May 17, 2000

Mr. James F. Mallay
Director, Nuclear Regulatory Affairs
Siemens Power Corporation
2101 Horn Rapids Road
Richland, WA 99352

SUBJECT: ACCEPTANCE FOR REFERENCING OF LICENSING TOPICAL REPORT EMF-2209(P) REVISION 0, “SPCB CRITICAL POWER CORRELATION” (TAC NO. MA6639)

Dear Mr. Mallay:

The subject topical report was submitted by the Siemens Power Corporation (SPC) by letter dated September 24, 1999. This topical report describes the analyses conducted by SPC pertaining to the application of the SPCB critical power correlation to the ATRIUM-9B and to the ATRIUM-10 fuel designs. The ATRIUM-9B fuel design is a 9x9 square array, while the ATRIUM-10 fuel design is a 10x10 square array. Both fuel designs are fixed at axial locations by ULTRAFLOW spacers and use an internal square water canister, replacing a 3x3 array of rods. The ATRIUM-9B fuel assembly contains 72 full-length rods (no part-length rods), and the ATRIUM-10 fuel assembly is made up of 83 full-length rods and 8 part-length rods.

The SPCB correlation uses planar average values of coolant mass velocity, enthalpy, and pressure to predict planar average critical heat flux. Although SPCB is a generic correlation (applicable to both ATRIUM-9B and ATRIUM-10), it is very similar to the original ANFB-10 correlation that is currently used to predict critical heat flux for the ATRIUM-10 fuel assemblies.

The staff has reviewed the topical report and the additional information and finds that the topical report is acceptable for referencing. Our safety evaluation (SE) is provided in Enclosure 1.

Pursuant to 10 CFR 2.790, we have determined that the enclosed SE does not contain proprietary information. However, we will delay placing the SE in the public document room for a period of ten (10) working days from the date of this letter to provide you with the opportunity to comment on the proprietary aspects only. If you believe that any information in the enclosure is proprietary, please identify such information line by line and define the basis pursuant to the criteria of 10 CFR 2.790.

The staff will not repeat its review and acceptance of the matters described in the report, when the report appears as a reference in license applications, except to assure that the material presented is applicable to specific plant involved. Our acceptance applies only to the matters described in the report.

In accordance with the procedures established in NUREG-0390, the NRC requests that SPC publish accepted versions of the report, including the safety evaluation, in the proprietary and non-proprietary forms within 3 months of receipt of this letter. The accepted versions shall incorporate this letter and the enclosed evaluation between the title page and the abstract. The accepted versions shall include a “-A” (designating accepted) following the report identification symbol. The accepted versions shall also incorporate all communications between SPC and the staff during this review.

Should our criteria or regulations change so that our conclusions as to the acceptability of the report are no longer valid, SPC and the licensees referencing the topical report will be expected to revise and resubmit their respective documentation, or to submit justification for the continued effective applicability of the topical report without revision of their respective documentation.

Sincerely,

/***RA by R A Gramm For/***

Stuart A. Richards, Director
Project Directorate IV and Decommissioning
Division of Licensing Project management
Office of Nuclear Reactor Regulation

Project No. 702

Enclosure: Safety Evaluation

In accordance with the procedures established in NUREG-0390, the NRC requests that SPC publish accepted versions of the report, including the safety evaluation, in the proprietary and non-proprietary forms within 3 months of receipt of this letter. The accepted versions shall incorporate this letter and the enclosed evaluation between the title page and the abstract. The accepted versions shall include an "-A" (designating accepted) following the report identification symbol. The accepted versions shall also incorporate all communications between SPC and the staff during this review.

Should our criteria or regulations change so that our conclusions as to the acceptability of the report are no longer valid, SPC and the licensees referencing the topical report will be expected to revise and resubmit their respective documentation, or to submit justification for the continued effective applicability of the topical report without revision of their respective documentation.

