XN-NF-929(NP)(A)

ANF-929(NP)(A)
Supplements 1, 2, 3 &4

XN-NF-929(NP)(A)
Correspondence

ADVANCED NUCLEAR FUELS CORPORATION

Spray Heat Transfer Coefficients for Jet Pump BWR Fuel Assemblies with Water Rods

March 1992

XN-NF-929(NP)(A)

ANF-929(NP)(A)
Supplements 1, 2, 3 &4

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Correspondence

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SPRAY HEAT TRANSFER COEFFICIENTS FOR JET PUMP BWR FUEL ASSEMBLIES WITH WATER RODS

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XN-NF-929(NP)(A)

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XN-NF-929(NP)(A) CORRESPONDENCE	LETTERS FROM R.A. COPELAND, REFERNCED IN XN-NF-929(P)(A)

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

December 6, 1991

Mr. R. A. Copeland
Manager, Reload Licensing
Advanced Nuclear Fuels Corporation
2101 Horn Rapids Road
P. O. Box 130
Richland, Washington 99352-0130

Dear Mr. Copeland:

SUBJECT: ACCEPTANCE FOR REFERENCING OF TOPICAL REPORT XN-NF-929(P), AND SUPPLEMENTS 1 THROUGH 4, "SPRAY HEAT TRANSFER COEFFICIENTS FOR JET PUMP BWR FUEL ASSEMBLIES WITH WATER RODS" (TAC NO. M63183)

The U.S. Nuclear Regulatory Commission (NRC) staff has completed its review of the Advanced Nuclear Fuels Corporation (ANF) licensing topical report XN-NF-929 and its Supplements 1 through 4, "Spray Heat Transfer Coefficients for Jet Pump BWR Fuel Assemblies with Water Rods."

The staff finds the report to be acceptable for referencing in licensing applications to the extent specified and under the limitations delineated in the report and the associated NRC evaluation (Enclosure 1). The evaluation provides the basis for accepting the report.

The staff will not repeat the review of the matters described in the report and found acceptable when the report appears as a reference in licensing applications, except to ensure that the material presented is applicable to the specific plant involved. The staff's acceptance applies only to the matters described in the report.

Following the procedures established in NUREG-0390, "Topical Report Review Status," the staff requests that ANF publish an accepted version of this report with the review questions and answers within 3 months of receiving this letter. The accepted version shall incorporate this letter and the enclosed evaluation after the title page. The accepted version shall include an "-A" (designated accepted) following the report identification symbol.

Sincerely,

Ashok C. Thadani, Director
Division of Systems Technology
Office of Nuclear Reactor Regulation

Enclosure:
XN-NF-929 Evaluation

ENCLOSURE 1

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION
RELATING TO SPRAY HEAT TRANSFER COEFFICIENTS FOR
ANF 9X9 FUEL ASSEMBLY ARRAYS FOR BWR CORES

The Advanced Nuclear Fuels Corporation (ANF) proposed a set of convective heat transfer coefficients in the topical report XN-NF-929 and in Supplements 1 through 4 to that report for Boiling Water Reactor (BWR) 9x9 fuel assembly arrays under spray cooling conditions. ANF submitted topical report XN-NF-929 and its supplements for the U.S. Nuclear Regulatory Commission (NRC) to review and approve as a part of a licensing method for a large break loss-of-coolant accident (LOCA) analysis. The NRC received technical assistance from the Idaho National Laboratory (INEL) under contract FIN-D6030 (Project 4) in reviewing the topical report. The NRC has reviewed the technical evaluation report (TER), which is included in Appendix A of this safety evaluation report (SER). The staff concurs in the recommendations made by INEL and finds that the proposed convective heat transfer coefficients in the topical report XN-NF-929, Supplement 1, are acceptable as a part of a licensing method for a large break LOCA analysis under the following conditions:

1. The proposed convective heat transfer coefficents can be used only in the evaluation of the ANF 9x9 fuel rod array geometry with the upper tie plate configuration described in References 2 and 3 of the attached TER.

2. Additional supporting information must be provided to justify the continued use of the proposed coefficiants if applications occur such that the assumptions, or boundary conditions for the tests and supporting analytical computations described in References 3 through 8 of the attached TER do not bound the coolant conditions calculated by the ANF-approved emergency core cooling system (ECCS) evaluation model.

3. The proposed convective heat transfer coefficients can be used only for those plants with rod power levels bounded by assumptions in Table 2.1 of Reference 3 of the attached TER and axial power shapes bounded by the top-peaked and bottom-peaked power distributions defined on pages 6, 7 and 8 of Reference 6 in the attached TER. Otherwise, additional justification is needed to support the continued use of the proposed heat transfer coefficients for BWR ECCS licensing analyse the ANF 9x9 rod bundle array.

4. If the heat transfer coefficients are used for non-jet pump BWR applications and if the peak local oxidation is more limiting at locations other than the peak power position, additional justification will be needed for using the constant convective heat transfer coefficients in predicting peak local cladding oxidation. The other restrictions above should also be addressed.

The staff reviewed the ANF's submittals and INEL's TER and concludes that the proposed convective heat transfer coefficients specified on page 3 of Reference 3 in the attached TER are acceptable for use in large break LOCA analyses and licensing applications when the conditions stated above are satisfied.

TECHNICAL EVALUATION REPORT

ANF PROPOSED BWR CONVECTIVE SPRAY HEAT TRANSFER COEFFICIENTS

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L. W. Ward

September 1991

EG&G Idaho, Inc.
Idaho Falls, Idaho 83415

Prepared for the
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
Under DOE Contract No. DE-AC07-76ID01570
FIN No. D6030, Project 4

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ABSTRACT

The Advanced Nuclear Fuels (ANF) Corporation has proposed a set of convective heat transfer coefficients for Boiling Water Reactor 9 X 9 fuel assembly arrays under spray cooling conditions. ANF has undertaken an experimental program in conjunction with supporting analyses to identify a bounding set of spray cooling convective heat transfer coefficients for use in performing Emergency Core Cooling System (ECCS) licensing performance analyses for Boiling Water Reactors. The ANF proposed convective spray cooling heat transfer coefficients are to be used for the ANF 9 X 9 rod assembly arrays. The proposed heat transfer coefficients represent an increase in value relative to those recommended in Appendix K to 10CFR50.46, which are pertinent to 7 X 7 rod arrays.

A review of the document entitled, "Spray Heat Transfer Coefficients for Jet Pump BWR Fuel Assemblies with Water Rods," XN-NF-929(P), was performed. This document provided a description of the test facility, test data, and methods for establishing a bounding set of coefficients to be used for Boiling Water Reactor ECCS licensing calculations. Following this initial review and request for additional information, ANF reevaluated their test data and performed additional analyses to make corrections to their initial proposed set of convective heat transfer coefficients. The modified set of convective heat transfer coefficients was then reviewed and following a second series of requests for additional information, ANF performed additional analyses to establish the bounding nature of the coefficients. The subsequent supporting analyses performed by ANF, demonstrated that the modified set of ANF proposed convective spray heat transfer coefficients corrected previous deficiencies and were shown to bound pertinent test data and important plant initial operating conditions. Based on the review contained in this Technical Evaluation Report, it is recommended that the modified set of convective heat transfer coefficients be considered for performing Boiling Water Reactor ECCS licensing analyses for the ANF 9 X 9 fuel rod assembly arrays.

SUMMARY

This Technical Evaluation Report presents a review and evaluation of the Advanced Nuclear Fuels (ANF) Corporation proposed convective heat transfer coefficients for use in performing ECCS licensing evaluations of Boiling Water Reactor performance. ANF proposes to use the heat transfer coefficients during the spray cooling phase of the Loss of Coolant Accident (LOCA) analysis of Boiling Water Reactors (BWR) with 9 x 9 fuel rod assembly arrays. The purpose of this report is therefore to present the results of the review of supporting experimental data, analyses, and responses to requests for additional information provided by ANF to justify the proposed convective heat transfer coefficients.

Review of the ANF documentation describing the test facility, test conditions and test results presented in ANF-929(P) identified several deficiencies. ANF reevaluated their data and proposed a new set of modified coefficients in ANF-929(P) Supplement-1. This new set of proposed convective coefficients corrected the previous deficiencies, however additional information documented in ANF-929(P) Supplements 2, 3, and 4 was provided by ANF to present the additional analytical support needed to justify the bounding nature of the modified set of coefficients. Supplement 2 provided justification for the range of applicability for the coefficients, while Supplements 3 and 4 along with some supporting analyses were necessary to show that the proposed coefficients bounded the variations in axial power distributions.

Based on technical evaluation and review contained herein, it is recommended that the modified set of convective spray cooling heat transfer coefficients proposed by ANF be accepted for ECCS licensing analyses of Boiling Water Reactors with ANF 9 X 9 fuel assembly arrays.

TECHNICAL EVALUATION REPORT

ANF PROPOSED BWR CONVECTIVE SPRAY HEAT TRANSFER COEFFICIENTS

1. INTRODUCTION

The cooling rate of fuel rods during the spray period of a Boiling Water Reactor (BWR) loss of coolant accident (LOCA) is governed by the combination of radiation and convection heat transfer at the fuel rod surface. The methodologies used by the Advanced Nuclear Fuels (ANF) Corporation to calculate the axial and radial fuel rod temperature-time behavior following a LOCA have the ability to also compute the radiation portion using basic first principles, however the convective heat transfer coefficient used in the analytical tools are input as constants based on experimental data. Appendix K of 10 CFR 50.46 contains recommended convective spray cooling heat transfer coefficients, which were obtained from the BWR-FLECHT program of Reference 1, but are based on a 7 x 7 rod bundle geometry with no water rods. Figure 1, attached, shows the values of the convective coefficients recommended by Appendix K applied to a 9 x 9 rod bundle with two water rods on the diagonal and for the four basic positions in the bundle. These four basic bundle positions include: rods in the four corners, rods in the outer row, all other rods, and the canister wall. Question marks are indicated in Figure 1 for the water rods since the values for these locations will also need quantification.

To calculate the energy removal rate at a fuel rod surface by convection, the convection heat transfer coefficient, once determined is then multiplied by the difference between the rod surface temperature and a reference coolant sink temperature. The Appendix K recommended values for the convection heat transfer coefficients are based on use of the coolant saturation temperature as the reference temperature. In reality, this reference temperature is the coolant channel steam temperature so that both the actual steam temperature and the magnitude of the channel fluid flow rate govern the rate of heat removal due to convective cooling. To determine a bounding value of the convective heat transfer coefficients for the four basic rod positions described above, with particular interest in the value for the water rod , ANF conducted a series of experiments.

The experimentally determined coefficients were then used by ANF as input to the HUXY code to perform fuel rod heatup calculations as part of the methodology to determine peak clad temperature following LOCA conditions for BWRs employing the ANF 9 X 9 rod bundle arrays. In addition to the convective heat transfer coefficient, the HUXY code also requires bundle geometry, surface emissivities, material properties, and power to name a few. The HUXY code computes the radiant energy removal rate and then adds the convective portion to obtain the total energy removal rate at all axial locations along the rod.

ANF performed spray cooling tests for 9 x 9 rod bundle arrays to arrive at a proposed set of coefficient values, including the water rods, to be used for BWR ECCS licensing performance analyses. The documentation describing the tests and results is presented in Reference 2. Based on these tests, ANF recommended heat transfer coefficients to be applied to bundles containing water rods and identified these coefficients in Reference 2 for replacing the values given in Figure 1. Following a review of the test hardware, test conditions, and recommended heat transfer coefficient values, deficiencies in the heater rod m[illegible]ing technique and heater rod material properties assumed in the ANF analys[illegible] were identified and brought to the attention of the ANF staff following the initial review. In addressing these deficiencies and in response to additional requests for additional information, ANF reevaluated their data and proposed a modified set of heat transfer coefficients and presented the new values on page 3 of Reference 3. This modified set of heat transfer coefficients represented a 30% reduction in the values proposed earlier in Reference 2. Following the review of the Reference 3 modified set of coefficients, [illegible]ew requests for additional information were issued for justification for the range of applicability of the heat transfer coefficients that would be encountered during application to a BWR ECCS licensing analyses. The response to this request was documented in Reference 4. The request for additional information also included the need to justify applicability of the modified set of heat transfer coefficients to the range of allowable variations in axial power distribution. As a consequence, ANF performed analyses using the COBRA-TF code to identify the variation in convective heat transfer coefficient due to power shape and documented their responses in

References 5, 6, 7, and 8. These requests were necessary since the test data developed in the Reference 2 experimental program was based on a cosine axial power distribution only, while allowable BWR operating conditions can include axial power shapes skewed toward either the top or bottom of the active core.

The remainder of this Technical Evaluation Report documents the review, evaluation and approval of the material described above for establishing a bounding set of convective heat transfer coefficients for ECCS analysis of the ANF 9 X 9 fuel rod bundle arrays. Section 2 below provides a brief description of the test facility, while Section 3 discusses the resolution of pertinent issues raised during the review process. Section 4 presents the restrictions for using these new spray cooling heat transfer coefficients while Section 5 presents a summary of the conclusions.

2. TEST DESCRIPTION

ANF constructed a test facility known as FCTF for determining the fuel rod convective heat transfer coefficients during LOCA conditions for the period of time following activation of the core spray. As described in Reference 2, the facility consisted of an electrically-heated full length 9 x 9 rod bundle array surrounded with a canister located inside a thermal shield. The heater rods contained boron nitride to insulate the resistance coil windings from the stainless steel rod cladding material. The resistance windings in the rods were stepped to approximate a chopped cosine power distribution. Two hollow heater tubes were placed in the middle of the bundle to represent water rods. During some tests, power was disconnected to four heater rods to simulate a bundle with six water rods. Thirty-one tests were performed simulating two water rods in the bundle while four tests were conducted containing six water rods. Forty-five of the eighty-one rods along with the canister wall included thermocouples attached at several elevations.

