0414-12-F04 (Rev. 001, 03/10/2016)

AREVA

ACE/ATRIUM 11 Critical Power Correlation - RAIs

ANP-10335Q1NP
Revision 1

Topical Report

January 2018

AREVA Inc.

Nature of Changes

Item	Section(s) or Page(s)	Description and Justification
1	Page 50	Revised RAI #14.

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Nomenclature

Acronym	Definition
ASCII	American Standard Code for Information Interchange
BT	Boiling Transition
BWR	Boiling Water Reactor
CFR	Code of Federal Regulations
CHF	Critical Heat Flux
CP	Critical Power
CPR	Critical Power Ration, defined to be the assembly critical power divided by the assembly operation power
DC	Direct Current
ECPR	Experimental Critical Power Ratio, defined as the calculated critical power divided by the measured critical power
LPF	Local Peaking Factor
MCPR	Minimum CPR of all assemblies in the reactor core
NIST	National Institute of Standards and Technology
PWR	Pressurized Water Reactor
RAI	Request for Additional Information
SDE	Statistical Design of Experiments

1.0 INTRODUCTION

A boiling water reactor ACE/ATRIUM™* 11 critical power correlation topical report is provided in Reference 2. This document provides responses to a Request for Additional Information (RAI) (Reference 1) on that topical report.

* ATRIUM is a trademark of AREVA Inc.

Question 1:

Please provide references to documents describing the test loop and facility in greater detail, as well as the quality assurance program to be applied.

Response 1:

All of the data for the ACE/ATRIUM 11 critical power correlation were taken at the AREVA KATHY thermal-hydraulic test loop located in Karlstein, Germany. Figure 1 shows that the thermal hydraulic test facility is a high pressure water heat transfer loop containing a test vessel (shown in Figure 2) with the test assembly and upper and lower bus bars, high pressure coolers, a direct contact condenser, an electrically heated pressurizer, and the main circulation pumps. Two inlet flow lines of different sizes are shown. The different sizes allow fine control of the flow rate over a broad range. The test loop is rated at [ ] The DC power supply consists of four thyristor controlled rectifiers, providing a total electrical current of [ ]

The data acquisition system samples the analog signals of the loop instrumentation, digitizing them with 16 bit analog to digital converters and stores the signals on hard disk. The hardware of the data acquisition system is based on National Instruments SCXI-bus components (Reference 32). [ ] Six PC's are used: one controls the acquisition and data flow, three provide display and visualization of selected channels including thermocouples during CHF tests. One computer is used to display test results following each test run and one computer is used by the test monitoring engineer to access results directly. The data acquisition software is based on the programming language of "LabView". Evaluation software is applied to transfer the raw data (voltage) into physical values (pressure, temperature, etc.) is written in "C".

Key instrumentation in the KATHY loop is described in the response to RAI question 11.

Test loop uncertainties are given as part of the response to RAI questions 10 and 13.

A general description of the KATHY loop with additional details is available in [ ] The quality assurance program applied to the testing is provided in [ ] The quality assurance program is periodically audited by the AREVA U.S. Fuel group to ensure that the testing work performed under it satisfactorily meets the requirements of 10 CFR 50 Appendix B.