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/RA by R. A. Gramm For/

Stuart A. Richards, Director
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Enclosure: Safety Evaluation

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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION RELATING

TO TOPICAL REPORT EMF-2209(P), REVISION 0,

"SPCB CRITICAL POWER CORRELATION

SIEMENS POWER CORPORATION

TAC NO. MA6639

1.0 BACKGROUND

EMF-2209(P) describes the methodology behind the application of the SPCB correlation to the SPC's ATRIUM-9B and ATRIUM-10 fuel designs, (Refs. 1 and 2). EMF-2209(P) provides test data taken specifically at the Siemens test facility at Karlstein, Germany, in support of the application of the SPCB correlation to the ATRIUM-9B and ATRIUM-10 fuel designs and to the determination of the associated correlation, “Additive Constants.” The ATRIUM-9B fuel has no part-length rods, but the ATRIUM-10 fuel does.

The additive constants are determined in accordance with the NRC-approved procedure described in References 3 and 4. The uncertainties associated with these additive constants are then used in the approved SPC safety limit methodology for boiling water reactor (BWR) fuel designs. The approved methodology is used to ensure that less than 0.1 percent of the fuel rods are in boiling transition during steady-state operation and during anticipated operational occurrences, in accordance with the General Design Criterion 10 and the Standard Review Plan, Section 4.4.

The SPCB correlation is new but similar to the ANFB-10 correlation, described in References 3 and 5. However, the definitions of the associated parameters (inlet sub-coolant, pressure, and mass flow) as described in Reference 3 are not changed for the application of the new SPCB to the SPC ATRIUM-9B and ATRIUM-10 fuel designs. The technical analysis of the SPCB correlation and its exclusive application to the ATRIUM-9B and ATRIUM-10 fuel designs is presented below.

2.0 TECHNICAL EVALUATION

The SPCB correlation is a new correlation designed and developed to address the critical power behavior of the SPC ATRIUM-9B and ATRIUM-10 fuel designs. The SPCB correlation is designed for application in steady-state, transient, and Loss of Coolant Accident critical heat flux (CHF) calculations for the ATRIUM-9B and ATRIUM-10 fuel designs.

The SPCB correlation was developed to predict assembly critical power for the ATRIUM-9B and ATRIUM-10 fuel designs. The correlation was developed to predict the limiting rod in a bundle and account for local spacer effects and bundle geometry on critical power by a set of constants, typically referred to as "Additive Constants," one constant for each rod in the bundle. Each individual fuel design requires a unique set of additive constants.

The SPCB correlation is an empirically derived expression that is a complex function of the input parameters: local coolant enthalpy, mass flow, and pressure. These input parameters cover the ranges of pressure, mass velocity, and inlet cooling, consistent with expected operating and accident conditions. The correlation is based on local coolant conditions predicted from uniform and non-uniform axial power distribution test data. The correlation includes correction factors to account for geometry and non-uniform axial power distributions that deviate from the test data conditions.

Low-flow and high-flow behavior of the correlation are captured by refining the parameters in the correlation equations (Ref. 1). These parameters address the impacts of the variations in the local enthalpy from the planar average enthalpy. One of these parameters is the F-effective, which characterizes the fuel rod local behavior, such as enthalpy rise, and which also factors additive constants into the calculations. The additive constants account for the fuel bundle geometry and spacer effects on the critical power behavior of the bundle (Refs. 3 and 4).

2.1 SPCB Database and Test Strategy

The SPCB database consists of data taken at the SPC test facility at Karlstein, Germany. The test setup comprises electrically heated bundles that are physically the same as the ATRIUM-9B and the ATRIUM-10 fuel assemblies. The tests are designed to reproduce the local conditions typically present in a BWR fuel assembly and support the full range of applicability for the SPCB correlation.

Different test programs were developed to accumulate a database representative of the appropriate statistical requirements for the ATRIUM-9B and the ATRIUM-10 fuel designs. The tests selected and the number of points required were dictated by the requirements of the statistical design of experiment SDE (Refs. 6 and 7). This approach ensures that an adequate number of tests are performed and that sufficient data are gathered to perform appropriate simulation of the behavior of the ATRIUM-9B and the ATRIUM-10 fuel designs.

Both steady-state and transient tests were performed as part of the validation of the SPCB correlation. In each case, the tests were designed to include test runs with peaked rods located adjacent to the internal water channel.

The database comprises more than 2500 data points taken in a large number of tests performed at the SPC test facility. The database consists of upskew, downskew, and cosine axial power shapes accounting for adjacent rod positions, rods on the interior of an assembly, and rods adjacent to the water canister (channel), a feature unique to the ATRIUM fuel design.