A boiler was connected to the lower plenum to preheat the system and supply steam upflow during the test to simulate lower plenum flashing and steam generation from the lower plenum internals. A coolant injection system supplied spray water to the upper plenum, the outside of the canister, and the lower plenum. The test matrix included tests with various combinations of cooling flows applied to the bundle.

A computer was used to control the test parameters such as power and flow as well as record the measured data. The majority of the tests utilized a power curve based on the 1971 ANS standard decay heat curve increased by 20%. The bundle pressure was only slightly above atmospheric to simulate the low pressure conditions experienced during the period of time when the core spray is activated following a LOCA.

To quantify the choice of the convective heat transfer coefficient at the different rod bundle locations, the HUXY code was executed with a range of constant input convective heat transfer coefficients necessary to predict the test data rod surface temperatures at selected locations along the rod. The

HUXY code computes the convective cooling component based on the information input to the code and then adds this energy removal rate to the radiation heat transfer to compute a total energy removal rate. With the appropriate convective coefficient and the planar radiation modelling technique, HUXY can then compute the fuel rod cladding surface temperature.

A summary of the review and evaluation of the ANF responses to selected requests for additional information is provided in the following section.

3. REVIEW OF THE ANF PROPOSED HEAT TRANSFER COEFFICIENTS AND RESPONSES TO THE REQUESTS FOR ADDITIONAL INFORMATION

This section presents a summary of the documentation presented in References 2 through 8. The review of the original test data and supporting analytical analyses presented in Reference 2 identified several deficiencies and as a consequence, additional information and analyses were requested to justify the initial set of convective heat transfer coefficients. Upon re-evaluation of the Reference 2 data, ANF proposed modifications to the coefficients to correct the deficiencies and documented their results in Reference 3. The modified values were then reviewed and the ANF responses to the requests for additional information and analyses were documented in the supplementary reports presented in References 4 through 8. This section summarizes the review of with the ANF responses given in these documents. The review concurs with the ANF responses, unless otherwise noted.

REVIEW OF THE ANF RESPONSE TO THE REQUESTS FOR ADDITIONAL INFORMATION PROVIDED IN REFERENCE 2

This section presents a brief discussion of the ANF responses to the requests for additional information regarding the test facility, test conditions, and test data documented in the Reference 2 ANF experimental program to quantify convective heat transfer coefficients for the ANF 9 X 9 rod bundle array. The ANF responses for several selected topics of importance are categorized by subject in the various sub-section headings identified below.

3.1 Heat Transfer Coefficients Around the Water Rod

Enhanced cooling may be expected for rods that share a common fluid sub-channel with a water rod since the steam would tend to be cooler in such channels. Of the eight rods surrounding a water rod shown in Figure 1, four rods have two sub-channel quadrants in common with the water rod while the remaining four rods on the diagonal have only one sub-channel quadrant in common with the water rod. As such, it may not be appropriate to assign a convective coefficient with the values defined in Reference 2 for the four diagonal rods which is the same value used to simulate the convective coefficient for the other four rods, since they are only cooled by only one sub-channel. ANF stated that although the diagonally opposed rods are not cooled as well as the regularly opposed rods, the value proposed in Reference 2 is still considered sufficiently conservative to bound the conditions at all of these rod locations.

3.2 Heat Transfer Coefficients at Other Elevations

During the period prior to bottom reflood, spray from the upper plenum can penetrate the upper tie plate and flow downward through the bundles. One would expect the heat transfer coefficients to be larger near the top of the bundle because the water will be vaporized as it flows downward. Reference 2 discussed the heat transfer at the bundle midplane only, also noting that Appendix K does not address axial variations in the heat transfer rate when using the Appendix K recommended values. ANF was asked to check data below the midplane bundle elevation to confirm that the recommended convective coefficients would be acceptable at all elevations. Upon further investigation, ANF demonstrated that the 60 and 48 inch bundle elevation temperatures were also over predicted, so use of the single value was appropriate at these other elevations.

It is important to also note that Figure 2.7 from Reference 2 suggests that if Test 110 had not been terminated at 193 seconds, HUXY may not have been conservative at the 48-inch elevation, however these spray only tests are now considered to be outside of the representative data base and can therefore be excluded from consideration.

3.3 Power and Temperature Uncertainties

In response to questions regarding power and measured rod temperature uncertainties, ANF replied that the temperature uncertainty was 5.2°F at

2000°F while the power uncertainty was 3.3 kW at 318 kW. ANF stated that these uncertainties are bounded by the modified convective coefficients proposed in Reference 3.

Additional requests for information from the review of Reference 2 identified the need to address all uncertainties in the data. ANF modified the originally proposed coefficients and addressed the uncertainty issue in Reference 3 discussed below.

REVIEW OF THE ANF RESPONSE TO THE REQUESTS FOR ADDITIONAL INFORMATION PROVIDED IN REFERENCE 3

Reference 3 discusses the results of the reevaluation of the spray test data results and documents the ANF response to the additional requests for information. A summary of the ANF responses given in Reference 3 is discussed below.

3.4 Fuel Rod Model Used to Predict the Data

Audit heatup calculations of Test 110 using the correct material properties and more appropriate heater rod modelling technique suggested that the HUXY material properties and input model should be examined. Because the audit calculations showed that clad temperature was underpredicted, it was also recommended that the ANF proposed heat transfer coefficient of Reference 2 be reduced. As a consequence, ANF reviewed the HUXY code calculations and made appropriate modifications. These ANF corrections consisted of increasing the HUXY code boron nitride density in addition to including, in the HUXY model, the effect of the heater coil located inside the boron nitride region. ANF also reduced the convective heat transfer coefficient to the values given on page 3 of Reference 3.

3.5 Spray Rates Used in the ANF Tests

The Appendix K recommended heat transfer coefficient value of 1.5 Btu/hr-ft^2-°F where based on GE data presented in Reference 1 which used spray rates of approximately 2.5 gpm. ANF has proposed a coefficient with a value, listed as Item 2 on page 3 of Reference 3, based on their data which utilized a spray rate of approximately 10 gpm. When questioned ANF stated that there is sufficient ECC water to give each fuel bundle a rate of between 16 and 23 gpm, based on bounding calculations using the ANF Evaluation Model. The original BWR-FLECHT data collected by GE in Reference 1 used a low spray value because at that time the SSTF data supporting the buildup of a pool of liquid above the top of the core was not available. The SSTF data shows that a water level of about 10 inches develops in the upper plenum which causes the water to be distributed to the central bundles regardless of the spray nozzle angles, spray profiles, and spray rates. This is due to the fact that as long as the spray rate is in excess of the water downflow rate, a water pool will develop in the upper plenum just above the top of the core. Excess water will flow into the bypass region. Since the water downflow rate into the bundle from this pool is limited by the upward steam flow, this counter-current flow condition limits the magnitude of the liquid which enters the bundle. As such, all bundles, including the central bundles, experience a water downflow rate that is basically insensitive to the spray flow rate.

3.6 Uncertainty Analysis

Justification for the convective heat transfer coefficients to be used for ECCS licensing analyses should take into account uncertainties. When questioned, ANF responded that uncertainties such as power, emissivity and temperature would not be meaningful because spray and steam updraft flow rates dominate the test results, and the test flow rates were chosen to be conservative in nature rather than best estimate. Furthermore, the choice of the steam flow and spray rates bound the uncertainty in the parameters input to the HUXY code.

REVIEW OF THE ANF RESPONSE TO THE REQUESTS FOR ADDITIONAL INFORMATION PROVIDED IN REFERENCES 4, 5, 6, 7, and 8

Additional requests for information and supporting analyses were requested of ANF to demonstrate that these newly proposed coefficients bounded the range of expected conditions following a LOCA. The applicability of the heat transfer coefficients to a range of expected conditions following a LOCA was justified and provided in Reference 4. Lastly, since the test conditions used to develop the proposed set of coefficients was based on a single cosine axial power distribution, ANF needed to demonstrate that their choice of heat transfer coefficients bounded the coefficients that could result from the variation in axial power shapes that could occur in BWR systems during power operation. As such, ANF performed additional analyses using the COBRA-TF code to study the variation in convective heat transfer coefficient for a range of axial power distributions. Since the Reference 5, 6, and 7 analyses stated the variation in heat transfer coefficient was negligible, of particular concern was the fact that the amount of water assumed to be entrained in the steam flowing through the bundle was too high. This excessively high entrainment rate, when used to assess the sensitivity to power shape, resulted in underpredicting the peak clad temperature by 200 °F at the peak power location for Test 820 shown in Reference 7. When questioned ANF performed a final set of sensitivity studies choosing an entrainment rate which captured the test data peak clad temperature response for Test 820. This final sensitivity study was documented in Reference 8 and is of particular importance since changes in axial power shape was shown to strongly influence the convective heat transfer coefficient. Moreover, this study showed that when the appropriate entrainment rate is used, a 25% reduction in the convective heat transfer coefficient can occur at the limiting rod position (i.e. hot spot) due to changes in axial power distribution. This evaluation does not agree with the ANF Reference 8 contention that "the convective heat transfer coefficient is not very sensitive to axial power shape" since the 25% reduction in heat transfer coefficient, illustrated in Figure (2) of Reference 8 is considered quite significant. More importantly, the ANF choice of the minimum convective coefficient, listed as Item 2 on page 3 of Reference 3, remained bounding with respect to the test data, since the minimum heat transfer coefficient calculated in the Reference 8 sensitivity analysis was found to be approximately 12% higher when the appropriate entrainment rate was employed in the calculations. ANF also stated that comparisons with other test data would not change the conclusions based on the evaluations given in the References 6, 7, and 8 since Test 820 utilized the most conservative boundary conditions. These boundary conditions bounded the coolant and other pertinent conditions calculated by the ANF approved ECCS Evaluation Model during the spray cooling period of the LOCA so that comparisons to other less limiting tests were not necessary.

ANF also stated that while the use of the proposed convective heat transfer coefficients will result in a conservative predictions of fuel rod peak cladding surface temperature, the choice of the proposed constant minimum heat transfer coefficients of Reference 3 will also result in a bounding calculation of peak local clad oxidation at the peak power position for the axial shapes assessed in Reference 8. For jet pump BWR applications, ANF stated that use of the proposed heat transfer coefficients would result in a bounding calculation for local clad oxidation at all positions along the rod since the clad temperature data for TEST 820 was similarly bounded. Additional justification would be needed for local oxidation for non-jet pump BWR applications.

Based on the review of the ANF spray heat transfer test data, analyses, and responses to the request for additional information documented in References 2 through 8, it is recommended the convective spray heat transfer coefficients proposed be accepted for licensing evaluations assessing BWR ECCS performance for the ANF 9 X 9 fuel rod bundle arrays. These coefficients are identified on page 3 of Reference 3.

4. RESTRICTIONS

Since the choice of the convective heat transfer coefficients depend on several important parameters established by the ANF bundle geometry, choice of the test parameters, supporting analysis assumptions, and limiting conditions for plant operation, a list of restrictions regarding the use of the proposed coefficients is given below.

1. The use of the convective heat transfer coefficients shall be limited to only evaluations of the ANF 9 x 9 fuel rod array geometry with the upper tie plate configuration and associated pertinent geometries described in References 2 and 3.

2. Should applications or changes occur such that the assumptions, pertinent inputs and/or boundary conditions for the tests (and/or supporting analytical computations) described in References 3 through 8 no longer bound the coolant conditions calculated by the ANF approved ECCS Evaluation Model, then additional supporting information will be needed to justify the continued use of the proposed coefficients.

3. The use of the proposed convective heat transfer coefficients are limited to those plants with rod power levels bounded by the Reference 3, Table 2.1 assumptions and axial power shapes bounded by the top and bottom peaked power distributions defined in Reference 6 on pages 6, 7, and 8. That is, should plant axial power distributions occur with axial peaking factors which are more skewed toward the top or bottom of the active core than those presented in Reference 6 (or should a more limiting shape or rod

previously evaluated), then additional justification using the methods of Reference 6 will be needed to support the continued use of the proposed heat transfer coefficients for BWR ECCS licensing analyses of the ANF 9 X 9 rod bundle array.

4. If the heat transfer coefficients are used for non-jet pump BWR applications and should peak local clad oxidation be more limiting at locations other than the peak power position, then additional justification for use of the constant convective heat transfer coefficient in prediciting peak local cladding oxidation will be needed. The other restrictions above would also need to be addressed as well.

Restriction 4 is based on the fact that the test program and supporting analytical evaluations established convective heat transfer coefficients for the purpose of determining the peak clad temperature. While the limiting oxidation position is usually located at or near the vicinity of the peak power position, peak local clad oxidation can in some instances occur elsewhere along the rod. As such, the location of the peak local oxidation could occur at rod locations where use of the constant convective coefficient, which is bounding for peak clad temperature assessments at the peak power position, may not be bounding for local oxidation.

5. CONCLUSIONS AND RECOMMENDATIONS

A review of the ANF proposed convective heat transfer coefficients for use in performing ECCS licensing analyses of the ANF 9 X 9 fuel rod bundle array was performed. The results of the review demonstrates that the minimum convective heat transfer coefficient, identified as Item 2 on page 3 of Reference 3, results in fuel rod axial surface temperatures which bound the pertinent test data and results. ANF has provided adequate justification for using the proposed spray cooling heat transfer for analyzing fuel rod heatup in ANF 9 x 9 BWR fuel bundles following a hypothetical loss-of-coolant accident. These coefficients are intended for use in performing ECCS licensing analyses during the period of time following a LOCA when the core spray has been activated. The set of spray cooling convective heat transfer coefficients recommended for approval in this Technical Evaluation Report are identified on page 3 of Reference 3.