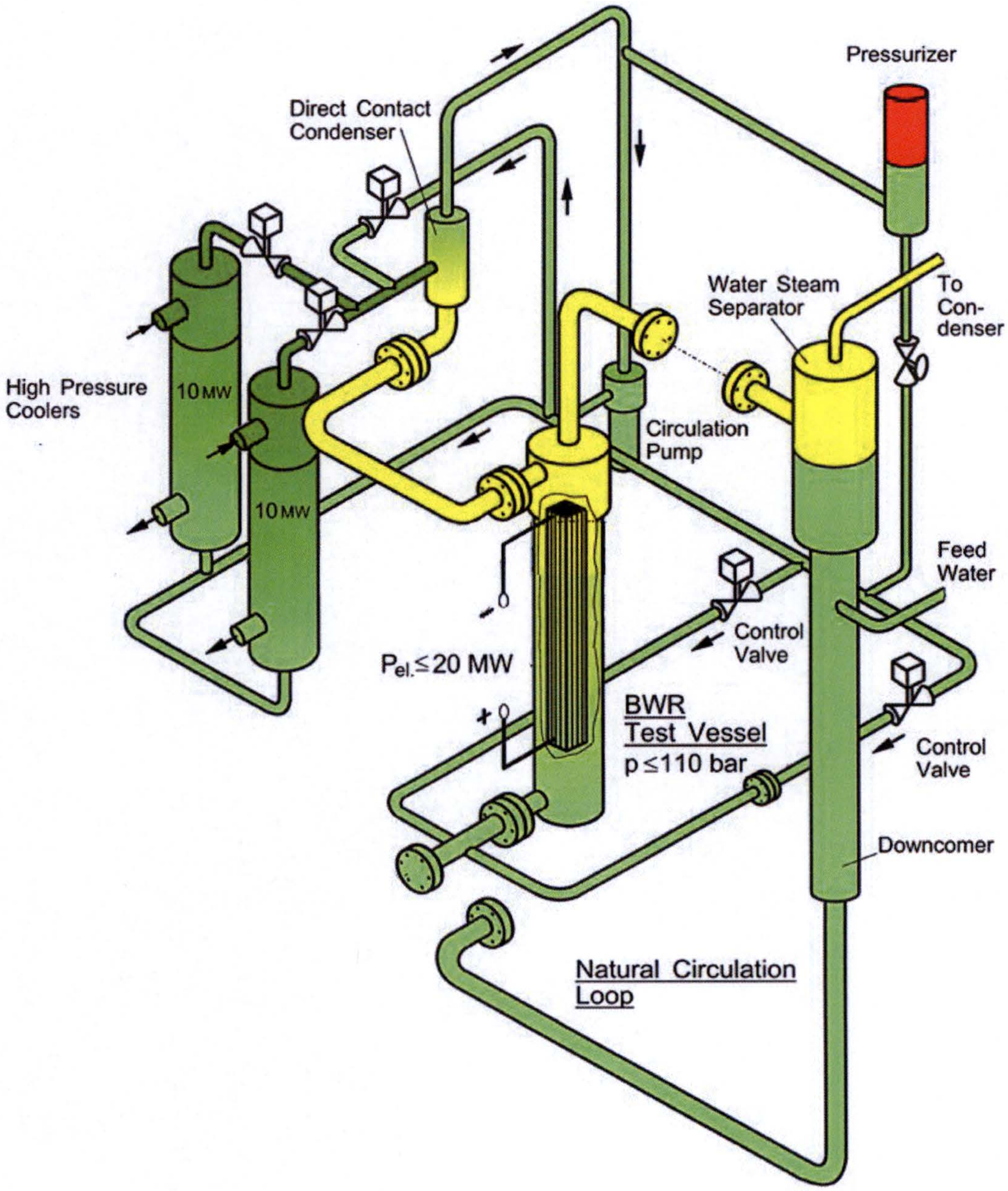

Figure 1. KATHY Thermal-hydraulic Test Loop

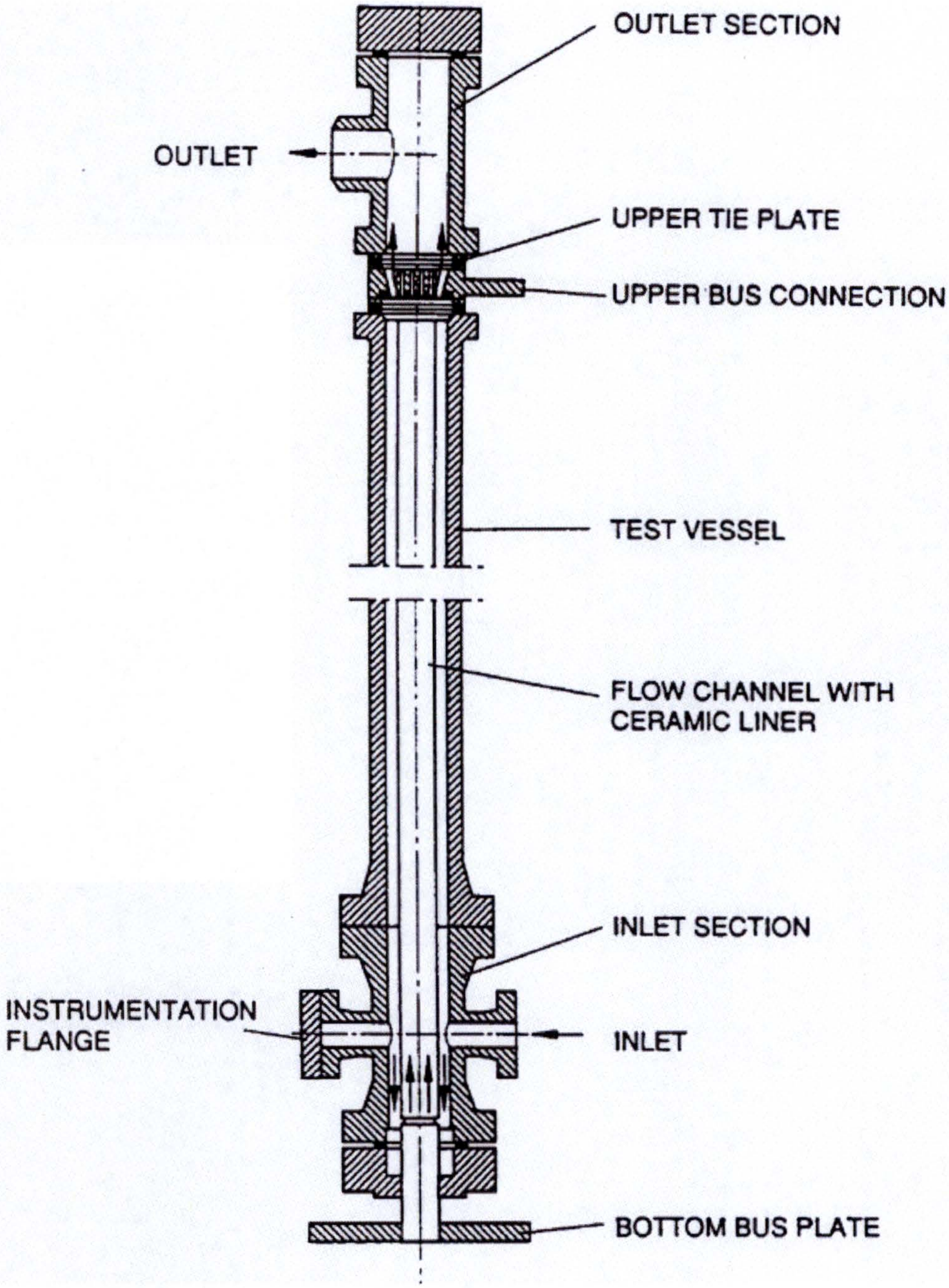

Figure 2. KATHY BWR Test Vessel

Question 2:

Please provide a description of benchmarks performed with KATHY against other testing facilities, as well as a reference to documents where these benchmarks are described in detail.

Response 2:

Two tests have been performed in KATHY test facility – STS 2.1 and STS 2.2 – to benchmark it versus corresponding ATLAS loop tests ATA 714C and ATA 714D. Tests have been run with the ATRIUM-9 bundle design, cosine axial power profile and similar radial power distribution (peaking pattern). The peaking pattern for the tests is shown in Figure 3. Figure 4 and Figure 5 show the comparison between ATLAS and KATHY loop tests. The mean value close to unity and the low standard deviation for both peaking patterns confirms that the KATHY loop and ATLAS loop provide equivalent results. The KATHY loop was successfully benchmarked.

The benchmark is documented in **[ ]**

[ ]

Figure 3. Peaking Patterns for Benchmark Tests

[ ]

Figure 4. Comparison Between KATHY and ATLAS Loop Tests STS 2.1 and ATA 714C

Figure 5. Comparison Between KATHY and ATLAS Loop Tests STS 2.2 and ATA 714D

Question 3:

Only **[** **]** *were tested in the development of the ACE/ATRIUM 11 correlation. Please provide a justification for not testing* **[** **]**.

Response 3:

The influence of **[** **]** on critical power has been quantified by experimental data collected for each fuel assembly design that has been licensed.