The local power peaking patterns were selected to determine the effects of the upskew axial power profiles as compared to the cosine power profiles in several regions of the test bundle. Local power peaking data were also collected at the corners, the peripheral rows, as well as around the internal water canister to ensure complete understanding of the fuel CHF behavior, particularly in these regions.

The internal water canister is a major and unique characteristic of the SPC's ATRIUM fuel design, It replaces a 3X3 matrix of fuel rods. The rectangular canister is designed so that the subchannels around it are regular in size, typical of those addressed by the original base ANFB correlation. The test matrixes of the ATRIUM-9B and the ATRIUM-10 fuel designs used at the SPC test facility included tests to confirm the behavior of the fuel surrounding the internal water canister. Neither the ATRIUM-9B nor the ATRIUM-10 fuel design showed any abnormal behavior around the internal water canister.

2.2 Description of the Additive Constants

Correlation parameters such as F-effective (F_{EFF}) account for the local peaking factor effect on the bundle critical power. F_{EFF} is constructed in two parts. One part depends solely on the peaking factors of the rod of interest and its immediate neighbors (F_{EFFO}); the other part, termed the "additive constant," accounts for other local effects, such as bundle geometry and spacer effects. These spacer and bundle geometry effects influence the critical power behavior of the bundle. Therefore, an offset term is applied to each rod in the bundle, subject to the rod's position in the bundle. This offset term is called the "additive constant." The additive constant can be considered as a flow/enthalpy redistribution characteristic of a particular lattice/spacer design. So the additive constants are unique to a particular fuel design. They are explicitly determined for each lattice/spacer design configuration and are utilized in design calculations for the corresponding fuel bundle (Ref. 3).

To assert the ability of the correlation to predict steady-state as well as transient upskew and downskew axial power shape, only the cosine test data were used in the determination of the additive constants, thus validating the use of the additive constants in steady-state and transient calculations. The additive constants are experimentally determined from a large data bank representative of the power profile expected during the operational range of the ATRIUM-9B and the ATRIUM-10 fuel designs.

3.0 STATISTICAL ASPECTS OF THE SPCB CORRELATION

The statistical aspects of the SPCB correlation consist of applying appropriate statistical techniques (Refs. 6 and 7) to the SPCB database. These techniques involve the evaluation of distribution characteristics, figures of critical power ratios (CPRs) with respect to each characteristic within the correlation, descriptive statistics for subgroups of data, descriptive statistics for additive constants and additive constants uncertainty, and conservatism of the SPCB critical power correlation. A good correlation would place the CPR near 1.00 (unity), with a very small associated uncertainty.

The correlation study examined the CPR in a series of tests. A total of 12 tests were performed: 7 tests pertained to the ATRIUM-9B and 5 tests pertained to the ATRIUM-10 fuel designs. For the ATRIUM-9B fuel, three of the seven tests were conducted with a chopped cosine shaped axial power profile, one test with a downskew power profile, and two tests with an upskew power profile. For the ATRIUM-10 fuel, three of the five tests were conducted with a chopped cosine shaped axial power profile, one of the five tests with a downskew power profile, and one test with an upskew power profile. Each test was repeated many times ("runs"). The input variables into each run entered the experimental design at different levels to reflect a diversified operating environment, resulting in a database containing in excess of 2500 data points. Twenty percent of this data was used to validate the correlation, while the remaining 80 percent was used to develop the SPCB correlation.

The multiplicity of runs within each test was required in order to involve various levels of input factors (inlet flow, inlet sub-cooling, and pressure). For most of the runs, these factors were selected at random, following standard statistical procedures (Refs. 6 and 7). For dryout testing, additional runs were made following a two-level, three-factor factorial design to ensure that the entire range of interest (including “corner to corner”) was represented.

Review of SPC calculations shows that the average CPR appears to be very near 1.0. That ratio is retained without any apparent trend across inlet mass velocity (Mlb/hr-ft^2), enthalpy (Btu/lbm), pressure (psia), the best estimate of the F_{EFF}, or the axial offset. The overall CPR mean for the ATRIUM-9B 1629 data points was calculated to be 0.996, and the CPR mean for the ATRIUM-10 1028 data points was calculated to be 0.996.

