APPENDIX – H

BEACH Code Benchmark at Higher Initial Cladding Temperatures

Note: This appendix was originally added in its entirety in Revision 5 of BAW-10166 for the purpose of extending the initial cladding temperature restriction imposed in the SER for Revision 2.

H.1 Introduction

The performance of the BEACH code has been validated with reflood phase benchmarks to FLECHT, FLECHT-SEASET, REBEKA, G2, CCTF, and SCTF tests (see Table H-1). During the NRC review for Revision 2 of BEACH, additional information was requested (Reference H-5) on the range for certain benchmark test parameters and it was requested that these be related to the expected plant parameter ranges. The ranges provided were representative of Westinghouse- or Combustion Engineering-designed PWRs, since at that time those were the only plant designs to be licensed with analyses from BEACH. The provided parameter range became SER limitation number one in Revision 2 of BEACH (Reference H-6). Revision 3 of BEACH was subsequently submitted and approved (Reference H-7), also focusing on the Westinghouse or CE plants. Revision 4 of BEACH, which was also applicable for the B&W designed plants, was submitted and approved in January 1994 (Reference H-8). The SERs on Revisions 3 and 4 preserved the previous parameter ranges specified as a restriction in Revision 2.

After approval of Revision 4 of BEACH, the BWNT LOCA EM was submitted for review and approval (Reference H-3). This report had 21 BEACH application cases with typical B&W-plant cladding temperatures between 1800 and 1900 F at the onset of core reflood. As stated in the SER for BWNT LOCA (Reference H-4), these application cases were well behaved and found to be reasonable and acceptable, because the solution was shown to be stable and converged. However, the initial temperature range specified in the SER on BEACH Revision 2 was specified as 950 to 1640 F. Therefore, the cladding temperatures in the approved BWNT LOCA EM demonstration cases (Reference H-2) were above the acceptable range specified in the BEACH SER.

Framatome ANP recognized that there was no explicit statement in the SER on BWNT LOCA acknowledging that the temperature limit could be extended to the range provided in the EM demonstration cases. In addition, it was recognized that there was a possibility that future BWNT LOCA EM cases could potentially exceed the maximum temperature included in the demonstration cases. Therefore, Framatome ANP initiated a review of the available reflood test data that could be used as additional validation for BEACH applications at initial cladding temperatures beyond the range specified in the SER on Revision 2 of BEACH.

H.2 BEACH Benchmark to FLECHT Test 34420

The benchmark ranges, as given in the SER for Revision 2 of BEACH, cover initial hot spot cladding temperatures up to 1640 F. An additional benchmark of FLECHT-SEASET (full length emergency core cooling heat transfer - separate effects tests and system effects tests), Test 34420 has been performed to justify increasing the BEACH code initial cladding temperature range. This test has an initial cladding temperature of 2045 F and is one test in a series of experiments that has been used extensively to validate the existing BEACH analysis ranges (Table H-1). The test data were readily available (Reference H-1), and the initial conditions were input to the existing FLECHT-SEASET benchmark model used in the BEACH Appendix G assessment cases and described in BEACH Appendix C.

The key test parameters are summarized in Table H-1. They are similar to Test 30817 (except for the initial clad temperatures), which was reported in Revision 4 of BEACH. The pressure is 39 psia with an inlet fluid temperature of 124 F. There is a flat radial power profile with a maximum axial power peak of 0.74 kW/ft. The initial cladding temperature is 2045 F and the flooding rate is 1.53 in/sec.

The BEACH-calculated results using these boundary conditions are shown in Figures H-1 though H-10. Figure H-1 shows the good comparison of measured-to-predicted PCT versus core elevation. Figure H-2 shows the quench front advancement. BEACH matched the quench front data well up to 150 seconds, and conservatively under-predicted the advancement thereafter. Figures H-3 through H-10 give pairs of clad temperatures and filtered heat transfer coefficients at elevations of 4, 6, 8, and 10 ft above the bottom of the core. The BEACH heat transfer plots shown in Figures H-4, H-6, H-8 and H-10 were filtered for plotting purposes with a rolling average computed over seven points (at one per second) covering the 3 seconds before and after the time shown. The delayed quench for the upper core is seen in Figures H-7 and H-9. The clad temperature evolution at the peak power location (6 ft) is quite good as shown in Figure H-5.