[

]

[ ]

Table 1. Characteristics of Designs Suitable for Fitting

[ ]

[ ]

Table 2. Tests for Correlation Fitting and Validation

[ ]

Table 3. Number of Data Points in Each Data Base

[ ]

Table 4. Summary of ECPR Results

[ ]

Table 5. [ ] Prediction Accuracy Results

[ ]

[ ]

Figure 6. Lattice and Part Length Rod Positions

Question 4:

Please discuss the range of tested transient conditions, specifically including a discussion of **[ ]**.

Response 4:

The ACE/ATRIUM 11 correlation is a steady-state correlation constructed from **[ ]** A limited amount of transient data is collected only for the purpose of validating the correlation under transient conditions. The kinds of transients that are performed are based on parametric effects of the principal boundary conditions pressure and mass flow rate.

Margin to critical power increases as the flow rate is increased. Therefore, one of the principal transient types is the flow decreasing transient.

Margin to critical power decreases as the pressure is increased. Therefore, one of the principal transient types is a pressure increase transient, with an associated power increase.

In BWR, pressure decreasing transients are not CPR limiting – the CPR margin actually increases from the start of the transient. There is a detailed discussion of BWR pressure decreasing transients and the applicability of the **[ ]** in Reference 3, RAI #16.

Question 5:

Please provide additional justification for the use of [ ] *up to* [ ] *when the highest tested* [ ] *is* [ ].

