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April 14, 1980

Mr. Richard P. Denise
Assistant Director for Reactor Safety
Division of Systems Safety
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

SUBJECT: TAFY BOL Pin Pressure for LOCA Analyses

Dear Mr. Denise:

B&W has performed studies on certain ECCS Evaluation Model improvements since our letter of April 2, 1980 on the above subject. As a result of these studies, B&W expects that these improvements can be used to offset the impact of the increased BOL pin pressure calculated with a mechanistic fuel densification model. Accordingly, B&W has now started a more detailed evaluation of these improvements prior to incorporating them into the ECCS Evaluation Model.

During our meeting with the NRC Staff on March 26, 1980, it was established that the TAFY Code conforms to 10 CFR 50, Appendix K. The NRC Staff, however, indicated a future requirement for either a mechanistic fuel densification model to replace the TAFY densification model or additional justification for the continued use of the TAFY Code. B&W plans to justify the continued use of TAFY with the improvements discussed above. We also plan to incorporate a mechanistic fuel densification model in place of the TAFY model at the time when any future substantial LOCA re-analysis is required for other reasons.

The attachment contains a summary of the ECCS Evaluation Model improvements which B&W is presently evaluating. The evaluations, except for the pin-to-pin radiation model, are expected to be completed within three months. The pin-to-pin radiation model is expected to require six months.

We will periodically update you on this matter. In the meantime, if you have questions, please contact me.

Very truly yours,

J. H. Taylor
Manager, Licensing

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JHT/dsv
Attach.

ECCS Evaluation Model Improvements

In B&W's present evaluation model, many areas of conservatism exist. In exploring these areas, improvements have been identified which would offset the present concern and would at the same time be technically more correct. A list of these improvements can be seen in Table 1. An explanation of each improvement is included in this section. A comparison of REFLOOD2 and REFLOOD3 is also presented to complete the information which was sent previously (Letter, J.H. Taylor (B&W) to R.P. Denise (NRC), "TAFY BOL Pin Pressure,", April 2, 1980).

TRADE-OFFS

CHANGES TO ECCS EVALUATION MODEL	COMMENTS
1. PIN TO PIN RADIATION (THETA1-B)	ΔT_{RUP} REDUCTION OF 150°F ΔT_{UNRUP} REDUCTION OF 18°F
2. CRAFT RUPTURE BLOCKAGE FACTOR (V.H.)	CHANGING V.H. FROM 1.0 TO 0.5 REDUCED PCT BY 40°F
3. IMPROVEMENTS IN REFLOOD HEAT TRANSFER, SWITCH FROM FLECHT AND CRF-3 TO BWF AND CRF-4	ΔT REDUCTION ~50°F PROVIDING PCT AT EOAH $<$2000°F
4. DECAY POWER REDUCTION (0 TO 20 EFPD)	9% LOWER THAN INFINITE DECAY POWER
5. BYPASS MODEL	SWITCH BYPASSED DOWNCOMER WATER FROM CONTAINMENT TO BROKEN COLD LEG NODE. ΔT REDUCTION ~50°F BY SHORTENING ADIABATIC HEATUP PERIOD
6. PIN PRESSURE BASED ON POWER SHAPE PROFILE	POTENTIAL FOR AVOIDING MID-BLOWDOWN RUPTURE. ΔT REDUCTION ~100°F
7. PLANT AND/OR CYCLE SPECIFIC ANALYSIS	ΔT REDUCTION ONLY IF VOLUME AVERAGE FUEL TEMPERATURE AND PIN PRESSURE ARE LOWER THAN SYSTEMS REQUIREMENTS SPECIFICATION

CRAFT Rupture Blockage Factor

A review was made to investigate the blockage coefficient used in the CRAFT blowdown analysis. It was found that experimental data[1,2] justified the removal of B&W imposed conservatisms. A statistical treatment[3] of the experimental data provided a basis for predicting the amount of coplaner blockage that can be expected for LOCA conditions. Based on these results, it was determined that a blockage coefficient of 0.5 maintained a conservative posture and should be used in CRAFT blowdown calculations. A blockage coefficient of 1.0, which represents a 75% coplaner blockage, was used in the ECCS evaluation model used for the generic licensing submittal under which present plants operate. A reduction in the blockage coefficient from 1.0 to 0.5 resulted in reducing the peak cladding temperature by about 40F.

References

[1] W.A. Fiveland and A.R. Barber, "Rupture Characteristics of Zircaloy-4 Fuel Cladding Supplemental Report — Ruptured Clad Geometry," Alliance Research Center Report 4702, February 1978.

[2] A.R. Barber and W.A. Fiveland, "Rupture Characteristics of Zircaloy-4 Fuel Cladding Part II — Flow Loss Characteristics of Ruptured Clad Geometry," Alliance Research Center Report 4713, December 1978.

