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Responses to RAI on Topical Report BAW-10166 Appendices H and I

Ref.: 1. Letter from the NRC (Drew Holland) to Framatome ANP, Inc. (James Mallay), "Request for Additional Information on Topical Report BAW-10166PA, Revision 4, 'BEACH – Best Estimate Analysis Core Heat Transfer – A Computer Program for Reflood Heat Transfer During LOCA' Appendices H and I (TAC No. MB3866), dated May 7, 2002.

The NRC issued an RAI on Appendices H and I to topical report BAW-10166 on May 7, 2002 (see Reference 1). The responses to the questions contained in this RAI are enclosed.

The timely completion of the review of this topical report is important because the analyses performed using this methodology are scheduled to be submitted by September 2002 to support the fuel reload at North Anna that is scheduled for March 2003.

Very truly yours,

Gerald S Holm

James F. Mallay, Director
Regulatory Affairs

Enclosure

cc: D. G. Holland
F. R. Orr
Project 693

Framatome ANP, Inc.

2101 Horn Rapids Road
Richland, WA 99352

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

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D045

Enclosure 1

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Responses to RAI on Topical Report BAW-10166
Appendices H and I

1. Question: The BEACH code has been compared to the FLECHT-SEASET and FLECHT cosine series reflood test data. Since these data contain non-powered rods, thimbles, and filler materials, rod-to-rod thermal radiation can constitute as much as 20 – 30 percent of the total heat removal capability. In the FLECHT cosine series tests, a radial power profile in the bundle is simulated that will increase the rod-to-rod radiation is not modeled in BEACH, please demonstrate that thermal rod-to-rod radiation is not appreciable in the test comparisons. For those tests and hot rod locations where rod-to-rod radiation is appreciable, comparing the BEACH rod surface heat transfer coefficient to the test data is considered inappropriate since the overall test data heat transfer coefficient contains convection in addition to thermal radiation. In this case, thermal rod-to-rod radiation should be subtracted from the test data so that only convection remains for the comparison. This will assure that the BEACH calculated convective heat transfer coefficient was not tuned to match test data containing convection plus rod-to-rod thermal addition.

Response: Framatome-ANP developed the BEACH "Best-Estimate Analysis Core Heat Transfer" code to predict reflood heat transfer for the hot rod and the hot and average bundles. The predictive capabilities of BEACH were assessed over a wide range of boundary conditions that generally encompassed the expected ranges over which the code would be applied. Code benchmark predictions were compared against test data from a variety of facilities by using the transient cladding surface temperature response as the primary measure, although derived assessments were made to the quench front, PCT versus elevation, and in some cases normalized heat transfer coefficient versus time. The effects of radiation on the cladding temperature predicted by BEACH in the benchmarks are considerably less than the 20 to 30 percent stated in the question, as demonstrated in the following discussion.

Rod-to-Filler Radiation

A low-mass housing was used in the FLECHT skewed power tests and in the FLECHT-SEASET tests. Both test bundles have similar filler pieces on the bundle periphery. The behavior of the housing (including the fillers located on the periphery adjacent to the housing) was evaluated as part of the FLECHT skewed power test program (Section 4.9 of WCAP 9108). The effect of a cold or hot housing temperature on the rod surface temperature and the corresponding heat transfer coefficient, excluding peripheral rods, was found negligible. It was concluded that performing reflood tests with an unheated low mass housing is acceptable, since the cold housing did not significantly affect the reflood heat transfer and hydraulic behavior of the rod bundle. Further, since the data used in the FLECHT and FLECHT-SEASET benchmarks are from the inner rods, the housing/filler has a negligible impact on the data used to assess a BEACH prediction that excludes modeling the heat capacity of any filler or housing metal. Having a number of tests that predicted the maximum rod temperature within two rods of the housing, viz., unblocked Test 30619 and blocked Tests 62304, 61005, 62211, 62413, 61314, 63018, and 62819, further supports this conclusion.

Rod-to-Thimble Tube Radiation

Framatome ANP reviewed the effect of radiant heat transfer to thimble tubes on the data used for BEACH assessments. The FLECHT-SEASET blockage Test 61607 was selected as the primary basis for evaluating the effect of rod-to-thimble tube radiation. This test, with maximum cladding temperatures near 2100 F, was selected because it has large temperature rises that would magnify radiation effects. The bundle used in this test differed somewhat from the FLECHT-SEASET bundle where all of the inner rods were either face-adjacent to a thimble tube or at a 45-degree angle to a thimble tube. For Test 61607, the two 21-rod blockage islands were replaced with all rods that had stainless steel sleeves installed over them to simulate the blockage due to swelling and rupture. The axial locations of the center of the sleeves varied from 69 to 75 inches above the bottom of the heated length. This blockage region without thimble tubes adjacent to rods provided an opportunity to study rod-to-thimble tube radiation effects relative to test results versus the unblocked tests that each had a thimble tube face-adjacent or at a 45-degree angle. Also, this test had representative effects of flow diversion from the swelling and rupture blockage that could occur in an actual fuel bundle. Framatome ANP acquired all the thermocouple PCT data from the INEL data bank to make additional comparisons of rods in different bundle locations.

The measured PCT values were divided into three groups based on orientation to a thimble tube and plotted in Figure 1-1 versus the BEACH prediction for Test 61607. The results of the test indicate the following:

1. The average of the maximum temperatures for the 72 indications in rods in the blockage islands that are at least one row away from the thimble tubes is 2108 F. This average maximum temperature is only 22 F greater than the average maximum temperature of 2086 F for the 70 indications in rods adjacent to thimble tubes. Therefore, the PCT for rods in the blockage islands and adjacent to the thimbles are essentially identical.

2. The maximum cladding temperatures for rods adjacent to the thimble tubes ranged from 1976 F to 2188 F. The PCTs for the rods away from the thimble tubes ranged from 1927 F to 2173 F. Therefore, the PCTs for rods adjacent to and away from the thimbles are nearly the same.

3. The comparable thermocouple readings between 6 and 8 feet in the outer unblocked region had an average maximum temperature of 2047 F for 147 data points with a range of 1896 F to 2166 F. These rods are predominantly adjacent to thimble tubes and are somewhat cooler. They receive some heat transfer benefit from flow diversion out of the blockage region.

4. There are indications from blockage Test 61607, as well as from some of the unblocked tests, that show the maximum PCTs occur in rods adjacent to thimble tubes. Out of 10 of the blocked tests that have PCTs above 2000 F, three of them (Tests 61607, 61412, and 62919) have PCTs in rods adjacent to thimble tubes. All of the FLECHT-SEASET unblocked tests that had PCTs of 2000 F or greater produced PCTs adjacent to thimble tubes.

Separation of the data into the three groups is an effective way to observe the effect of thimble tubes on blockage zone rod temperatures. The closeness of the data ranges and average cladding temperatures suggests that if there is a radiation contribution, it is much smaller than 20 percent. Further, the data scatter observed for the different groups of thermocouples that approach the limiting PCT value are similar despite the differences in proximity to the thimble tubes. Therefore, use of all the data for rods adjacent to and away from thimble tubes is appropriate for benchmarking without any adjustment for rod-to-thimble tube radiation effects.

Rod-to-Rod Radiation

FLECHT-SEASET test bundles used a flat radial power profile. Therefore, there would be very limited pin-to-pin radiation for the rods one or two rows away from the periphery of the bundle. This conclusion is drawn from the same comparisons discussed above for the rod-to-thimble tube radiation.

Rod-to-Filler Radiation BEACH Modeling

The BEACH code does not model rod radiation to the housing, filler metal, or unheated rods. The metal mass from the low-mass housing, filler material, or unheated rods in the FLECHT skewed power tests and in the FLECHT-SEASET tests is therefore not modeled in the BEACH benchmarks. Exclusion of this metal in the BEACH benchmark model inherently imposed a no heat loss boundary condition on the channel prediction, thereby maximizing the bulk fluid temperatures that are used for the heat transfer application. This method, which excludes the metal capacities from the unheated rods or core baffle plates, is applied and used in plant application models to maintain a consistency of approach that ensures appropriate translation to the hot channel plant application.

Rod-to-Thimble Tube Radiation BEACH Modeling

The BEACH code does not have a model that accounts for the rod radiation to the thimble tubes. The metal mass from the thimble tubes in the FLECHT skewed power tests and in the FLECHT-SEASET tests is therefore not modeled in BEACH benchmarks. The thimble tubes are, however, considered in the development of the unit cell flow area and hydraulic diameter used in the benchmark. This method, which excludes the metal capacities from the thimble tubes, is applied and used in plant application models to maintain a consistency of approach that ensures appropriate translation to the hot channel plant application.

Rod-to-Rod Radiation BEACH Modeling

The BEACH code does not have a rod-to-rod radiation model. Prior to Revision 5 of BEACH, all of the rods in the bundle were modeled with a uniform radial power equal to the hot rod radial power factor, and all rods had identical 95/95 confidence values for the hot rod fuel initial temperatures. Therefore, there were no differences that could produce a temperature variation within the bundle or between adjacent bundles. However, future analyses can simulate multiple rods with different initial temperature distributions using RELAP5/MOD2 Revision 4 (Reference 1-1). The temperature differences will translate in the analysis as changes in the bundle bulk coolant conditions. This simplistic modeling of an actual fuel assembly retains substantial conservatism. An accurate simulation would alter both the initial temperature and the fuel pin power, which would create an opportunity for substantial inter-pin radiation, which is not simulated by BEACH. Therefore, by not including rod-to-rod radiation, BEACH calculates conservatively higher cladding temperatures.

Code Comparisons to Test Data

The previous discussions addressed the effects of radiation heat losses in the test data used to benchmark the BEACH code as well as the code modeling input and plant application methods. The validity of the code comparisons was determined based on cladding temperature predictions, not heat transfer coefficients. The FLECHT heat transfer coefficient is a derived parameter that is calculated from the total heat removal rate and normalized to the clad surface temperature to saturation temperature difference. It is the total for all convection and radiation heat transfer when published for the test data. The BEACH , back-calculated heat transfer coefficient, is a total energy transport coefficient as calculated by the mechanisms modeled by BEACH.

The BEACH benchmark predictions in Appendices G, H, and I present cladding temperatures as functions of time and maximum PCT versus elevation for comparison against test data. The results show that the BEACH predictions generally bound 85 percent of the PCT data. This type of comparison shows that BEACH heat transfer is more representative of a bounding representation than of a best-estimate prediction. Moreover, the gapped rod benchmark for the REBEKA-6 test given in Appendix G shows that BEACH retains additional conservatism for PCTs above the rupture location because of the establishment of a second quench front at the zone of rupture. This means that in plant cases where the PCT is above the rupture location, BEACH predictions will generally be more conservative than the solid rod FLECHT and FLECHT-SEASET predictions would indicate.

The mixing vane grid assembly G-2 benchmark given in Appendix G also shows that BEACH conservatively predicts the PCT for the grids that add turbulence to improve the downstream heat transfer by improved mixing and droplet evaporation. Therefore, in plants having fuel assemblies with mixing vane grids and intermediate flow mixing grids, BEACH will calculate even more conservative PCTs.

In the FLECHT cosine series tests, the rod-to-rod radiation contribution could possibly have been larger than in other FLECHT series because of heater rod group radial power differences. The heater rods in the tests presented in Section I.3 and I.4 operated at three radial power levels (1.1, 1.0, and 0.95 referenced to the bundle rod average power). The BEACH benchmarks simulated only the average power rod with a radial peak of 1.0. The data in the PCT comparison plots for Tests 8037, 3215B, and 3316B, shown in Figures I-8, I-18, and I-10, respectively, include only the 1.1 radial power rod thermocouples. For Test 0791, shown in Figure I-9, the data include both the 1.1 and 1.0 radial power rod thermocouples. The BEACH benchmarks, simulating only a 1.0 radial peak, conservatively predict the PCTs for these tests, including those pins peaked at a radial of 1.1. This demonstrates that the effects of radiative (rod-to-rod) heat transfer are not embedded in BEACH modeling of the overall reflood heat transfer process. Were that not the case, BEACH--modeling only the 1.0 radial peaking--would have underpredicted the test PCT data for the rod group with a 1.1 radial peaking. It is concluded that the BEACH prediction for these tests reasonably simulates only the convection and radiation to coolant processes. Therefore, BEACH predictions are conservative relative to best estimate calculations for the FLECHT cosine series tests.