Response 5:

All ACE correlations have been developed utilizing the [

]

Table 6. [ ]

[ ]

[ ]

[ ]

Table 7. KATHY Tests for [ ]

[ ]

[ ]

[ ]

Figure 7. Critical Power vs. [ ] for ATRIUM-10

[ ]

Figure 8. Critical Power vs. [ ] for ATRIUM 10XM

[ ]

Figure 9. Critical Power vs. [ ] for ATRIUM 11 [ ]

[ ]

Figure 10. Critical Power vs. [ ] calculated by ACE/ATRIUM 11 [ ]

[ ]

Table 8. [ ] of ATRIUM Fuel Assembly Designs for Cosine Axial Power Profile

[

]

Table 9. Impact on Critical Power Due to the Uncertainty of the [ ]

[ ]

Question 6:

Please provide additional details on the method used to develop [ ]. *Any response should discuss* [ ].

Response 6:

A part of the critical power test program is specifically designed to determine [ ]

[ ]

[ ]

[ ]

[ ]

Question 7:

As discussed in Section 9.0 of ANP-10335P, the [
] *in the test assembly is different from that of the production assembly. Please provide additional justification for why a correlation developed with this difference in the test assembly would be applicable to a production assembly. Any justification should specifically address the parameters that could be affected by such a difference and the approximate magnitude of the impact.*

Response 7:

Since the test assembly is heated directly, an electrical current flows through the rods.

[

]

Question 8:

Please provide a brief discussion of the procedures for measuring steady-state and transient critical power data points. Also provide references to documents discussing the critical power test procedures in further detail, including the conditions required to ensure stability and the criterion for determining that dryout has occurred.

Response 8:

Steady-state Testing

The methodology developed for performing dryout testing is fairly standard. The procedure is described in [ ] and applied for all tests.

[ ]

Transient Testing

Transient dryout tests are performed according to a transient test specification [

], which defines the test bundle, the initial conditions and [

]

Question 9:

Please provide additional information about the design of the ACE/ATRIUM 11 critical power tests, including a discussion of how bias was eliminated from the testing program. Page 7-9 of ANP-10335P referenced full map, partial map, and statistical design of experiments tests – please define each of these terms and discuss how the experimental design differs between them. Also, please include a reference for a document discussing procedures for design of experiments for the KATHY loop.

Response 9:

ATRIUM 11 consists of an 11x11 square array of rods. It contains 92 full length rods, 12 short part length rods, 8 long part length rods, and one central water channel that occupies a 3x3 array. Due to the 1/8 symmetry of the fuel assembly, there are 13 unique positions for the full length rods, 3 unique positions for the short part length rods and 2 unique positions for the long part length rods. **[**

]

The process of critical power correlation development is described in AREVA Operating Procedure **[** **]** of the Fuel Business Unit. After defining a List of Requirements for the correlation – e.g. fuel assembly geometry, correlation form, application range, licensing requirements, and I&C requirements – a Design Technical Specification Document is issued including the scope of the test program. The adequacy of the test program for ACE/ATRIUM 11 has been formally reviewed and approved within AREVA.

For the design of the ATRIUM 11 tests, **[**

]

[ ]

Figure 11. [ ] Regions of ATRIUM 11 [ ]

Critical power tests for ATRIUM 11 have been designed to obtain data:

[ ]

The test program is also intended to cover the range of applicability, including:

[ ]

In total, [ ] have been measured for ACE/ATRIUM 11 correlation development and validation (see Table 10). All the above mentioned objectives for the ATRIUM 11 critical power test have been met. Compared to ATRIUM 10XM the [

]

Table 10. ATRIUM 10XM and ATRIUM 11 Test Program Comparison

[ ]

Standard map has been applied for the tests [

]

Statistical design of experiments (SDE) has been applied for the tests [

] SDE consists of [

]

Full map has been applied for the tests [ ] Full map contains data at [

]

Partial map has been measured [

]

[

]

Table 11. Maps Tested for Different [ ]

[ ]

Table 12. Maps Tested With [ ]

[ ]

Table 13. Data Density [ ]

[ ]

Question 10:

Please provide the values of measurement uncertainties in the KATHY loop, with a focus on the uncertainties in the parameters discussed in Section 6.13 of ANP-10335P. Please also provide a brief discussion of how each value was derived.

Response 10:

The measurement uncertainties of the experimental variables are:

[ ]

Question 11:

Please provide a discussion of the instrumentation provided in the KATHY loop. The information provided should include a brief discussion of how diversity and redundancy of key measurements are ensured.

Response 11:

In order to provide experimental data for critical power correlation development reliable measurements are required for the [

] and bundle power. All these measurements are performed by calibrated and redundant measurement devices. In addition [

]

[

]

[

]

Bundle power

Electrical bundle power is the product of the electrical current and voltage.

