Westinghouse Non-Proprietary Class 3

WCAP-12472-NP
Addendum 3

October 2004

BEACON™ Core Monitoring and Operation Support System

Westinghouse

Westinghouse Non-Proprietary Class 3

WCAP-12472-NP
Addendum 3

October 2004

BEACON™ Core Monitoring and Operation Support System

Page Intentionally Left Blank

Westinghouse Non-Proprietary Class 3

WCAP-12472-NP
Addendum 3

October 2004

BEACON™ Core Monitoring and Operation Support System

Authors:

W.A. Boyd
M.A. Book
T. Morita

Approved: *[signature]*
R. W. Miller, Manager
Core Monitoring Products

Westinghouse Electric Company LLC
4350 Northern Pike
Monroeville, PA 15146-2886

Page Intentionally Left Blank

TABLE OF CONTENTS

Page Intentionally Left Blank

LIST OF TABLES

Page Intentionally Left Blank

LIST OF FIGURES

Page Intentionally Left Blank

Introduction

Westinghouse has decided to create an upgraded core monitoring product by merging the functions of three existing products into one. These three products, the BEACON™ core monitoring system, COLSS and CETOP-D, have been in use for years by Westinghouse and are well known by the NRC.

The Best Estimate Analyzer for Core Operation – Nuclear (BEACON) system[1] was developed to improve the operational support for pressurized water reactors. It is an advanced core monitoring and support package which uses current instrumentation in conjunction with a fully analytical methodology for an on-line generation of 3D power distributions. The system provides core monitoring of the power limits delineated in the Technical Specifications, core measurement reduction, core follow and analysis and core predictions. The methodology for calculating and applying measurement uncertainties was reviewed and approved by the NRC in the BEACON topical report.[1]

The Core Operating Limit Supervisory System (COLSS)[6] was developed to help maintain a Combustion Engineering (C-E) supplied pressurized water reactor within its Limiting Conditions for Operation (LCO). It is also a core monitoring system which uses data from plant instrumentation in conjunction with a fully analytical methodology for on-line generation of core power level, a synthesized power distribution and power operating limits for departure from nucleate boiling ratio (DNBR) and linear heat rate (LHR). The system provides core monitoring of the LCOs delineated in the Technical Specifications. The methodology for calculating and applying measurement uncertainties in the system was reviewed and approved by the NRC in the COLSS uncertainty report.[4]

CETOP-D[5] is a thermal hydraulic analysis computer code for C-E designed plants and fuel. The CETOP-D code can provide more accurate DNBR results [ ]a,c.
CETOP-D has been reviewed and approved for use in design analysis for all C-E designed plants in plant specific safety evaluation reports (For example see Reference 8).

Although both BEACON and COLSS are core monitoring systems, they each have some features and capabilities that are not in the other. Therefore Westinghouse has decided to incorporate portions of COLSS and the CETOP-D code into the BEACON system and upgrade it to support core monitoring applications on C-E designed plants. This BEACON topical report addendum will describe the merged system and the updated uncertainty analysis methodology. The new functions and methods merged into the BEACON system will initially be applied as an option for C-E plants currently using COLSS. For the purposes of this report this optional BEACON level of functions and methods will be called BEACON-COLSS. The BEACON-COLSS nomenclature will designate an optional level in the BEACON system that can support and replace COLSS in C-E designed plants. In the future, the BEACON-COLSS option, with appropriate modifications to be consistent with safety analysis methodologies, can be offered to other PWRs.

As noted above, the COLSS and BEACON core monitoring systems have been approved by the NRC and in operation for a number of years at C-E and Westinghouse designed plants. There are no new methods or functions being developed or applied in the BEACON-COLSS product level. Because of the differences in the core power distribution calculations in BEACON and COLSS and the use of CETOP-D, the COLSS uncertainty methodology will be updated to be consistent with the merged BEACON-COLSS product. The purpose of this BEACON topical report addendum is to provide the information needed to review and approve the uncertainty analysis methodology that will be applied to the BEACON-COLSS product level. The uncertainty methodologies for BEACON and COLSS were previously documented and approved. This report will reference these documents in many places and in many cases the referenced information is reproduced in this report to provide detail for convenience of review.

Chapter 1 will provide background information on the licensing and operational status of BEACON and COLSS. Chapter 2 will describe the new features that will be merged into the BEACON system to create the BEACON-COLSS product level. Chapter 3 will review the BEACON systems basic core monitoring methodology. Chapter 4 will present the updated uncertainty methodology developed for the BEACON-COLSS level and the results from the uncertainty analysis performed for two plants that currently use COLSS. Chapter 5 will provide information on the plant specific Technical Specification changes needed to implement BEACON-COLSS. Chapter 6 will discuss the plant specific application requirements for the BEACON-COLSS product level.

