Proj. 702

SIEMENS

September 21, 2000
NRC:00:042

Document Control Desk
ATTN: Chief, Planning, Program and Management Support Branch
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

Publication of Approved Version of EMF-2292(P) Revision 0, *ATRIUM™-10: Appendix K Spray Heat Transfer Coefficients*

Ref.: 1. Letter, Stuart A. Richards (NRC) to James F. Mallay (SPC), "Acceptance for Referencing of Siemens Power Corporation Topical Report EMF-2292(P), Revision 0, *ATRIUM™-10: Appendix K Spray Heat Transfer Coefficients* (TAC NO. MA6785)," September 13, 2000.

Enclosed are copies of the approved version of the topical report EMF-2292(P) Revision 0, *ATRIUM™*-10: Appendix K Spray Heat Transfer Coefficients* accepted for referencing by the NRC in Reference 1. The enclosed copies of the report conform with procedures established in NUREG-0390.

The affidavit provided with the original submittal of this topical report satisfies the requirements of 10 CFR 2.790(b) to support the withholding of the proprietary version of the report from public disclosure.

Very truly yours,

James F. Mallay

James F. Mallay, Director
Regulatory Affairs

/arn

Enclosures (15 proprietary/12 nonproprietary)

cc: N. Kalyanam
Project No. 702

D056 1/12 non-prop. 1/15 prop.

* ATRIUM is a trademark of Siemens.

Siemens Power Corporation

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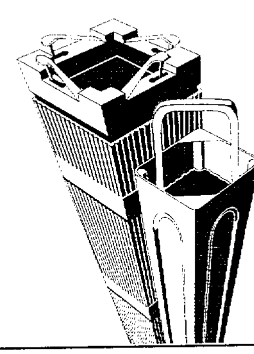
SIEMENS

EMF-2292(NP)(A)
Revision 0

ATRIUM™-10: Appendix K Spray Heat Transfer Coefficients

September 2000



Siemens Power Corporation
Nuclear Division

Siemens Power Corporation

ISSUED IN SPC ON-LINE DOCUMENT SYSTEM
DATE: 9/21/00

EMF-2292(NP)
Revision 0

ATRIUM™-10: Appendix K Spray Heat Transfer Coefficients

Prepared: ____________________ 9/27/99
D. M Turner, Test Engineer, Richland Test Facilities — H. D. Curet, Manager, Product Licensing — Date

Reviewed: ____________________ 9/24/99
L. G. Riniker, Engineer, BWR Safety Analysis — Date

Concurred: ____________________ ________
M. E. Garrett, Manager, BWR Safety Analysis — Date

Approved: ____________________ 9/24/99
R. E. Collingham, Manager, Safety Analysis Methods — Date

arn

U.S. Nuclear Regulatory Commission
Report Disclaimer

Important Notice Regarding the Contents and Use of This Document

Please Read Carefully

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

September 13, 2000

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

SUBJECT: ACCEPTANCE FOR REFERENCING OF SIEMENS POWER CORPORATION TOPICAL REPORT EMF-2292(P), REVISION 0, "ATRIUM™-10: APPENDIX K SPRAY HEAT TRANSFER COEFFICIENTS" (TAC NO. MA6785)

Dear Mr. Mallay:

Topical Report EMF-2292(P), Revision 0, "ATRIUM™-10: Appendix K Heat Transfer Coefficients," was submitted for NRC review by the Siemens Power Corporation (SPC) by letter dated September 27, 1999.

This topical report presents SPC experimental results and HUXY computer code calculations that substantiate that the application of 10 CFR Part 50 Appendix K convective heat transfer coefficients during loss of coolant accident spray cooling of the ATRIUM™-10 fuel design is conservative. A similar topical report demonstrating the conservatism of the Appendix K spray heat transfer coefficients for the ANF 9x9 fuel design with an internal water canister has previously been approved.

The staff has reviewed the topical report and finds it acceptable for referencing in licensing actions as stated in our enclosed safety evaluation (SE).

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 the 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,

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

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

TOPICAL REPORT EMF-2292 (P), REVISION 0

"ATRIUM™-10: APPENDIX K SPRAY HEAT TRANSFER COEFFICIENTS"

SIEMENS POWER CORPORATION

PROJECT NO. 702

1.0 INTRODUCTION AND BACKGROUND

By letter of September 27, 1999 (Reference 1), Siemens Power Corporation (SPC) requested NRC review and acceptance for referencing in licensing actions, Topical Report EMF-2292(P), Revision 0, "ATRIUM™-10: Appendix K Spray Heat Transfer Coefficients."

Appendix K, paragraphs I.D.6 and I.D.7, of Part 50 of Title 10 of the Code of Federal Regulations (10 CFR Part 50) specifies for reactors with jet pumps, convective heat transfer coefficients be used under spray cooling conditions for the fuel rods and channel box for a 7x7 fuel rod array design. SPC has conducted a series of experimental tests in their fuel cooling test facility (FCTF) (Reference 2) for their ATRIUM™-10 fuel design (Reference 3), a 10x10 fuel rod array with an internal water canister (IWC). These tests were performed to confirm that the spray cooling convective heat transfer coefficients prescribed in 10 CFR Part 50 Appendix K for 7x7 rod arrays are conservative for the 10x10 array when used for loss of coolant accidents (LOCA) analyses in jet pump boiling water reactors (BWR). SPC previously performed a similar test series for its ANF 9x9 rod array with IWC fuel design (Reference 4), which was reviewed and approved by the NRC.