These coefficients were chosen to bound the effects of the variation in coolant conditions predicted by the currently accepted ANF LOCA ECCS Evaluation Model in addition to accounting for the variation in axial power distribution that is allowed to occur in BWRs utilizing the ANF 9 X 9 fuel bundle during power operation.

6. REFERENCES

1. General Electric Company, Heat Transfer in a Simulated BWR Fuel Bundle Cooled by Spray Under Loss-of-Coolant Conditions, GEAP-13086, June 1970.

2. EXXON Nuclear Company, Spray heat Transfer Coefficients For Jet Pump BWR Fuel Assemblies With Water Rods, XN-NF-929(P), September 1986.

3. Advanced Nuclear Fuels Corporation, Answers to Questions Posed by the Nuclear Regulatory Commission Staff and Consultants on the Advanced Nuclear Fuels BWR 9x9 Spray Cooling Period Heat Transfer Coefficients, ANF-929(P) Supplement 1, April 1988.

4. Advanced Nuclear Fuels Corporation, Evaluation of Range of Applicability of Heat Transfer Coefficients Proposed for 9X9 BWR Fuel, ANF-929(P) Supplement 2, May 1989.

5. Advanced Nuclear Fuels Corporation, Answers to Further Questions Posed by the Nuclear Regulatory commission Staff and Consultants (May 1989) on the ANF BWR 9X9 Spray Cooling Period Heat Transfer Coefficients, ANF-929(P) Supplement 3, August 1989.

6. Advanced Nuclear Fuels Corporation, Answers to Further Questions Posed by the Nuclear Regulatory Commission Staff and Consultants (November 1989) on the ANF BWR 9X9 Spray Cooling Period: Evaluate the Effect of Changed Axial Power Distribution, ANF-929(P) Supplement 4, December 1990.

7. Letter from R. A. Copeland (ANF) to B. K. Sun (USNRC), Response to Questions on ANF-929(P) Supplement 4, April 10, 1991.

8. Letter from R. A. Copeland (ANF) to B. K. Sun (USNRC), Response to Questions on ANF-929(P) Supplement 4, July 9, 1991.

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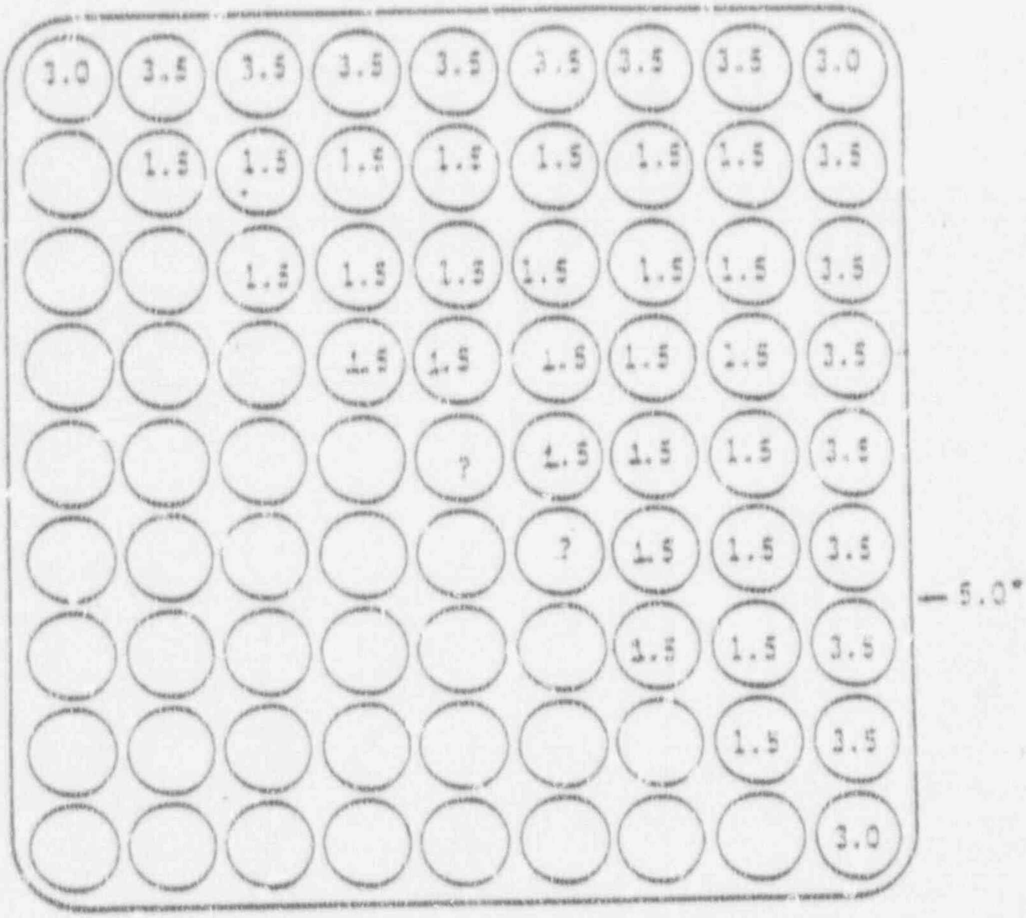

Coefficient Units are BTU/hr-ft^2-°F

*Each side of the canister has a coefficient of 5.0.

Figure 1. Appendix K specified convective heat transfer coefficients applied to a 9 x 9 rod bundle with two water rods.

XN-NF-92 ,NP)(A)

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SPRAY HEAT TRANSFER COEFFICIENTS FOR JET PUMP BWR
FUEL ASSEMBLIES WITH WATER RODS

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EXXON NUCLEAR COMPANY, INC.

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XN-NF FOO-786 (7/80)

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SPRAY HEAT TRANSFER COEFFICIENTS FOR JET PUMP BWR FUEL ASSEMBLIES WITH WATER RODS

1.0 INTRODUCTION

The EXEM[1] BWR ECCS evaluation model, which is based upon phenomenological representations, was benchmarked against simulated reactor data covering a variety of fuel designs, and received generic NRC approval[2] for application to jet pump BWR plants. Confirmatory tests verified EXEM's applicability to 9x9 fuel[3]. However, a more accurate assessment of the spray heat transfer coefficients for Exxon Nuclear Company's (ENC) 9x9 fuel design has resulted from spray cooling tests. This document describes essential features of spray cooling tests and presents analysis with HUXY[4] which is the part of EXEM[1] used for fuel heatup analysis. The heatup analysis uses spray heat transfer coefficients to model the heatup during the spray cooling period of a LOCA.

Appendix K of 10 CFR 50.46 provides values for spray heat transfer coefficients. Inspection of the data on which Appendix K spray heat transfer coefficients are based (5) shows that the test program used a 7x7 array with no passive water rods. Appendix K and the NRC approval of HUXY[4] affirm that modifications to the spray heat transfer coefficients may be made with appropriate data supporting the modifications. ENC justified the use of the 7x7 coefficients for 8x8 fuel in references[6-8] and further justified the use of 7x7 coefficients for 9x9 fuel in reference[3]. This report justifies the improved spray heat transfer related to water rod presence during the spray heat transfer period.

This report describes Exxon Nuclear's experimental and computational programs which justify the above enhanced spray heat transfer coefficients

2.0 SUMMARY

An experimental test program was conducted with ENC's Fuel Cooling Test Facility (FCTF) to determine the effect of water rods on spray heat transfer coefficients for adjacent heater rods. The FCTF electrically heated prototypical fuel assembly tests simulated ENC's 9x9 fuel design in a jet pump application.

The tests were numerically simulated with HUXY. Measured quench rates were conservatively predicted with a wet side heat transfer coefficient on the passive water rod

The spray heat transfer coefficient ahead of the quench front on the passive water rods was conservatively represented

. For heated rods adjacent to passive water rods, a spray heat transfer coefficient yields conservative predictions shown in Figure 2-1. These values were found to provide conservative predictions for all of the tests that were evaluated with HUXY and are considered applicable for 8x8 and 9x9 fuel analysis. In this regard these values are independent of test parameters. As a result of the tests and post-test analyses, the values listed below are recommended for EXEM ECCS licensing calculations of jet pump BWR plants with ENC's 8x8 and 9x9 fuel assemblies. These justified spray heat transfer coefficients adequately represent heat transfer, while maintaining reasonable conservatism, within a bundle during the initial period of rated spray.

	Spray Coefficient (BTU/hr-ft^2-$^\circ$F)
Corner rods	
Side rods	
Rods adjacent passive water rods	
Interior rods	
Passive water rods	
Channel (each side)	

* These rods are treated the same as side rods.

** These rods are treated the same as the channel.

Page 2-3 has been deleted.

3.0 TEST FACILITY DESCRIPTION

Exxon Nuclear Company has designed and constructed the Fuel Cooling Test Facility (FCTF) to determine the hydrodynamic and heat transfer performance of ENC fuel during the reflood portion of a postulated LOCA. Data gathered during FCTF testing is used to support analytical models and correlations which are used in heatup and reflood analyses. The facility is capable of simulating jet pump and non-jet pump BWR conditions, as well as PWR conditions. A schematic of the facility as used in jet pump BWR testing is shown in Figure 3.1.

Of principal interest to the facility is the single electrically heated test fuel assembly. For tests described in this report, the test fuel assembly is prototypic of ENC's 9x9 fuel design, although the facility can be used to test other fuel designs. The test fuel assembly is housed within a canister as shown in a cross-section view in Figure 3.2. The channel and thermal shield outside the canister effect boundary conditions on the assembly typical of those found in a reactor.

Other components of FCTF include instrumentation, coolant injection system, a water treatment system, a mass balance system, interconnecting pipes and valves, an AC power supply, and a computer system for data acquisition and process control.

Pages 3-3 to 3-7 have been deleted.

4.0 TEST MATRIX

The FCTF test matrix for jet pump BWRs is summarized in Table 4.1. Other significant test parameters were temperature, power, and coolant flow rates.

The patterns of passive rods designated, These figures display the local relative power distribution for each rod. Passive rods are those with zero power. Test rods are numbered across from the upper left. Figure 4.1 shows the location in the assembly. The water rods are are collectively referred to as passive rods, i.e., those rods generating zero power.

In Table 4.1, initial temperature and initial power are target values. Initial conditions in each test were established in a preheat phase when a sensor indicated that a target value was reached. The spray test was initiated when one of the measured temperatures reached the initial temperature. For low initial temperature tests, the power would continue to rise until it matched the decay power level prescribed for the test through the data acquisition and control system. When the target temperature is reached, other measured rod temperatures at that plane are scattered due to dependence on local power.

Table 4.1 indicates three target values of power.

Typical power decay curves are shown in Figure 4.3 for high power (test 110) and medium power (test 1270) tests. Test 110 used the 1971 ANS + 20% power decay curve while test 1270 simulated more realistic conditions with the 1979 ANS power decay curve. Most testing was done with the ANS + 20% power decay. Test series 12xx was programmed to track the 1979 ANS power decay curve.

Pages 4-3 to 4-6 have been deleted.

5.0 HUXY DESCRIPTION

Exxon Nuclear Company uses the EXEM computational model to perform ECCS licensing calculations for nuclear reactor fuel reloads for both jet pump and non-jet pump BWR plants. EXEM consists of four codes: RODEX2 for stored energy, RELAX for blowdown phenomena, FLEX for refill/reflood phenomena, and HUXY for fuel heatup analysis. During simulation of the spray cooling period of a postulated LOCA, HUXY uses spray heat transfer coefficients to predict peak clad temperature (PCT). The FCTF tests of ENC's 9x9 fuel design with passive rods simulated this spray period. By initializing HUXY with the test parameters at the onset of spray, the spray heat transfer coefficients are established by conservative prediction of test PCTs.

A HUXY analysis provides predicted transient rod temperatures at the plane of interest. It is assumed that the plane of interest is the assembly hot plane. At the plane of interest the energy equation is solved for each rod at each time step. The applied energy equation is

$$\frac{\partial}{\partial t}(\rho C T) = \frac{1}{r}\frac{\partial}{\partial r}\left(k r \frac{\partial T}{\partial r}\right) + q''' \tag{1}$$

with the boundary condition at the surface being

$$-k \left.\frac{\partial T}{\partial r}\right|_{r=R} = q_{rad} - q_{MWR} + q_{conv} \tag{2}$$

Rod-to-rod and rod-to-canister thermal radiation is computed

View factors are computed by the

Emissivities are

assigned to all dry surfaces and wetted surfaces. The inverse radiation matrix is calculated by the code

. Since radiation exchange depends on rod and canister surface temperatures, solution of rod temperatures at each time step involves iteration of the boundary condition.

Each rod exchanges heat with the fluid by an effective convection heat transfer coefficient which accounts for both convection and rod-to-fluid radiation.

6.0 HUXY MODEL

Selected test runs were modeled with HUXY. Each simulation required an input model defining code control, model parameters, test assembly description, and test conditions.

Code control defines simulation time, time step size, output point frequency, plot parameters, etc.

Model parameters are defined in Table 6.1. Spray heat transfer coefficient assignments are shown

A number of test assembly parameters are the same for all selected tests.

Test conditions refer to boundary conditions, initial conditions and bundle power. The boundary condition for each rod includes convection and radiation heat sources. The steam temperature seen by the rods and canister for convection was input in HUXY.

Pages 6-3 to 6-8 have been deleted.

7.0 RESULTS

From the FCTF tests identified in Table 4.1, were selected analysis. The selected tests are summarized in Table 7.1. The selected tests provide a representation

It was on these criteria that the tests were selected for analysis.