1.0 Background

A topical report on "BEACON Core Monitoring and Operations Support System," was submitted to the USNRC in April, 1990 and was approved in February, 1994.[1] The key aspects of the report are 1) the methodology used to obtain the measured power distribution from the Westinghouse standard instrumentation system, i.e., the movable incore detectors, core exit thermocouples and excore detectors, and 2) the methodology for assessing uncertainties to be applied to the measured power distribution and Technical Specifications with BEACON as the source of the measured power distribution.

An addendum to the topical report was submitted to the USNRC in May, 1996 and was approved in September, 1999.[2] The key aspects of this addendum are 1) the new optional methodology in BEACON to predict the Rhodium self-powered neutron detector (SPD) responses and 2) the methodology to assess uncertainties to be applied to the measured power distribution and Technical Specifications for SPD plants using BEACON as the source of the measured power distribution.

A second addendum to the topical report was submitted to the USNRC in March, 2001 and was approved in February, 2002.[3] The key aspect of this addendum is the new optional methodology in BEACON to predict Platinum or Vanadium SPD responses for application in obtaining the measured power distribution for SPD plants using BEACON as the source of measured power distribution.

In certain Combustion Engineering (C-E) supplied NSSSs, the Core Operating Limit Supervisory System (COLSS) is used to monitor the current core conditions and margin to the LCOs. COLSS is an on-line core monitoring system that provides information on, margin to and alarms for specific Technical Specification limits such as total core power, linear heat rate, DNBR, azimuthal tilt and ASI.

A report on the COLSS Modified Statistical Combination of Uncertainties (MSCU) was submitted to the USNRC in July 1987 and approved in October 1987.[4] The main aspect of the report is the modified statistical combination methodology to assess uncertainties to be applied to the measured DNBR and peak linear heat rate such that the power operating limits have at least a 95/95 probability/confidence level. In addition, COLSS has been described in a topical report[6] that was provided for NRC information.

The BEACON system is in operation at approximately 50 plants around the world with movable and fixed incore detector designs. There are 26 plants in the US using the BEACON system of which 11 have licensed BEACON for on-line monitoring of the Technical Specification LCO's. COLSS has been in operation at a number of C-E designed NSSS since the early 1980's. It is currently in licensed operation at 7 C-E plants in the US and 5 C-E plants in Korea.

2.0 New BEACON Features

Portions of the COLSS core monitoring system and the CETOP-D thermal hydraulics code are being merged into the BEACON system to create an optional level to BEACON. This optional level to the BEACON system will be called BEACON-COLSS and will allow the BEACON system to monitor the LCOs and Technical Specification limits at C-E plants that currently use COLSS.

COLSS is a digital computer based on-line core monitoring system that is used to provide information to aid the operator in complying with the Technical Specification operating limits on Departure from Nucleate Boiling Ration (DNBR), Linear Heat Rate (LHR), Axial Shape Index (ASI), azimuthal power tilt and total core power. It does not activate any safety equipment, initiate any automatic actions or provide any direct input to safety systems.

BEACON is also a digital computer based on-line core monitoring system that can monitor DNBR, LHR, ASI (or Axial Offset) and power tilt. The three dimensional power distribution methodology used in BEACON is significantly more advanced than the synthesis method used in COLSS. In addition, BEACON provides the operator with predictive and analysis capabilities not present in COLSS and a graphical user interface which is more advanced than that in COLSS.

CETOP-D is the computer code used in thermal hydraulic analyses for CE-designed plants. It is typically benchmarked and adjusted via comparisons to the more detailed multistage thermal hydraulic computer code TORC[7]. CETOP-D will provide more accurate DNBR calculations [

]^{a,c}.

COLSS currently consists of modules which calculate [

]^{a,c}.

Figure 1 illustrates the overlap and combination of the functional groups in BEACON and COLSS. These functional groups will be merged to produce an optional BEACON-COLSS product level that can replace COLSS and monitor the existing LCOs. The merger of these functions does not remove or eliminate any of the existing BEACON functions but simply adds additional optional capability to the BEACON system. [

]^{a,c}.

3.0 BEACON Monitoring Methodology

The BEACON system has the capability of predicting the SPD current with the methods defined in Section 3 of the Addendums to WCAP-12472-P-A.[2,3] A summary of these methods is provided below. Once the predicted power distribution and detector currents are calculated the power distribution inference can be performed by using the BEACON core monitoring power distribution methodology. The monitored power distribution determined by BEACON is defined by the following basic equation reproduced from the BEACON topical addendums.

[ ]$^{a, c}$

The ratio of I_M/I_P indicates the difference between the measured and predicted flux distribution. The best estimate measured power distribution is obtained by adjusting the predicted power distribution by the I_M/I_P current ratio.