H.3 Summary and Conclusions

This benchmark of FLECHT-SEASET Test 34420 provides additional confirmation that the mechanistic modeling of BEACH is adequate and acceptable for reflood heat transfer prediction in LOCA applications. The adequacy of the code predictions is demonstrated in this benchmark for increased initial cladding temperatures of up to 2045 F, which encompasses the expected range of B&W plant initial clad temperatures at the onset of core reflood.

Table H-2 shows the updated BEACH assessment range, the previous SER restriction from BEACH Revision 2, and the expected plant range for the hot channel heat structures for a limiting CLPD break. Based on the benchmark of FLECHT-SEASET test 34420 data to BEACH predictions provided herein, there is ample justification for extending the maximum initial cladding temperature range from 1640 F to 2045 F.

H.4 References

H-1. M. J. Loftus, et al., "PWR FLECHT SEASET Unblocked Bundle, Forced and Gravity Reflood Task Data Report, Volume 2: Appendix C," Westinghouse Electric Corporation, WCAP-9699, NUREG/CR-1532, September 1981.

H-2. FTI Topical Report BAW-10192PA, Rev. 0, "BWNT LOCA – BWNT Loss-of-Coolant Accident Evaluation Model for Once-Through Steam Generator Plants," June 1998.

H-3. Letter J. H. Taylor, B&W, to R. C. Jones, NRC, "BWNT LOCA – BWNT Loss-of-Coolant Accident Evaluation Mode for Once-Through Steam Generator Plants," JHT/94-18, February 15, 1994.

H-4. Letter J. E. Lyons, NRC, to J. H. Taylor, B&W, "Acceptance for Referencing of Topical Report BAW-10192-P, 'BWNT Loss-of-Coolant Accident Evaluation Model for Once-Through Steam Generator Plants' (TAC No. M89400)," February 18, 1997.

H-5. Letter R. C. Jones, NRC, to J. H. Taylor, B&W, "Request for Additional Information on BAW-10166, Revision 2, BEACH," January 19, 1990.

H-6. Letter A. C. Thadani, NRC, to J. H. Taylor, B&W, "Acceptance for Referencing of Licensing Topical Report, BAW-10166P, Revision 2, 'BEACH – Best Estimate Analysis Core Heat Transfer, A Computer Program for Reflood Heat Transfer During LOCA'," August 13, 1990.

H-7. Letter A. C. Thadani, NRC, to J. H. Taylor, B&W, "Acceptance for Referencing of Topical Report BAW-10166P, Revision 3, 'BEACH'," May 30 1991.

H-8. Letter A. C. Thadani, NRC, to J. H. Taylor, B&W, "Acceptance for Referencing of Topical Report BAW-10166P, Rev.4, 'BEACH: Best Estimate Analysis Core Heat Transfer'," January 31, 1994.

Table H-1. BEACH Benchmark Comparison Cases.

Test Number	Flooding Rate (in/sec)	System Pressure (psia)	Initial Temperature (F)	Rod Power (kW/ft)	Coolant Temperature (F)
FLECHT-SEASET 31504 [5]	0.97	40	1585	0.70	123
FLECHT-SEASET 31805 [5]	0.81	40	1600	0.70	124
FLECHT-SEASET 30817 [5]	1.53	39	987	0.70	128
FLECHT-SEASET 31302 [5]	3.01	40	1597	0.69	126
FLECHT-SEASET 32333 [5]	6.36 to 5 sec 0.82 onward	40	1631	0.70	125
FLECHT-SEASET 34209 [5]	1.07	20	1636	0.72	90
FLECHT-SEASET 32235 [5]	6.53 to 5 sec 0.98 to 200 sec 0.62 onward	20	1630	0.70	88
FLECHT-SEASET 31922 [5]	1.07	20	1621	0.40	95
FLECHT SEASET 34420 [4]	**1.53**	**39**	**2045**	**0.74**	**124**
FLECHT 13609 [5]	1.0	21	1600	0.70	87
CCTF C2-6 [5]	Variable	29 [1]	1200 [2]	0.45 [2]	Variable
CCTF C1-19 [5]	Variable	29 [1]	1422	0.69	Variable
SCTF S3-15 [5]	Variable	29 [1]	1472	0.59	Variable
FLECHT-SEASET 61607 [5]	0.81	40	1612	0.70	127
G-2 561 [5]	1.00	20	1400	0.55	108
REBEKA-6 [5]	1.18	59-73	1409	0.61	275[3]

[1] Initial pressure (after reflood initiation, pressure went to ~40 psia).