SPC uses a multi-rod heat-up model, embodied in the HUXY computer code (References 5 and 6), to calculate fuel rod response during the core spray cooling period of a LOCA, in accordance with 10 CFR Part 50, Appendix K. The HUXY code results, using the convective heat transfer coefficients prescribed in Appendix K, were compared with experimental results obtained from a series of fuel heatup tests to demonstrate conservatism for the ATRIUM™-10 fuel design.

2.0 TECHNICAL EVALUATION

The topical report describes the 10x10 test bundle mechanical design and the series of 23 experimental tests performed in the FCTF and further describes the multiple HUXY calculations performed for each test. The selection of the experimental conditions were chosen to simulate the heat transfer response for BWR 3, 4, and 5/6 plant designs. The HUXY calculations simulate each test condition, but use the Appendix K prescribed heat transfer coefficients. The radiation emissivity input data are conservatively chosen to maximize the calculated cladding temperature. The topical report presents the experimental data and provides a comparison of these data with the corresponding HUXY calculations, in terms of the maximum temperature as a function of spray cooling time.

For each test the maximum cladding temperature predicted by HUXY exceeded the maximum measured cladding temperature.

2.1 Experimental Tests

The test bundle simulated a full-scale ATRIUM-10 BWR fuel assembly, including the upper tie plate, electrically heated rods, eight prototypical spacers, and an IWC. The inlet orifice, lower tie plate and outer assembly channel box were also simulated. The heated rods used a typical axial power profile. Thermocouples were placed at five elevations above the bottom of the rod heated length to span the location of the peak cladding temperature. The general initial and transient test conditions were maintained to be similar to the previously conducted 9x9 spray heat transfer tests approved in Reference 4.

2.2 HUXY Input

The HUXY calculations used the initial power, decay profile, spray initiation and test termination times from the experimental test data. The measured initial average temperature of the instrumented rods and the channels were input to HUXY, along with the local and axial power peaking factors for each elevation to be modeled. The approved assembly channel quenching methodology from Reference 5 was used for the HUXY calculations. The prescribed Appendix K spray heat transfer coefficients for rods and channels were applied at spray initiation. Further conservatism was introduced by assigning no delay time to the IWC quench calculations.

2.3 Comparison of Analytical Results and Experimental Data

The topical report first presented results of individual rod temperature comparisons between code calculations and test results during the transient test heat-up period prior to spray initiation and power decay, to confirm the adequacy of the test configuration and the computer model. The comparisons of calculated versus measured rod temperature after spray initiation were then displayed, along with a comparison of the 9x9 IWC and ATRIUM-10 data, for each class of BWRs being modeled. The measured temperature histories for the three rods that achieved the highest temperature were compared with the HUXY predicted temperatures for the highest three rods at each of four axial thermocouple elevations for each transient test sequence. In all cases, the final measured three highest test temperatures were less than or equal to the three highest HUXY predicted temperatures for each test sequence. HUXY, with the Appendix K coefficients, did not predict temperature turnaround and decrease at any axial location for any of the tests, although some test measurements did show temperature decreases.

3.0 EVALUATION

SPC conducted a series of 23 tests for the ATRIUM-10 bundle and performed multiple HUXY predictive calculations for each test. The calculations simulated each test condition, but used the heat transfer coefficients prescribed in Appendix K. The results show that, for each test, the maximum predicted cladding temperature exceeded the maximum measured cladding temperature. This demonstrates that the use of the Appendix K heat transfer coefficients in the emergency core cooling system (ECCS) analyses of ATRIUM-10 fuel bundle design is conservative. The results were also compared to similar tests previously conducted that were reviewed and approved by Reference 4 for the ANF 9x9 internal canister fuel design, showing similar conservatism. The staff finds that the SPC calculations consistently and conservatively overpredict the measured peak cladding temperatures. This finding shows the topical report to be an acceptable demonstration of the conservatism of the application of the Appendix K coefficients.

4.0 CONCLUSIONS

The staff has reviewed the evaluations described in Topical Report EMF-2292(P), Revision 0, "ATRIUM™-10: Appendix K Spray Heat Transfer Coefficients." The staff also reviewed the limitations imposed on SPC ECCS model applications from prior topical report SERs (References 7 and 8) and the proposed application is consistent with the limitations. The staff also reviewed the previous similar SPC 9x9 spray cooling tests and comparisons with the ATRIUM™-10 results to substantiate the data trends and the continued conservatism of application of the Appendix K coefficients. The reported test results, along with the references, demonstrate the acceptability of the application of Appendix K coefficients for use during the spray cooling period of LOCA analyses for jet pump BWR plants with ATRIUM™-10 reload fuel assemblies. The staff concludes that, as discussed above, Topical Report EMF-2292(P), Revision 0 is acceptable for referencing in licensing applications.

5.0 REFERENCES

1. Letter from J. F. Mallay (SPC) to U. S. NRC, "Request for Review of EMF-2292(P), Revision 0, "ATRIUM™-10: Appendix K Spray Heat Transfer Coefficients," NRC:99:041, September 27, 1999.