[

]^{a,c}

[ ]a, c

The tolerance factors are generated based on the measurement quality of the associated SPD. If the accuracy of a SPD measurement at a certain location is considered to be low, then a large T_j value can be assigned to that location. The fitting function can then deviate from the measurement at that location and approach the least square fitted value. High accuracy locations will have a low T_j value and the fitting function will go through the measured data. The generation of the tolerance factors is described in Section 5.3 of WCAP-12472-P-A [1].

The ratio of the measured to predicted flux ratio in each node is defined as the incore calibration constant for that node. The calibration factor for each node is interpolated and the resultant constant is then multiplied by the predicted node power and node peak power to generate the measured nodal parameters. The 3-D power distribution is then normalized to unity.

The 3-D measured power distribution will then be used to determine the 3D peaking factor to be used in the LHR POL calculation and the hot pin power distributions to be used in the DNBR POL calculation. [

]a,c

4.0 Monitoring Uncertainty Methodology

The uncertainty analysis methodology for BEACON has been described in Section 5 of Addendum 1 of WCAP-12472-P-A. [2]. The corresponding uncertainty methodology for COLSS is described in CEN-356(V)-P-A[4]. For the BEACON-COLSS product level, the uncertainty analysis methodology will be a combination of the BEACON and the COLSS methodologies. [

]a,c Each of these methodologies will be described below and references provided to previously approved documents.

4.1 Power Peaking Factor Uncertainty

The uncertainty of the BEACON "measured" peaking factors includes the following parametric sensitivities.

[ ]a, c

[ ] a, c

The BEACON power distribution uncertainty methodology is designed to determine the 3D power peaking factor (F_q), integrated radial peaking factor (F_r) and LHR measurement uncertainties for a wide range of the SPD detector operating conditions and core conditions. The method includes a statistical simulation of various core state conditions, power distributions and SPD behavior based on the measurement variability. This is done by comparing the differences between sets of "true" and "measured" 3D power distributions where the "true" condition represents the actual core power distribution and the "measured" condition represents the measured power distribution as inferred by the monitoring system including the above parametric sensitivities. Figure 2 shows the logic flow of the uncertainty analysis methodology.

[

]a,c

The "measured" power distribution is then generated using the detector currents with the method described above in Section 3. Deviations between the "true" and "measured" power peaking factors are calculated using equation 3. [

]a,c

[ ] a, c

The simulation methodology is described in detail in Section 5 of WCAP-12472-P-A [1] and is the same whether using thermocouples or SPDs for measurement data. The flow diagram of the peaking factor uncertainty analysis process is shown in the upper half of Figure 2. This methodology is applicable to any required power peaking factor including Fq, LHR POL and Fr. [

$]^{a,c}$ the power peaking uncertainties are cycle independent functions of the number of SPDs available and the measurement variability of the SPDs.

Each measured peaking factor uncertainty is defined as a function of the fraction of inoperable detectors and the detector measurement variability. The basic form of this function is shown in equation 3 and equation 4 of Addendum 1 to WCAP-12472-P-A[2] and is included in this report as equations 7 and 8 in Section 4.3.1. [

$]^{a,c}$ The method of calculating the total power peaking factor uncertainty is described in Section 5 of Addendum 1 to WCAP-12474-P-A [2] and summarized in Section 4.3.1 of this submittal.

The current COLSS LHR POL uncertainty analysis uses a similar methodology. However, the COLSS LHR POL uncertainty is calculated each cycle since the power synthesis technique used in COLSS causes it to vary based on fuel management. The use of a cycle specific 3D power distribution in BEACON eliminates this cycle dependency in the BEACON-COLSS uncertainty analysis results.

4.2 DNBR Uncertainty

In the COLSS DNBR POL Modified SCU methodology[4], the power and core state parameters and system parameter uncertainties are [

$]^{a,c}$ to produce the DNBR POL uncertainty with a 95/95 probability/confidence level. The current COLSS uncertainty analysis of the "measured" DNBR power operating limit includes the following parametric sensitivities.

[ ]

a, c

This methodology is unchanged for the BEACON-COLSS level except that the portions related to the power distribution synthesis are replaced by the BEACON 3-D power method. The methodology is described below for completeness of this report. Figure 2 shows the logic flow for the DNBR POL uncertainty methodology.

The DNBR POL uncertainty analysis [

]^{a,c}

The CETOP-D code[5] is used to calculate the DNBR POL for the potentially limiting channels from the "true" and "measured" power distributions. [

]^{a,c}

[ ] a, c

[

]^{a,c} Table 1 shows an example of how the thermal hydraulic parameters and the DNBR pdf are applied in the DNBR POL uncertainty analysis.

The deviation between the "true" and "measured" DNBR POLs for each case is then calculated using equation 5 and the results statistically analyzed to determine the 95/95 uncertainty on the DNBR POL.