[3] B.E. Bingham and A.L. Lowe, Jr., "Application of Experimental Data to Analytical Evaluation of Cladding Failure Distribution," Nuclear Technology, Volume II, August 1971.

BWF and CRF-4 Correlations

The FLECKA code[1], a reflooding heat transfer coefficient correlation, has been used to calculate heat transfer coefficients during the reflood portion of the LOCA transients. This correlation is based on experimental data and is basically the correlation presented in the PWR FLECHT Final Report[2].

The differences between FLECKA and the FLECHT Final Report correlation are related to the assumed initial (and constant) term of the heat transfer coefficient and are explained fully in BAW-10104, section 4.3.6.5. A time-dependent reflood heat transfer correlation[4], BWF, along with a carryout rate fraction, CRF-4, and a quench time correlation have been developed to improve the accuracy of predicting reflood heat transfer coefficients. These correlations are based on the FLECHT test data[2,3] and are a function of inlet core flooding velocity, system pressure, peak linear heat rate, inlet coolant subcooling, initial midplane cladding temperature, and elevation. Table 1 lists the range of system parameters for these correlations.

The BWF correlation has several significant advantages over the FLECHT correlation utilized in FLECKA code:

1. BWF increases the correlated elevation range from 4-8 feet to 2-10 feet.
2. It alters the initial cladding temperature range from 1200-2200F to 760-2150F.
3. It reduces the average % error between measured and predicted heat transfer coefficients.
4. Improvements in reflood heat transfer, switching from FLECHT and CRF-3 to BWF and CRF-4 reduces peak cladding temperature by approximately 50F providing that the PCT at end of adiabatic heatup is less than approximately 2000F. This temperature margin is required to prevent the PCT from exceeding 2200F.

References

[1] K.C. Heck, et al., "FLECKA, Procedure to Calculate Reflood Heat Transfer Coefficients," NPGD-TM-357, March 1976.

[2] F.F. Cadek, et al., PWR FLECHT, WCAP-7665, Westinghouse, April 1971.

[3] F.F. Cadek, et al., "PWR FLECHT Final Report Supplement," WCAP-7931, Westinghouse, October 1972.

[4] G.F . Malan, "BWF Reflood Heat Transfer and CRF-4 Carryout Rate Fraction Correlations for Pressurized Water Reactors," NPGD-TM-373, September 1976.

Table 1. Range of System Parameters — Abscissa Values

Inlet velocity, V, in./s	Pressure P, psia	Peak power, E, kW/ft	Subcooling ΔT, F	Initial cladding temperature T_o, F
1.0	15.	0.69	16.	310(a)
2.0	35	1.24	90.	760
4.0	58	1.40	140.	1200
6.0	90.		189.	1530
10.0				2150

(a) Only the quench time data were available for FLECHT tests with initial cladding temperatures below 760F; therefore, the BWF heat transfer coefficient correlation is limited to a minimum initial cladding temperature of 760F.

Bypass Model

The present ECCS evaluation model takes the bypassed fluid from the downcomer and directly dumps the fluid into the containment. A more realistic approach is to take the bypassed fluid from the downcomer and place it in the broken cold leg node. The additional water, which has to pass through the break should cause more fluid to remain in the lower plenum at the end of blowdown. This in turn would reduce the adiabatic heat up time. This more realistic treatment of bypass may reduce peak cladding temperatures approximately 50F.

PIN TO PIN RADIATION

At present, B&W does not include the benefits of pin to pin radiation in the ECCS evaluation model. The benefits of incorporating such a model can be large when considering certain pin and guide tube arrangements that can exist in the fuel assembly. The benefits of pin to pin radiation will be active for the entire transient. During blowdown, refill, and reflood, energy will be transported from the hot zone to cooler, surrounding regions.

In recent analyses, a preliminary estimate was made to measure the effect of the presence of an additional heat sink during adiabatic heatup. A FLECHT coefficient of 1 BTu/hr-ft^2-F was used during the adiabatic heatup period for this evaluation. The use of this FLECHT coefficient produces a linear heat flow out of the cladding of approximately 100 to 200 BTu/hr-ft during adiabatic heatup. The peak cladding temperature of the ruptured node decreased by 150F when compared to similar analyses which did not contain the adiabatic heatup FLECHT coefficient. Similarly, the unruptured node saw a 18F reduction in peak cladding temperatures.

Decay Heat

In all LOCA analyses, the fission product decay heat has been 1.2 times the values for infinite operating time in the 1971 ANS Standard. This follows the guidelines of 10 CFR 50, Appendix K.