For this reason the set of spray heat transfer coefficients are defined by analysis of a select group of tests.

Excess spray results in water accumulation in the upper plenum.

Further review of measured PCT in Table 4.1 indicates, as would be expected, a strong dependence on imposed steam flow and bypass leakage. Should a LOCA occur in a jet pump BWR, it is expected that a large inventory of water will be in the lower plenum at the time of spray and flash to steam as pressure decays. This steam generation in the lower plenum is expected to cause steam upflows much greater than those applied in the tests. Those tests exhibiting zero imposed steam flow are substantially conservative because even modest steam upflows are seen to reduce peak temperatures by hundreds of degrees. In some cases this reduces the heatup from initial temperatures by as much as half.

7.1 Temperatures

In a postulated LOCA in a jet pump BWR, reflood is expected to limit PCT after spray initiation. Therefore, comparison of temperatures between test data and HUXY predictions is of interest primarily within this time frame. To establish the conservative quality of the specified spray heat transfer coefficients it is only necessary that HUXY overpredict the peak measured temperatures during this portion of the transient.

Comparison of measured and predicted peak temperatures is shown in Figure 7.1. The bar graph not only indicates peak temperatures but also the heatup relative to initial temperatures. A tabulation of data and predictions is given in Table 7.2.

The transient temperature response of the test rod exhibiting the PCT is shown in Figures 7.2 through 7.10. The HUXY prediction of the peak temperature transient is shown for comparison.

Figures 7.11 through 7.19 show predicted versus measured rod temperatures on a rod-to-rod comparison. The comparisons are taken at the times indicated in the figure titles.

These results support acceptance of the proposed spray heat transfer coefficients.

7.2 Spray Heat Transfer and Quench on Passive Rods

The spray heat transfer coefficient on passive rods is assigned a value of in the HUXY model. The wet-side heat transfer coefficient on passive rods is assigned a value of in the HUXY model, . Acceptability of these coefficients depends on conservative temperature and quench predictions by HUXY

Pages 7-5 to 7-31 nave been deleted.

8.0 CONCLUSIONS AND RECOMMENDATIONS

The essential features of the test results and analyses show:

With regard to EXEM ECCS licensing calculations for jet pump BWR's, conservative predictions are obtained by:

- Using a spray heat transfer coefficient of on heater rods adjacent to water rods,
- Using a spray heat transfer coefficient of on water rods,
- Using a wet-side heat transfer coefficient of . on water rods and heater rods, and
- Using of spray heat transfer coefficients on other rods and the canister.

These values are applicable to a HUXY simulation of the spray heat transfer heatup transient in a postulated LOCA for a jet pump BWR.
Other conditions of the model described in this report must also be consistently applied.

9.0 REFERENCES

1. R. E. Collingham, "Exxon Nuclear Methodology for Boiling Water Reactors, Volume 2, EXEM: ECCS Evaluation Model Summary Description," XN-NF-80-19(P), Volume 2, Exxon Nuclear Company, September 1980.

2. Safety Evaluation Report by the Office of Nuclear Regulatory Regulation on the Exxon Nuclear Company EXEM: ECCS Evaluation Model for Conformance to 10 CFR 50, Appendix K by the Office of Nuclear Reactor Regulation, December 1981.

3. "Exxon Nuclear Company Jet Pump BWR Refill and Reflood Fuel Cooling Test Program for 9x9 Fuel," XN-NF-84-59, Revision 1, June 1986.

4. "HUXY: A Generalized Multi-Rod Heatup Code With 10 CFR 50 Appendix K Heatup Option - User's Manual," XN-CC-33(A), Revision 1, Exxon Nuclear Company, November 1975.

5. "Heat Transfer in a Simulated BWR Fuel Bundle Cooled by Spray Under Loss-of-Coolant Conditions," GEAP-13086, General Electric Co., San Jose, CA, June 1970.

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

7. Exxon Nuclear Company, "Spray Cooling Heat Transfer Test Results Phase 2 Facility and Test Data ENC 8x8 BWR Fuel," XN-NF-78-12, May 1979.

8. Exxon Nuclear Company, "Spray Cooling Heat Transfer Phase 1 Test Results ENC 8x8 BWR Fuel 60 and 65 Active Rods," XN-NF-75-36, September 1975.

9. E. M. Sparrow and R. D. Cess, Radiation Heat Transfer, Belmont, CA, Brooks/Cole, 1966.

10. W. H. McAdams, Heat Transmission, New York, McGraw Hill Book Company, Inc., 1954.

11. J. D. Kahn and L. H. Steves, "2DQ, A Two Dimensional Rewetting Model, XN-74,25, Revision 1, October 30, 1974.

ADVANCED NUCLEAR FUELS CORPORATION

ANF-929(NP)(A)
Supplement 1
Issue Date 4/5/89

ANSWERS TO QUESTIONS POSED BY THE NUCLEAR REGULATORY COMMISSION STAFF AND CONSULTANTS ON THE ADVANCED NUCLEAR FUELS BWR 9X9 SPRAY COOLING PERIOD HEAT TRANSFER COEFFICIENTS

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February 1989

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ANF 3145.629A (4/86)

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ACKNOWLEDGEMENTS

I take this opportunity to acknowledge the following contributions to the lators into this document: Dr. R. B. MacDuff performed the test work; Mr. Carl Wheeler (Numerical Applications, Inc.) executed the HUXY comparisons and prepared the data comparisons and engineering notebooks; Mr. Larry Wiles (Numerical Applications, Inc.) prepared the HUXY input decks, code updates to treat the test fuel assembly design, and preliminary data comparisons. Mr. D. M. Turner provided detailed review and verification of the HUXY treatment and input deck; Mr. J. G. Ingham prepared the model applications discussions; Dr. D. S. Rowe (Rowe & Associates) performed the Evaluation Model test conditions predictions; Messrs. D. R. Swope, D. F. Richey, D. M. Turner, and Dr. B. Vaishnavi performed quality assurance verification of data comparisons; Mr. J. A. Bryant plotted final figures; Ms. Sue Allen prepared the final document.

1.0 INTRODUCTION

The Exxon Nuclear Company (now Advanced Nuclear Fuels Corporation, ANF) submitted a report documenting heat transfer performance of BWR 9x9 fuel types during simulated LOCA conditions. The results from tests were submitted in the report Spray Heat Transfer Coefficients for Jet Pump BWR Fuel Assemblies with Water Rods[1] (Note: References are located at the end of each section). The fuel types tested represent a range of water rods likely to be used in current and future fuel designs. All other aspects of design were identical. fuel types are intended to operate at the same bundle power. The report was reviewed by the Nuclear Regulatory Commission Staff and consultants. Several questions and concerns were identified. These arose from meetings and telephone conversations with the NRC staff and consultants on September 30, 1988, November 9, 1987, and October 28, 1987.

This report documents the spray heat transfer coefficients that should be used with the ANF 9x9 BWR fuel designs. The submittal of these coefficients is in response to paragraph D.6 of Appendix K, which requires that "following the blowdown period, convective heat transfer shall be calculated using coefficients based on appropriate experimental data."

The experiments were conducted under conditions appropriate to the BWR LOCA spray cooling period as calculated by the Advanced Nuclear Fuel EXEM BWR ECCS Evaluation Model (EM). Figures 1.1 through 1.6 present results for Evaluation Model calculations

No model treatments are revised in changing fuel types, only code input as would be appropriate for plant and fuel specific changes. Therefore, the use of coefficients appropriate to the 9x9 fuel types is a change in fuel type not LOCA/ECCS model.

Each section of this document addresses a concern/question posed in the aforementioned communications. These are summarized in the Table of Contents.

2.0 SUMMARY

In response to questions/concerns mentioned in the Introduction, ANF undertook a reevaluation and reanalysis of the data. The reevaluation supports the following heat transfer coefficient (HTC) groups and convective heat transfer coefficients for ANF 9x9 fuel types:

different rod heat transfer groups were analyzed, and Evaluation Model (EM)[2] comparisons with the data for each of the groups are presented. Selection of the above heat transfer set yields a reasonably uniform bound of data appropriate to the event after the time of rated spray. time of rated spray is a bounding maximum time to reflood appropriate to the ANF EM. The heat transfer coefficients are referenced to as local fluid temperatures are not generally defined.

One important feature of the test and analysis program is the conclusion reached regarding the convective heat transfer.

2.1 Overview of Test Program

Pages 4 to 9 have been deleted.

Section 2.0 References

1. Spray Heat Transfer Coefficients for Jet Pump BWR Fuel Assemblies with Water Rods, XN-NF-929(P), September 1986.

2. Exxon Nuclear Methodology for Boiling Water Reactors EXEM BWR ECCS Evaluation Model, XN-NF-80-19(P)(A), Volumes 2, 2A, 2B, 2C, September 1982.

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

3.0 RESULTS OF REANALYSIS OF THE TEST DATA

ANF has reanalyzed the data using a fuel rod simulator model. All heater rod components have been represented in the analysis, and the density of Boron Nitride dielectric reflects as built conditions. The rod heat transfer coefficient distribution used in analysis of the two configurations is presented in the Figure 3.1.

Key aspects of the reanalysis are cited below and parameters used in the HUXY rod model are presented in Table 3.1:

1. Boron Nitride density was revised.

2. Test normalized axial power used in the analysis was revised to as built of . Rod bundle local normalized power distribution was revised to the actual tested.

3. The maximum temperature history of each of heat transfer groups for tests All other tests are of equal or lesser challenge and analysis would show equal or greater bound. The attached maximum temperature plots (Figures 3.2 through 3.6) illustrate the relative challenge of tests within each test series confirming the above assertion. The tests applicable to the heat transfer coefficient data base and test matrix are shown in Table 2.1. Finally, data comparison

4. The HUXY code is compared to preheat "adiabatic heat up" test data proper rod modeling, power, and input. (Please see Section 8.0 for further discussion of confirmation of the heater rod model.)

5.

6. Conservatism in the analysis of the data is assured by the following assumptions:

The results of the analysis are summarized in Table 3.2, "Summary of HUXY Comparisons to 9x9 BWR Test Data." Figures 3.7 through 3.154 present results for each test elevation analyzed as summarized in the table.

There are five categories of underprediction of the data as is shown in Table 3.2. These are:

Pages 13 to 16 have been deleted.

4.0 RELATIONSHIP OF THE CONVECTIVE HEAT TRANSFER COEFFICIENTS TO THE EM

The ANF LOCA/ECCS Evaluation Model (EXEM)[1] has been reviewed and approved[2] by the NRC as being in accordance with the requirements of Appendix K. The ANF LOCA/ECCS Evaluation Model is composed of several computer codes and documentation which are used as described in Figure 4.0 and references to this section.

For LOCA analysis purposes, the ANF BWR EXEM methodology can be visualized as two parallel calculations, a system calculation, and a fuel or heatup calculation. The system calculation considers the core as an average and calculates the transient boundary conditions on the core resulting from a postulated LOCA. The heatup calculation determines the response of the individual fuel rods in the maximum power fuel assembly to the imposed system boundary conditions resulting from LOCA. As indicated in Figure 4.0, the BWR EXEM methodology further subdivides the two parallel LOCA calculations into three LOCA time periods: (1) blowdown, (2) refill or spray cooling, and (3) core reflood. The spray period heat transfer coefficients are used only in the refill portion of the fuel heatup calculation of the BWR EXEM model. Specifically, the coefficients are included in the input to the HUXY calculation for the refill portion of the transient. HUXY uses spray heat transfer coefficients from the time of rated LPCS injection to time of hot node reflood (taken from FLEX). These coefficients are to be applicable for the fuel design being licensed. The coefficients listed in Appendix K are appropriate for 7x7 fuel designs.

Following the time of hot node reflood, the Appendix K reflood heat transfer coefficient (25 BTU/hr-Ft^2-F) is used. HUXY/BULGEX output is the peak clad temperature (PCT) and maximum fraction of clad oxidation.

Section 4.0 References

1. Exxon Nuclear Company, "Exxon Nuclear Methodology for Boiling Water Reactors," Volume 2, XN-NF-80-19(P)(A), Revision 1, June 1981.

2. Safety Evaluation Report on the ENC EXEM: ECCS Evaluation Model for Conformance to 10 CFR 50, Appendix K by the Office of Nuclear Reactor Regulation, December 1981.

3. Exxon Nuclear Company, "RODEX2, Fuel Rod Thermal-Mechanical Response Evaluation Model," XN-NF-81(P)(A), Supplements 1 & 2, Revision 2, March 1984.

4. Exxon Nuclear Company, "RELAX: A RELAP4 Based Computer Code for Calculating Blowdown Phenomena," XN-NF-80-19(P), Volume 2A, May 1980.

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

6. Exxon Nuclear Company, "BULGEX: A Computer Code to Determine the Deformation and the Onset of Bulging of Zircalloy Fuel Rod Cladding," XN-74-21, Revision 2, December 31, 1974/XN-74-27, Revision 2, December 31, 1974.

7. Safety Evaluation by USNRC on RELAP4-EM/ENC 28B, (ENC letter dated October 30, 1978), forwarded by NRC letter from T. A. Ippolito to W. S. Nechodom, March 30, 1979.

8. Exxon Nuclear Company, "FLEX: A Computer Code for the Refill and Reflood Period of a LOCA," XN-NF-80-19(P), Volume 2B, May 1980.

9. Exxon Nuclear Company, "Spray Heat Transfer Coefficients for Jet Pump BWR Fuel Assemblies with Water Rods," September 1985.

10. 10 CFR Part 50, Appendix K, ECCS Evaluation Models, Code of Federal Regulations, January 4, 1984.