To evaluate the quality of the correlation, the staff independently calculated a CPR 95/95 upper tolerance limit (Refs. 8 and 9) for each test, for each profile, and for the entire set of runs. The staff 95/95 calculation was compared to SPC’s 95/95 calculation. Apart from rounding errors and conservative table interpolations, the staff’s calculation was in total agreement with SPC’s calculation. This limit is interpreted to mean that one is 95 percent sure that at least 95 percent of the population of runs yields a CPR value no higher than 1.022 for ATRIUM-9B and a value of 1.034 for ATRIUM-10. SPC’s calculations also show that for any test or grouping of tests, the percentage of runs that fall below their associated tolerance limits is at least 95.7 percent for ATRIUM-9B and 96.8 percent for ATRIUM-10.

The submittal contains charts and tables reflecting CPR behavior across different mass velocity (Mlb/hr-ft^2) for individual tests. Although some tests show higher CPR values associated with high mass velocity, the reverse is true for other tests, and no dependency between CPR and mass velocity is apparent.

Another objective of SPC’s study that involves statistical consideration is the determination of the additive constant for both fuel types. The additive constant is a statistical adjustment to the measure of the F_{EFF} to account for the effect of the rod’s geometric position within the assembly. This adjustment has two components: a calculated additive constant and a measure of uncertainty associated with the calculation. In the development of the additive constants, SPC uses only the cosine profile data. However, the measure of the associated uncertainty is calculated from the entire database, containing cosine, upskew, and downskew test data.

The main contributors to this uncertainty are two sources of variability: “within test variability” and “between test variability.” The within test variability is given as a weighted average in which the weighting factors are the number of runs per test. The between test variability is given as a weighted average of the difference between the F_{EFF} for a rod in a test bundle and the average F_{EFF} for the test bundle. The weighting factors are the number of boiling transitions for a rod in the test bundle. The square root of the sum of the squares (the two sources of variability) give the measure of variability associated with the calculation of the additive constant. In-depth review of the statistical section of the submittal leads the staff to concur with the statistical methods used and the results obtained by the vendor.

4.0 SPCB CORRELATION BEHAVIOR

The SPCB correlation was tested to ensure smooth functions and no significant discontinuities in its behavior over the entire range of operability of the fuel. Flow, enthalpy, and pressure-dependent functions within the correlation, such as the “Tong Factor” correction for both fuels, was investigated for its behavior over the entire applicable range of the fuels. A number of tests were conducted to determine the sensitivity of the major functions within the SPCB correlation to flow, inlet subcooling, pressure variation, F_{EFF}, and axial power shape.

Review of the data, figures, and tables indicates that the SPCB correlation behaves well over the applicable range of the fuel.

5.0 SPCB CORRELATION VALIDATION

SPC performed several tests to validate the behavior of the SPCB correlation in steady-state and transient events. The validation database consisted of 20 percent of the total steady-state data points that were not included in the correlation database. The remaining 80 percent of the database (the so-called verification set) was used to develop the correlation. In addition, data were collected from tests conducted on an ATRIUM-10P assembly that contained more part-length fuel rods than are usually found in a typical ATRIUM-10 assembly. These tests were conducted to demonstrate the ability of the SPCB correlation to capture the effects of the part-length rods, as well as the correlation agreement with the data. The predicted SPCB correlation between critical power versus the measured critical power for these tests showed very good agreement.

Two sets of transient tests were performed as part of the validation process. Both tests were designed to peak rods around the internal water canister. The difference between the two tests is that the first test had rods with a chopped cosine-shaped axial power profile and the second had rods with an upskew axial power shape. Another purpose of the tests was to validate the concept that the additive constants can be derived from steady-state cosine tests and applied to other axial shapes under transient conditions.

The transient tests performed were the simulated load rejection with no bypass (LRNB) events that consisted of power, pressure ramps, and flow decay. Power forcing functions were programmed to produce transient heat flux on the surface of the rod typical of an LRNB event. Parameters monitored during the tests were power, inlet flow, system pressure, inlet temperatures, and cladding temperatures.