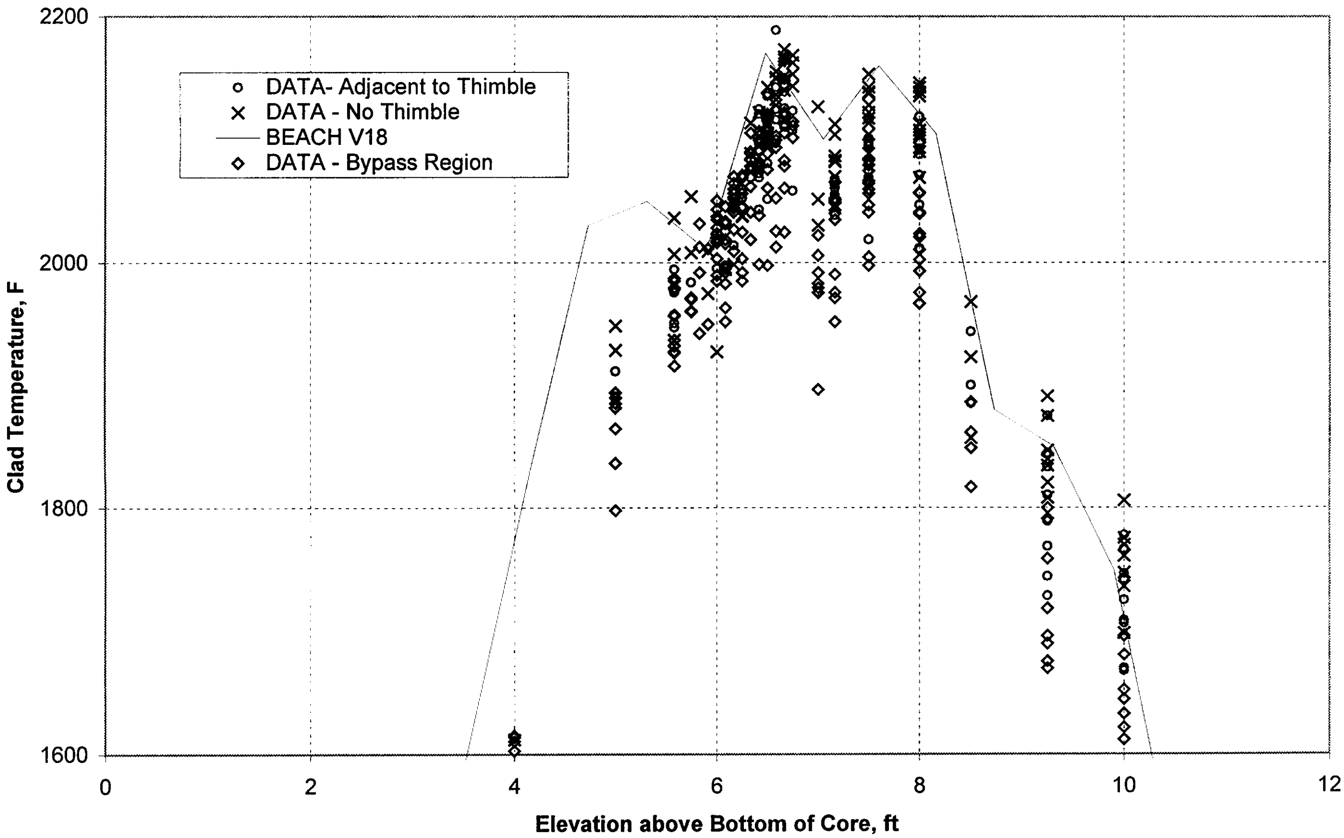
Conclusion

The potential effects of radiation to colder structures or rods in the test data and facilities used to validate the BEACH reflood heat transfer code were evaluated. Radiation to the housing, filler, unheated rods, and adjacent rods for the FLECHT and FLECHT-SEASET tests was evaluated based on detailed test data comparisons. It was concluded that the radiation effects on rods that could achieve limiting PCTs were substantially lower than the 20 to 30 percent stated in the question. Further, the methods used to benchmark the test data neglect the heat capacity of the unheated metal structures. This approach is identical to that used in evaluation model (EM) applications, assuring that the conservatism demonstrated in the benchmark predictions is appropriately translated to plant licensing applications. It is concluded that the Appendix H benchmark used to validate the increase in the range of initial cladding temperatures is acceptable. It demonstrates conservatism in the reflood heat transfer application. It is also concluded that the reduced flooding rate benchmarks, presented in Appendix I, are conservative relative to a best-estimate prediction. The adequacy of these predictions is sufficient to support approval of the boundary condition range changes to BEACH EM licensing application.

References:

1-1. Letter Leslie W. Barnett - NRC to James F. Mallay - Framatome ANP, "Safety Evaluation of Framatome Technologies Topical Report BAW-10164P Revision 4, 'RELAP5/MOD2-B&W, An Advanced Computer Program for Light Water Reactor LOCA and Non-LOCA Transient Analysis' (TAC Nos. MA8465 and MA8468)," April 9, 2002.

Figure 1-1 FLECHT-SEASET Benchmark Prediction and Test Data for Blockage Test 61607



2. Question: The BEACH prediction of Test 8037 shows in Figure I-12 that BEACH predicts a very early quench due to the overprediction of the quench front advance. The premature quench prediction suggests that clad oxidation could be severely underpredicted if this occurs during a plant calculation. Please explain why the BEACH code overpredicted the quench front advance resulting in the early quench. Since this test contained an increase in the subcooling of the inlet coolant, the overprediction could be due to anomalies in the sub-cooled boiling model. Also, provide additional information demonstrating that this behavior occurs infrequently when BEACH is compared to other test data, particularly for those FLECHT tests which produce peak clad temperatures (PCTs) greater than 2000°F.

Response: The difference in quench front advancement between the BEACH benchmark of FLECHT Test 8037 and the data is not consistent with comparisons observed in other benchmarks. The BEACH quench front advancement has been addressed in previous reviews, and only the benchmarks for FLECHT 8037 and FLECHT-SEASET 31302 show substantial deviations between test data and code predictions.

In the FRAMATOME ANP response to RAI 1 on Revision 4 of BEACH (page 5-291 in BAW-10166PA, Revision 4), quench front advancement benchmarks for six FLECHT-SEASET tests were documented. The BEACH predictions were conservative or within the range of the data for all of the comparisons except for Test 31302. Further, the benchmarks of CCTF, G-2, and REBEKA-6 all result in conservative predictions of quench front advancement.

Comparisons to tests similar to Test 8037 do not show corresponding results with respect to quench front advancement. The essential parameters for Test 8037 are low flooding rate, medium pressure, medium subcooling, and medium power. Test 0791 is similar in flooding rate and power but involves low pressure and low subcooling. The BEACH benchmark of the Test 0791 quench front advancement is conservative. The variable flooding rate tests documented in Appendix I (Tests 3215B and 3316B) are high and low pressure, medium subcooling (approximately 90 F subcooling), high power, and low flooding rate after a short initial high flow period. Except for the initial high flooding rate, these tests are comparable to Test 8037. For both tests the quench front is reasonably benchmarked. Thus, the results from Test 8037 are not consistent with those from other tests.

As mentioned in the RAI, there is substantial subcooling present in Test 8037. However, BEACH has been benchmarked against a number of FLECHT-SEASET tests with similar subcooling. The response to RAI 1 on Revision 4 of BEACH documents six such tests. Five of these benchmark the quench front advancement quite well. This previous response also provides data comparisons for CCTF, SCTF, and REBEKA-6 tests, all of which benchmark very well. FLECHT-SEASET Test 61607 compared well, but there was not sufficient data to establish a sound conclusion. Thus, for the benchmarks provided in Appendix G of the BEACH topical and in Appendix I, BEACH generally predicts appropriate quench front advancement rates.

Although the quench rate may be a measure of the ability to compute local and core-wide oxidation, it is not important in the assessing the PCT. This issue was also addressed in the response to RAI 1 on BEACH Revision 4. As discussed in that response, the reduction of BEACH predicted temperatures at medium temperatures is not nearly as consequential as the overprediction of temperatures near the peak cladding temperature. Of the six tests presented in the response, four of the five that benchmarked the quench front acceptably involved PCTs between 2000 and 2200 F. One of the five had a PCT of 1600 F. The one case included for which the quench front advanced too quickly, Test 31302, was at a high flooding rate, 3 in/s, and had a low peak temperature of 1600 F. Thus, within the comprehensive benchmarks provided for BEACH, only Test 8037 provides the combination of high cladding temperatures and early advancement of the quench front. These results, however, are contradicted by the more realistic variable flooding rate test benchmarks presented in Appendix I.

In summary, the difference in quench front advancement between the data and the benchmark of Test 8037 is not consistent with other BEACH benchmarks. BEACH, in general, successfully predicts quench front advancement acceptably for the FLECHT test series and is substantially conservative in comparison to other test series.

3. Question: What is the uncertainty in the temperature in the clad temperature versus elevation plots from the FLECHT data comparisons shown in Figures I-1, I-2, I-3, I-4 and I-5 from BAW-10166PA, Revision 5? These plots failed to capture some of the thermocouple temperatures along the axis of the FLECHT heater rods. Please show that when the uncertainty in temperature is included, the BEACH calculated temperatures capture all of the temperature data points.

Response: In complying with the requirements of 10CFR50.46 and Appendix K to 10CFR50, the BEACH code was designed to provide a conservative yet realistic prediction of the available reflood heat transfer data. Although BEACH predictions bound most data, BEACH was never intended to bound all available data. Typically, BEACH benchmarks bound more than 85 percent of the data from FLECHT, FLECHT-SEASET, or FLECHT SET tests and 100 percent of the data from CCTF or SCTF tests. BEACH also benchmarks well against REBEKA-6 and G2 tests. In prior reviews, NRC has agreed that the predictive nature of BEACH is conservative and has agreed that the reflood heat transfer mechanisms are adequately conservative.

An uncertainty analysis for the FLECHT-SEASET program is provided in Appendix D of Reference 3-1, the FLECHT-SEASET Unblocked Bundle, Forced and Gravity Reflood Task Data Report, Volume 1. The standard deviation reported for the temperature measurements for elevated temperatures near the peak is between 4 and 5 F, which is on the order of 2 percent of the temperature rise during these tests and cannot be considered as significant relative to the results. A more significant effect is the individual heater rod temperature differences within the test assembly as indicated by the dispersion of measured cladding temperature data.

FLECHT test assemblies are bundles of individual heater rods. Each heater rod is only partially instrumented, so it is not possible to obtain a complete rod test history from the measurements of any specific rod. Rather, the transient behavior is inferred from measurements taken on multiple rods. The BEACH benchmarks are run with inputs that are characteristic of the average heater rod across the test assembly to achieve an appropriate simulation of the local fluid conditions within the assembly. Figure 3-1 provides the initial temperature distribution, as a function of core height, selected for benchmarking FLECHT-SEASET Test 34006, along with the reported initial temperature data. Figure 3-2 provides the same information in a measured data-to-predicted format. In this case, the prediction is for the initial distribution assumed for the benchmark calculation. As can be observed, the BEACH initial temperature distribution assumption is a reasonable representation of the averaged heater rod conditions within the assembly but does not correspond to individual heater rod characteristics.

The FLECHT tests were intended to represent a fuel assembly at the beginning of the reflood phase. To do this, the assembly was initially powered with a steam-only environment in the assembly and allowed to heat to the desired initial condition. Once the assembly was hot, the test was then commenced by the initiation of reflooding and the programmed decay heat power.

The initial deviations among bundle average temperatures at any elevation and among individual heater rod temperatures were established during this initial heatup and are characteristic of differences between heater rods. The sources of the differences are not known. Because the causes are unknown, BEACH benchmarks are performed for the average rod parameters, and the measure of the benchmark is the ability of BEACH to produce a reasonable average of the rod PCT data. Figure 3-3 shows the peak temperature results of Test 34006 in measured-to-predicted format for each thermocouple reported.