[2] Medium power zone (radial bundle power factor is 1.092).

[3] The inlet subcooling is variable based on the change in system pressure.

[4] Benchmark case added in Revision 5 to justify initial reflood clad temperatures up to 2045 F.

[5] Benchmark cases previously analyzed for BEACH, as summarized in Table 2-1 (page 5-213).

Table H-2. Comparison of the BEACH Benchmark and Application Ranges

Parameter	BEACH Benchmark Assessment Range (also see response to NRC Question 2 on BEACH Revision 2)	SER Restriction on BEACH Revision 2	Expected HC Plant Range for Limiting CLPD Breaks [1] BEACH Application Range
Power (kW/ft)	0.4 – ***0.74*** [2]	0.4 – 1.0	0.4 – 1.0
Pressure (psia)	20 – 73	15 – 73	15 – 73
Maximum Initial Cladding Temperature (F)	980 – ***2045*** [3]	950 – 1640	950 – ***2045***
Inlet Subcooling (F)	5 – 144	0 – 180	0 – 180
Flooding Rate (in/sec)	0.61 – 6.5	0.5 – 10	0.5 – 10
Grid Blockage	0 – 0.55	0.0 – 0.55	0.0 – 0.55
Rupture Blockage	0 – 0.51	0.0 – 0.60	0.0 – 0.60

Notes:

[1] The plant parameter ranges given here are for the hot channel in the classical limiting (2A guillotine) CLPD break for PWRs. Other break locations, break sizes, and average (or other low power) channels may challenge the expected ranges given, although these non-limiting breaks or lower power channels will not produce limiting PCTs. For example, a (2A guillotine) hot leg break is larger and will initiate reflood sooner such that the core power may be higher (i.e. 1.2 kW/ft), although this case will not produce a limiting PCT. Smaller hot or cold leg breaks may initiate reflood with lower initial cladding temperatures, but these break scenarios will not produce limiting LOCA consequences. Likewise, the average channel may have lower initial power levels and cladding temperatures, although this channel only influences the whole-core hydrogen generation calculation.

[2] This linear heat rate limit was 0.72 kW/ft in the BEACH Revision 2 TER.

[3] The extension to 2045 F is based on the FLECHT-SEASET 34420 benchmark described in Revision 5 of BEACH.

FIGURE H-1. PEAK CLAD TEMPERATURE AT ELEVATIONS, FLECHT-SEASET TEST 34420.

