall uncertainty analysis using the typical PVNGS
input values results in a DNBR overall uncertainty factor of
[   ]

Table 3-1

Components Combined in the DNBR pdf

Parameter	Mean	Std. Deviation at 95% Confidence
Inlet flow distribution	[	]
Enthalpy rise factor		
Systematic pitch (in)		
Systematic clad OD (in)		
Heat flux factor		
CE-1 CHF correlation		
TORC code uncertainty		
DNBR pdf	[	]

*   Inlet flow distribution uncertainty [   ] for
    System 80 plants.

** Includes 5% cross-validation uncertainty

Table 3-2

Secondary Calorimetric Power Measurement Uncertainty Components

Parameters	Units	STD. Deviation at 95% Confidence*
Feedwater Flow (delta P transmitter)	IN. of H_2O	
Feedwater Temperature	°F	
Steam Flow (delta P transmitter)	IN. of H_2O	
Blowdown Mass Flow Rate	KPPH	
Steam Quality	-	
Secondary Pressure	PSIA	

[   ]

Table 3-3

COLSS State Parameter Ranges and Measurement Uncertainties

Parameters	Unit	Ranges	Measurement Uncertainty
Core Inlet Coolant Temperature	(°F)		
Primary Coolant Pressure	(psia)		
Primary Coolant Mass Flow	(10^6 lbm/hr. ft^2)		
Incore Detector Signal	(%)		
CEA Position	(inches)		

[   ] |

Table 3-4

Uncertainty Component [   ] in COLSS DNBR
Uncertainty Analysis

Parameter	Mean	Std. Deviation at 95% confidence
System Parameter Uncertainty DNBR pdf		
Radial Peaking Factor Measurement Uncertainty		
Secondary Calorimetric Power Measurement Uncertainty*		

Table 3-5

Uncertainty Components [   ] to Determine
COLSS DNBR Overall Uncertainty Factors

Parameter   Value

Fuel Rod Bow Penalty on Fxy

Computer Processing Uncertainty

Simulator Model Uncertainty

Table 3-6

CPCS State Parameter Ranges and Uncertainties

Parameters	Unit	Ranges	Measurement Uncertainty
Core Inlet Coolant Temperature	(°F)		
Primary Coolant Pressure	(psia)		
Primary Coolant Mass Flow	(10^6 lbm/hr-ft^2)		
Ex-core Detector Signals	(% power)		
CEA Positions	(inches)		

Startup Measurement Uncertainties

- Rod Shadowing Factor

- Shape Annealing Matrix**

- Boundary Point Power Correlation Coefficient

[*   ]

**Assumed Excore Noise Level During Test

(27)

Table 3-7

Uncertainty Component [   ] in CPC DNBR
Overall Uncertainty Analysis

Parameter	Mean	Std. Deviation of 95% Confidence
System Parameter Uncertainty DNBR pdf		
Radial Peaking Factor Measurement Uncertainty		
Secondary Calorimetric Power Measurement Uncertainty		
Neutron Flux Power Synthesis Uncertainty*		

[

]

(28)

Table 3-8

Uncertainty Components [   ] to Determine
CPC DNBR Overall Uncertainty Factors

Parameter	Value
Fuel Rod Bow Penalty on Fxy	
Computer Processing Uncertainty	[ ]
Simulator Model Uncertainty	

Figure 3-1

DNBR PROBABILITY DENSITY FUNCTION

PROBABILITY DENSITY, F(X)

DNBR, X

FIGURE 3-2

COLSS DNBR OVERALL UNCERTAINTY ANALYSIS
WITH MODIFIED SCU

FIGURE 3-3

CPC DNBR OVERALL UNCERTAINTY ANALYSIS
WITH MODIFIED SCU

4.0   CONCLUSION

This report describes changes to the current SCU Program which
are designed to improve plant operating performance and
flexibility and reduce unnecessary trips. These changes result
in a Modified SCU Program which is applicable to all C-E plants
with digital monitoring and protection systems. The overall
uncertainty factors determined using the Modified SCU program
continue to ensure that the COLSS POL calculations and the CPCS
DNBR and LPD calculations will be conservative to at least a 95%
probability and 95% confidence level. The initial application of
the Modified SCU program is planned for PVNGS Unit 1 Cycle 2.
The Modified SCU program methodology has been applied to PVNGS
using typical models and input data and results in DNBR overall
uncertainty factors of [   ] for COLSS and [   ] for CPCS.

5.0   <u>REFERENCES</u>

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