2. XN-NF-81-46, "Exxon Nuclear Company Jet Pump BWR Refill and Reflood Fuel Cooling Test Program," August 10, 1981.

3. EMF-98-006(P), Revision 0, "Mechanical Design Evaluation for Siemens Power Corporation ATRIUM™-10 BWR Reload Fuel to 54 MWd/kgU Assembly Exposure," January 1998.

4. ANF-CC-33(P)(A), Supplement 2, "HUXY: A Generalized Multirod Heatup Code with 10 CFR 50 Appendix K Heatup Option," Siemens Power Corporation, January 1991.

5. XN-CC-33(P)(A), Revision 1, "HUXY: A Generalized Multirod Heatup Code with 10 CFR 50 Appendix K Heatup Option," Exxon Nuclear Company, November 1975.

6. EMF-CC-102(P), Revision 1, "HUXY: A Generalized Multirod Heatup Code with 10 CFR 50 Appendix K Heatup Option," Siemens Power Corporation, February 10, 1999.

7. ANF-91-048(P)(A), "Advanced Nuclear Fuels Corporation Methodology for Boiling Water Reactors EXEM BWR Evaluation Model," Advanced Nuclear Fuels Corporation, January 1993.

8. ANF-91-048(P)(A), Supplements 1 and 2, "BWR Jet Pump Model Revision for RELAX," Siemens Power Corporation, October 1997.

Principal Contributor: E. Kendrick

Date: September 13, 2000

SIEMENS

September 27, 1999
NRC:99:041

Document Control Desk
ATTN: Chief, Planning, Program and Management Support Branch
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

Request for Review of EMF-2292(P) Revision 0, "ATRIUM™-10 Appendix K Spray Heat Transfer Coefficients"

Ref.: 1. ANF-CC-33(P)(A) Supplement 2, "HUXY: A Generalized Multirod Heatup Code with 10 CFR 50 Appendix K Heatup Option," Advanced Nuclear Fuels Corporation, January 1991.

Ref.: 2. Letter, H. Donald Curet (SPC) to Document Control Desk, "ATRIUM-10 Mechanical Design for Increased Burnup," NRC:98:008, January 30, 1998.

Fifteen proprietary and 12 nonproprietary copies of topical report EMF-2292(P) Revision 0, "ATRIUM™-10: Appendix K Spray Heat Transfer Coefficients" are being submitted to the NRC for review and acceptance for referencing in licensing actions. (NOTE: Three proprietary copies and one nonproprietary copy have been sent directly to Mr. Nageswaran Kalyanam). This topical report presents experimental results and HUXY computer code calculations that substantiate that the application of 10 CFR 50 Appendix K convective heat transfer coefficients during LOCA spray cooling of ATRIUM™-10 fuel is conservative. A similar demonstration of the conservatism of Appendix K spray heat transfer coefficients for ANF 9x9 fuel with an internal water canister was previously approved (Reference 1).

Copies of Reference 1 and the report EMF-98-006(P) Revision 0, "Mechanical Design Evaluation for Siemens Power Corporation ATRIUM™-10 BWR Reload Fuel to 54 MWd/kgU Assembly Exposure," which was previously provided to the NRC by Reference 2, have been forwarded to Mr. Kalyanam and are provided for the convenience of the reviewer of the subject topical report.

SPC requests approval of this topical report within six months because of its anticipated application in analyses to be performed for SPC's customers.

Siemens Power Corporation

2101 Horn Rapids Road
Richland, WA 99352

Tel: (509) 375-8100
Fax: (509) 375-8402

Some of the information contained in the enclosed topical report is considered to be proprietary to Siemens Power Corporation. As required by 10 CFR 2.790(b), an affidavit is enclosed to support the withholding of this information from public disclosure.

Very truly yours,

James F. Mallay, Director
Regulatory Affairs

cc: Mr. N. Kalyanam (w/Enclosures)
Mr. J. L . Wermiel
Project No. 702 (w/Enclosures)

AFFIDAVIT

STATE OF WASHINGTON)
) ss.
COUNTY OF BENTON)

I, James F. Mallay, being duly sworn, hereby say and depose:

1. I am Director, Regulatory Affairs, for Siemens Power Corporation ("SPC"), and as such I am authorized to execute this Affidavit.

2. I am familiar with SPC's detailed document control system and policies which govern the protection and control of information.

3. I am familiar with the SPC information included in report EMF-2292(P) Revision 0, "ATIRUM™-10 Appendix K Spray Heat Transfer Coefficients," September 1999 referred to as "Document" transmitted by letter NRC:99:041. Information contained in this Document has been classified by SPC as proprietary in accordance with the control system and policies established by SPC for the control and protection of proprietary and confidential information.

4. This Document contains information of a proprietary and confidential nature and is of the type customarily held in confidence by SPC and not made available to the public. Based on my experience, I am aware that other companies regard information of the kind contained in the Document as proprietary and confidential.

5. This Document has been made available to the U.S. Nuclear Regulatory Commission in confidence, with the request that the information contained in the Document will not be disclosed or divulged.

6. This Document contains information which is vital to a competitive advantage of SPC and would be helpful to competitors of SPC when competing with SPC.