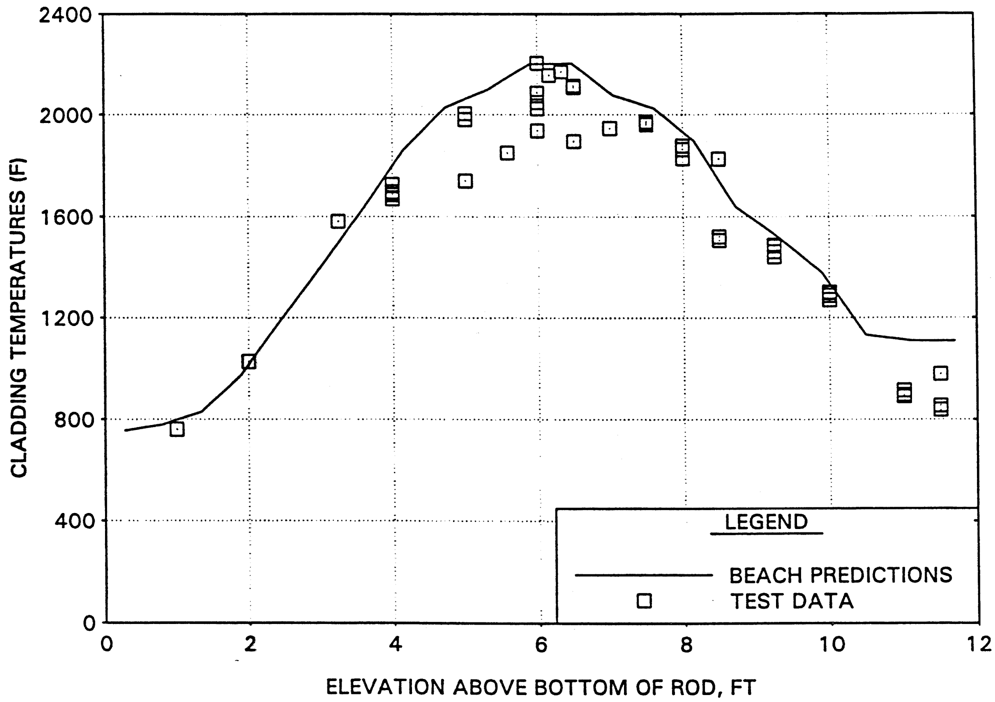

FIGURE H-2. QUENCH FRONT ADVANCEMENT VS TIME, FLECHT-SEASET TEST 34420.

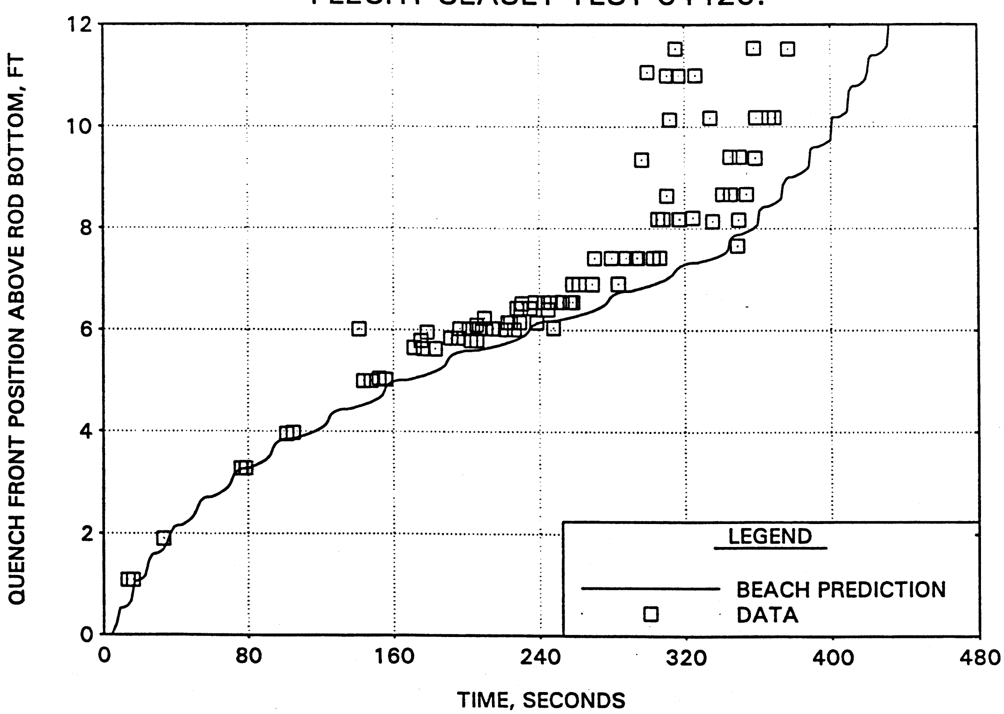

FIGURE H-3. CLAD TEMPERATURE,
FLECHT-SEASET TEST 34420.