Evaluations of the effects of mechanistic densification clearly show that the limiting initial conditions (per results of a LOCA) occur at BOL. Shortly after BOL the severity of initial conditions decrease monotonically to a much less severe state. Following this, conditions there can be a gradual increase in severity but cannot approach the BOL condition during current fuel element life times. The actual peak BOL condition occurs at approximately 2 EFPD. Fuel elements which have exposures greater than that will not experience as limiting an initial condition and will, therefore, achieve lower cladding temperature during the LOCA. The imposition of infinite operation decay heat levels poses a severe penalty when applied to these limited exposure fuel elements.

B&W proposes that Appendix K was meant to apply infinite operation to the average core and to the hot channel when credit was attempted for recent reduced power operating history of a fairly significantly burned element. In our case, no measurement of assembly power history is intended but rather a categorical statement is made that after the peak initial conditions are past the resultant cladding temperature is lower. We, therefore, propose that the decay heat be based on 1.2 times the ANS decay heat curve for exposure equal to that which could have occurred for 100% power operation up to the time of peak initial conditions, i.e,, approximately 2 EFPD. We further propose that the total core decay heat power be based on 1.2 times ANS for infinite operation. If the time of peak initial conditions exceeds 20 EFPD we would use the infinite rule for both local and total power.

The result of this change will be to reduce the peak cladding temperature about 50F.

Pin Pressure Based on ECCS Power Shape Profile

To produce conservative values of pin pressure which could be used independent of peak axial power location B&W has previously used a conservative pin power profile. The magnitude of this conservatism was determined in recent analyses using the TACO code. These analyses compared the resulting pin pressures produced by the conservative power profile and the actual axial power shapes which are used in the ECCS LOCA limits evaluations. (A plot of the linear heat rate versus rod position can be seen in Figure 1 for the axial power shapes being compared.) Documentation of the basis for the ECCS LOCA limits power shape is contained in BAW-10104.

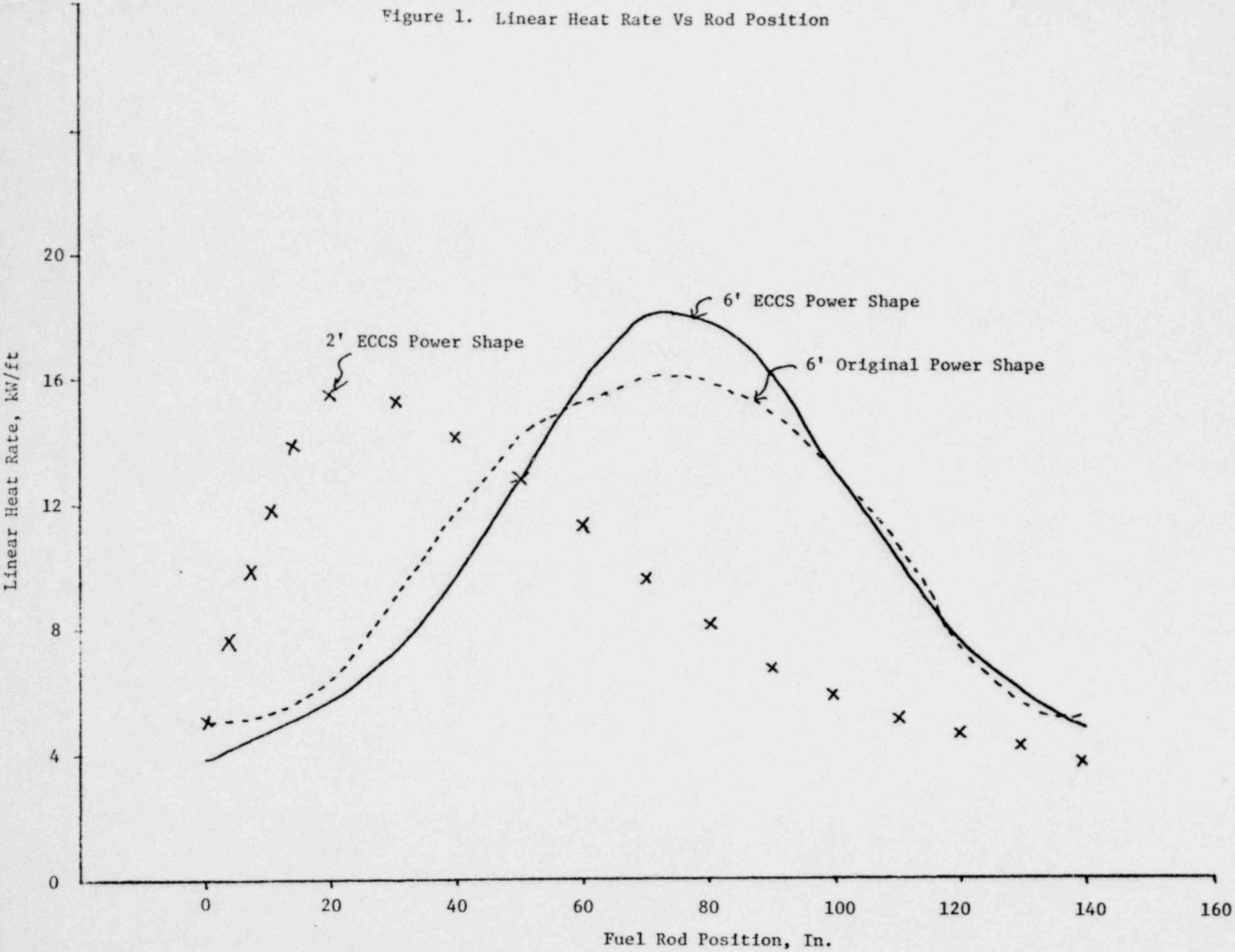
The results of the pin pressure study can be seen in Table 1. It can be seen that there exists a 10 psi margin for the 6 foot elevation when comparing the two power shapes. This margin exists because a fuel rod which has the original power shape has slightly more power than a rod which has a power shape being employed in the ECCS analysis. This same reasoning applies when comparisons are made at the 2 foot core elevation. Here, the pressure drops 86 psi when a consistent treatment is utilized in determining pin pressure.