5.0 TEST DATA APPROPRIATE TO THE DATA BASE FOR DETERMINATION OF CONVECTIVE HEAT TRANSFER COEFFICIENTS

ANF has removed from the data base submitted as basis for determining heat transfer performance of the 9x9 fuel.

The tests in the heat transfer coefficient data base are identified in Table 2.1.

This selection is supported by the phenomena description in the NRC Compendium report[1] which describes the ECCS heat transfer phenomena during the post-blowdown period in a BWR. Under single failure conditions, the following occurs:

a. The bypass region rapidly fills with ECC and the bypass fluid enters the bottom of the core in countercurrent flow through the bypass region coolant holes in the lower tie plate and channel to tie plate seals. Due to steam updraft from lower plenum venting, the bypass fluid is retained in the fuel assembly for cooling.

b. The lower plenum continues to depressurize and fluid contained in the lower plenum continues to boil off resulting in significant steam updraft through the core.

c. The upper plenum rapidly fills with subcooled ECC to the level of the spray spargers. The subcooled ECC condenses the steam exiting the core and some liquid flows countercurrent through the upper tie plate to cool the assembly from the top. In the peripheral region where the fuel assemblies are "tightly orificed," and the ECC is more subcooled, the condensation of steam exiting the upper tie plate is sufficient to suppress steam updraft and these fuel assemblies transition within about 10 seconds to a co-current downward flow resulting in a ready means to convey fluid to the lower plenum.

d. The balance of the core transitions into countercurrent and co-current upwards flow regimes. The heat transfer coefficient never drops below 20 BTU/hr-ft2-F. The countercurrent flow assemblies rapidly refill with ECC from the bypass region while the co-current upwards assemblies remove most of the steam from the lower plenum while entraining the bypass leakage to cool the fuel.

The ANF tests modeled

appropriate to this scenario with an electrically heated test fuel assembly. ANF concludes that the test data reported reasonably bounds the coolant conditions calculated by its approved EM, and therefore provides adequate basis for the proposed convective heat transfer coefficients. (Please see Section 10.0 for further discussion.)

Section 5.0 Reference

1. Compendium of ECCS Research for Realistic LOCA Analysis, NUREG-1230, December 1988.

6.0 STEAM UPFLOW RATES FROM THE ANF ECCS EM FOR JET PUMP BWR (EXEM)

Analysis with the ANF BWR EM (Reference 1) was performed for the limiting break for BWR 3, 4, and 5/6 plants.

These are reported in Section 10.0. ANF concludes that the test data reported reasonably bounds the coolant conditions and therefore provides adequate basis for the proposed convective heat transfer coefficients.

Section 6.0 References

1. Exxon Nuclear Methodology for Boiling Water Reactors EXEM BWR ECCS Evaluation Model, XN-NF-80-19(A), Volumes 2, 2A, 2B, 2C, September 1982.

7.0 CONFIRMATION OF THE VALUE OF THERMAL EMISSIVITY USED IN THE DATA EVALUATION

Steady state heating tests were performed on an 8x8 test fuel assembly fabricated of the same materials as for the 9x9 test. These results were documented and submitted to the NRC for review and approval. Based on the tests and analysis, ENC (Exxon Nuclear Company) and the NRC concluded that a value of thermal emissivity of   is appropriate for use. These results are summarized below.

Advanced Nuclear Fuels Corporation (previously, Exxon Nuclear Company) conducted BWR FLECHT type tests in the ANF owned Fuel Cooling Test Facility (FCTF) during 1975. The results of the tests were reported in XN-75-36.(1) The tests were conducted with a full sized BWR 8x8 fuel assembly with nonuniform axial heating. The objective of the tests were to verify the applicability of the Appendix K 7x7 heat transfer coefficients to 8x8 fuel types for non-jet-pump BWR without imposed downdraft. The testing confirmed that the referenced heat transfer coefficients were conservative to the data.

Several tests were run in the test program to verify the value of the thermal emissivity   used in the data analysis. The tests and analysis confirmed that a value of   is appropriate for use.

Two test series, with the heated assembly at nearly steady-state conditions of 1400 and 1600 F (nominal) peak rod temperature were conducted with two tests each. An analysis of the resulting emissivity data was performed which resulted in an estimate of the average value of thermal emissivity   additional analysis of sensitivity of calculated PCT to measured PCT was performed with two values of emissivity. These results are reported in Supplement 1 to XN-75-36.

The results of the tests are summarized in Table 7.1 (Table 1.1 of Supplement 1 of XN-75-56):

TABLE 7.1 AVERAGE INDICATED EMISSIVITY

The results show that use of a value of thermal emissivity in reduction of the test data to heat transfer coefficients is justified.

The sensitivity of predicted PCT with emissivity was also evaluated and compared to test results for of the referenced 8x8 (XN-75-36) tests. The sensitivity calculation used emissivity of . The referenced Appendix K heat transfer coefficients were used in the calculations. The predicted PCT was compared to measured PCT The results are summarized in Table 7.2 (Table 1.2 of Supplement 1 of XN-75-36):

TABLE 7.2[a] PEAK TEMPERATURE COMPARISONS[b]

These results indicate that the sensitivity to emissivity is small, and that the PCT was conservatively predicted. As the emissivity increased with bundle age (consistent with increased oxidation of surfaces with age) and the measured average emissivity is from .66 to .71, a value of .67 is appropriate for use in data reduction.

Section 7.0 References

1. Spray Cooling Heat Transfer Phase 1 Test Results ENC-8x8 BWR Fuel 60 and 63 Active Rods, XN-75-36.

2. Appendix K to 10CFR50.46, (39 FR 1003), Paragraph I.D.6.b., January 4, 1974.

3. Spray Cooling Heat Transfer Phase 1 Test Results ENC - 8x8 BWR Fuel 60 and 63 Active Rods, Interim Report, XN-75-36, Supplement 1, Exxon Nuclear Company, October 1975.

8.0 EVALUATION OF UNCERTAINTIES

Instrumentation is calibrated prior to and during the test program. The rod temperature measurement thermocouples and power measurement are of particular importance since they provide the direct gage of relevance to the Appendix K acceptance criteria. Other measurements

to which the temperature data has reduced sensitivity and the data has some variance. As the range of test parametric variables can be expected to conservatively bound the uncertainties of these variables, the parametric variables need be known to a lesser precision and an uncertainty evaluation of parametric variables is not necessary.

All fuel assembly and inert componant thermocouples are lot calibrated as per standard RDT-C7-6T

Power is measured by six watt transducers which are calibrated by using precision voltage and resistance measurements.

In order to verify the HUXY code fuel thermal model used in the data evaluation, adiabatic heat-up calculations were performed for the test preheat period and compared to data . Results of the analyses as well as power input to the code are presented

The preheat period is the time during which the test fuel assembly is brought up to the desired initial temperature. There is no significant coolant introduced to the facility during this time. Normally, a purging steam flow is introduced to preserve the steam atmosphere. The preheat period is therefore nearly adiabatic and the temperatures are low enough that radiant energy exchange is a small part of energy input and is analyzed as such with HUXY accounting for only radiant energy exchange, power input, and rod thermal capacitance.

Adequate margin exists in the data and analysis to comfortably accommodate any additional convolution of test and calculational uncertainties.

Heat up calculations similar to those performed were performed for in order to verify rod locals and power group power for The final results are presented in Figures 8.15 through 8.21.

Another problem in data interpretation was noted. The bundle hardware had aged to the point where the six and eight foot thermocouples were covered by the six and eight foot spacers for the tests.

The test data was conservatively analyzed. The power used in the analysis of the power groups which exhibited poor correspondence was reduced such that the temperature of the lowest temperature thermocouple in that power group is not over-predicted. This assures a conservative interpretation of the data.

The conservative interpretation of the test data results in the analyses reasonably bounding the expected behavior. Therefore, the analysis includes an appropriate consideration of the uncertainties and no further application of penalties is needed.

9.0 EFFECT OF PRESSURE DEPENDENT CORE FLOW RATE AND AFFECT ON CORE SPRAY

The rate at which ECCS water would be sprayed into the upper plenum during a LOCA depends on the ECCS design and the pressure in the upper plenum. The fraction of the injected ECCS water which flows downward through a fuel bundle depends on factors such as counter-current-flow. As discussed further in Section 10.0, CCFL limitations produce a pool of water in the upper plenum. This pool of water provides a source of coolant to the fuel bundles which is not affected by core spray over time as long as rated spray is maintained.

The primary concern of small breaks is that the pressure might not drop low enough for the low pressure ECCS systems to become active until a long time after the mixture level drops below the top of the core. This is not a concern for the proposed BWR spray heat transfer coefficients for two reasons. The first reason is because BWRs have an Automatic Depressurization System (ADS). ADS is the ECCS which opens the safety/relief valves in order to increase the rate of depressurization so the low pressure ECCS can become effective. The second reason is because spray heat transfer coefficients are not used in ANF LOCA methodology until after the pressure has decreased sufficiently for the low pressure core spray to achieve its rated flow rate.

10.0 VERIFICATION OF THE TEST MATRIX

The test matrix is based on ANF Jet Pump BWR EM calculations for BWR 3, 4, and 5/6 yielding the range of bundle power and maximum rod temperature at

the refill period. The results of the calculations performed are presented in Figures 1.1 through 1.6, and in Table 10.1.

Historically, BWR FLECHT tests conservatively simulated upper plenum ECC injection. The minimum spray flow per channel was approximately 3.25 gpm. Later tests conducted in the Steam Sector Test Facility (SSTF) and Japanese Eighteen Degree Sector Test (ESTA) demonstrated that with prototypic core steam updraft, the upper plenum ECC accumulated in the upper plenum resulting in a pool of liquid above the core which assured distribution of ECC to all assemblies. Thus, the historic basis for BWR FLECHT type tests was shown to be abundantly conservative and a more appropriate basis is to develop the pool of fluid above the test assembly upper tie plate.

The ANF tests simulate appropriate test conditions by apportioning sufficient ECC liquid in the test vessel upper plenum and bypass leakage

Analysis of hydraulic test results shows that the method of ECC injection in the ANF tests reasonably obtained conditions observed in larger scale tests, further confirming the test matrix. Reference ' describes results of selected SSTF tests. It is noted in the discussion of Test SRT - 3 (26)

(Reference system transient test) that a residual level of water (10 inches collapsed level) is established in the upper plenum (which should assure all assemblies receive coolant). The conductivity element readings in the vicinity of the HPCS sparger indicate that the upper plenum two-phase level resides at the elevation of the HPCS spargers. The pool of water is reported to develop very early (approximately 10 sec).

The Compendium (Reference 5, Page 6.5-12) notes: "A residual amount of liquid always remained in the upper plenum whenever the spray flow exceeded CCFL limited drainage through the core. This residual liquid remained even after CCFL breakdown and drainage of the bulk of upper plenum liquid. Liquid could therefore flow to the tops of the fuel channels regardless of the distribution of the spray over the tops of the channels."

. The cooling conditions used in the tests are bounded by the EM calculations because an Appendix K heat transfer coefficient of 25 BTU/hr-ft^2-F is appropriate at time of significant entrainment at the plane of interest. The test data clearly show higher initial steam updraft results in greater cooling (see Figures 3.2 through 3.6 for relative challenge of tests and Table 2.1 for test conditions). Therefore, the test conditions are conservative relative to the EM conditions.

Therefore, the higher spray is appropriate and develops cooling boundary conditions appropriate to EM assumptions in accord with the requirements of Appendix K.

Page 35 has been deleted.

Section 10.0 References

1. BWR Refill-Reflood Program Task 4.8 - TRAC-BWR Model Qualification For BWR Safety Analysis, Final Report, Md. Alamgir, NUREG/CR-2571, October 1983.

Compendium of ECCS Research for Realistic LOCA Analysis, NUREG-1230, December 1988.

11.0 VARIATION OF CONVECTIVE HEAT TRANSFER COEFFICIENT WITH AXIAL LOCATION

Convective heat transfer was analyzed

as permitted by instrumentation availability. The HUXY calculation with the proposed heat transfer coefficients reasonably bounds the data

12.0 BASIS FOR THE PROPOSED ROD HEAT TRANSFER GROUPING

The analysis examined heat transfer groups. The peak rod temperature within each group at each edit time during the analysis are compared. Thus, the test PCT rod along with other rod groups is captured for the comparison. The rods within each heat transfer group are collected according to rod location:

This grouping results in reasonable bounding of all powered rods distributed through the rod array.

13.0 THE EFFECT OF CORE SPRAY DISTRIBUTION WITH ANF FUEL

The Compendium of ECCS Research[1] discusses the core spray distribution with respect to ECCS heat transfer. The discovery of the difference of spray angle from spray sparger nozzles between steam or air resulted in substantial research into core spray distribution. The General Electric tests conducted in steam, air and finally the SSTF confirmed that all assemblies receive a significant fraction of design spray flow. However, more importantly, the SSTF tests showed that a pool of water rapidly develops above the core due to the CCFL at the upper tie plates and the copious water injected into the upper plenum. The tests showed that even when the peripheral assemblies transition to co-current downflow (siphoning off ECC to lower plenum) a residual pool of collapsed minimum liquid level of 10 inches water remained thus assuring that all assemblies received the maximum flow that upper tie plate CCFL would permit. The Compendium concludes that this phenomenon should be considered during any reevaluation of spray distribution for licensing calculations.

The ANF designed upper tie plate area for flow is similar to that of the fuel it replaces to maintain hydraulic compatibility. The area for flow is the principal parameter in calculating the counter current flow. Thus, the counter current flow behavior at the upper tie plate/upper plenum interface will be nearly the same regardless of fuel type.