To assess BEACH against individual heater rod data would require modeling the individual heater rod. This is not possible since the required information is not available. The best that can be said is that the measured deviations in cladding temperatures after the initial heatup, just prior to the initiation of reflooding, result from differences built into the heater rods. Most of the potential causative mechanisms would continue to act during the transient, making the initial temperature deviation an estimate of the difference throughout the transient. Some potential mechanisms, such as an irregularity in boron nitrite packing, would be stronger during an adiabatic heating than during the reflooding transient. Therefore, an expected adjustment for the BEACH benchmark prediction lies between zero and the temperature difference at transient initiation. Figure 3-4 plots the measured temperature data against adjusted BEACH predicted temperatures. The adjustment is made by adding the initial temperature deviation between BEACH and measured data to the BEACH transient data. In the figure, the triangular data points result from a positive adjustment, indicating that the heater rod was hotter than the BEACH initial condition assumption. The circular data points correspond to data that was cooler in the initial condition.

Figures 3-5 through 3-16 present the same information as Figures 3-2, 3-3 and 3-4 for the remaining FLECHT-SEASET tests in Appendix I, Tests 31203, 31701, 35807, and 35912. The comparisons for Tests 35807 and 35912 were developed only for core elevations below 6 feet. For tests beyond 34610 in the SEASET series, the bundle was seriously distorted between 60 and 90 inches making the data above about 5 feet unusable for code verification. The unadjusted comparisons show that BEACH either accurately predicts or bounds approximately 80 percent of the available data but does not bound the maximum temperature reported for Tests 34006 and 31701. This is only slightly below the BEACH historical performance. When the BEACH prediction is adjusted by the difference in initial cladding temperatures, the differences between the measured data and the calculated results is reduced, the peak reported temperatures are essentially the same as the BEACH prediction. In fact, only a few data points in Test 34006 involve high temperature BEACH predictions that lie below the data. Therefore, the BEACH benchmark predictions of FLECHT-SEASET documented in Appendix I suitably bound or capture the available test data.

References:

3-1. FLECHT SEASET Program NRC/EPRI/Westinghouse Report No. 7, "PWR FLECHT SEASET Unblocked Bundle, Forced and Gravity Reflood Task Data Report" Volume 1, Westinghouse Electric Corporation, June 1980.

Figure 3-1 FLECHT-SEASET 34006: Initial Temperatures, BEACH Input and Data

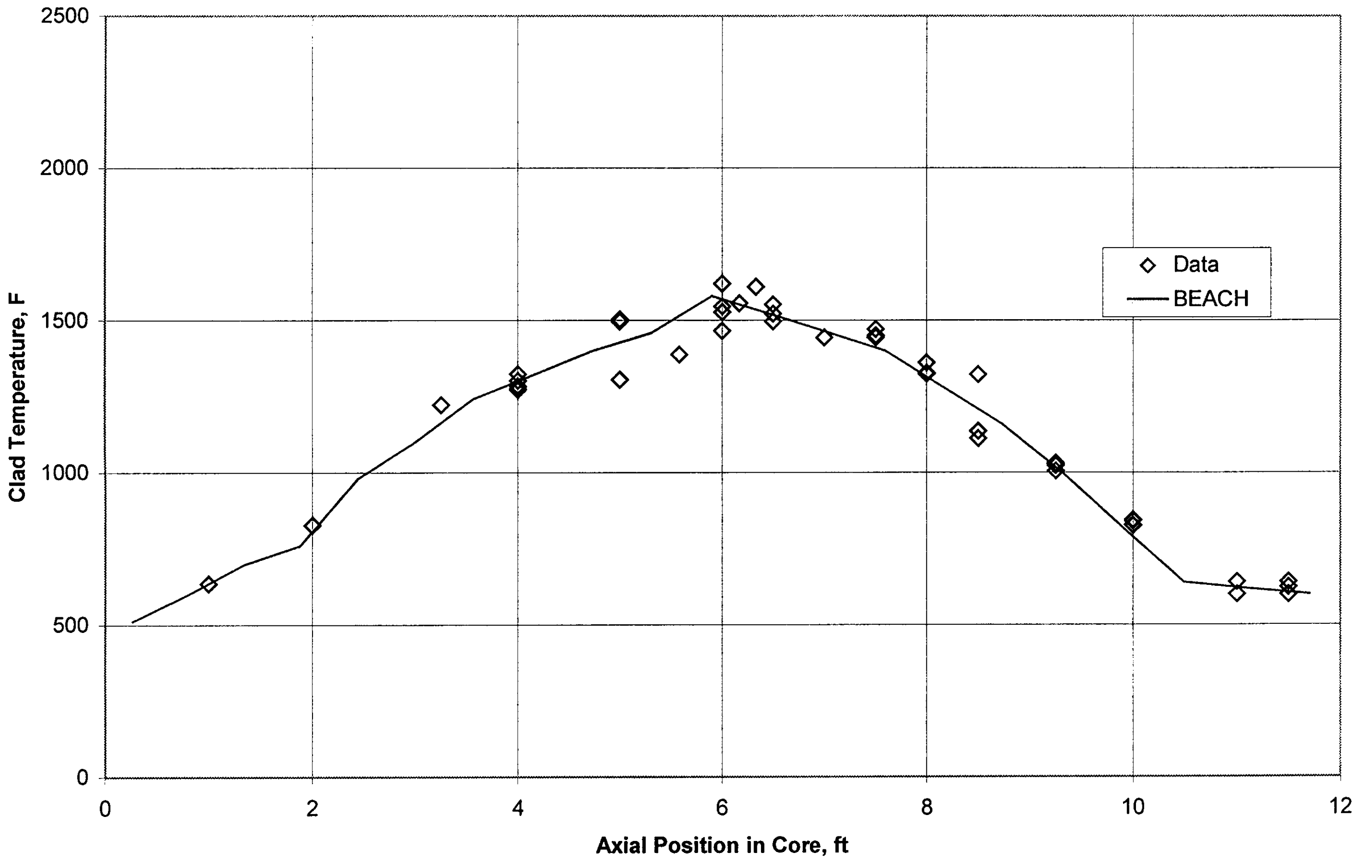


Figure 3-2 FLECHT-SEASET 34006: Measured Initial Temperature to BEACH Initialization

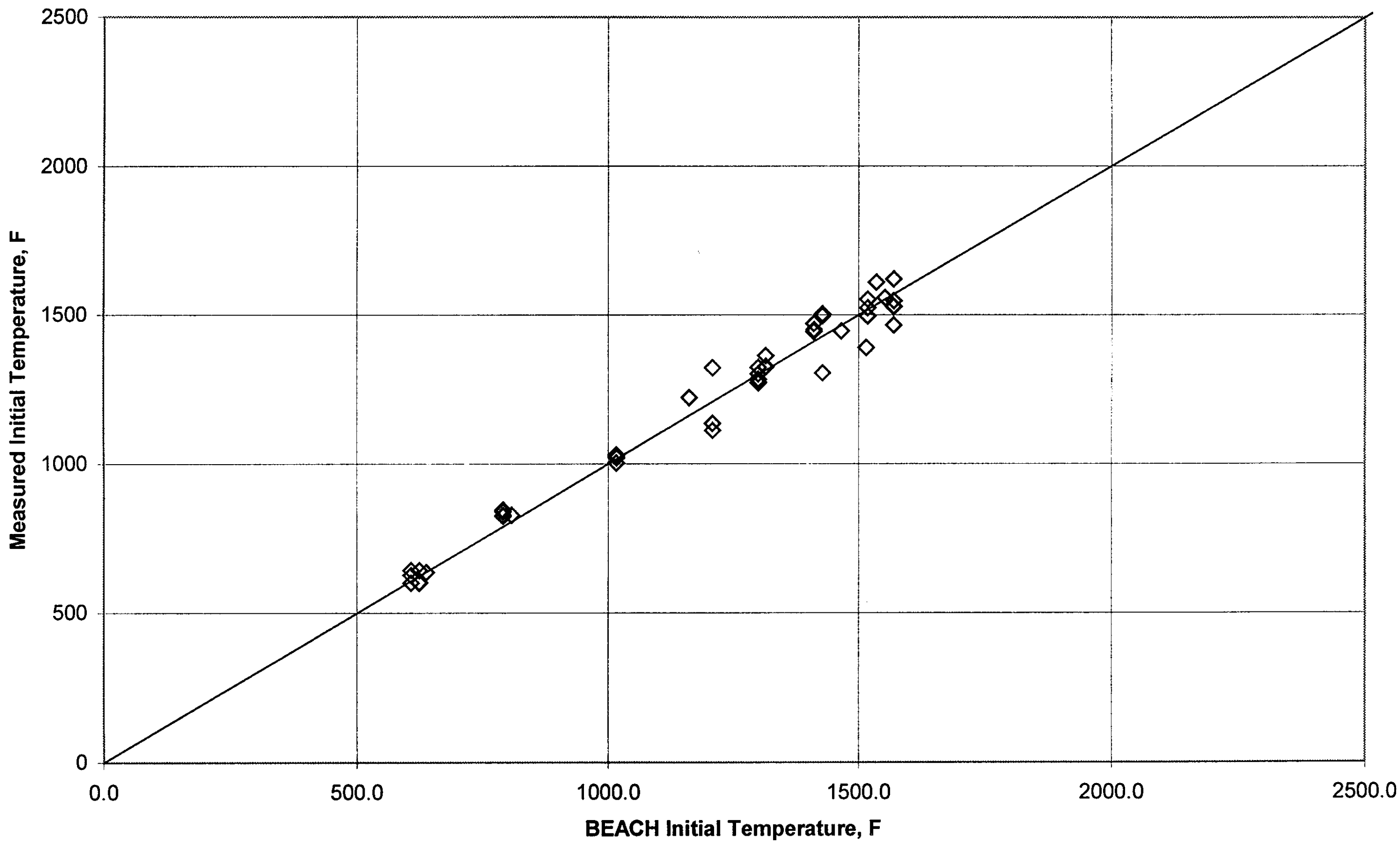


Figure 3-3 FLECHT-SEASET 34006: PCT at all Elevations, Measured to BEACH Prediction