[ ] a, c

To determine the uncertainty on the DNBR POL, [

]^{a,c}

[

]a,c

This is an approved methodology that is used in the current COLSS DNBR POL analysis and described in various reports such as Sections 2.3.2 and 2.3.3 of CEN-283(S)-P, Part II.[9] The derivation of the uncertainty methodology is provided in Appendix A of this report for convenience.

[ ] a, c

Due to the [

]a,c

4.3 Application of the Uncertainty Methodology

The BEACON-COLSS peaking factor and LHR POL uncertainty methodology is unchanged from the licensed methodology in Addendum 1 to WCAP-12472-P-A[2]. The DNBR uncertainty method is unchanged from the licensed methodology in CEN-356(V)-P-A[4] except for the inherent changes due to neutronics and thermal-hydraulics modeling improvements. [

]a,c

The BEACON-COLSS uncertainty methodology was applied to two C-E designed plants in order to demonstrate the application of the methodology, illustrate expected measurement uncertainties and compare them to current COLSS values. The key parameters and SPD design features of the selected plants are shown in Table 2. The SPD detector layouts of both plants are shown in Figure 4 and Figure 5. The axial profile of the detector layout is the similar for the both plants and is shown in Figure 6.

Pairs of "true" and "predicted" 3-D power distributions for use in the uncertainty analysis were generated by simulation of the BEACON system. [ ]a,c

[

]a,c The pair generation covers the following conditions.

[ ] a, c

[

]a,c

The measured power peaking factor and LHR POL uncertainty for BEACON-COLSS will be defined as a function of the following parameters.

- SPD measurement variability
  [

  ]a,c.

- Fraction of inoperable detectors
  [

  ]a,c.

This provides [ ]a,c that will be considered for this analysis.

4.3.1 LHR POL and Fr Measurement Uncertainties

For a given pair of "true" and "predicted" power distributions with a selected SPD measurement variability and fraction of inoperable detectors, the measured power distribution $P_m(x,y,z)$, is obtained as described above in Section 4.1 and illustrated in Figure 2. The peaking factor deviation from the "truth", (Δ_1) is then calculated as defined in equation 3 for each case. To ensure good statistical accuracy, [

]^{a,c}

The measurement uncertainty is defined by the [

]^{a,c}

The peaking factor uncertainties show [

]^{a,c} The functional form of the bounding equations is reproduced below. These equations can have more terms depending on the shape and data range needed to bound the limiting uncertainties.

[

] a, c

This approach is used to calculate the measurement uncertainty in the 3D peaking factor (F_q) and integrated radial peaking factor (F_r) and is consistent with the licensed methodology in Addendum 1 to WCAP-12472-P-A[2]. The F_q uncertainty is used in BEACON-COLSS as the uncertainty in the LHR POL. The F_r and local F_q/LHR POL measurement uncertainties for the two plants in this analysis are shown in Figures 7 through 10 [

]a,c

The LHR POL uncertainties are compared to the uncertainty results calculated using the standard COLSS methodology. The results from the calculations are shown in Table 5. [

]a,c

4.3.2 DNBR POL Uncertainty

The DNBR POL is the relative power which produces the target DNBR for the measured neutronics and thermal hydraulics conditions. The target DNBR is defined as the 95/95 upper tolerance limit of the plant specific DNBR probability distribution (pdf). An example of this function is shown in Figure 11. To determine the DNBR uncertainty, the DNBR POL is calculated at the "true" and "measured" core conditions, denoted by POL_T and POL_M as described above in section 4.2 and illustrated in Figure 2. The deviation from the "truth", (Δ_2) is then calculated as defined in equation 5 for [

]a,c

The "true" and "measured" POLs are calculated as follows for each case:

1. POL_T
   - A "true" power distribution is used for each case.
   - [

     ]a,c
   - [ ]a,c
2. POL_M
   - A "measured" power distribution is used for each case.
   - [

     ]a,c
   - [ ]a,c

As a result of the [

]a,c

[ ]a,c. The thermal hydraulic parameters and the target DNBR information for Plant A and Plant B are shown in Table 6 and Table 7.

In this analysis the [

]a,c The BEACON-COLSS DNBR POL uncertainties are compared to the uncertainty results calculated using the standard COLSS methodology. The results from both calculations are shown in Table 8. [

]a,c

5.0 Technical Specification Modifications

The basic LHR and DNBR monitoring process for the BEACON-COLSS product level is the same as that used in COLSS and does not require any changes in the limits being monitored. Therefore, for plants currently using COLSS, the DNBR and LHR related Technical Specification LCOs 3.2.1 and 3.2.4 will be unchanged upon implementation of BEACON-COLSS. In addition, BEACON-COLSS will perform the same azimuthal tilt and ASI monitoring that is currently performed by COLSS so that LCOs 3.2.3 and 3.2.7 will not need to be modified. LCO 3.2.2 currently requires that the "measured PLANAR RADIAL PEAKING FACTORS ... be less than or equal to [those] used in ... COLSS ... and ... CPC". Since BEACON-COLSS will use the 3D measured power distribution information directly, this LCO can be modified to remove COLSS from its requirements. The Technical Specification Bases associated with these LCOs may need to be updated to be consistent with the use of BEACON-COLSS.