Section 13.0 References

1. Compendium of ECCS Research for Realistic LOCA Analysis, NUREG-1230, December 1988.

Pages 41 to 140 have been deleted.

ADVANCED NUCLEAR FUELS CORPORATION

ANF-929(NP)(A)
Supplement 2
Issue Date: 5/3/89

EVALUATION OF RANGE OF APPLICABILITY OF HEAT TRANSFER COEFFICIENTS PROPOSED FOR 9X9 BWR FUEL

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April 1989

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1.0 INTRODUCTION

Supplement 1 of this report documents the heat transfer coefficient set for ANF 9x9 fuel designs with water rod(s). This heat transfer coefficient set is to be used during the spray period cooling of LOCA/ECCS analysis for boiling water reactors. The coefficients were established based on comparison of the spray period fuel heat up code, HUXY, to rod group temperature history for most limiting and appropriate tests.

To verify that the spray fluid heat transfer coefficients are applicable over the range of parameters that would be encountered in an application analysis, this document examines the difference between the HUXY predictions and test data to determine if there are any trends which may indicate reduction in conservatism over the proposed range of application. The results of the work show that the coefficients are appropriate over the full range of applicability.

2.0 THE ANALYSIS METHOD

The range of initial test conditions, and BWR LOCA/ECCS Evaluation Model (EM) range of conditions at time of rated spray are presented in Table 10.1 of Supplement 1 of ANF-929(P). Review of this table indicates that the proposed heat transfer coefficients should be justified for higher initial rod temperature and bundle power. The following evaluation provides this justification. The evaluation performed are analyses of the trends and scatter in the prediction of the test data. These analyses and the conservatism in the data, and application of the data support the use of the revised heat transfer coefficients over the full range of the ANF Evaluation Model application.

In the accepted ANF Evaluation Model (EM), the HUXY code treats rod power, rod temperature, and thermal radiative heat transport at the plane of interest in the fuel assembly. The "convective" coefficients are defined as the residual heat transport in excess of the fuel rod thermal radiative energy balance as calculated by HUXY when compared to appropriate test data. The convective coefficients are input to the code and assumed to be constant from the time of rated spray to the time of significant entrainment at the plane of interest. The test data provides basis for the appropriate set of "convective" heat transfer coefficients. The power, temperature, and the thermal radiative fraction of rod heat transport are included in the EM treatment. The remaining fraction of the rod heat transport is treated using the "convective" coefficients. The question, therefore, to be addressed is to demonstrate the "convective" heat transfer is conservative such that there is no reduction in the margin outside the test conditions. This question is addressed by analyzing the data trends and scatter in relation to the range of application.

The "goodness of prediction" of the test data together with relevant independent test variables are presented in Table 1. The HUXY predictions of the test data are evaluated by quantifying the temperature difference (Td) of the prediction and test data for all tests predicted. A positive Td indicates a bounding or conservative prediction.

3.0 RESULTS

The data presented in Table 1 are graphically presented in

Pages 5 to 6 have been deleted.

Therefore, the use of the convective heat transfer coefficients proposed in Supplement 1 to ANF-929(P) are appropriate and conservative over the entire range of test data. Furthermore, use of the heat transfer coefficients at initial temperature and power higher than the range used in the tests is appropriate because of the conservative trend in prediction of the data and physical phenomena, and no limitation need be placed on the application in this regard.

Pages 8 to 25 have been deleted.

ADVANCED NUCLEAR FUELS CORPORATION

ANF-929(NP)(A)
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ANSWERS TO FURTHER QUESTIONS POSED BY THE NUCLEAR REGULATORY COMMISSION STAFF AND CONSULTANTS (MAY 1989) ON THE ADVANCED NUCLEAR FUELS CORPORATION BWR 9X9 SPRAY COOLING PERIOD HEAT TRANSFER COEFFICIENTS

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2.0 COMPARISON OF 8X8 AND 9X9 FUEL RESPONSE FOR A BWR 6

Figure 2.1 shows results of a heat up analysis performed using the Advanced Nuclear Fuels Corporation approved LOCA/ECCS evaluation model.[a] The Figure compares the spray period heat up response for ANF 8x8 and 9x9 fuel types for the limiting (DEG/RD, C_D=1; 8x8-2, 9x9-5 fuel) break. The 8x8 heat up analysis used heat transfer coefficients approved by the USNRC for use for BWR 8x8 fuel (Reference a). The 9x9 analysis used the heat transfer coefficients proposed for 9x9 fuel as described in ANF-929(P), Supplement 1.[b] Local power peaking, rod heat transfer grouping, etc., appropriate for each fuel design are used in the analysis.

Figure 2.1 shows the limiting rod temperature rise from time of rated spray for each fuel type. The lower curve is for the 9x9 fuel.

Reflood related cooldown is shown for the 8x8 fuel

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[a]Exxon Nuclear Company, Exxon Nuclear Methodology for Boiling Water Reactors, XN-NF-80-19(P)(A), Volumes 2, 2A, 2B, 2C, September 1982.

[b]Advanced Nuclear Fuels Corporation, Answers to Questions Posed by the Nuclear Regulatory Commission Staff and Consultants on the Advanced Nuclear Fuels BWR 9x9 Spray Cooling Period Heat Transfer Coefficients, ANF-929(P), Supplement 1, February 198?.

It should be noted that the fuel temperature during the blowdown period would be expected to be different for the two fuel types. The principal cause is the reduction of linear heat generation rate (LHGR) in 9x9 fuel rod design when compared with the 8x8 design. This reduction in LHGR results in reduced stored internal energy and average fuel temperature. For example, an 8x8 design with 144 inch active fuel length with the fuel assembly operating at 6 MW, full power, and containing two water rods (62 active rods), the average linear heat generation rate is 8.06 kW/ft. A 9x9 fuel assembly with five water rods, 6 MW power, 144 inch length would have average liner heat generation rate of 6.58 kW/ft. Thus, initial stored energy of the 9x9 fuel design would be approximately 80% of the 8x8 design fuel and resultant lower fuel temperature.

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3.0 ANSWER TO QUESTION 1

What is the effect of the axial power shape on the heat transfer coefficients? Would different axial power shapes affect PCT or have an adverse impact on any hot spots? Should this effect be considered in the evaluation since the plant limiting axial power shapes may differ from that used in tests to develop the spray heat transfer coefficients?

The HUXY code[a] treats internal power generation and thermal radiation at the axial plane of interest and therefore accounts for axial power distribution. Fuel rod and channel quench are also axially dependent in the approved ANF Evaluation Model (EM). The proposed convective heat transfer coefficients do not change with change in elevation (consistent with the 7x7 Appendix K and ANF approved 8x8 heat transfer coefficients). The effect of axial location and bundle power on the convective heat transfer coefficient set is examined in Supplement 2.[b] The analysis shows

The bounding minimum margin[d] of the EM prediction of the test data is maintained as is shown in Supplement 2. As shown, the HUXY prediction with the proposed spray heat transfer coefficients bound the data for all of the elevations and powers. As discussed in

[a]HUXY: A Generalized Multirod Heatup Code with 10 CFR 50, Appendix K Heatup Option User's Manual, XN-CC-33(A), Revision 1, November 1975.

[b]Evaluation of Range of Applicability of Heat Transfer Coefficients Proposed for 9x9 BWR Fuel, ANF-929(P), Supplement 2, April 1989.

[c]Answers to Questions Posed by the Nuclear Regulatory Commission Staff and Consultants on the Advanced Nuclear Fuels BWR 9x9 Spray Cooling Period Heat Transfer Coefficients, ANF-929(P), Supplement 1, April 1989.

[d]Note: "margin" is defined as the difference between the HUXY/EM prediction of the test data and the test data. Positive margin is for an overprediction.

Supplement 1, the coefficients were established to bound the test with the most conservative conditions. Thus, the EM calculation adequately accounts for changes in axial power distribution as described above. The lack of sensitivity of convective heat transfer to elevation may be explained by the fluid probably remaining near saturation conditions because of the two-phase flow, the interphasic mass and heat transfer, and the flow probably being dispersed. With these conditions, the transport properties and fluid velocity are not significantly changed. Therefore the convective heat transfer coefficient would be expected to be relatively independent of axial elevation.

In the INEL review, reference was made to an analysis by R. Griebe[a] of the BWR FLECHT tests. Analysis of the test data as reported in the document illustrated a sensitivity of heat transfer coefficient to elevation at 10.8 ft and 1.2 ft (discussion beginning page 39). In the referenced test(s), cooling was by top spray only with stagnant lower plenum. The test scenario of the referenced Griebe report and performed by General Electric was developed to be the most conservative bounding set of conditions. In the Griebe report, the heat transfer coefficient at near to the top and bottom of the heated length was greater or less than at midplane. In spray only, fluid droplets enter the fuel by countercurrent flow to steam. In the spray cooling scenario, droplets migrate to the channel because of inability to wet fuel rods but to wet the channel. A falling film on the channel evaporates, resulting in steam cooling the lower elevations of the assembly. An axial location is (may be) reached wherein there is either deficient fluid in the film or deficient radiant heat flux from the fuel to develop significant steam. Thus, the lower reaches of the bundle would exhibit lesser steam generation and lesser convective cooling. Conversely, the upper reaches of the fuel receive greater cooling from droplets as being nearer the source. These explain the cause for the difference in heat transfer at the extremes of the fuel. The extreme ends of the fuel are not of interest to LOCA analysis because of lesser power there.

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[a]Boiling Water Reactor-Full Length Emergency Core Cooling Heat Transfer (BWR FLECHT) Test Project. Final Report on Atmospheric Pressure Stainless Steel Experiments, Griebe, R. W., et. al., Aerojet Nuclear....'73.

Griebe concludes (near bundle mid plane) there is no pronounced sensitivity of total heat transfer coefficient to initial temperature; the effect of spray rate is not appreciable; and no dependence of the total heat transfer coefficient up to the time of rod quench can be attributed to bundle power.

If power was peaked to bottom, lesser heat input would go to the top of the assembly. Therefore, the falling film of coolant on the channel would survive farther down the assembly to cool the bottom peaked configuration. Top peaked fuel does so because of insertion of control rods. Insertion of rods results in lower assembly power which is lesser challenge to LOCA limits.

Four significant changes in the LBLOCA have since occurred: 1) Interstitial cooling water is metered into the bypass region by holes in the lower tie plate wall rather than lower core support plate; 2) While depressurizing, the steam in the lower plenum vents through the core, resulting in significant steam updraft through the core; 3) A residual pool of water remains in the upper plenum such that all fuel receives ECC from the upper plenum limited by CCFL phenomena; 4) Large scale integral and separate effects tests have confirmed a scenario which leads to prompt turnaround of the temperature excursion, and mitigating phenomena.

As the bypass (interstitial) region fills rapidly, ECC leaks in reverse flow to above the side entry orifice (significant amounts, like 6 gallons per minute) through the tie plate interstitial cooling holes and channel to tie plate joint seal. The updrafting steam retains or entrains the ECC in the fuel which results in cooling of the bottom of the fuel. Pool boiling entrainment of liquid (counter current flow limited assembly) or more vigorous entrainment by steam updraft (co-current flow limited assembly) results in cooling at all elevations substantially greater than the spray only scenario, while ECC still penetrates the upper tie plate from the pool of water in the upper plenum similar to the spray scenario. Thus, the real scenario develops cooling in addition to the spray only scenario. The fuel is cooled from both top and bottom with the result that the fuel with power peaked either at top or bottom of fuel would be cooled.

Therefore, although the BWR FLECHT stainless steel tests showed an axial dependence at the extremes of the fuel, changes to the fuel design, and improved knowledge of the LOCA event have shown the early tests more conservative than necessary and not representative of the phenomena. The ANF tests used the current fuel design (i.e., accounting for lower tie plate cooling holes), and the information derived from NRC sponsored test programs to establish the bounding tests. The heat transfer coefficients developed from the ANF tests show the EM prediction to reasonably bound the test data at all elevations of interest using a constant value of convective heat transfer coefficient.

4.0 ANSWER TO QUESTION 2

<u>What is the effect of rod ballooning and rupture on such factors as PCT, oxidation of the fuel and on the distribution of flow in the core? Such factors [should be] be considered in the evaluation.</u>

As required by 10 CFR Appendix K, rod ballooning must be considered in the EM. In the approved ANF methodology,[a] the swelling and rupture treatment[b] is consistent with NUREG-0630. The Baker-Just cladding metal water reaction correlation is used, both sides of the clad oxidize after burst in accord with the requirements of 10 CFR 50.46 and Appendix K. The thermal radiation view factors within the HUXY calculation change as the fuel swells, thus inhibiting radiant heat transport. The proposed heat transfer coefficients are used in the ANF EM in accordance with the treatment of ballooning required by 10 CFR 50.46 and Appendix K (Part I, B; and Part I, D.6).

The effect of cladding swelling and perforation on heat transfer capability was tested in the BWR FLECHT program. In one test with a pressurized Zircaloy bundle,[c] twelve rods perforated. It is concluded in the referenced report that there was no change in the heat transfer ... observed subsequent to cladding swelling and perforation.

Blockage effects have been an issue for PWR because of the "steam cooling" requirement of 10CFR50.46 Appendix K. Based on PWR results[d] the effect of blockage produces an insignificant effect on core

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[a]<u>Exxon Nuclear Methodology for Boiling Water Reactors EXEM BWR ECCS Evaluation Model</u>, XN-NF-80-19(P)(A) Volumes 2, 2A, 2B, 2C, September 1982.

[b]<u>Exxon Nuclear Company ECCS Cladding Swelling and Rupture Model</u>, Exxon Nuclear Company, Inc., XN-NF-82-07(P)(A), Revision 1, November, 1982.