7. The information contained in the Document is considered to be proprietary by SPC because it reveals certain distinguishing aspects of SPC licensing methodology which secure competitive advantage to SPC for product optimization and marketability, and includes information utilized by SPC in its business which affords SPC an opportunity to obtain a competitive advantage over its competitors who do not or may not know or use the information contained in the Document.

8. The disclosure of the proprietary information contained in this Document to a competitor would permit the competitor to reduce its expenditure of money and manpower and to improve its competitive position by giving it valuable insights into SPC licensing methodology and would result in substantial harm to the competitive position of SPC.

9. This Document contains proprietary information which is held in confidence by SPC and is not available in public sources.

10. In accordance with SPC's policies governing the protection and control of information, proprietary information contained in this Document has been made available, on a limited basis, to others outside SPC only as required and under suitable agreement providing for nondisclosure and limited use of the information.

11. SPC policy requires that proprietary information be kept in a secured file or area and distributed on a need-to-know basis.

12. Information in this Document provides insight into licensing methodology developed by SPC. SPC has invested significant resources in developing the methodology as well as the strategy for this application. Assuming a competitor had available the same

background data and incentives as SPC, the competitor might, at a minimum, develop the information for the same expenditure of manpower and money as SPC.

13. The foregoing statements are true and correct to the best of my knowledge, information, and belief.

SUBSCRIBED before me this 24th

day of September, 1999.

Sue M. Galpin

SUE M. GALPIN
COMMISSION EXPIRES
NOTARY
PUBLIC
FEB. 27, 2000
STATE OF WASHINGTON

Sue M. Galpin
NOTARY PUBLIC, STATE OF WASHINGTON
MY COMMISSION EXPIRES: 02/27/00

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

November 30, 1999

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

SUBJECT: REQUEST FOR WITHHOLDING FROM PUBLIC DISCLOSURE - EMF-2292(P), REVISION 0, "ATRIUM™-10: APPENDIX K SPRAY HEAT TRANSFER COEFFICIENTS" (TAC NO. MA6785)

Dear Mr. Mallay:

By your letter dated September 27, 1999, and affidavit of September 24, 1999, you submitted a request for review of Siemens Power Corporation (SPC) report EMF-2292(P), Revision 0, "Atrium™-10: Appendix K Spray Heat Transfer Coefficients." A nonproprietary version was submitted for placement in the NRC public document room.

We reviewed your application in accordance with the requirements of 10 CFR 2.790 and determined that the submitted information sought to be withheld contains proprietary commercial information and should be withheld from public disclosure. This was conveyed to you by our letter dated October 26, 1999. The report number stated in the October 19, 1999, letter was "EMF-2892(P)" instead of "EMF-2292(P)". There is no SPC Topical Report EMF-2892(P) currently in-house for review.

We apologize for any inconvenience this may have caused. If you have any questions regarding this matter, I may be reached at (301) 415-1480.

Sincerely,

Nageswaran Kalyanam, Project Manager, Section 2
Project Directorate IV and Decommissioning
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Project No. 702

EMF-2292(NP)
Revision 0

ATRIUM™-10: Appendix K Spray Heat Transfer Coefficients

September 1999

Nature of Changes

Item	Page	Description and Justification
1.	All	This is a new document.

Contents

Tables

Figures

1.0 Abstract

Siemens Power Corporation conducted a series of tests in its fuel cooling test facility (FCTF) to confirm that the spray heat transfer coefficients prescribed by the NRC are conservative when used to perform LOCA analyses for the ATRIUM™-10 fuel design. SPC had performed an almost identical set of tests for its ANF 9x9 internal canister fuel design, the results of which were accepted by the NRC. These new tests were necessary to demonstrate that similarly conservative results would be obtained when the prescribed heat transfer coefficients were used with the ATRIUM-10 fuel design.

The results of the ATRIUM-10 tests confirmed that the use of the NRC-prescribed convective heat transfer coefficients to predict ATRIUM-10 fuel heatup in jet pump BWRs is conservative.

2.0 Introduction and Summary

SPC uses the HUXY computer code (References 1 and 2), which is a multirod heatup model, to calculate fuel rod response during the core spray cooling period of a LOCA, as prescribed in 10CFR50, Appendix K. The HUXY code was used to demonstrate that the use of the convective heat transfer coefficients given in Appendix K are conservative when applied to SPC's ATRIUM-10 fuel design. The HUXY results were compared to results obtained from a series of fuel heatup tests.

SPC performed 23 tests in its FCTF and conducted numerous HUXY calculations for each test. The calculations simulated the test conditions but used the heat transfer coefficients prescribed in Appendix K. The results show that for each test the maximum cladding temperature predicted by HUXY exceeded the maximum cladding temperature measured. SPC concludes that the use of the Appendix K heat transfer coefficients in the ECCS analysis of its ATRIUM-10 fuel design is conservative.

During each test, the temperature histories were recorded for the three rods that attained the highest cladding temperature during the transients. These temperature histories were obtained at several axial locations, including locations that bracketed where the peak cladding temperature was shown to occur. These temperature histories were then compared to the corresponding HUXY calculations.

In making the comparison between test results and HUXY calculations, it was observed that in some cases the highest test temperatures reached occurred in rods that were in locations different from that calculated by HUXY. In all cases, however, the three highest test temperatures were less than the three highest temperatures from the HUXY predictions. (As noted earlier, the maximum cladding temperature calculated by HUXY always exceeded the measured maximum temperature.)