It will be necessary to update the incore system operability specification in the Technical Requirements Manual (TRM) associated with the Technical Specifications. Therefore, Section 3.3.3.2 of the TRM will be updated to define the minimum number of incore detectors and distribution of detectors for BEACON-COLSS as described in Section 6 of Addendum 2 to WCAP-12474-P-A [3].

It will also be necessary to update the list of references in the plant specific COLR to include the BEACON topical report.

Any plant that implements the BEACON-COLSS level [

]a,c

6.0 Plant Specific Applications

The BEACON measured power distribution accuracy is dependent on the accuracy and reliability of both the calculational model and the plant instrumentation system.

The uncertainty analysis for COLSS as described in CEN-356(V)-P-A Revision 01-P-A[4] is typically performed each cycle since the accuracy of the COLSS DNBR and LHR POLs is dependent on the details of the core design. This dependency is caused primarily by the power distribution synthesis methods in COLSS. Plants that implement the BEACON-COLSS product level will update the BEACON neutronics model every cycle consistent with the core design. Therefore, the accuracy of the BEACON-COLSS DNBR and LHR POLs will not be dependent on cycle-to-cycle core design changes.

The uncertainty analysis will be performed using the methodology described in this report each time BEACON-COLSS is applied to a new plant. The plant and cycle specific components used in the BEACON model and the uncertainty analysis will be determined on a plant-specific basis and confirmed each cycle. Generic uncertainty components will be reevaluated when the BEACON-COLSS product level is applied to plant or core designs that differ sufficiently to have an impact on the data methods and assumptions in this submittal.

These plant-cycle specific application requirements are unchanged from those specified in the BEACON topical report and addendums.

7.0 Conclusion

Westinghouse has merged the BEACON and COLSS core monitoring systems to produce the optional BEACON-COLSS core monitoring product level for initial application to the C-E plants with COLSS. The combined monitoring system provides benefits in the areas of power distribution, DNBR and LHR monitoring accuracy, power distribution analysis and prediction capability. These benefits should allow plants to operate more efficiently and help avoid undesirable operational situations.

The NRC approved uncertainty analysis methods of both systems are similar and have been integrated to produce an analysis method that is consistent with the COLSS licensed MSCU methodology and takes advantage of the 3-D neutronic analysis methods in BEACON. Uncertainty analyses have been performed on two C-E plants to confirm that the integrated uncertainty methodology does perform as expected and the results are consistent with those obtained from the COLSS SCU methodology.

Before implementation of the BEACON-COLSS product level at a plant, DNBR and LHR POL uncertainties will be calculated using the methodology outlined in this report. These uncertainties will be applied to BEACON-COLSS in the same way they are currently applied to COLSS.

REFERENCES

1. Beard, C. L., Morita, T., "BEACON – Core Monitoring and Operations support System," WCAP-12472-P-A, August 1994.

2. Morita, T., "BEACON – Core Monitoring and Operations support System," WCAP-12472-P-A Addendum 1-A, January 2000.

3. Boyd, W. A., "BEACON – Core Monitoring and Operations support System," WCAP-12472-P-A Addendum 2-A, April 2002.

4. "Modified Statistical Combination of Uncertainties," CEN-356(V)-P-A Revision 01-P-A, May 1988

5. "CETOP-D Code Structure and Modeling Methods for San Onofre Nuclear Generating Station, Units 2 and 3," CEN-160(S)-P Revision 1-P, September 1981.

6. "Overview Description of the Core Operating Limit Supervisory System (COLSS)," CEN-312-P Revision 02-P, November 1990.

7. "TORC Code – A Computer Code for Determining the Thermal Margin of a Reactor Core," CENPD-161-P-A, April 1986.

8. Safety Evaluation Report, NUREG-0712 Supplement 4 for San Onofre Generating Station Units 2 and 3, Docket Nos. 50-361 and 50-361, Section 4.4.6.1.

9. "Statistical Combination of Uncertainties, Part II", CEN-283(S)-P, October, 1984.

10. "Statistical Combination of Uncertainties, Part I", CEN-283(S)-P, October, 1984.