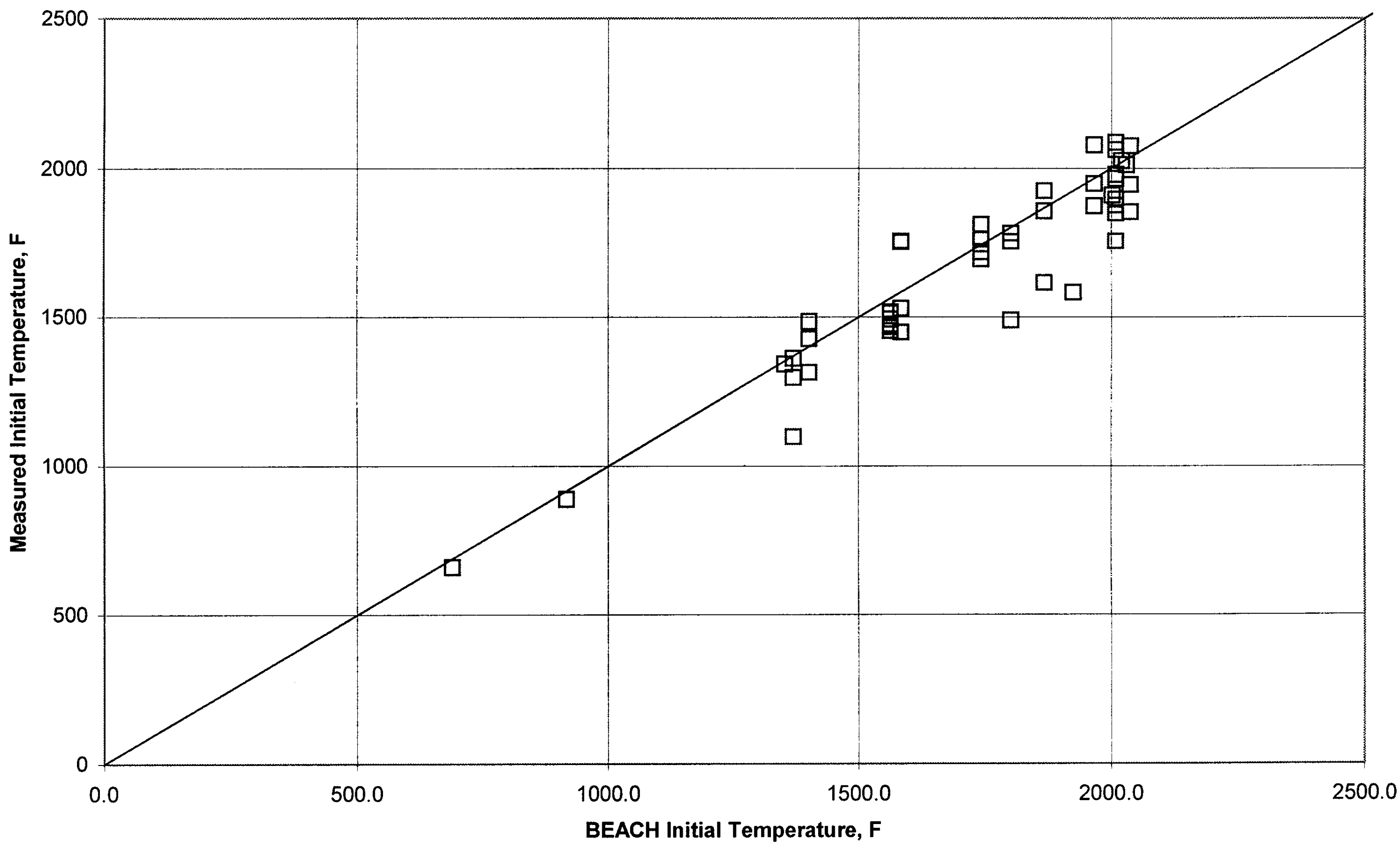


Figure 3-4 FLECHT-SEASET 34006: PCT at all Elevations, Measured to Adjusted BEACH Predicted

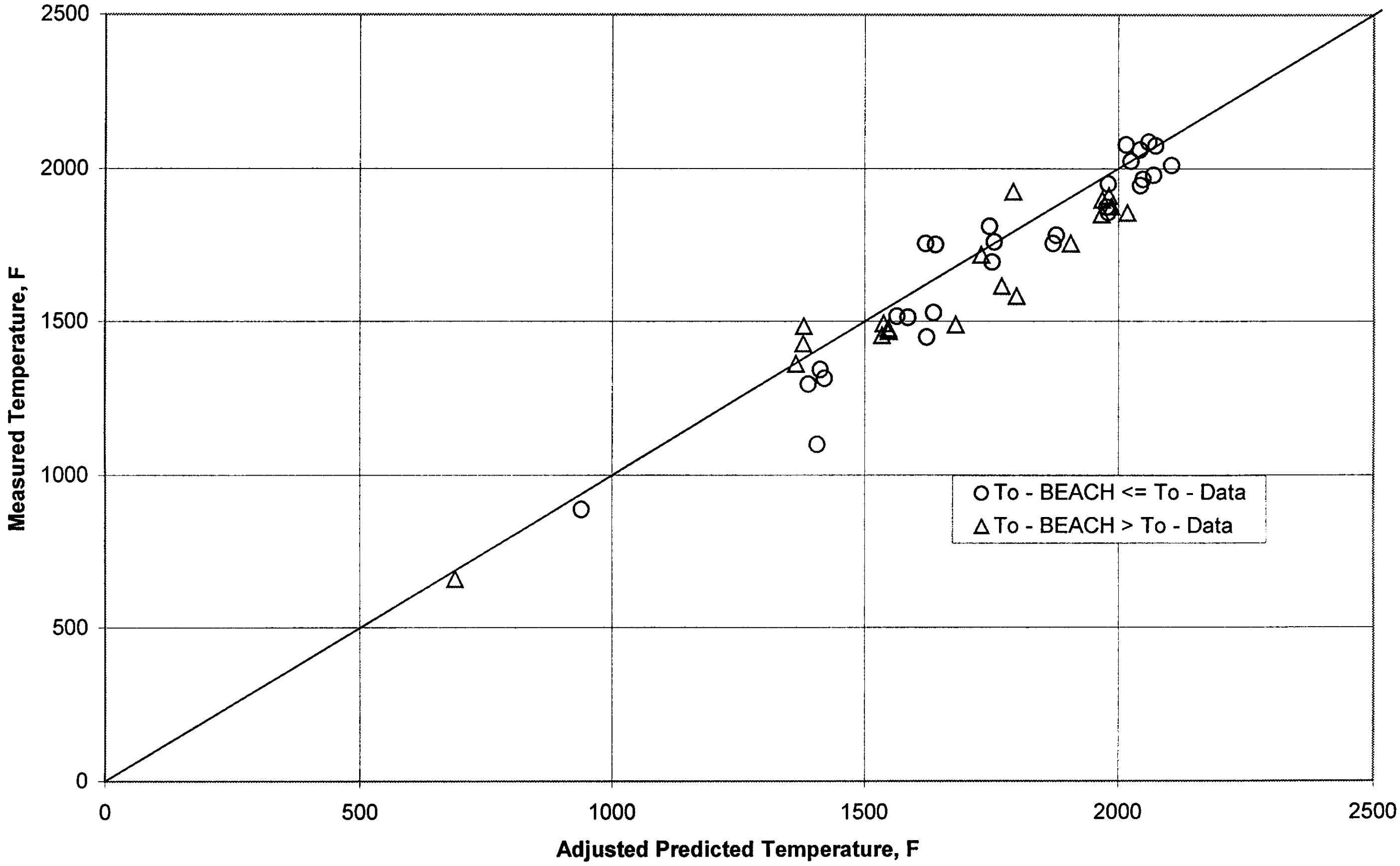


Figure 3-5 FLECHT-SEASET 31203: Measured Initial Temperature to BEACH Initialization

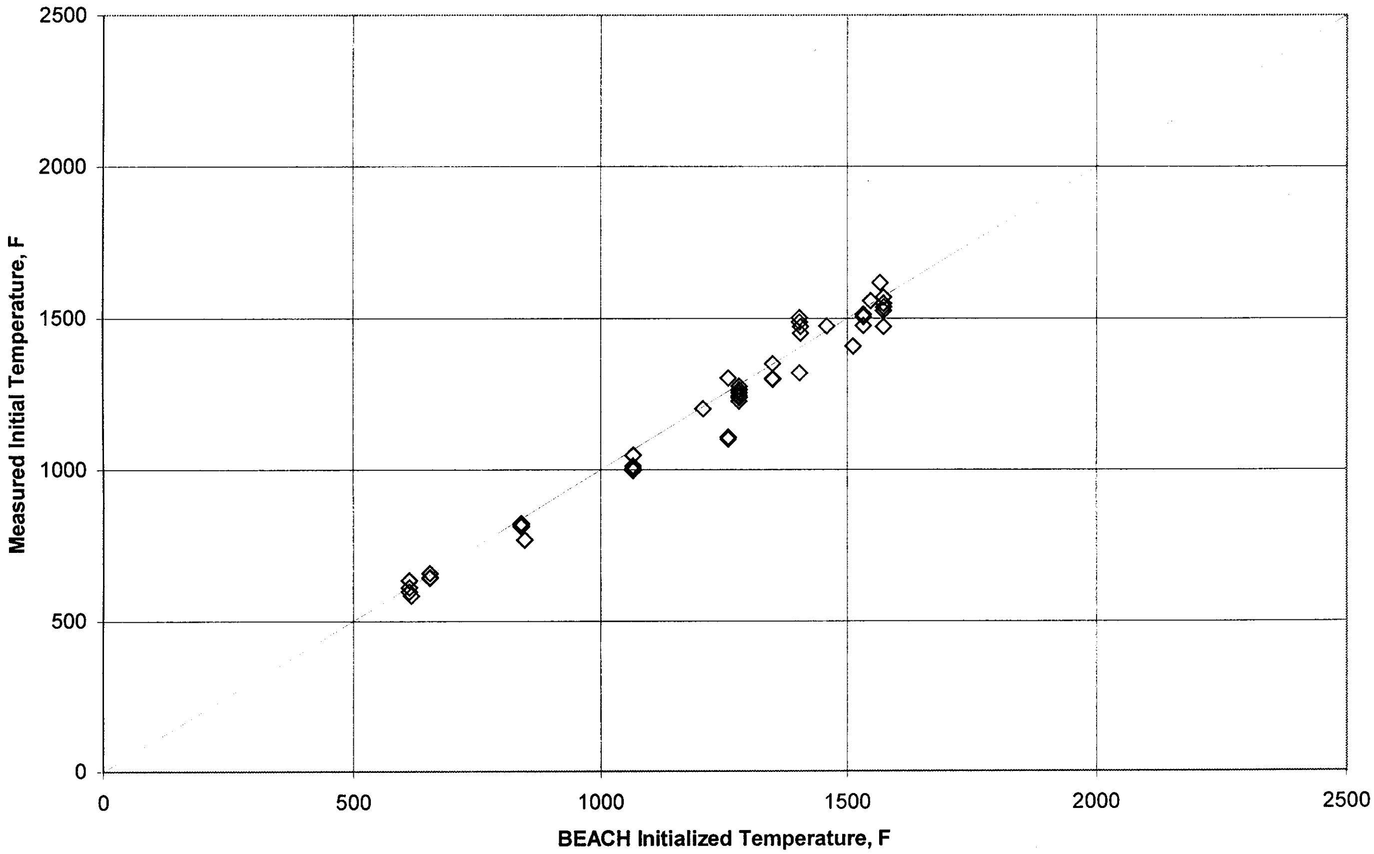


Figure 3-6 FLECHT-SEASET 31203: PCT at all Elevations, Measured to BEACH Predicted

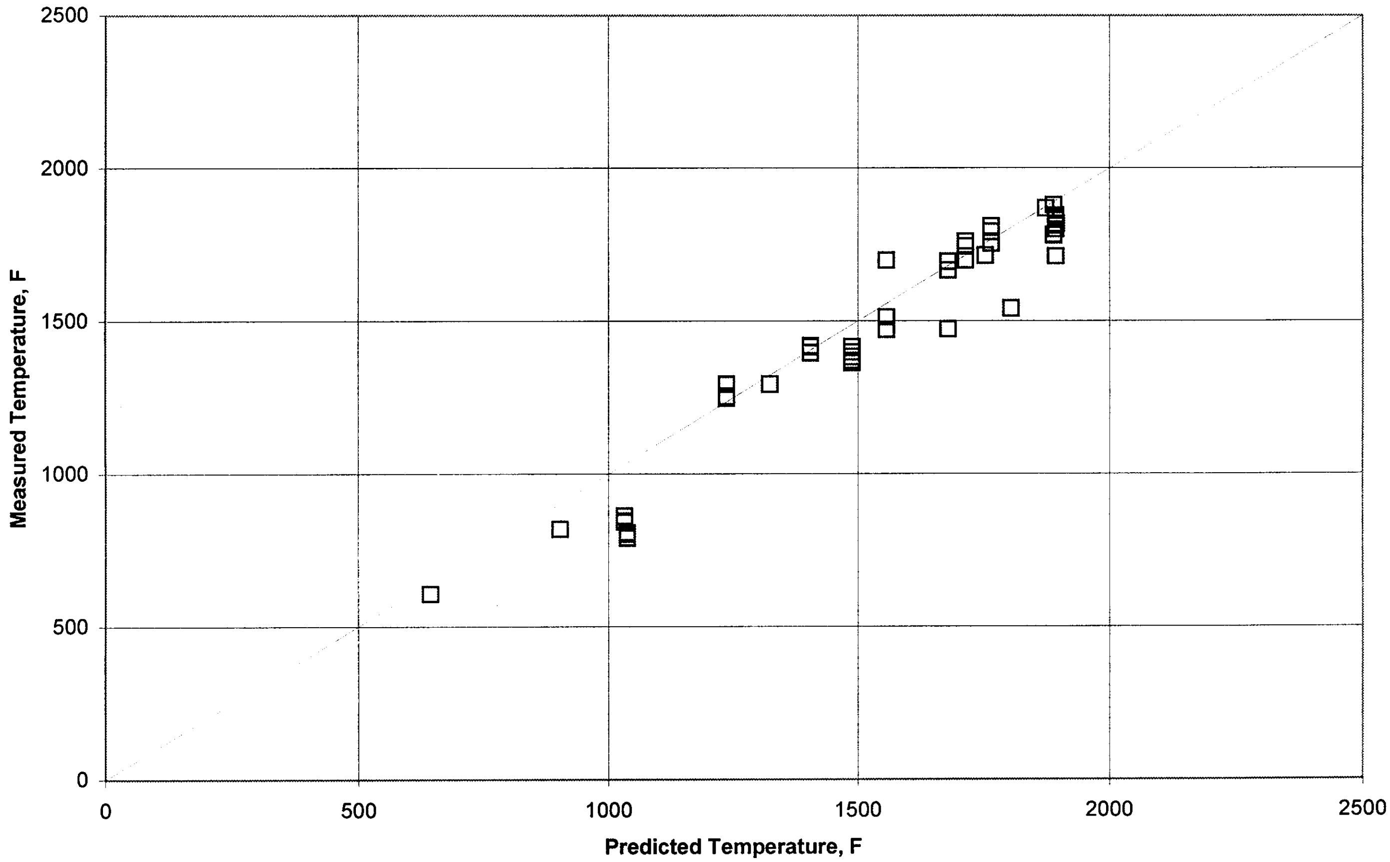


Figure 3-7 FLECHT-SEASET 31203: PCT at all Elevations, Measured to Adjusted BEACH Prediction