In addition, even though no delay time was assumed for the inner water channel quench calculations in HUXY, the predicted maximum temperatures for the three hottest rods were still conservative relative to the test results. (As noted in Section 6, there was one exception to these conservative results at an axial location some three feet above where the peak cladding temperature occurred.) The conservatism of the calculated results is further demonstrated by the fact that HUXY never predicted a quench point where a temperature turn-around would occur, even though some test results showed this behavior during spray cooling.

3.0 Experimental Bundle Description

The test bundle consisted of a simulated full-scale ATRIUM-10 BWR assembly with an upper tie plate (UTP), electrically heated rods, eight (8) spacers, and an inner water channel (IWC). The orifice box, simulated lower tie plate (LTP), and outer assembly channel, which had to accommodate plumbing and electrical power connections, were also designed to function as their associated ATRIUM-10 components. A detailed description of the ATRIUM-10 design can be found in the report EMF-98-006(P) Revision 0, "Mechanical Design Evaluation for Siemens Power Corporation ATRIUM™-10 BWR Reload Fuel to 54 MWd/kgU Assembly Exposure." This report was provided by Reference 3 to the NRC.

4.0 Test Procedures

Table 1 Jet Pump BWR Spray Heat Transfer Test General Conditions

Table 2 Achieved Test Conditions for FCTF ATRIUM-10 Updraft Tests

5.0 HUXY Input Description

10 CFR 50 Appendix K prescribes a set of convective heat transfer coefficients for safety (ECCS) analysis calculations during the LOCA spray cooling period of jet pump BWR plants with 7x7 fuel assembly arrays. The values of these prescribed coefficients are 3.0, 3.5, 1.5, and 1.5 BTU/hr-ft^2–°F for fuel rods located in the outer corners, outer row, next to the outer row, and those remaining in the interior of the assembly, respectively. In addition, a coefficient value of 5.0 BTU/hr-ft^2–°F is to be applied to both sides of the channel box during the spray cooling period and a 60 second delay added to the calculated wetting time of that channel box. Appendix K also requires that convective heat transfer for assembly geometries other than 7x7 be calculated using coefficients based on appropriate experimental spray heat transfer data. Siemens Power Corporation (SPC) performed ATRIUM™-10 tests in its FCTF to confirm that the spray heat transfer coefficients prescribed in Appendix K are conservative when used to perform ATRIUM-10 LOCA heatup analyses with the HUXY code (References 1 and 2).

The ATRIUM-10 tests were performed in the same manner and for the same purpose as the tests with the ANF 9x9 internal canister fuel design reported to and approved by the NRC in Reference 4. Additionally, the results from both tests were very similar and confirmed that the use of Appendix K convective heat transfer coefficients to predict ATRIUM-10 fuel heatup in jet pump BWRs is conservative.

This section describes some of the major code inputs used to generate the HUXY code rod temperature predictions. For each HUXY calculation, local and axial power peaking factors were input for the elevation being modeled. From the test data the following input was generated:

- Power achieved at time of spray initiation
- Power decay profile
- Spray initiation time
- Test termination time
- Average temperature of instrumented rods and channel at test initiation

The standard SPC approved assembly channel quenching methodology (Reference 1) was used for the HUXY evaluations.

In addition to the input generated from the test data, the following Appendix K spray heat transfer coefficient values (applied at spray initiation) were input to the HUXY code:

- Appendix K specified spray heat transfer coefficients (applied at spray initiation)
- 3.0 BTU/hr-ft^2-°F for outer corner rods
- 3.5 BTU/hr-ft^2-°F for all other outer rods
- 1.5 BTU/hr-ft^2-°F for all other rods
- 5.0 BTU/hr-ft^2-°F for the IWC
- 5.0 BTU/hr-ft^2-°F for the assembly channel (outer canister)

Per the model used for BWR 9x9 designs with an internal water canister (Reference 3), a coefficient value of 5.0 BTU/hr-ft^2-°F was applied to the outer surface of the IWC during the spray period. No IWC quench time delay was incorporated.

6.0 Analytical/Experimental Data Comparison Results

[

] Figures 1, 2, and 3 present representative results of individual rod temperature comparisons performed during the heat-up period (prior to spray initiation and power decay) of the test transients. The generally good agreement of test and code predicted temperatures during the heat-up period confirms 1) the material properties input for the rods, IWC, and channel, 2) the accuracy of the code heat transfer calculations during the heat-up period prior to spray initiation, and 3) the integrity of the assembly throughout the test program.

Test and HUXY results for Tests 57, 58, and 91 listed in Table 2 are shown in Figures 4, 5, and 6. The conduct of these tests were very similar to 9x9 tests - 1050, 1051, and 1056 - presented in Reference 3. Table 3 includes the test conditions for both the ATRIUM-10 tests and 9x9 spray heat transfer tests conducted to simulate predicted spray heat transfer conditions for each class of BWRs.