1. Voltage measurement

[

]

2. Electrical current measurement

[

]

Question 12:

Please briefly describe the calibration of the instruments at the KATHY facility, including the frequencies of instrument calibration and reasons for those frequencies. Please also include a reference to a document describing the calibration in detail.

Response 12:

Calibration for the sensors is done in the calibration lab. The calibration lab has a controlled and monitored environment. Calibration for the DAQ-channels is [

]

Question 13:

Please discuss the uncertainties associated with measurement of critical power in both steady-state and transient testing. Any response should include a quantification of the measurement uncertainty and a description of how the value was obtained.

Response 13:

The ACE critical power correlation is a [ ] correlation. [

] To apply the correlation to a particular fuel design, design specific data are needed to determine the correlation coefficients.

[

]

Steady-state Measurement Uncertainty

The steady-state critical power measurement uncertainty is determined [

]

[

]

[

]

Transient Test Measurement Uncertainty

For licensing the critical power correlation, transient measurements were used [

]

Question 14:

Please discuss the heat losses from the test section, including how these losses vary depending on key parameters (test section power, flow rate, etc.).

Response 14:

In the KATHY loop, the heater rod bundle is housed in a ceramic liner. This liner serves to simulate the flow channel and to electrically insulate the spacers from each other.

[

]

The heat losses of the KATHY Loop have been analytically evaluated and are experimentally checked at the beginning of every testing day. Generally, the test section heat losses depend on [

] For thermal equilibrium conditions (long term heat losses), test section heat losses depend on the temperature difference across the test vessel insulation.

In order to achieve thermal equilibrium (quasi steady state temperature profile in the test section and ring chamber), [ ]

In the heat balance measurements, the bundle power is compared to the enthalpy change between the test section inlet and outlet. For single phase flow, the difference between the two parameters is equal to the test section heat loss. In order to prevent water evaporation in the heat balance measurements, inlet enthalpy is kept sufficiently low. For ATRIUM 11 tests, the average value of the experimentally determined heat loss is [ ] the standard deviation is [ ]. Compared to the measured critical power [ ] these heat losses are negligible and the magnitude is less than [ ]

[ ]

[

]

Both the analytical estimate and the measurements show that the heat loss of the test loop during the critical power testing is quite small.

Although the heat loss has been minimized through test facility design, AREVA does consider the heat loss to be important and therefore considers it important to monitor it during the BWR test programs. The frequent checks performed during the test program confirm that the test loop was operating as designed and that the experimental setup results in the expected level of heat loss. In the design of the KATHY loop, the temperature measurement that is applied to determine the inlet enthalpy is upstream of the test bundle. Figure 2 (RAI #1) shows that when the test vessel is reached the flow moves downward and then enters the rodded section of the bundle at the bottom. Figure 4.3 of ANP-10335P shows that between the lower tie plate and the upper tie plate, each full length rod has a lower end extension (low resistance), a high resistance section forming the heated length, and an upper end extension (low resistance). The part length rods are missing the upper end extension. The rod end extensions dissipate a small amount of heat that is proportional to the bundle power [

]

Question 15:

It is not clear how the initial conditions and boundary conditions for the ACE/ATRIUM 11 correlation were chosen. Please explain the initial and boundary conditions for the ACE/ATRIUM 11 correlation in further detail, especially including the **[**
] *discussed in ANP-10335P Section 6.7.*

Response15:

[

]

Question 16:

Please provide a discussion of the process used to fit the coefficients detailed in Section 6 of ANP-10335P. Since it is the staff's understanding that [ ]*, the response should include a discussion of* [ ]*. The response could be a reference to an existing document.*

Response 16:

A description of the procedure for fitting of the coefficients of the ACE/ATRIUM-10 critical power correlation was provided in Reference 3 in Appendix A. This information was provided in response to Reference 3 RAI #3, #4, #5, #6, #7, #8, #9, #10, #31, and #35. The process describes the fitting of [ ] Once the process is complete (step 11), [ ] according to the method provided in the respective topical reports. This same process was used in the development of the ACE/ATRIUM 10XM correlation, Reference 7.

The assessment of the correlation for a particular [ ] includes an examination of the overall statistics, mean and standard deviation of ECPR, [ ]

[

]

The final ATRIUM 11 correlation has good behavior.