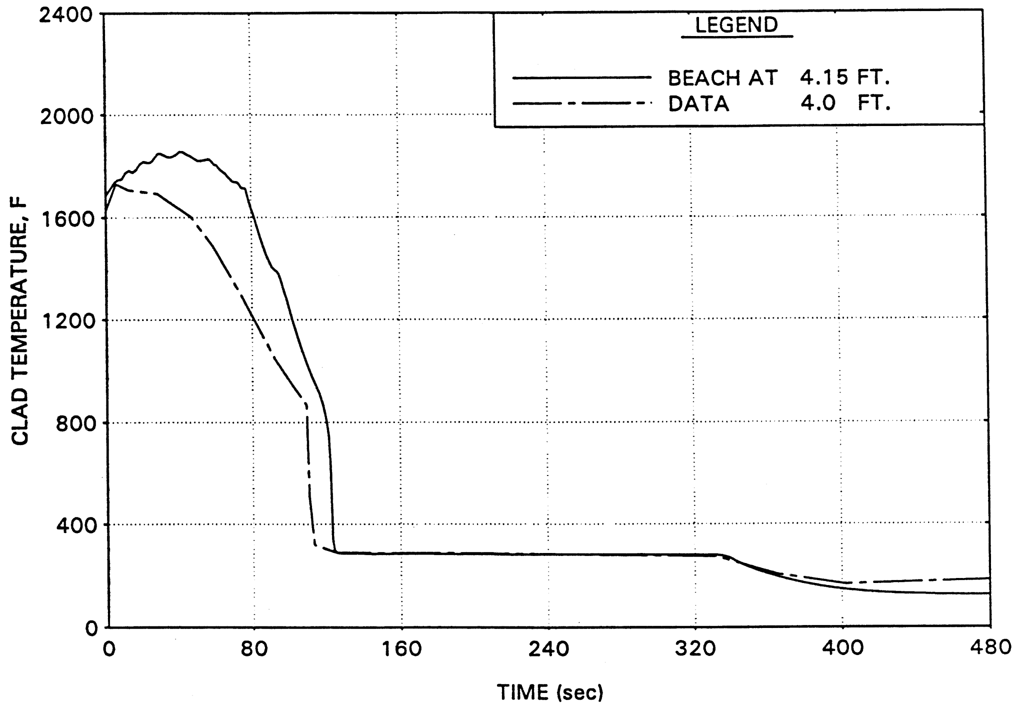

FIGURE H-4. FILTERED CLAD HEAT TRANSFER COEFFICIENT,
FLECHT-SEASET TEST 34420.

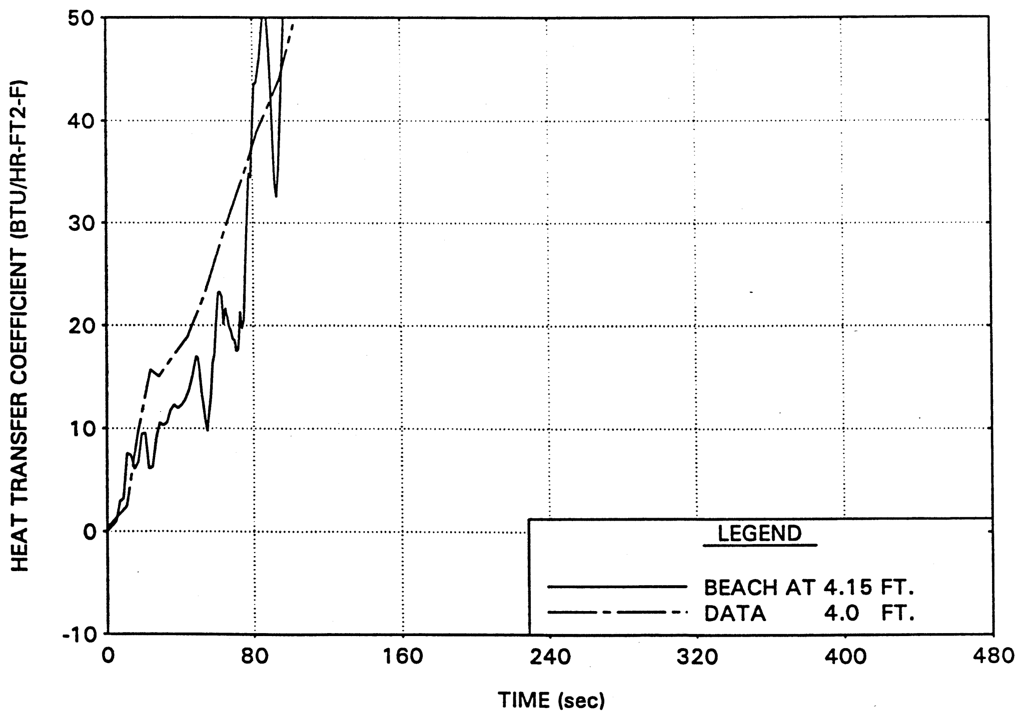

FIGURE H-5. CLAD TEMPERATURE, FLECHT-SEASET TEST 34420.