Page Intentionally Left Blank

Table 1

Application of Thermal Hydraulic Parameters in DNBR POL Uncertainty Evaluation

[ ] a, c

Table 2

Characteristics of Modeled Plants

Plant ID	Plant Type	Rating (MWth)	Cycle	Number of Assemblies	Number of ICI Strings	Number of SPDs per String, Active Length
Plant A	C-E	2815	5	177	45	5, 40 cm
Plant B	C-E	3441	12	217	56	5, 40 cm

Table 3

Plant A - Pairs of "True" and "Predicted" Core Conditions

a, c

Table 4

Plant B - Pairs of "True" and "Predicted" Core Conditions

a,

Table 5

COLSS and BEACON-COLSS
Comparison of LHR POL Uncertainties*

[ ] a, c

Table 6

Thermal Hydraulic Parameters used in Uncertainty Analysis

a, c

Table 7

DNBR Probability Density Functions used in Uncertainty Analysis

[ ] a, c

Table 8

COLSS and BEACON-COLSS Comparison of DNBR POL Uncertainties

[ ] a, c

Figure 1

BEACON-COLSS Merged Functional Groups

a, c

Figure 2
BEACON-COLSS Uncertainty Analysis Flow Logic

a, c

Figure 3

DNBR POL Uncertainty Evaluation Method

a, c

Figure 4

Plant A
SPD Layout and Cold Loop Inlet Positions

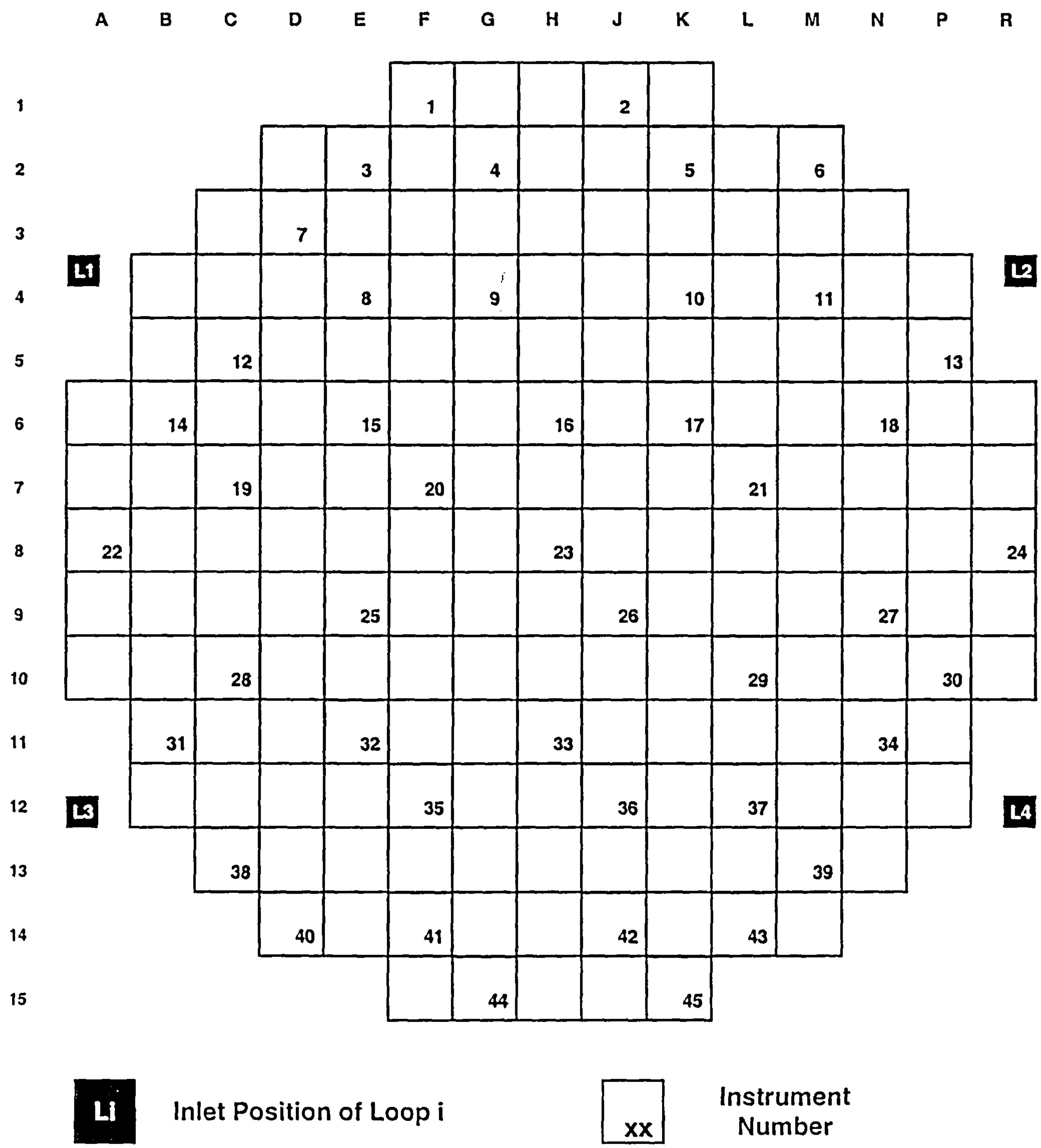


Figure 5

Plant B
SPD Layout and Cold Loop Inlet Positions

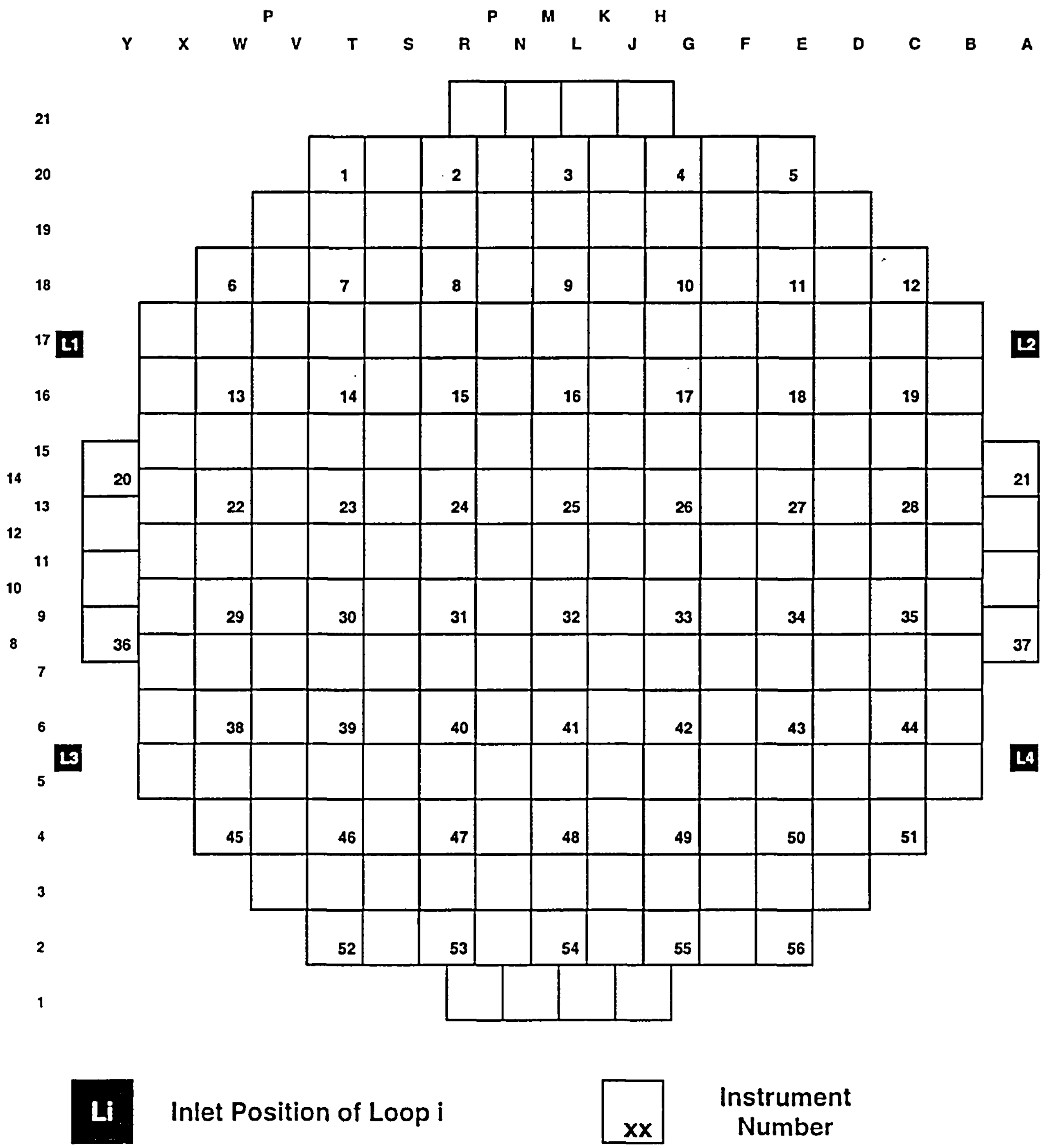
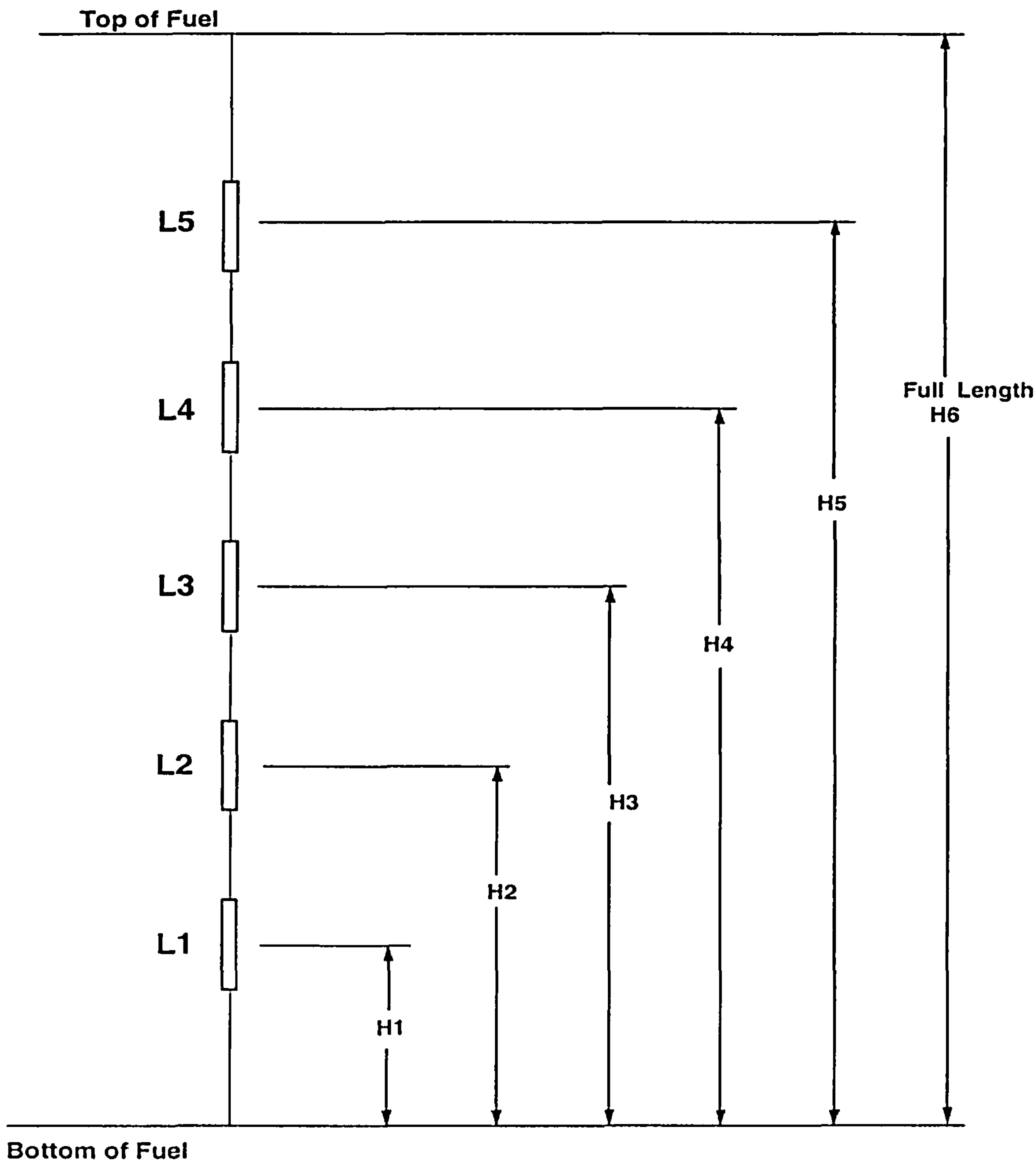