Question 17:

What is the criterion for determining [ ] *in the second-to-last paragraph of Page 6-22 in ANP-10335P?*

Response 17:

With the critical power correlation and a set of additive constants, the critical power correlation is applied to each measurement in the critical power data base defining data set. The critical power is calculated as the power that causes [

]

Question 18:

What was the purpose of the [ ]*? What is* [ ] *and how is it defined?*

Response 18:

[ ]

[

]

Table 14. STS119.01 Combined Statistics (Rod Position 28)

[

]

Question 19:

What is the basis for selecting [ ] *of the data for correlation and* [ ] *for validation? How does* [ ] *impact the correlation uncertainty? The response should address both the ECPR uncertainty and the additive constant uncertainty.*

Response:

AREVA enlisted the assistance of a prominent experimental heat transfer expert, Dr. Robert J. Moffat, Stanford University, to assist with formalizing the process for correlation development. The result of this collaboration was a formal correlation development guideline [ ]. It describes the need for partitioning a data set prior to correlation development. The basis for partitioning comes from Reference 12, Section 6.4.7.

> *"Sometimes it is not practical or possible to obtain additional data for model validation. In such cases, prior to model fitting, the complete data set is split into two subsets by some reasonable criterion. One subset is used to carry out the regression analysis and model development process, as discussed in the previous sections of this chapter. Once a satisfactory prediction equation has been developed, the other data set is used to validate it; that is, to see how well it predicts."*

Criteria for performing the partitioning are not provided in Reference 12. However the recommendation of Dr. Moffat was incorporated into Reference 24 and is a random selection of the data, placing [ ] in the defining data set and [ ] in the validating data set. Both References 12 and 24 state that partitioning into two data sets should not be performed if the number of data points is less than 2p+25 where p is the number of unknown coefficients being fit.

To investigate the effect of the choice of where to place each data point – defining or validating – the partition of the data was performed [ ]

[

]

Table 15. Overall Statistics Applying Multiple Partitions of Experimental Data

[

]

Question 20:

Please discuss in additional detail why it is considered appropriate [ ]. *Were* [ ] *discussed in Section 7.3 applied to the correlation during the uncertainty assessment?*

Response 20:

The results of [ ] are not used either in the fitting of the correlation or in the determination of the uncertainty. With respect to the ACE/ATRIUM 11 critical power correlation (and its predecessors), [ ] are used solely for the purpose of confirming that the correlation has the correct behavior.

[ ]

[

]

Now consider the dryout measurements. If one looks at the best estimate fit of the critical power correlation to the steady-state experimental critical power data, it is observed that [

] This is expected.

Consider the hypothetical case where [

]

[

] provide a confirmation that the behavior of the ACE/ATRIUM 11 correlation is as expected.

[

]

Question 21:

The topical report states in Section 6.13.1 that there is no lower limit on [ ]. *Does AREVA plan to use the ACE/ATRIUM 11 correlation* [*below*]*? If so, please provide additional justification.*

Response 21:

The ACE critical power correlation cannot be applied to [ ] The correlation is implemented in a software library that is named ACELIB. ACELIB checks against [ ]

Question 22:

Does AREVA plan to use the ACE/ATRIUM 11 correlation at **[ ]** *greater than* **[ ]**? *If so, will some kind of upper limit on* **[ ]** *actually be applied?*

Response 22:

For limiting and near limiting assemblies, a **[**

] is applied. **[**

]

No upper limit is imposed on **[ ]**

Question 23:

Please clarify when the **[** **]** *will be applied.*

Response 23:

[ ]

Question 24:

Please provide plots of the computational domain. These plots should use pairs of the key parameters ([ ]*) for the x-axes and y-axes. Separate versions of the plots should be included for the correlation and validation data, as well as the combined dataset. Each plot should also include lines denoting the computational range of each parameter.*

For each obvious region that lacks experimental data (especially validation data) lying within the computational domain, please justify why it is not possible to enter this region in an operating reactor. Alternatively, justify the correlation's behavior in the region.

Response 24:

The computational domain plots are provided in Figure 12 through Figure 17 (combined data set), Figure 18 through Figure 23 (Defining data set), and Figure 24 through Figure 29 (Validating Data Set). The range of applicability of the ACE/ATRIUM 11 critical power correlation is shown by dashed lines in these plots. The critical power measurements are shown by symbols. The domain range of the application of the critical power correlation to limiting or near limiting assemblies is shown by a box.

The application data are [ ]

The [ ] are covered well by the experimental data.

[ ]

[

]

All areas of the range of applicability are adequately covered as described in Reference 2.