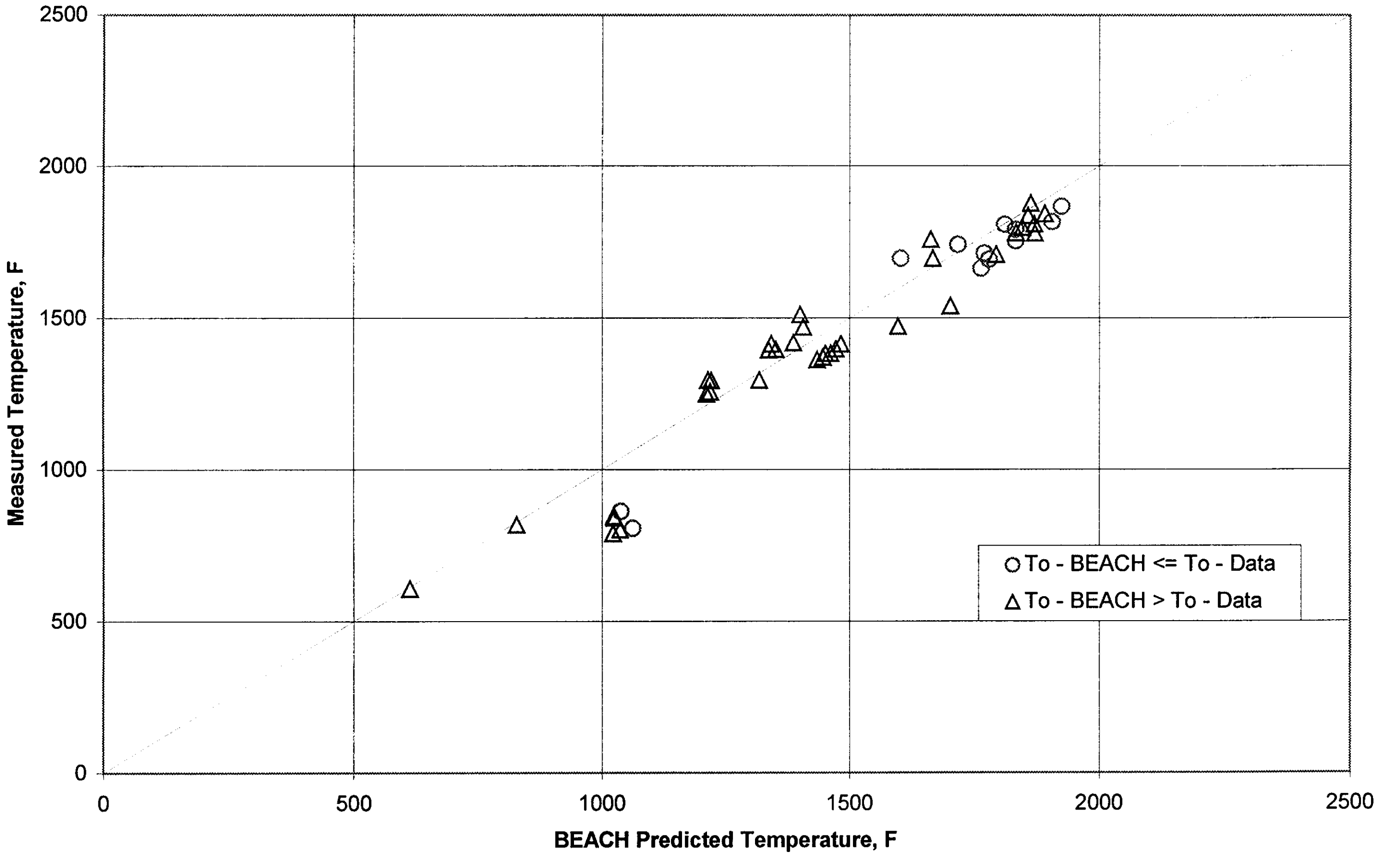


Figure 3-8 FLECHT-SEASET 31701: Measured Initial Temperature to BEACH Initialization

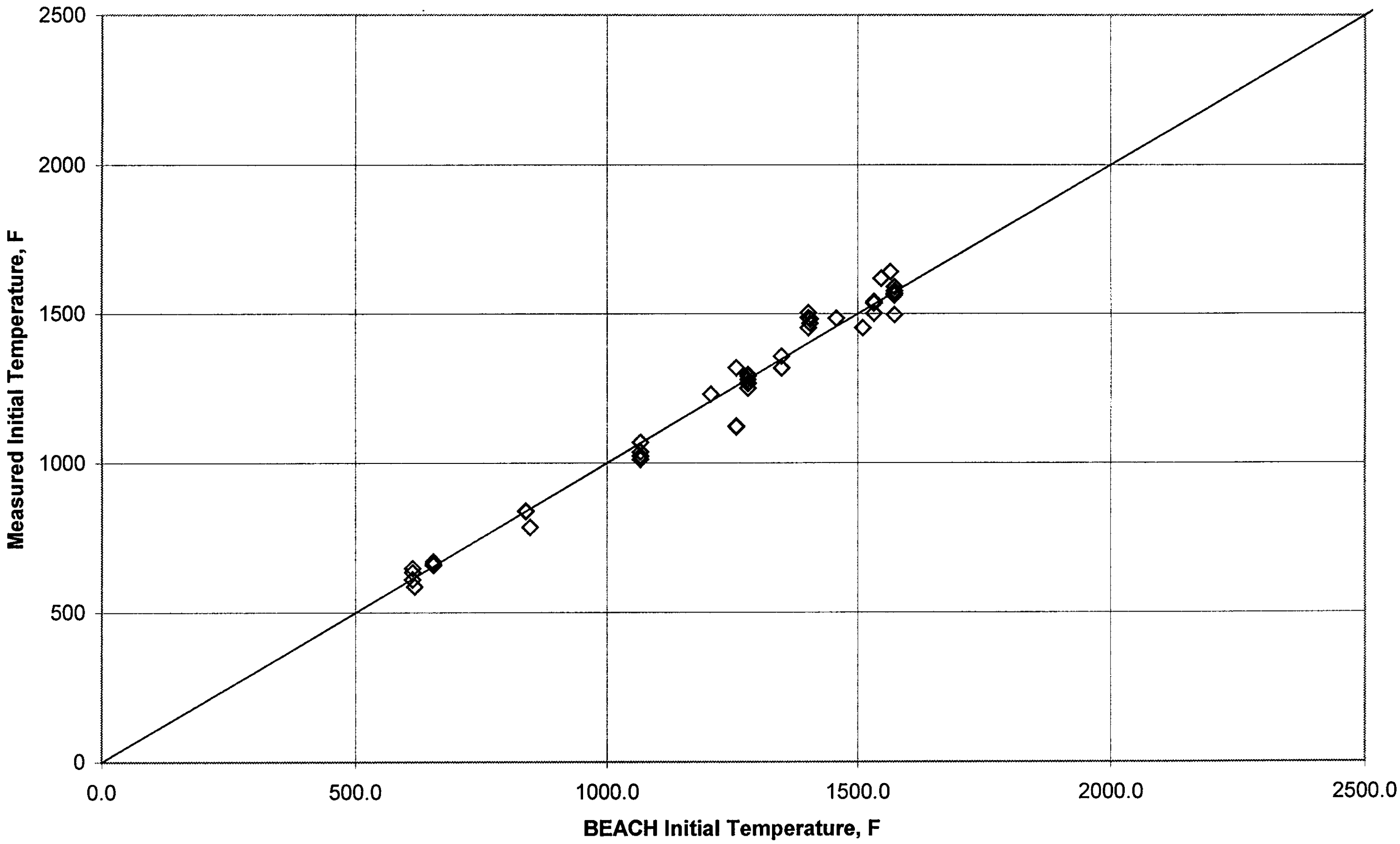


Figure 3-9 FLECHT-SEASET 31701: PCT at all Elevations, Measured to BEACH Prediction

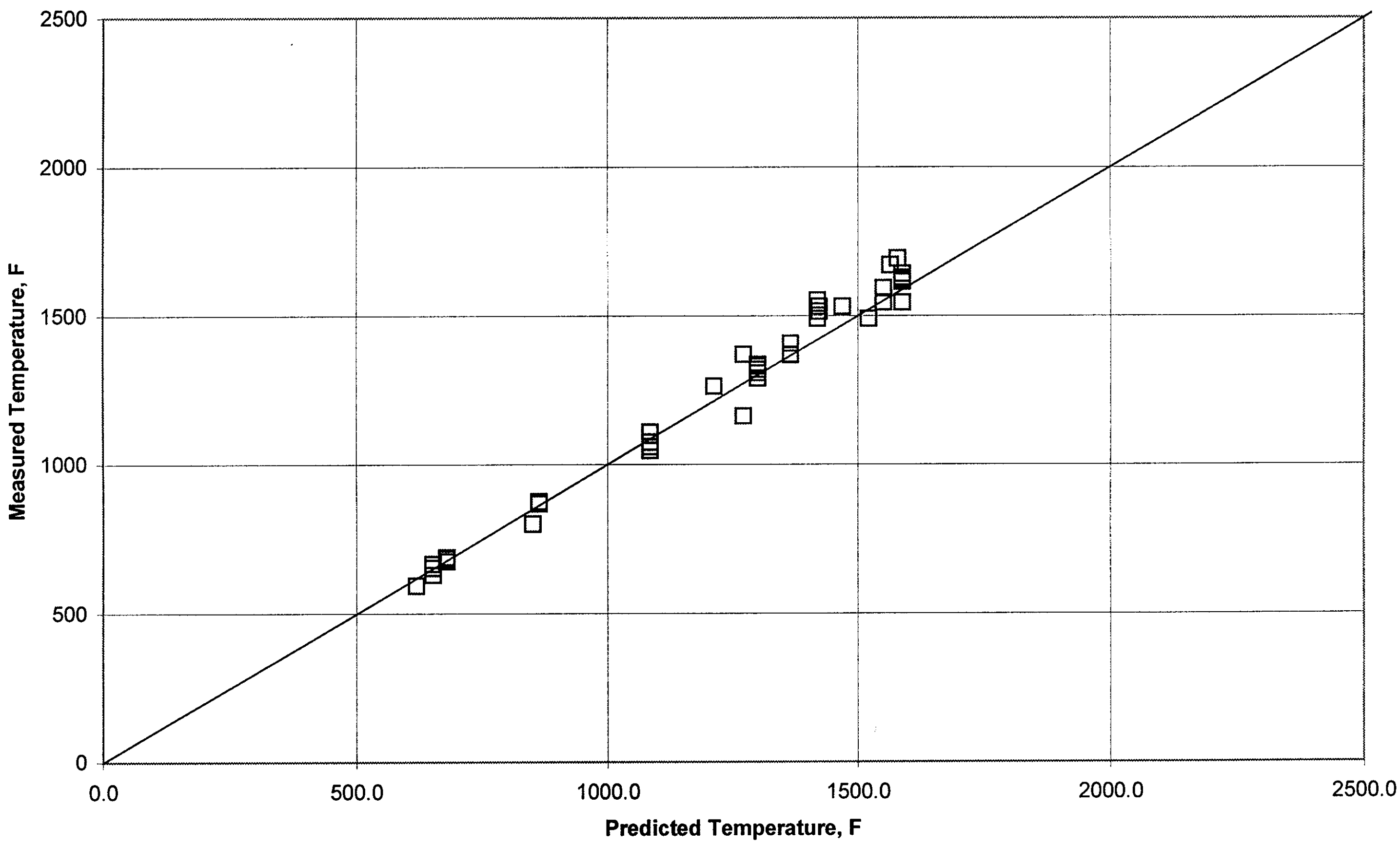


Figure 3-10 FLECHT-SEASET 31701: PCT at all Elevations, Measured to Adjusted BEACH Prediction