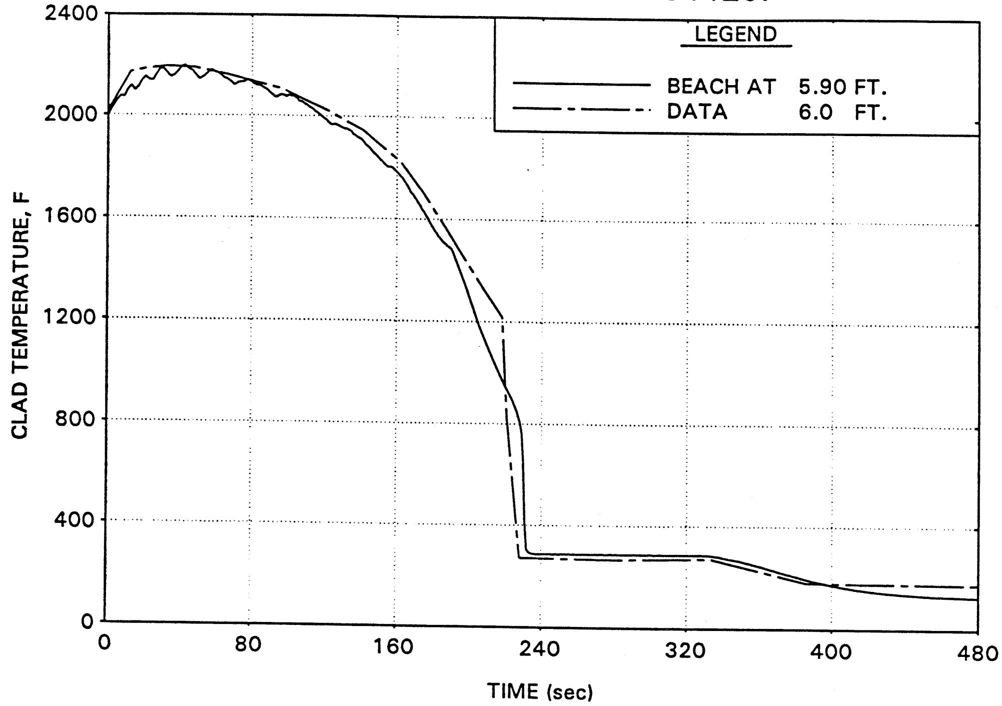

FIGURE H-6. FILTERED CLAD HEAT TRANSFER COEFFICIENT, FLECHT-SEASET TEST 34420.