[ ]

Figure 12. Computational Domain of [ ] (Combined)

[ ]

Figure 13. Computational Domain of [ ] (Combined)

[ ]

Figure 14. Computational Domain of [ ] (Combined)

[ ]

Figure 15. Computational Domain of [ ] (Combined)

[ ]

Figure 16. Computational Domain of [ ] (Combined)

[ ]

Figure 17. Computational Domain of [ ] (Combined)

[ ]

Figure 18. Computational Domain of [ ] (Defining)

[

]

Figure 19. Computational Domain of [
] (Defining)

[

]

Figure 20. Computational Domain of [
] (Defining)

[

]

Figure 21. Computational Domain of [
] (Defining)

[

]

Figure 22. Computational Domain of [
] (Defining)

[ ]

Figure 23. Computational Domain of [ ] (Defining)

[ ]

Figure 24. Computational Domain of [ ] (Validating)

[

]

Figure 25. Computational Domain of [
] (Validating)

[

]

Figure 26. Computational Domain of [
] (Validating)

Figure 27. Computational Domain of [ ] (Validating)

Figure 28. Computational Domain of [ ] (Validating)

[

]

Figure 29. Computational Domain of [
] (Validating)

Question 25:

Please provide additional explanation and justification of the trend of increasing ECPR standard deviation as a function of pressure. It is unclear to the NRC staff why this increasing variability should result from [ ]*, as discussed in Section 7.1.3 of ANP-10335P.*

Response 25:

The reason given for the ACE/ATRIUM 11 critical power correlation standard deviation increasing as a function of pressure is [ ] It was concluded that the correlation uncertainty is adequate. The basis for this conclusion comes first from [ ] and second, [ ]

[ ]

The ECPR data of the combined data set is binned by test and pressure (Table 16).

[ ]

[

]

Consider now if this behavior is a characteristic of only ACE/ATRIUM 11. A similar examination is performed with ACE/ATRIUM 10XM, binning the combined data set by test and pressure, as shown in Table 17. [

]

[

]

Table 16. ATRIUM 11 ECPR Binned by Test and Pressure (Combined)

[

]

Table 17. ATRIUM 10XM ECPR Binned by Test and Pressure (Combined)

[ ]

Question 26:

Please justify why the [ ] *is considered poolable, considering that the mean and standard deviation of the ECPR vary significantly between* [ ]. *Please also discuss why the* [ ] *provided in* [ ] *do not appear to appropriately match the data.*

Response 26:

[

]

[

] In general, unlike in a PWR CHF correlation topical report, no design limit will be found in the ACE/ATRIUM 11 topical report. In BWR, the safety limit is determined by a separate methodology (Reference 11). The essential uncertainty of the dryout correlation that goes into the safety limit methodology and calculation is [

]

[ ]

Figure 30. ECPR as Function of [ ]

Table 18. Statistics by [ ]

[ ]

Question 27:

There appears to be a non-conservative subregion between **[** **]** *on Figures 7.1 and 7.9. There is another potentially nonconservative region at* **[** **]**. *Please justify why it is acceptable to use the correlation in these areas. Any discussion should address how the correlation uncertainties presented in the topical report account for the uncertainty in these areas.*

Response 27:

The data points that are identified as lying in the range of power of **[**

]

The safety limit methodology is designed to work in conjunction with the critical power correlation to develop an accurate MCPR SL.

Question 28:

Please provide additional justification for why it is appropriate to represent the ACE/ATRIUM 11 uncertainty with the ECPR distribution determined from the [ ] *rather than the* [ ]. *The response should discuss how the correlation uncertainties will be applied in other methodologies.*

Response 28:

The reason that the [ ] is used to determine the additive constant uncertainty is [ ]

Each additive constant must be determined from applicable data. Reference 12, Section 6.4.7 page 363 says that partitioning should not be performed if the number of data points is fewer than 2p+25 where p is the number of unknown coefficients to be fitted. [ ]

The data and method being applied to determine the additive constant uncertainty came about in the process of addressing a non-conformance described in Reference 14. The summary stated "SPC failed to develop an adequate number of test points, and failed to test an adequate range of conditions to justify the uncertainty values for the 'additive constants' used in determining the SLMCPR for the ATRIUM-9 fuel design." The methodology for determining the additive constant uncertainty and insuring sufficient data are available for this was developed as part of resolving this non-conformance.

Question 29:

Will ACE/ATRIUM 11 be implemented in codes other than XCOBRA-T? If so, please discuss how it will be implemented and provide the criteria that will be used to demonstrate that the implementation was appropriate.

Response 29:

The ACE correlation is implemented in a code library named ACELIB. All production codes that implement the ACE correlation use this library. Thus, it is assured that each code is using a single implementation of the correlation, thus eliminating errors that are the result of different implementations. ACELIB was also used to benchmark the ACE/ATRIUM 11 critical power correlation reported in Reference 2. The ACE/ATRIUM 11 critical power correlation is implemented in the steady-state core thermal-hydraulics code XCOBRA (Reference 15), the transient core thermal hydraulics code XCOBRA-T (References 16 and 17), the core 3D simulator MICROBURN-B2 (Reference 18), the MCPR safety limit calculation code SAFLIM-3D (Reference 11), the LOCA code RELAX (Reference 19), and BWR transients code AURORA-B (Reference 20).