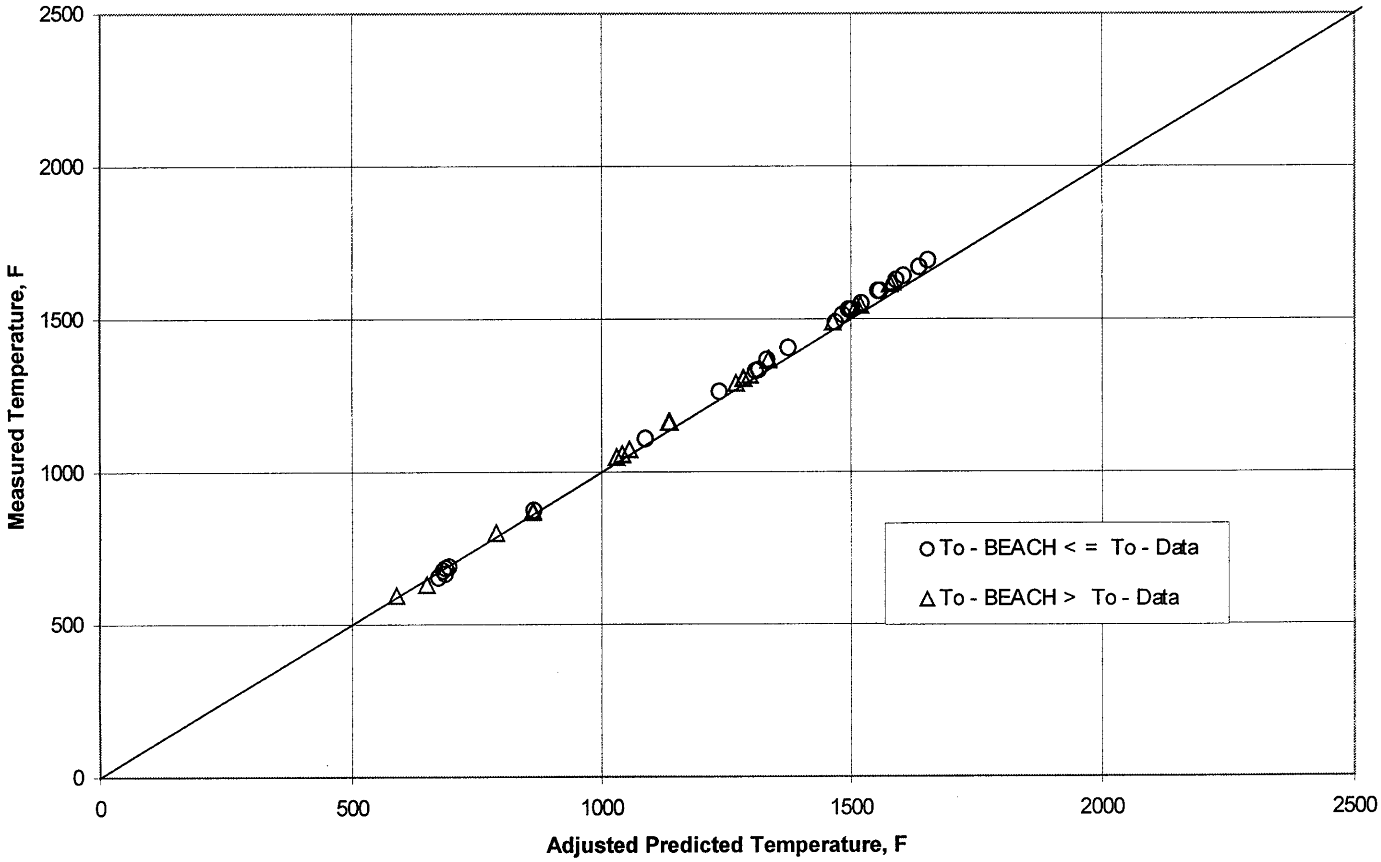


Figure 3-11 FLECHT-SEASET 35807: Measured Initial Temperature to BEACH Initialization for Elevations Below 6 feet

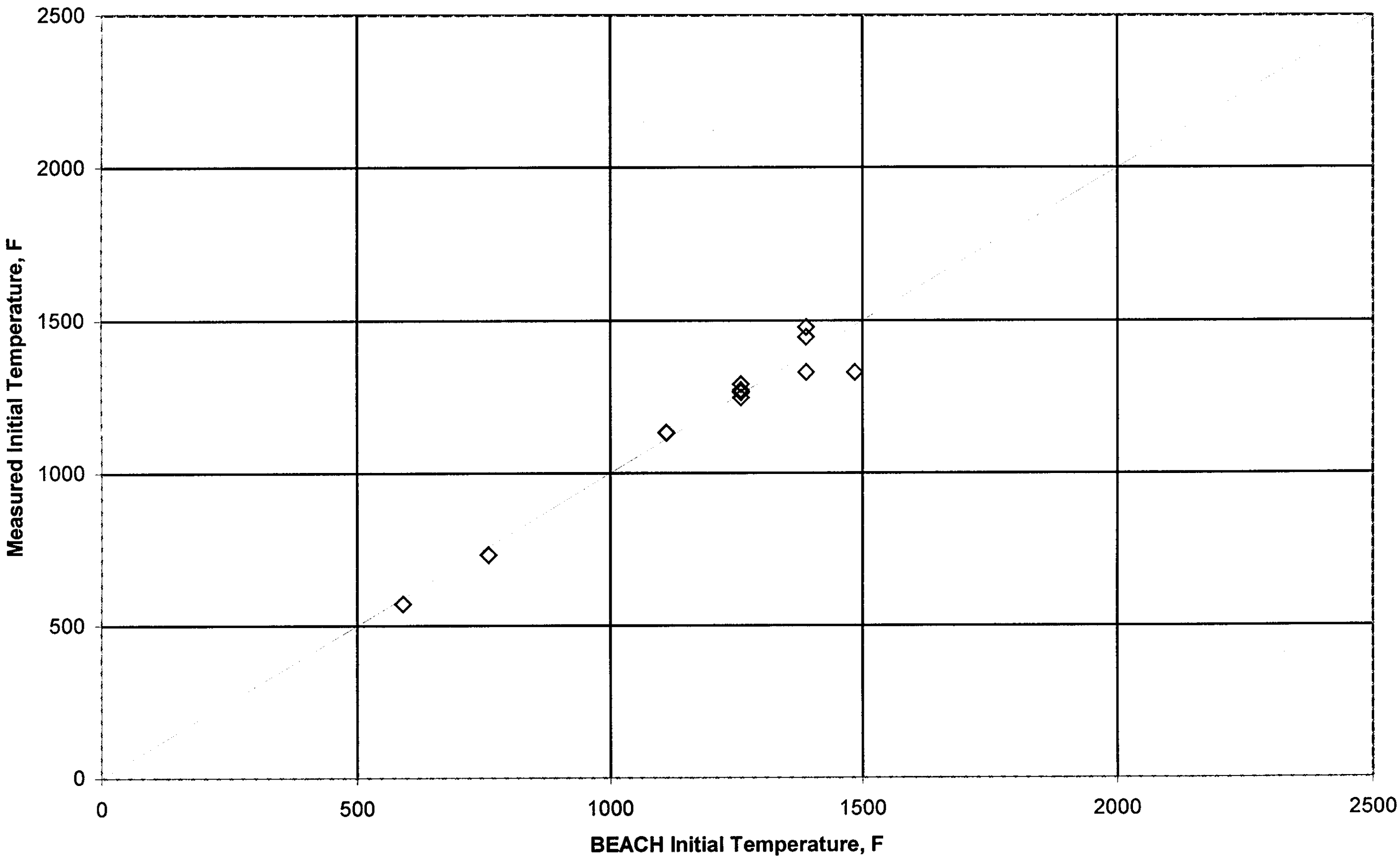


Figure 3-12 FLECHT-SEASET 35807: PCT at Elevations Below 6 feet, Measured to BEACH Prediction

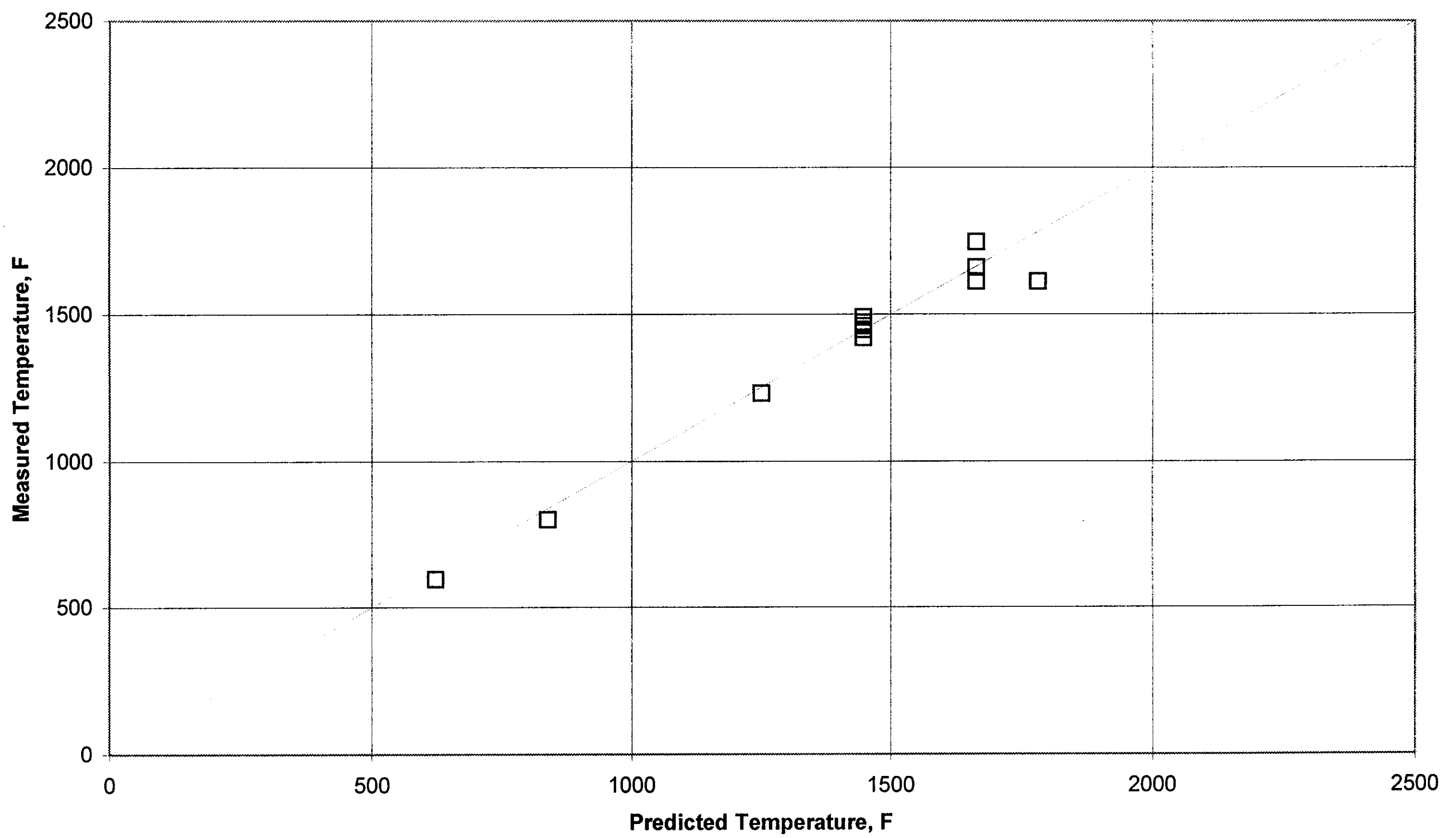


Figure 3-13 FLECHT-SEASET 35807: PCT at Elevations Below 6 feet, Measured to Adjusted BEACH Prediction