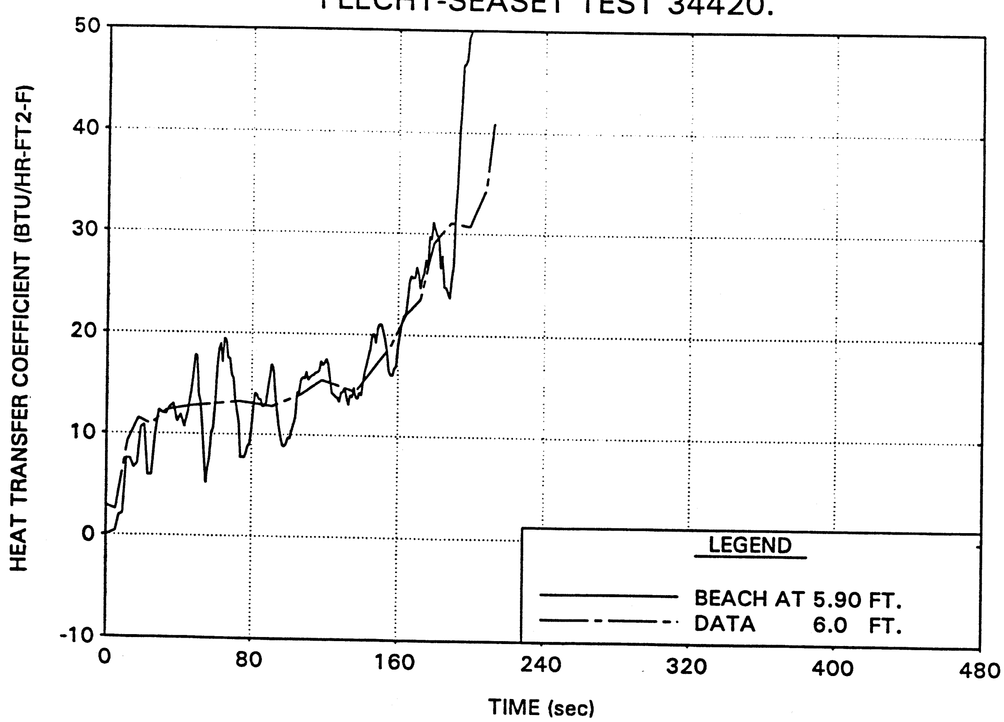

FIGURE H-7. CLAD TEMPERATURE,
FLECHT-SEASET TEST 34420.

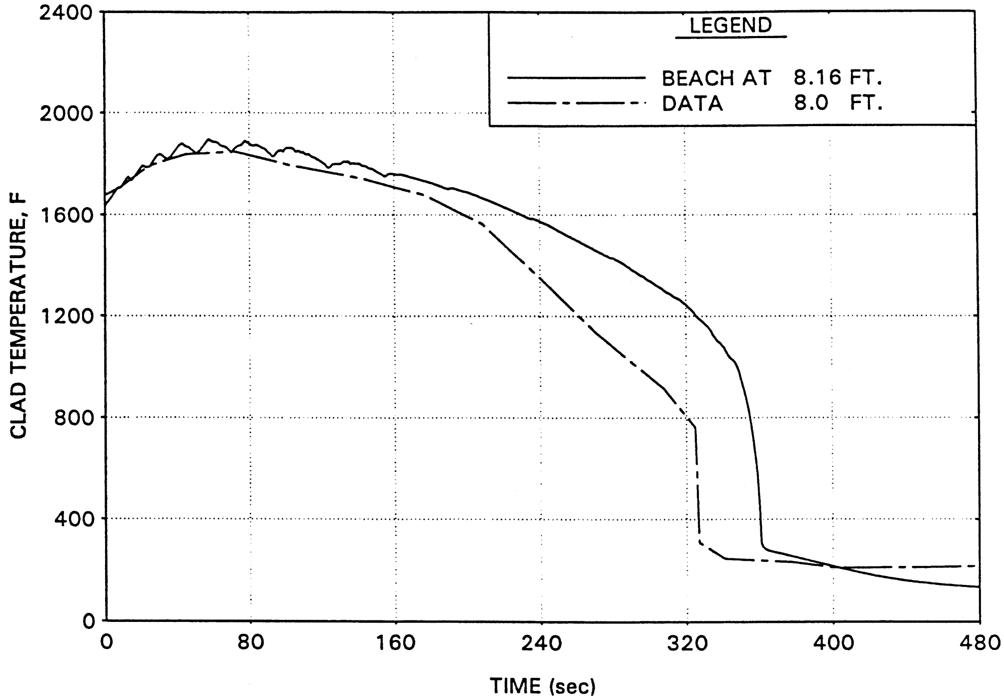

FIGURE H-8. FILTERED CLAD HEAT TRANSFER COEFFICIENT,
FLECHT-SEASET TEST 34420.