[c]<u>Emergency Core Cooling Tests of an Internally Pressurized, Zircaloy-Clad, 8x8 Simulated BWR Fuel Bundle</u>, General Electric Company, NEDO-20231, December 1973.

[d]<u>Compendium of ECCS Research for Realistic LOCA Analysis</u>, NUREG-1230, December 1988.

heat transfer (Page 6.6-52), the same conclusion as for BWR fuel noted in the above paragraph. Multiple assembly tests in the Slab Core Test Facility (SCTF)[a] support the same conclusion. These SCTF tests are important because although an open lattice arrangement, the assemblies are in parallel flow, two adjacent 16x16 assemblies blocked 60%; a very conservative test.

The maximum blockage corresponding to the clad rupture model in the approved ANF cladding swelling and rupture model[b] for 9x9 BWR fuel would be

Assuming no down stream recovery, the hydraulic loss coefficient based on bundle area for flow would be

Flow approximates the inverse square root of hydraulic resistance, and therefore the flow ratio would be

Thus, the distribution of assemblies in the respective flow regimes in parallel flow in the BWR core do not change significantly as a consequence of fuel rod swelling.

A lesser steam flow is negligible in comparison to the conservatism inherent in the ANF tests and related scenario.

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[a]<u>SCTF Core-I Reflood Test Results</u>, Hiromichi Adachi, et. al., Tenth Water Reactor Safety Research Information Meeting, NUREG/CP-0041, Vol 1, January 1983, beginning page 287.

[b]ibid, XN-NF-82-07(P)(A), pages 25 and 25.

5.0 ANSWER TO QUESTION 3

An ANF fax of April 7, 1989 showed the heatup of 9x9 fuel with the new heat transfer coefficients and 8x8 fuel with the old heat transfer coefficients. Details of the bundle input to generate the results contained in the fax were not provided. This information along with the remaining output from the computer run is needed.

The referenced figure is shown as Figure 5.1 in this answer (the same as Figure 2.1) Figure 5.1 shows the heat up for the PCT rod for 8x8 fuel and 9x9 fuel for a BWR 6 limiting break calculation as discussed in Section 2.0 of this supplement. The temperature rise appears

even though different convective heat transfer coefficients are used. The referenced discussion (Section 2.0) also offered a principal reason for the result as being the greater radiant flux for the 8x8 in comparison to the 9x9 fuel.

Figure 5.2 shows the relative location of the PCT rod for each case, in the HUXY rod array numbering scheme. These two cases are typical BWR 6 cases representing different optimized neutronic designs to best advantage fuel designs. As such, local peaking, gadolinia loading, and number of water rods are different. Therefore, the PCT rods occurred in different locations within the bundles. The 8x8 PCT rod occurs in the second rod row. The 9x9 PCT rod occurs near to the center of the bundle. This occurrence offers the opportunity for greater radiant heat transfer from the 8x8 PCT rod in comparison to 9x9 because of the greater radiant view factor to the cool channel.

Figures 5.3 and 5.4 are plots of the radiant and convective fluxes for the two PCT rods under comparison. Inspection of the two figures shows the convective flux to be dominant for 9x9 and recessive for 8x8. The radiant flux is dominant for 8x8 and recessive for 9x9. The 8x8 radiant flux is also much greater than the 9x9 radiant flux. The total flux is the greater for 8x8 a short time after rated spray. Thus, the greater radiant flux makes up for the lesser convective flux.

Pages 12 to 15 have been deleted.

6.0 ANSWER TO QUESTION 4

Would testing two or more bundles side by side give the same results as only one bundle? Do multi-dimensional flow perturbations or flow splits need to be considered in the evaluation?

Two Bundles

The fuel assemblies of the BWR 2, 3, 4, 5, and 6 types General Electric design Boiling Water Reactor core each act hydraulically independent. The core pressure drop is a common boundary condition. The bypass leakage to each fuel assembly is also independent of other fuel assemblies within the core because the bypass fills rapidly (within 10 seconds) throughout the core and remains filled. The bypass region has been shown in SSTF tests to fill rapidly because of excess ECC and lack of CCFL at the upper plenum interface. A two assembly test (e.g., the Two Bundle Loop Test Facility) with both assemblies side-by-side could result in a "core" pressure drop affected by either assembly. Thus, integral test results may differ from single assembly test results. However, if the assembly flow conditions for the single assembly test were identical to the individual flow of either assembly in the two bundle test, the heat transfer results from a single assembly test would be expected to be the same for the assembly simulated. In a reactor core with about 700 assemblies, any one assembly would not significantly affect core pressure drop. As each assembly is channeled, assembly cross-flow is not possible. Thus, single assembly tests can be appropriate.

Because each fuel assembly is hydraulically independent, multi-dimensional effects are limited to the interstitial spaces and lower and upper plenums. Any multi-dimensional effects within the fuel are implicitly included in the full-size test fuel assembly. Multi-dimensional effects increase flow to the interstitial (bypass) regions and eliminate the effect of one-dimensional predicted CCFL phenomena. There are no significant multi-dimensional effects in the lower plenum because the fuel is orificed to eliminate such effects. Because the lower plenum is an open expansion, multi-dimensional effects are limited to one dynamic head. Since the orifice loss coefficient is much greater than this dynamic head, any multi-dimensional effects in the lower plenum are minimal. The SSTF tests, and realistic code simulations reported in the open literature show a pool of water remains on top of the core even with peripheral assemblies draining ECC to the lower plenum, because of the steam updraft and copious ECC injected into the upper plenum. The tests show a minimum collapsed liquid level of 10 inches water in the upper plenum.[abc] Therefore, all the fuel assemblies receive all the ECC which can flow in countercurrent.

Therefore, multi-dimensional effects [u(x,y,z)] either promote improved cooling or are negligible.

Flow Splits

The LOCA/ECCS scenario for BWR 3, 4, 5, and 6 describes a core in parallel channel flow (as distinguished from "multi-dimensional"). The core is simultaneously in three flow regimes: co-current down (peripheral assemblies), countercurrent, and co-current up. The co-current down assemblies are full of water being siphoned to the lower plenum and therefore are not limiting. They transition to co-current down because of their relatively lower power, tighter orificing, and peripheral subcooling in the upper plenum pool. The co-current up assemblies are the high power assemblies and vent the majority of steam from the lower plenum. The co-current up fuel is actively cooled by entrained bypass ECC which leaks from bypass to above the side entry orifice. The bypass ECC is swept up into the fuel, cooling it. The number of assemblies necessary to vent most of the steam from the lower

[a] BWR Refill-Reflood Program Task 4.8-TRAC-BWR Model Qualification For BWR Safety Analysis, Final Report, NUREG/CR-2571, Md. Alamgir, General Electric Company, October 1983.

[b] 18 Degree Sector System Test (ESTA II), NUREG/CP 0058, Volume 3, Page 706, H. Nagasaka, et. al., Toshiba Corporation Nuclear Engineering Laboratory, 1985.

[c] Compendium of ECCS Research for Realistic LOCA Analysis, Page 6.5-12, Division of Systems Research, U.S. NRC, NUREG-1230, Revision 4, December 1988.

plenum (20 to 30 percent of total assemblies in core[a]) are in co-current up flow. The high power assemblies are not maximum temperature assemblies because the higher power "pumps" greater steam and entrained ECC. This has been demonstrated in TBL tests.[b] [Figure 11 page 661, and page 653.[c]] The balance of assemblies in the core are in countercurrent flow.

The countercurrent flow assemblies reflood prior to refill of the lower plenum due to CCF effects at the side entry orifice. Steam updraft from the lower plenum is sufficient to hold upper plenum CCF fluid and bypass leakage fluid above the side entry orifice. Updraft steam and pool entrainment of liquid cool the fuel above the liquid interface. This cooling continues until the lower plenum refills which leads promptly to reflood. The minimum heat

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[a]Development of Parallel Channel Models and Their Application to BWR LOCA Analysis, H. Suzuki, M. Murase, Hitachi Ltd., J.A. Findlay, F.D. Shum, General Electric Co., 2nd International Topical Meeting On Nuclear Power Plant Thermal Hydraulics And Operations, Tokyo, Japan, April 1986.

[b]TBL Analysis by Best Estimate Codes, T. Matsumoto, et. al., Proceedings Twelfth Water Reactor Safety Research Information Meeting, NUREG/CP-0058, Volume 3, October 1984.

[c]"There was a difference in the thermal-hydraulic behaviors between the two bundles during the blowdown period in this large break test. Axial void distributions at 40 s were different in the two bundles as shown in Figure 5. It seems that this difference was caused by the thermal-hydraulic interactions between two bundles. The vapor from the lower plenum could be easily blown-up through the high power bundle (Bundle B) because the coolant was porous due to the high void fraction. Because the upflow vapor entrained plenty of water, the flow pattern was co-current up-flow and the void fraction was below 1.0 even at the upper part of the bundle.

On the other hand, the residual vapor from the lower plenum was blown-up through the low power bundle (Bundle A). Because the vapor upflow rate was little, the flow pattern in the bundle was counter-current flow and a lot of water gathered in the lower part of bundle due to CCFL. As a result, the void fraction at the mid-plane reached almost 1.0. The calculated void distribution agreed with the test data in both bundles."

transfer coefficients for this region have been demonstrated to be greater than 10 $BTU/Hr\text{-}ft^2\text{-}F$.[a]

More than average steam is vented by the co-current up assemblies, peripheral assemblies almost none, and the balance the countercurrent assemblies. In this scenario, heat transfer coefficients are very high, and within 80 seconds of spray initiation the core has reflooded.

The present ANF evaluation model calculates

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[a]Compendium of ECCS Research for Realistic LOCA Analysis, Pages 6.5-6 and 6.5-8, Division of Systems Research, U.S. NRC. NUREG-1230, Revision 4, December 1988.

1.0 INTRODUCTION

As part of the response to NRC staff questions on ANF 929, Supplement 1 documented the heat transfer coefficient set for ANF 9x9 multiple water rod fuel designs. This heat transfer coefficient set is to be used during the spray period cooling of LOCA/ECCS analysis for boiling water reactors. The coefficients were established based on comparison of the accepted spray period fuel heat up code, HUXY, to rod group temperature history for most limiting and appropriate tests.

Supplement 2 of this report presented documentation which verified that the spray fluid heat transfer coefficients are applicable over the range of parameters that would be encountered in an application analysis. As such, Supplement 2 documented the examination of the difference between the HUXY predictions and test data to determine if there are any trends which may indicate reduction in conservatism over the proposed range of application. The results of the work showed that the proposed coefficients are appropriate and conservative over the full range of applicability.

This Supplement (Supplement 3) presents comparison of ANF Evaluation Model results for a typical BWR 6 limiting break calculation using ANF 8x8 and 9x9 fuel types. The 8x8 calculation used the convective heat transfer coefficients as approved for that fuel type, and the 9x9 fuel used the proposed heat transfer coefficients. The results presented compare the temperature rise from time of rated spray for each fuel type. Answers to further questions posed by the NRC staff and consultants are also presented in this supplement.

ADVANCED NUCLEAR FUELS CORPORATION

ANF-929(NP)(A)
Supplement 4

Issue Date: 12/11/90

ANSWERS TO FURTHER QUESTIONS POSED BY THE NUCLEAR REGULATORY COMMISSION STAFF AND CONSULTANTS (NOVEMBER, 1989) ON THE ADVANCED NUCLEAR FUELS CORPORATION BWR 9X9 SPRAY COOLING PERIOD HEAT TRANSFER COEFFICIENTS: EVALUATE THE EFFECT OF CHANGED AXIAL POWER DISTRIBUTION

Prepared by

12/10/90
C. E. Leach
Engineering Model Development
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December 1990

/trb

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1.0 INTRODUCTION

Supplement 1 of this report documents the convective heat transfer coefficient set for ANF 9X9 fuel designs with water rods(s). This heat transfer coefficient set is to be used during the spray cooling period of LOCA/ECCS analysis for boiling water reactors. The coefficients were established based on comparison of the spray period fuel heat up code, HUXY, to rod group temperature history for most limiting and appropriate tests. The axial power distribution used in the test is fixed. The relative peak power of the test is
is described in Supplement 1[1].

The purpose of this Supplement is to document the results of evaluation of the effect of axial power distribution on the 9X9 heat transfer coefficient set.

The advanced thermal hydraulics code COBRA TF[2] was used to evaluate these effects. Based on the analysis there is no significant effect of the power shape on the magnitude of the heat transfer coefficient at the peak power elevation. In fact, generally there is an increase in the magnitude of the heat transfer coefficient for the top and bottom skewed power profiles at the peak power elevation of the hot (interior) rods. Therefore, the use of tests
provides appropriate verification of the spray cooling period heat transfer coefficients.

2.0 QUESTION

The INEL has reviewed the proposed ANF 9X9 spray heat transfer coefficients for the NRC. In the meeting with INEL staff on November 2, 1989, to discuss the review, the INEL representatives noted that they had only one remaining concern with interpretation of the data: the potential sensitivity of the recommended convective heat transfer coefficients to changes in

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1 Answers to Questions Posed By The Nuclear Regulatory Commission Staff and Consultants on the Advanced Nuclear Fuels BWR 9x9 Spray Cooling Period Heat Transfer Coefficients, ANF929(P), Supplements 1,2,3; April, 1989.

2 Analysis of The FLECHT-SEASET 163 Rod Blocked Bundle Data Using COBRA TF, C.Y. Paik, et.al.; NUREG/CR-4166, October, 1985.

axial power distribution. Advanced Nuclear Fuels agreed to examine and report the sensitivity to changed axial power distribution using an advanced mechanistic thermal hydraulics code. As recommended by the INEL staff, ANF agreed to perform the sensitivity analysis using the COBRA TF code.