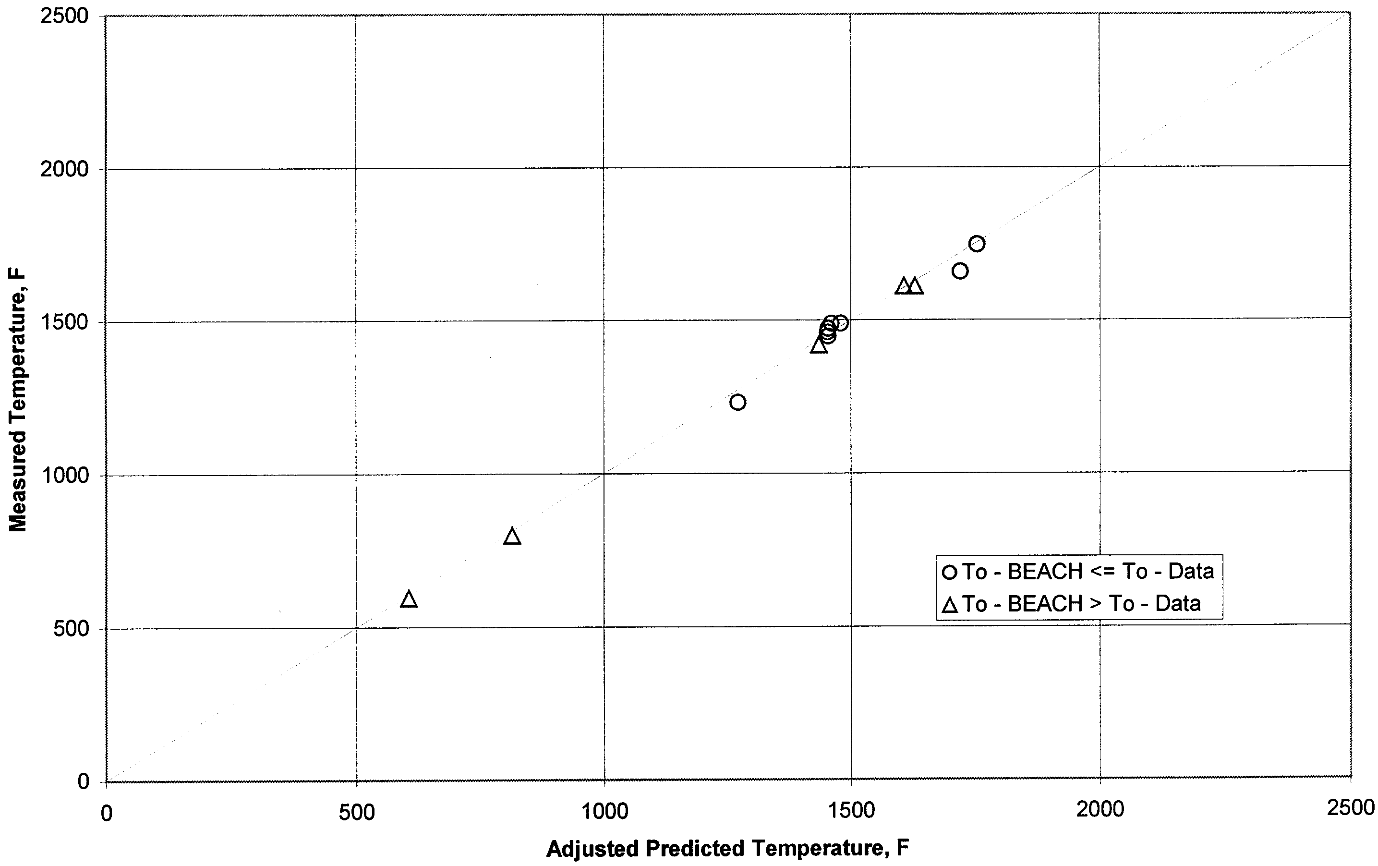


Figure 3-14 FLECHT-SEASET 35912: Measured Initial Temperature to BEACH Initialization for Elevations Below 6 feet

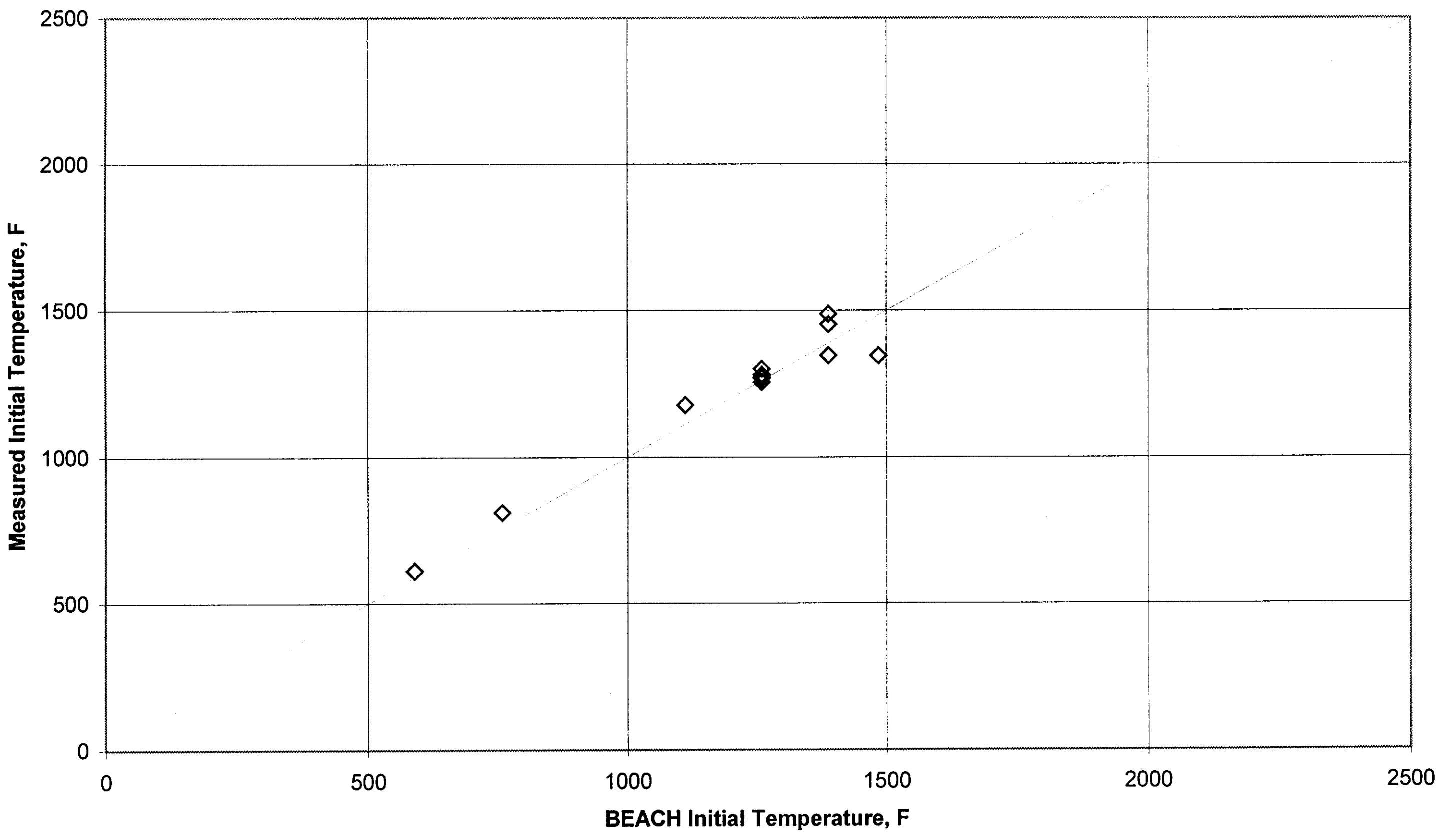


Figure 3-15 FLECHT-SEASET 35912: PCT at Elevations Below 6 feet, Measured to BEACH Prediction