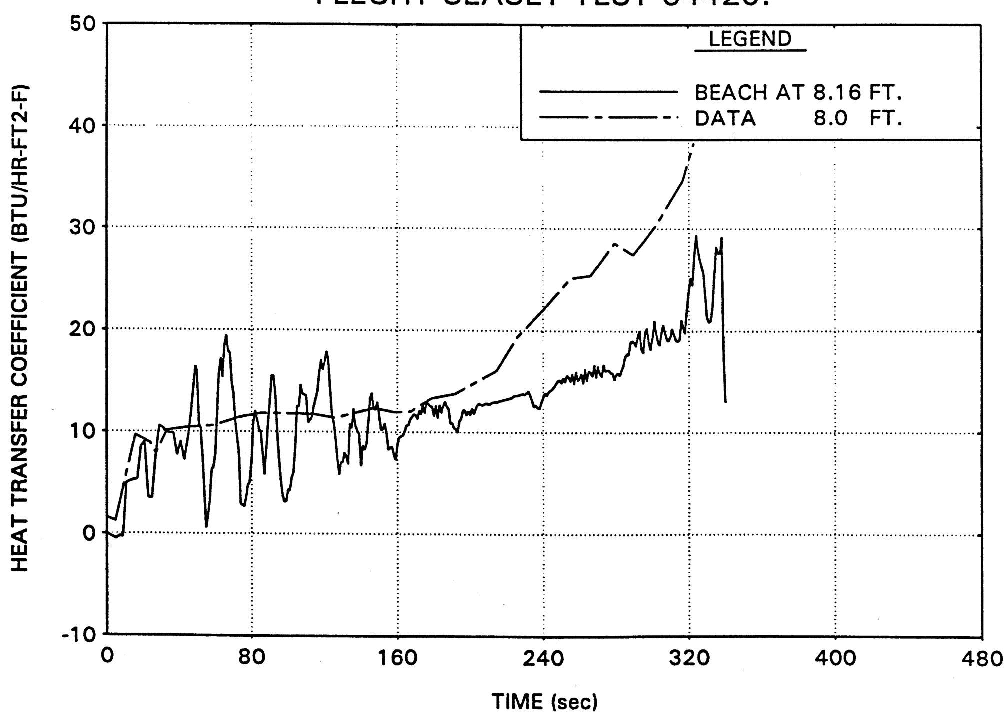

FIGURE H-9. CLAD TEMPERATURE,
FLECHT-SEASET TEST 34420.

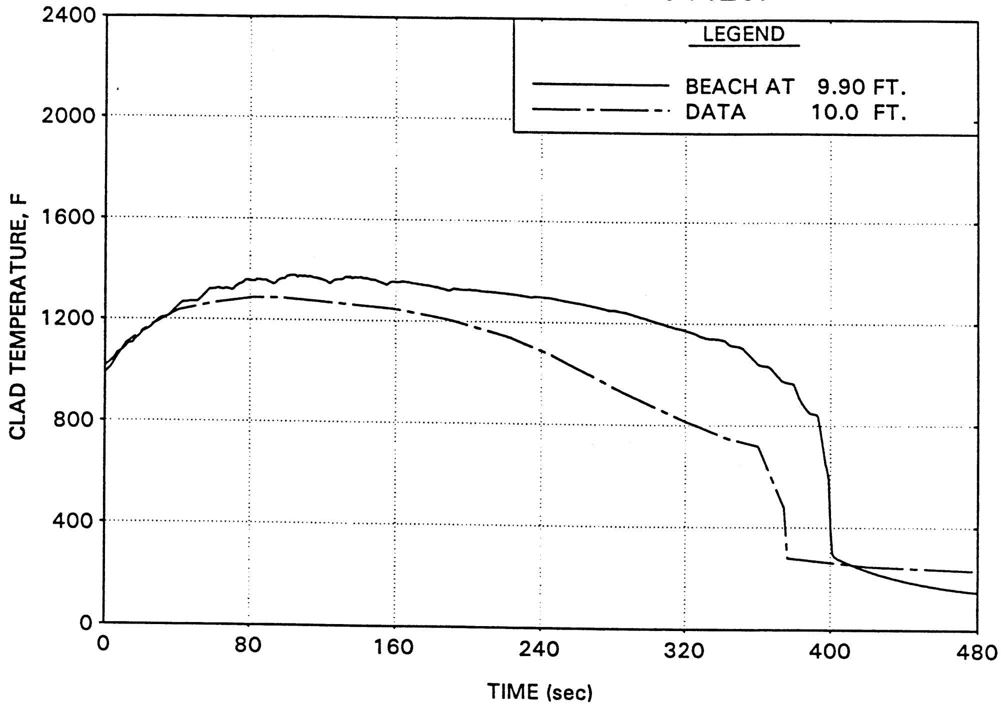

FIGURE H-10. FILTERED CLAD HEAT TRANSFER COEFFICIENT,
FLECHT-SEASET TEST 34420.