The transient thermal-hydraulic code, XCOBRA-T (Refs. 10 and 11), was used to predict the test results using the SPCB steady-state critical power correlation. XCOBRA-T calculates the fluid conditions at a specified time step. The CHF is calculated at each axial position and time step, then compared to the corresponding measured rod heat flux at the surface of the rod. The ratio of the calculated heat flux to the measured rod heat flux is defined to be the critical heat flux ratio (CHFR). When this ratio is unity, it is referred to as the minimum critical heat flux ratio (MCHFR), and it signifies “boiling transition” in a transient event. Comparison of measured and calculated time-to-boiling transitions for cosine and upskew transient tests shows that the XCOBRA-T calculated time-to-boiling transition values are conservative when compared to actual boiling transition time. This validation confirms the use of the steady-state SPCB correlation and the associated additive constants in evaluating transient events.

6.0 LOCAL PEAKING FACTORS

Although local peaking factors may be exceeded in controlled bundles, these bundles by definition are not limiting bundles, consequently, they do not factor in the calculation of the minimum critical power ratio (MCPR) safety limit. If, however, in the process of calculating the MCPR safety limit, the local peaking factor of 1.5 is exceeded, an additional additive constant uncertainty is applied on a rod-by-rod basis in accordance with Table 3.15 of Reference 1. These conditions have been agreed upon by both the NRC staff and SPC, (Ref. 12).

7.0 NON CONFORMANCE ISSUES

The submittal, as documented in Reference 1, is SPC's corrective action in response to Part 2 of notice of Nonconformance 99900081/97-01, as stated in Attachment II of SPC's letter to the NRC, dated February 24, 1998 (Ref. 13). The Nonconformance stated that: SPC failed to develop an adequate number of tests points and failed to test an adequate range of conditions to justify the uncertainty values for the "additive constants" used in determining the safety limit minimum critical power ratio (SLMCPR) for the ATRIUM-9B fuel design. This statement implies that SPC should have used larger uncertainty values in the SLMCPR determinations in order to reflect the full operability range of the ATRIUM-9B fuel design. In addition, because the results of the ANFB correlation are used as inputs to the safety limit methodology, this has immediate implications regarding the SLMCPR and the operating limit minimum critical power ratio (OLMCPR) of the Commonwealth Edition Company plants (Quad Cities Unit 2, Cycle 15, Dresden Unit 2, Cycle 15, and LaSalle County Unit 2, Cycle 8) and the Washington Public Power Supply System (Washington Nuclear Unit 2, Cycle 13) loaded with ATRIUM-9B fuel.

In response to this notice of Nonconformance, SPC developed and implemented interim methodologies (ANF-1125, Appendixes D and E) (Refs. 14 and 15), while performing additional dryout testing of the ATRIUM-9B design to obtain additional data to cover the extended range of thermal-hydraulic parameters for the ATRIUM-9B fuel design.

The NRC staff contends that with the submittal of EMF-2209(P), the vendor (SPC) has provided the additional data necessary for the SPCB critical power correlation to provide a rigorous treatment over the entire operating range of the ATRIUM-9B fuel. Thus, with the submittal of EMF-2209(P), all problems identified in the inspection report (Nonconformance 99900081/97-01, Part 2) related to the dryout methodology for ATRIUM-9B fuel have been addressed.

8.0 TECHNOLOGY TRANSFER

SPC described the technology transfer program (Ref. 16) which the licensees must successfully complete in order to perform their own thermal-hydraulic calculations using the SPCB correlation and the XCOBRA-T code in support of reload analyses. The overall process consists of training, benchmarking, and change control. In addition, SPC described the process for a licensee to implement the new correlation (SPCB). This process includes performance of an independent benchmarking calculation by SPC for comparison to the licensee-generated results to verify that the new CHF correlation is properly applied. The staff has reviewed the process and find it acceptable because training, bench-marking, and change control have been adequately addressed.

9.0 CONCLUSION

The staff has reviewed the analyses in Topical Report EMF-2209(P), Revision 0, "SPCB Critical Power Correlation ," and concludes that on the basis of its findings (presented above), Topical Report EMF-2209(P) is acceptable for licensing applications, in accordance with SPC's agreement, subject to the following conditions:

1. The SPCB correlation (as described in this submittal, Reference 1) is applicable to SPC ATRIUM-9B and ATRIUM-10 fuel designs, with a local peaking factor no greater than 1.5.