Not only was the conduct of the 9x9 and ATRIUM-10 spray heat transfer tests similar, so were the test results. The compared results for the 9x9 and 10x10 tests shown in Figure 7, 8, and 9 indicate that the spray heat transfer behavior for the two different fuel designs were remarkably similar. Upon examination, such behavior is to be expected as each fuel design has approximately the same stored energy at the initiation of the tests; also, the ECC delivery rates (i.e., heat removal capacity) for both test series were nearly the same. The three figures in Reference 3 for tests 1050, 1051, and 1056 were plotted with time zero being at time of spray initiation. However, the ATRIUM-10 data plots were plotted with time zero being at the time power was initially applied to the heater rods. Consequently, the comparison of the 9x9 and ATRIUM-10 data in Figures 7, 8, and 9 shows the start of the 9x9 data at the time of spray initiation. (The maximum rod temperatures shown in Figure 8 occurred at different elevations – for Test 1051 (9x9) the elevation was 87 inches and for Test 57 (10x10) it was 65 inches.)

Using the Appendix K coefficients, HUXY did not predict temperature turn-around at any location for any of the tests and, in general, significantly overpredicted maximum rod temperatures for those tests which experienced temperature turn-around and decrease. Figures 10, 11, and 12 provide examples of results for tests where those temperature turn-arounds occurred. Of the 23 ATRIUM-10 tests, only the recorded maximum rod temperature at the rod elevation of 105 inches for Test 66 exceeded the HUXY predicted temperature, as shown in Figure 13. This non-conservative difference between measured and predicted temperatures at that one elevation for one test was an exception out of about 350 predictions of the three hottest rods for each of the 23 tests. In fact, HUXY actually predicted the highest temperature to be 1760°F at the 69 inch elevation for Test 66, which is 232°F higher than the highest measured temperature for the test. HUXY predictions for elevations other than at the 105 inch elevation (65, 69, 75, and 85 inches) for Test 66 ranged from 195°F to 430°F higher than the measured temperatures.

Table 3 Comparison of Test Conditions for 9x9 and ATRIUM-10 Spray Tests

7.0 Conclusions

Comparisons of FCTF spray cooling test data and HUXY code rod temperature predictions show that the application of the Appendix K prescribed spray heat transfer coefficients results in conservative predictions of rod temperatures for the ATRIUM-10 design. The comparisons of data results from the previous 9x9 spray cooling tests (Reference 3) with the ATRIUM-10 results also substantiate data trends and the conservatism of application of the Appendix K coefficients. Therefore, the test results demonstrate the acceptability of the Appendix K coefficients for use during the spray cooling period of LOCA analyses for jet pump BWR plants with ATRIUM-10 assemblies.

8.0 References

1. XN-CC-33(P)(A) Revision 1, "HUXY: A Generalized Multirod Heatup Code with 10CFR50 Appendix K Heatup Option User's Manual," November, 1975.

2. EMF-CC-102(P) Revision 1, "HUXY: A Generalized Multirod Heatup Code with 10CFR50 Appendix K Heatup Option User's Manual," February 10, 1999.

3. ANF-CC-33(P)(A) Supplement 2, "HUXY: A Generalized Multirod Heatup Code with 10CFR50 Appendix K Heatup Option User's Manual," February, 1991.