The installation of the correlation in a code can be checked against the benchmarking. For the same power distribution and nodalization, and the same steady-state boundary conditions provided to ACELIB, the results should match the benchmark. However small (but insignificant) differences can be observed when different computing hardware and software platforms are used, or when different FORTRAN or C compilers are applied, as a result of round-off errors. [

]

Question 30:

Figures 2.1, 7.1, and 7.9 use units of kW. Were these intended to be MW?

Response 30:

Yes. The correct units for these three plots are "MW". Updated plots are provided in Figure 31 to Figure 33. The updated plots will be placed in the topical report.

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Figure 31. Comparison of Calculated to Measured Critical Power Data for the ATRIUM 11 Fuel Design

Figure 32. Calculated vs. Measured Critical Power (Defining)

Figure 33. Calculated vs. Measured Critical Power (Validating)

2.0 REFERENCES

General References

1. J. G. Rowley, "Request for Additional Information RE: AREVA Inc. Topical Report ANP-10335P/NP, 'ACE/ATRIUM 11 Critical Power Correlation' (TAC No. MF5841)," Letter to Gary Peters, Director, Licensing and Regulatory Affairs, AREVA Inc., dated April 11, 2016.

2. ANP-10335P, Rev. 0, "ACE/ATRIUM™ 11 Critical Power Correlation," February 2015.

3. J. G. Collier and J. R. Thome, "Convective Boiling and Condensation, Third Edition," Oxford University Press, Inc., 1996.

4. "General Electric BWR Thermal Analysis Basis (GETAB): Data, Correlation and Design Application," General Electric Co. Report No. NEDO-10958-A, January 1977.

5. EMF-2209(P)(A), Revision 3, "SPCB Critical Power Correlation," September 2009.

6. ANP-10249P-A, Revision 2, "ACE/ATRIUM-10 Critical Power Correlation," March 2014.

7. ANP-10298P-A, Revision 1, "ACE/ATRIUM 10XM Critical Power Correlation," March 2014.

8. Mitchell, Melanie. "An Introduction to Genetic Algorithms." MIT Press, 1996.

9. R. T. Lahey, Jr., and F. J. Moody, "The Thermal-hydraulics of a Boiling Water Nuclear Reactor," American Nuclear Society, 1977.

10. ANP-10249Q1P, Rev. 0, "Response to Request for Additional Information – ANP-10249P," April 9, 2007.

11. ANP-10307PA, Rev. 0, "AREVA MCPR Safety Limit Methodology for Boiling Water Reactors," June 2011.

12. "Statistical Methods for Nuclear Material Management," NUREG/CR-4604, Volumes 1 and 2, December 1988.

13. J.C.M. Leung, "Critical Heat Flux Under Transient Conditions: A Literature Survey," NUREG/CR-0056, June 1978.

14. Samual Collins, U.S. NRC. "Demand for Information and Notice of Nonconformance (Inspection Report 99900081/97-01," Letter to David McAlees, Siemens Power Corporation, October 27, 1997.

15. XN-NF-80-19(P)(A) Volume 3 Revision 2, "Exxon Nuclear Methodology for Boiling Water Reactors, THERMEX: Thermal Limits Methodology Summary Description," Exxon Nuclear Company, January 1987.

16. XN-NF-84-105(P)(A) Volume 1 and Volume 1 Supplements 1 and 2, "XCOBRA-T: A Computer Code for BWR Transient Thermal-Hydraulic Analysis," Exxon Nuclear Company, February 1987.

17. XN-NF-84-105(P)(A) Volume 1 Supplement 4, "XCOBRA-T: A Computer Code for BWR Transient Thermal-Hydraulic Core Analysis Void Fraction Model Comparison to Experimental Data," Advanced Nuclear Fuels Corporation, June 1988.

18. EMF-2158(P)(A) Revision 0, "Siemens Power Corporation Methodology for Boiling Water Reactors: Evaluation and Validation of CASMO-4 / MICROBURN-B2," Siemens Power Corporation, October 1999.

19. EMF-2361(P)(A) Revision 0,"EXEM BWR-2000 ECCS Evaluation Model," Framatome ANP, May 2001.

20. ANP-10300P, Revision 0, "AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Transient and Accident Scenarios," December 2009.

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32. "Getting Started with SCXI," National Instruments Corporation, Report No. 320515F-01, July 2000 Edition.