2. If, however, in the process of calculating the MCPR safety limit, the local peaking factor of 1.5 is exceeded, an additional uncertainty of 0.026 for ATRIUM-9B and 0.021 for ATRIUM-10 will be imposed on a rod-by-rod basis.

3. The SPCB correlation range of applicability is as follows:

Pressure (psia)	571.4 to 1432.2
Inlet Mass Velocity (Mlb/hr-ft^2)	0.087 to 1.5
Inlet Subcooling (Btu/lbm)	5.55 to 148.67
Design Local Peaking	1.5
Tested Local Peaking	1.45

4. Technology transfer will be accomplished only through the process described in Reference 16, which includes the performance of an independent bench-marking calculation by SPC for comparison to the licensee-generated results to verify that the new CHF correlation (SPCB) is properly applied for the first application by the licensee.

10.0 REFERENCES

1. Letter from H. D. Curet, of SPC to the U.S. Nuclear Regulatory Commission, submitting Topical Report EMF-2209(P), Revision 0, September 24, 1999.

2. Letter from J. F. Malley to the U.S. Nuclear Regulatory Commission, “Request for Additional Information (RAI) to Topical Report EMF-2209(P), “SPCB Critical Power Correlation,” Revision 0, March 20, 2000.

3. Letter from R. A. Copeland, of SPC, Transmittal of (A) version of ANF-1125(P) to the U.S. Nuclear Regulatory Commission, April 27, 1990.

4. Letter from H. D. Curet, of SPC to the U.S. Nuclear Regulatory Commission, submitting Topical Report EMF-1997(P), Revision 0, October 30, 1997, and Letter from H. D. Curet, submitting Topical Report EMF-1997(P), Supplement 1, Revision 0, January 29, 1998.

5. Letter from J. F. Malley to the U.S. Nuclear Regulatory Commission, “Request for Additional Information (RAI) to Topical Report EMF-1997(P), ANFB-10 Critical Power Correlation,” Revision 0, May 7, 1998.

6. “Statistical Methods for Nuclear Material Management,” NUREG/CR-4604, PNL-5849, December 1988.

7. G. J. Hahn, and S. S. Shapiro, “Statistical Models in Engineering,” Wiley, 1967.

8. H. W. Lilliefors, “On the Kolmogorov Test for Normality with Mean and Variance Unknown,” Journal of American Statistical Association, Vol. 62, June 1967.

9. R. E. Odeh and D. B. Owen,”Tables for Normal Tolerance Limits,” Table 1, Marcel Dekker, lnk, 1990.

10. “XCOBRA-T: A Computer Code for BWR Transient Thermal-Hydraulic Core Analysis,” XN-NF-84-105(P)(A), Volume 1, Supplements 1 and 2, Exxon Nuclear Company, Richland, WA 99352, February 1987.

11. “XCOBRA-T: A Computer Code for BWR Transient Thermal-Hydraulic Core Analysis, Void Fraction Model Comparison to Experimental Data,” XN-NF-84-105(P)(A), Volume 1, Supplement 4, Advanced Nuclear Fuels Corporation, Richland, WA 99352, February 1987.

12. Letter from J. F. Malley to the U.S. Nuclear Regulatory Commission, “SER conditions for EMF-2209(P) Revision 1, SPCB Critical Power Correlation,” April 20, 2000.

13. Letter, Samuel J. Collins, of NRC to David G. McLees, of SPC “Demand for Information and Notice of Nonconformance (Inspection Report 99900081/97-01),” EA97-495, dated October 27, 1997.

14. Letter from Don Curet, of SPC to the U.S. Nuclear Regulatory Commission, requesting review of ANFB Critical Power Correlation Uncertainty for Limited data Sets, ANFB-1125(P), Supplement 1, Appendix D, April 18, 1997.

15. Letter from J. F. Malley, of SPC to the U.S. Nuclear Regulatory Commission, “Request for review of ANFB Critical Power Correlation Determination of ATRIUM-9B Additive Constant Uncertainties, ANFB-1125(P), Supplement 1, Revision 0, August 11, 1998.

16. Letter from J. F. Malley to the U.S. Nuclear Regulatory Commission, “SER conditions for EMF-2209(P) Revision 1, SPCB Critical Power Correlation,” April 24, 2000.

Principal Contributor: A. Attard

Date: May 17, 2000