3.0 METHOD

The mechanistic thermal hydraulics code, COBRA TF was used to evaluate the effect of axial power distribution on convective heat transfer coefficients during spray period cooling in the flow and cooling regimes relevant to the ANF LOCA/ECCS treatment of BWR. The convective heat transfer coefficients are defined to be the heat transfer residual after accounting for thermal radiative cooling as calculated by the NRC approved model in the HUXY code (see Ref 1.). The HUXY code is mechanistic in treatment of thermal radiative cooling and has been assessed against experimental data[3].

To use the COBRA TF code to assess spray period heat transfer coefficients, two code modifications were required: the thermal radiative model, and the channel quench model (10 CFR50.46 and Appendix K). The performance of this modified COBRA TF code was assessed against a test case using the NRC approved HUXY code. The results of the assessment verified that NRC approved models were properly installed. The thermal modeling of the fuel rod simulators, channel, and other components in the COBRA TF model was also verified by the comparison against the HUXY results[4].

---

[3] Spray Cooling Heat Transfer Phase 1 Test Results FNC 8x8 BWR Fuel 60 and 63 Active Rods, XN-75-36.

[4] Note: The HUXY model was benchmarked against test data for three tests during adiabatic heat up. The HUXY input is from first principles. Correspondence between the HUXY predictions and test data is very close. These calculations are reported in ANF 929(P), Supplement 1, ibid.

ANF then benchmarked the modified COBRA TF Code against Test 820 data[5].

The results of the benchmark case demonstrated the ability of the code to predict cooling throughout the test assembly during the entire test.

4.0 RESULTS

Figure 4.1 presents the rod numbering scheme used in the analysis and following discussion. Rod number 1 is a "water" rod and is therefore unheated. We examined the convective heat transfer coefficients at selected times after coolant injection as well as an average value since HUXY uses a time invariant quantity. Table 4.1 presents the time averaged convective heat transfer coefficient for selected representative rods relative to the convective coefficient for the base case at peak power location, rod by rod. The value is an average of the coefficients at 84, 149, and 219 seconds after coolant injection.

5 See ANF 929(P), Supplement 1, ibid.

TABLE 4.1

Time Averaged Convective Heat Transfer Relative to Base Case

As may be seen, the time averaged convective coefficients are

Table 4.2 presents instantaneous values for the same rods, relative to the reference case rod at peak power location The results show the instantaneous value to

Pages 5 to 9 have been deleted.

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April 10, 1991
RAC:044:91

Dr. B. K. Sun
Reactor Systems Branch
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Office of Nuclear Reactor Regulation
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

Dear Dr. Sun:

Responses to NRC Questions on ANF-929(P)

Reference: 1. Rapifax, J. B. Sun (USNRC) to R. A. Copeland (ANF), "Request for Additional Information ANF Proposed Spray Heat Transfer Coefficients", February 22, 1991.

2. Letter, G. N. Ward (ENC) to G. C. Lainas (USNRC), "Transmittal of XN-NF-929(P)," September 18, 1986. GNW:102:86.

Attached are three copies of the responses to the NRC questions transmitted in the referenced rapifax. These responses provide additional information supporting the review of ANF-929(P).

Advanced Nuclear Fuels Corporation considers the information in these responses to be proprietary. The affidavit transmitted with the original submittal (reference 2) supports the withholding of this information from public disclosure (per the requirements of 10 CFR 2.790(b)).

If I can be of further help, please contact me at (509) 375-8290.

Very truly yours,

Bob Copeland

R. A. Copeland
Manager, Reload Licensing

/skm
cc: Mr. R. C. Jones (USNRC)

Response to the NRC's Request for Additional Information Regarding the Effect of Power Shape on Spray Heat Transfer Coefficients

April 8, 1991

Item 1: Please provide the convective heat transfer coefficient, drop size, steam velocity, steam temperature, and rod surface temperature versus time for rod number 2 at the peak power elevation, and five additional equally spaced positions along the core for each power shape presented in ANF-929(P), Supplement 4.

Response: The requested data is tabulated below. Graphical representation is also provided. The indicated elevations are measured from the bottom of the heated length. Time is measured from the begining of heatup, and the spray period begins at 1181 sec. on this time scale.

Table 1 : Steam Temperature for Rod 2, chopped-cosine power shape.

Table 2 : Steam Temperature for Rod 2, top-skewed power shape.

Table 3 : Steam Temperature for Rod 2, bottom-skewed power shape.

Table 4 : Temperature of Rod 2, chopped-cosine power shape.

Table 5 : Temperature of Rod 2, top-skewed power shape.

Table 6 : Temperature of Rod 2, bottom-skewed power shape.

Table 7 : Heat Transfer Coefficient for Rod 2, chopped-cosine power shape.

Table 8 : Heat Transfer Coefficient for Rod 2, top-skewed power shape.

Table 9 : Heat Transfer Coefficient for Rod 2, bottom-skewed power shape.

Table 10 : Droplet Diameter for Channel 2, chopped-cosine power shape.

The convective heat transfer coefficient shown in the COBRA-TF calculations is not directly comparable to the heat transfer coefficient proposed for use with the HUXY code in the ANF BWR large break LOCA evaluation model. The difference is that the HUXY heat transfer coefficient is based on saturation temperature instead of steam temperature. When the COBRA-TF coefficients are converted to the same basis as the HUXY coefficients, the convective heat transfer coefficient at the peak clad temperature for the bottom-peak case

It should be noted that the converted COBRA-TF heat transfer coefficients, unlike HUXY coefficient, do not include the radiative heat transfer to the droplets, which makes the comparison even more conservative.

The heat transfer coefficients calculated by COBRA-TF resulted in

Item 2: Please provide the code output for rod number 2 for the three power shapes at 84, 149, and 219 seconds for each of the locations supplied in 1 above.

Response: The requested code output is given below. Again, notice that the requested times: 84, 149, and 219 seconds correspond to 1265, 1330, and 1400 seconds respectively on the run time scale which begins with the heatup phase. In the rod edit, the given heat flux is the total of convection and radiation fluxes. To obtain the convective flux, subtract the radiative component given in the rightmost column. The highlighted rows correspond to the elevations given above, shifted by the unheated length.

Item 3: The magnitude of the convective heat transfer coefficient is very sensitive to the entrainment fraction and drop sizes entering at the bottom of the bundle. Please explain the method for calculating drop size and also provide justification for the entrainment fraction and drop sizes input to the code. Please provide the comparisons with experimental data under the same hydraulic conditions as those used in ANF-929(P), Supplement 4. The comparisons of the code predictions with experiment should include the parameters, with appropriate code output, similar to that requested in item 1.0 above.

Response:

Drop Size: An average diameter was estimated for the drops forming in the side inlet orifice using Tatterson-Hanratty correlation. The maximum diameter of drops that can be lifted by the steam flow in the bottom of the bundle was used as a cut-off for calculating the average entrained drop diameter assuming Nukiyama-Tanasawa droplet size distribution. The method is illustrated in the sketch of Fig. 3.1. A fixed value of the average drop diameter was used for all three power shapes. The uncertainties associated with the choice of the drop size are compensated for by the proper choice of drop mass flow rate.

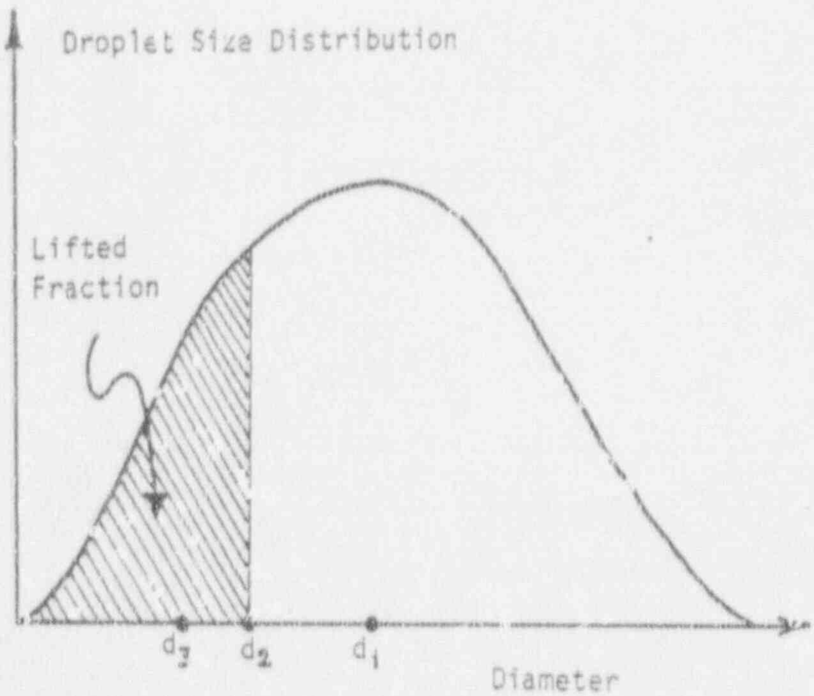
Entrainment Fraction: The entrained droplet mass flow rate was not measured in the experiment. This boundary condition was determined semi-empirically.

This droplet mass flow rate was used for all the three power shapes.

It is recognized that several combinations of droplet size and mass flow may also reproduce the measured temperatures. The values used in the current calculations are reasonable and within the physical constraints of the test. For example, it would not be reasonable to use larger drop size which cannot be lifted by the vapor flow in the bottom of the bundle. Smaller droplets are possible, but that requires reducing droplet flow rate to counteract the enhancement of interfacial heat transfer. The limit of reducing drop size and flow rate is reached if all the drops evaporate resulting in over-predicting rod temperatures at the upper elevations.

Comparison with Experiment: The cosine power shape data reported in the response to question 1 correspond with the TEST 820. The major test parameters:

were input to the code. The only code output suitable that is available for the comparison is the rod temperature for TEST 820. This is the comparison that was used to establish the entrainment fraction. Fig. 5.2 shows a typical full rod comparison at the time of peak clad temperature.



d_1 Average diameter of formed droplets

d_2 Maximum diameter of droplets that can be lifted by steam

d_3 Average diameter of lifted droplets, code input.

Fig. 3.1 Sketch of the entrained drop size estimation method.

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Dear Dr. Sun:

Response to NRC Question on ANF-929(P)

Ref: Rapifax, B. K. Sun (USNRC) to R. A. Copeland (ANF), "Request for Additional Information ANF Proposed Spray Heat Transfer Coefficients," June 12, 1991.

Attached is the response to the additional question on the proposed spray heat transfer coefficients (topical report ANF-929(P)), currently being reviewed by the NRC. The response involves an additional parametric study. Please consider the information contained in the response to be proprietary to Advanced Nuclear Fuels Corporation. The affidavit provided with the original submittal may be used to satisfy the 10 CFR 2.790(b) requirements to withhold the information from public disclosure.

If I can be of further help, please contact me at (509) 375-8290.

Very truly yours,

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Manager, Reload Licensing

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July 12, 1991
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RESPONSE TO THE NRC REQUEST FOR ADDITIONAL INFORMATION REGARDING THE EFFECT OF ENTRAINMENT ON SPRAY HEAT TRANSFER COEFFICIENT

July 12, 1991

COBRA-TF calculations have been performed to demonstrate the effect of entrainment on the spray heat transfer coefficient. Three of these runs have been made with the best estimate entrainment reduced by to examine the effect of reduced entrainment with chopped-cosine power shape. The reference run represented a best estimate calculation to fit clad surface temperatures. The most conservative run bounds the clad temperature data for the limiting rod #2 of the most conservative test (TEST 820) as shown in Figure (1), including the elevated temperature data point attributed to local spacer effect.

Two runs with entrainment reduced were made, one for top-skewed and one for bottom-skewed power shapes. All other parameters were kept the same. The calculated heat transfer coefficients for all cases at the respective peak elevation are plotted in Figure (2). The following observations can be made:

1. The heat transfer coefficient for all power shapes decreases as the entrainment is decreased. This behavior was expected and is consistent because less droplets are available for heat transfer.

2. The difference between the heat transfer coefficient for skewed power shapes relative to the base chopped-cosine case increases as the entrainment decreases.

3. The lowest heat transfer coefficient is calculated for the top-skewed power shape and reduced entrainment This was expected since the entrainment droplet fraction is minimum for that case.

4. The lowest calculated value of the heat transfer coefficient is which is sufficiently larger than the proposed value for HUXY code calculations.

The conclusion from these calculations is that the convective heat transfer coefficient is not very sensitive to axial power shape as sufficient supply of droplets exists. Therefore, the boundary spray heat transfer coefficients derived from cosine tests are appropriate for use in the ANF large break LOCA calculation model.

ANF also examined the differences in calculated heat transfer coefficients between ANF and the NRC reviewer. 's examination found that there are no real disagreements, only some minor differences in how the values were calculated. ANF based the valuation on the parameters obtained at the fixed nodes (marked with an asterisk in the output file), while the reviewer used the values at the dynamic nodes. These dynamic interpolation nodes are used by the code for the special purpose of tracking quench fronts, and ANF finds the fixed node values more appropriate. Also, ANF based the variation on the deviation from the base cosine value, while the reviewer provided the total range from the top-skewed to bottom-skewed shapes.

XN-NF-929(NP)(A)

ANF-929(NP)(A)
Supplements 1, 2, 3 & 4

XN-NF-929(NP)(A)
Correspondence

Issue Date: 3-18-92

SPRAY HEAT TRANSFER COEFFICIENTS FOR JET PUMP BWR FUEL ASSEMBLIES WITH WATER RODS

Distribution

USNRC/R.A. Copeland(15)