Figure 6

Plant Detector Length and Axial Locations



	H1	H2	H3	H4	H5	H6	
Plant A	38.1	114.3	190.5	266.7	342.9	381.0	(cm)
Plant B	35.8	112.0	188.2	264.4	340.6	381.0	(cm)

Figure 7

Plant A
Total F_r Uncertainties

a, c

Figure 8

Plant A
Total F_Q / LHR POL Uncertainties

a, c

Figure 9

Plant B
Total F_r Uncertainties

a, c

Figure 10

Plant B
Total F_Q / LHR POL Uncertainties

a, c

Figure11

Typical DNBR Probability Density Function

a, c

Page Intentionally Left Blank

APPENDIX A

Theory of the DNBR POL Uncertainty

A.1 Introduction

The DNBR POL uncertainty methodology to be employed for BEACON-COLSS is equivalent to the methodology that was developed and approved for C-E plants with COLSS as described in Part II of CEN-283(S)-P[9] and CEN-356(V)-P-A Revision 01-P-A[4]. The DNBR POL uncertainty methodology is shown here in more detail for convenience and clarity of this report. The uncertainty of the BEACON-COLSS measured DNBR POL is defined such that equation A-1 is true with a 95% confidence for 95% of population i .

[ ] a, c

The use of the [

]a,c

The DNBR [

]a,c

The DNBR POL is [

]a,c

[ ] a, c

[

]a,c This is illustrated in Figure 3 and equation A-3.

[ ] a, c

A.2 DNBR POL Uncertainty Verification

a, c

a, c