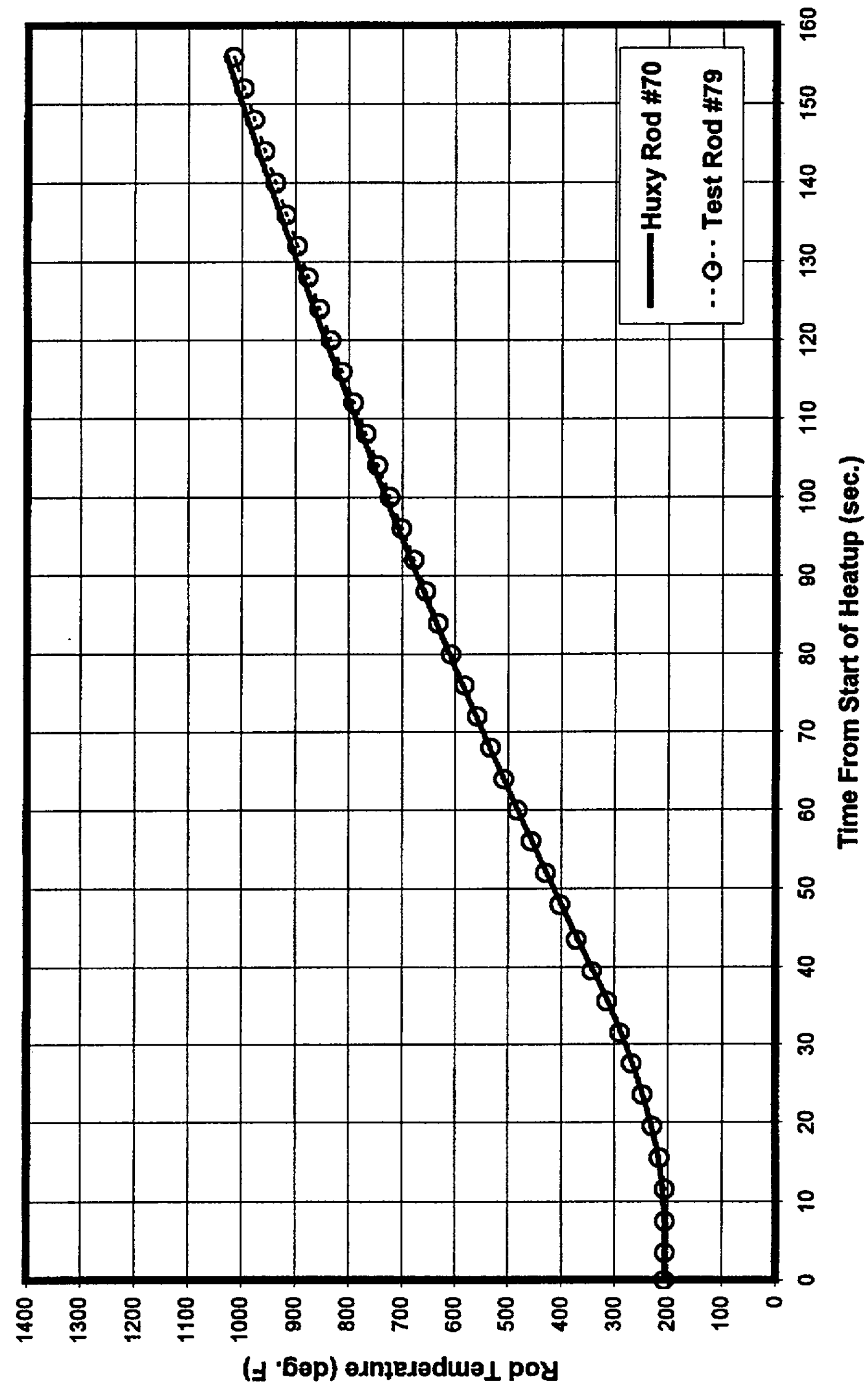


Figure 1 Test 59 – Adiabatic Heat-up Comparison – 65 Inch Elevation

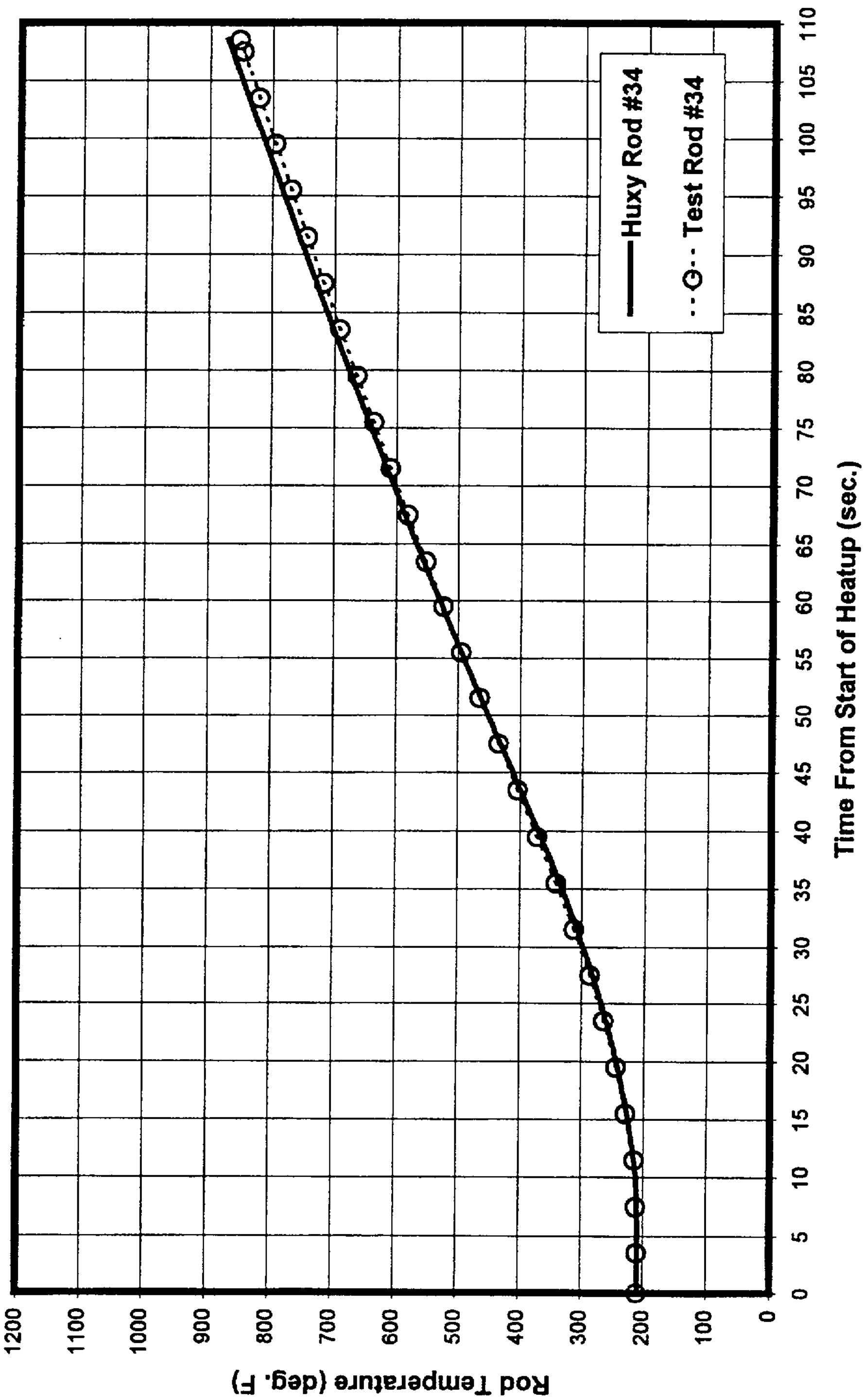


Figure 2 Test 63 – Adiabatic Heat-up Comparison – 85 Inch Elevation

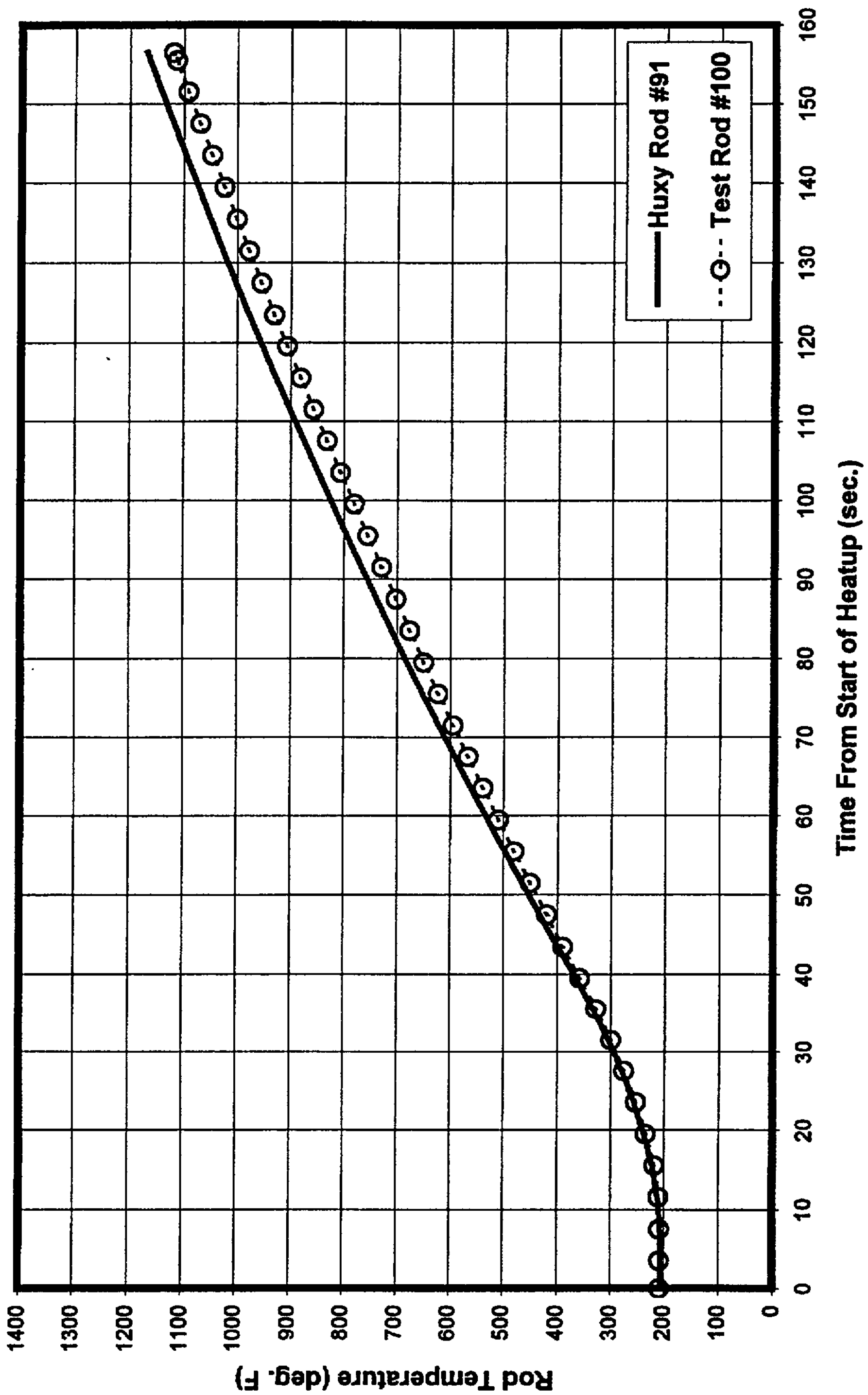


Figure 3 Test 66 – Adiabatic Heat-up Comparison – 105 Inch Elevation

Figure 4 Test 91 – HUXY – Test Data Comparison – 65 Inch Elevation

Figure 5 Test 57 – HUXY – Test Data Comparison – 65 Inch Elevation

Figure 6 Test 58 – HUXY – Test Data Comparison – 65 Inch Elevation

Figure 7 Comparison of BWR3 - 9x9 and 10x10 Spray Results

Figure 8 Comparison of BWR4 - 9x9 and 10x10 Spray Results

Figure 9 Comparison of BWR5/6 - 9x9 and 10x10 Spray Results

Figure 10 Test 69 – HUXY – Test Data Comparison – 65 Inch Elevation

Figure 11 Test 78 – HUXY – Test Data Comparison – 65 Inch Elevation

Figure 12 Test 90 – HUXY – Test Data Comparison – 85 Inch Elevation

Figure 13 Test 66 – HUXY – Test Data Comparison – 105 Inch Elevation

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