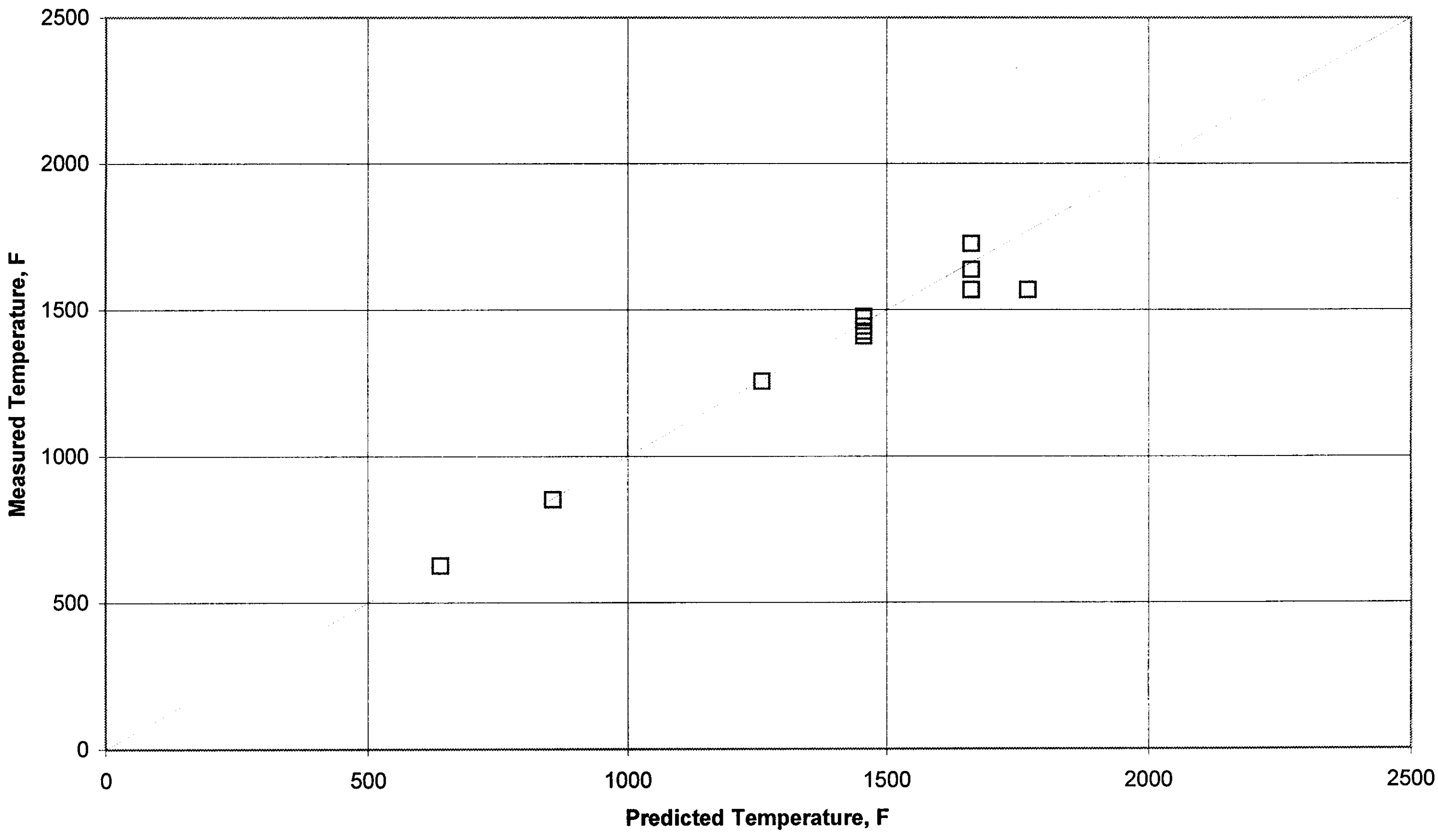
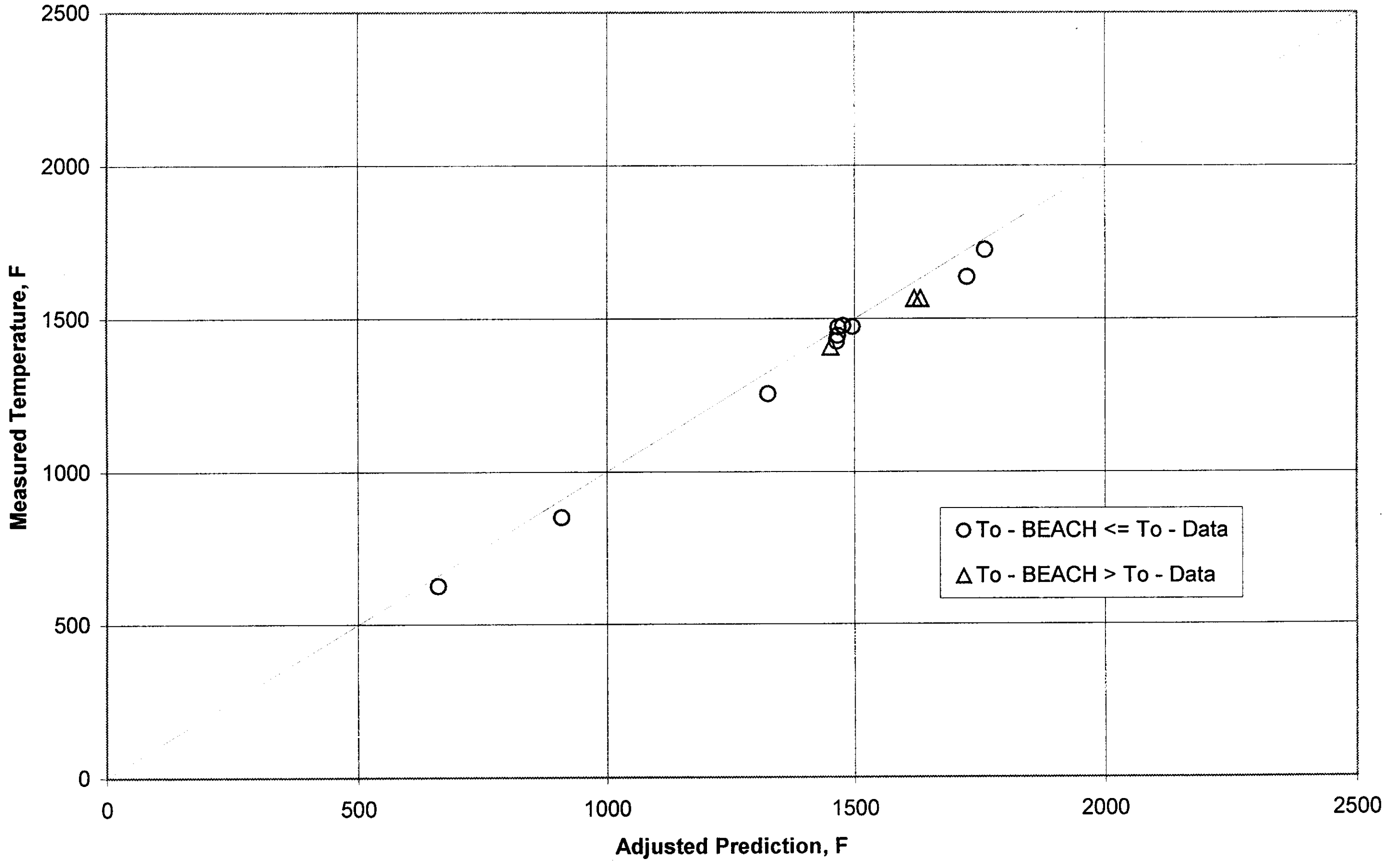


Figure 3-16 FLECHT-SEASET 35912: PCT at Elevations below 6 feet, Measured to Adjusted BEACH Prediction



4. Question: FLECHT-SEASET tests were used to demonstrate BEACH performance for low reflood rates and high initial reflood PCT loss-of-coolant accident (LOCA) events. In the FLECHT-SEASET test predictions to demonstrate BEACH low reflood rate performance, BEACH underpredicted the test PCT in 4 of the 5 cases. In the FLECHT-SEASET test prediction to demonstrate higher initial reflood temperature, the BEACH-calculated PCT also tended toward underprediction of the data. Please explain what is peculiar about the FLECHT-SEASET tests, or the BEACH modeling, that makes BEACH tend to underpredict their data at high temperatures?

Response: The primary reason for the underprediction of PCT is the difference between the BEACH benchmarks designed to predict the average heater rod within the test assembly and the individual heater rod test results. As discussed in the response to RAI 3, BEACH is benchmarked against the average heater rod in the test assembly to properly simulate the fluid conditions within the assembly. Simulation of individual heater rods is not attempted because the causative factors producing the individual rod performance are not available. Therefore, BEACH does not respond to and should not be measured against individual heater rod results. However, given the logical application of the difference between the individual rod and the average rod at test initiation as representative of the adjustment required to simulate individual rod performance, the graphs in Figures 3-4, 3-7, 3-10, 3-13, and 3-16 demonstrate that BEACH predicts the maximum cladding temperature data quite well for all five SEASET tests in Appendix I. These comparisons demonstrate that the temperature rises of individual rods are well predicted by BEACH. All PCTs are captured by BEACH, and only a few data points in Test 34006 involve a high temperature BEACH prediction that lies below the data.

From Figures 3-2 to 3-16, it is evident that a substantial reason for BEACH appearing to underpredict the peak cladding temperature data lies in the individual heater rod performance. Once this difference is accounted for, BEACH predictions are very close to the data. This is also true of the benchmark in Appendix H, which successfully bounds the test thermocouple data except for one thermocouple at 3 feet and another at 8.5 feet. BEACH is capable of predicting reflood heat transfer and cladding temperatures over a wide range of conditions. Additionally, as shown in Appendices G and I of the BEACH topical report, the code is very conservative when benchmarked against CCTF, SCTF, REBEKA-6, and the G2 facility. In addition, the NRC has previously concluded that

BEACH, with benchmarks demonstrating an essential bound, is adequately conservative as an Appendix K evaluation model. It is concluded that BEACH has been demonstrated to be adequately conservative for the prediction of PCTs during the low reflood rates presented in Appendix I.

5. Question: How do the Power shapes for North Anna and FLECHT and FLECHT-SEASET compare?

Response: The FLECHT and FLECHT-SEASET power shapes were selected for experimental practicality and plant operations that were typical about 30 years ago. The axial power shapes for the FLECHT series are central-peaked chopped cosines with axial peaking factors of 1.66, excepting one test assembly that had a top-skewed power peak. The heater rod peak powers at the beginning of reflood fall into three groups of approximately 0.4 kw/ft, 0.7 kw/ft, and 1.0 kw/ft.

The current power distribution management schemes for PWRs do not offer direct control of the axial power distribution. Rather, relying on power imbalance limits, the maximum axial peak at any elevation can be determined and limited. Radial peaking is controlled primarily through fuel management techniques. Centralized peaking similar to the chopped cosines simulated by the FLECHT test series is possible but atypical. However, the peak power simulated in the FLECHT series is characteristic of modern PWRs. North Anna operates with an expected maximum radial peaking factor of approximately 1.45, which, with uncertainties, increases to 1.55, which results in a peak power density at the beginning of reflood of approximately 0.7 KW/ft.

The peaking simulated during LOCA calculations is an approximation of the range of transient peaking distributions expected for a plant operating at the limiting conditions of operation. The radial power peaking is set to represent the limiting conditions achieved by the fuel cycle loading pattern. The axial peaking is varied and shifted to produce limiting total peaks from as low in the core as about 3 feet to as high as about 10 feet. Once a set of LOCA calculations is performed that offers sufficient plant operational flexibility and meets the requirements of 10CFR50.46, the total peaks for those calculations are enforced during plant operation through the application of power imbalance limits.

There is, therefore, no direct relationship between the power distributions to which modern PWRs are limited and the FLECHT and FLECHT-SEASET power distributions. Because BEACH deals mechanistically with the power distributions imposed and has been benchmarked against centrally peaked and outlet-peaked distributions in many different test programs, it is well suited for the determination of the reflood heat transfer process.

6. Question: Please provide the reference showing the BEACH drop size predictions compared to reflood data. If not available, please show a plot of drop sizes at the hot spot predicted by BEACH for the reflood tests presented in BAW-10166PA, Revision 4. For the FLECHT-SEASET cases, please also show the data as a comparison.

Response: The original spatial distribution of droplet diameter for the BEACH benchmark of FLECHT-SEASET Test 31805 at 200 seconds was provided in the response to RAI 14 on Revision 0 of the BEACH topical report. The response is documented on page 5-43, and the distribution is given in Figure 14-18 on page 5-115 of the BEACH topical report, Reference 6-1.

Modifications to the droplet configuration models were made in subsequent revisions to the topical report. The base droplet diameter is calculated using a critical Weber number of 2.5 (page 2.1-28.2 of Reference 6-1). This diameter is modified to account for the boiling length below the quench front and droplet breakup due to grid interactions. These calculations are described in detail on pages 2.1-28.2 and 2.1-29 of Reference 6-1.

Current BEACH droplet diameter distributions are shown in Figure 6-1 for benchmarks of FLECHT-SEASET Tests 31203 (1.5 in/s flooding rate), 31504 (1.0 in/s flooding rate), and 31805 (0.8 in/s flooding rate). For Tests 31203 and 31504, the BEACH droplet distribution is plotted at 100 seconds. Test 31805 calculated single-phase steam flow at 100 seconds making it necessary to plot the droplet diameter distribution at 150 seconds. From this figure, it can be seen that, away from the quench front at and above the 6 foot core elevation (the quench front for these runs varies between 3 and 4 feet at the edit times), the BEACH-calculated droplet diameters decrease from approximately 2.0 mm to nearly 0.5 mm. Appendix E in Reference 6-2, the FLECHT-SEASET Analysis Report, gives droplet diameters that were estimated from movie films for several tests. Figure E-8 in Reference 6-2 provides the droplet size distribution at 6 feet for Test 31504 from 200 to 206 seconds. The meaningful population range contains droplets of diameters from 0.4 mm to 1.5 mm with an average droplet diameter of about 0.8 mm. Figures E-11 and E-12 provide the same information for Test 31805 at the 3 foot and 6 foot elevations early in the test from 10 to 16 seconds. The meaningful population range contains droplet diameters from 0.6 mm to 1.3 mm with the average droplet being 0.9 mm in diameter.

The remaining tests reported obtain similar droplet size distributions. These data indicate that BEACH droplet diameters, ranging between 0.5 mm and 1.0 mm away from the quench front, are reasonable and sufficient for the determination of interphase heat transfer.

References:

6-1. BAW-10166PA Revision 4, BEACH Best Estimate Analysis Core Heat Transfer, A Computer Program for Reflood Heat Transfer During LOCA, Framatome ANP, Lynchburg, Virginia, February 1996.

6-2. N. Lee, S. Wong, H. C. Yeh, and L. E. Hochreiter, PWR FLECHT SEASET Unblocked Bundle, Forced and Gravity Reflood Task Data Evaluation and Analysis Report, NUREG/CR-2256, Westinghouse Electric Corporation, Pittsburgh, Pennsylvania, November 1981.

Figure 6-1 Droplet Diameter for FLECHT-SEASET Benchmarks