Pin pressure is very important in LOCA evaluations, since it determines the rupture time for the hot rod. Incorporation of consistent pin pressures may provide the potential for avoiding a mid-blowdown rupture of the hot rod in LOCA evaluations.

Table 1. Summary of the Pin Pressure Study

	Case 1 (orig calc)	Case 2 (6' rev calc)	Case 3 (2' rev calc)
Power shape used	Symmetrical cosine	ECCS	ECCS
Axial peaking factor at maximum power location	1.5	1.7	1.7
Fuel rod pressure, psia	1526	1516	1440

Figure 1. Linear Heat Rate Vs Rod Position



REFLOOD3

The TACO ECCS analyses have utilized the REFLOOD3 code, which is an improved version of REFLOOD2. REFLOOD2 was previously used to calculate the refill and reflood portions of the LOCA. The purpose of developing a new version of REFLOOD was to switch to a Fortran language that could be readily modified and use an automatic ordinary differential equation solver. The REFLOOD2 code is written in the MIMIC digital simulation language whereas the REFLOOD3 code is written in the Fortran language and uses the DGEARS solver which will optimize computer run time. The equations used in REFLOOD2 and REFLOOD3 to calculate the core refill and reflood transients are the same. The main difference is the solution techniques which are summarized in Table 1. Item 4 of Table 1 has been identified to have the most significant impact on the flooding rates. The Martinelli and Nelson two-phase multiplier correlation is used to calculate two-phase pressure drops across the core, for both REFLOOD2 and REFLOOD3. The polynomial surface fit technique in REFLOOD3 provides better accuracy and results in a lower pressure drop and higher flooding rates.

Figures 1-3 show the comparison between the flooding rates using the two versions of REFLOOD. It can be seen that the use of a polynomial surface fit to the Martinelli and Nelson two-phase correlation provides slightly higher core flooding rates. Figures 4-9 show the cladding temperature response for the three cases analyzed. Table 2 provides a summary of these results.

Table 1. REFLOOD2 Vs. REFLOOD3

Description	REFLOOD2	REFLOOD3
1. Language	MIMIC-MIMIC Processor (FORTRAN AND COMPASS)	Fortran - DGEAR Solver
2. Table Data	Linear Interpolation	Cubic Spline Curve Fit
3. Saturation Pressure	P_{sat} = Linear Function of Mass, Energy and Volume	Steam Table Search $P_{sat} = F (U,V)$ U = internal energy V = specific volume
4. Two-Phase Multiplier (Martinelli-Nelson)	Linear Interpolation	Polynomial Surface Fit
5. Friction Factor	F = F (Re, 0.00005) Table Input	F = F (Re, E/D) E/D is user input
6. Core HTC and CRF	FLECHT and CRF-3	1. FLECHT and CRF-3 2. BWF and CRF-4
7. Time Step	User Input Min. Time Step	Program Control to Meet Convergent Criteria = 10^{-5}

Table 2. Summary of Cladding Temperatures for REFLOD3 (FORTRAN) and REFLOOD2 (MIMIC)

Core Elev, Ft	Node	REFLOD2	REFLOOD3
2	Ruptured, °F/Time, s	1867/40.5	1847/40
	Unruptured, °F/Time, s	1919/40.3	1911/39.9
6	Ruptured, °F/Time, s	2066/45.5	2003/44.5
	Unruptured, °F/Time, s	2146/61.5	2114/59.6
10	Ruptured, °F/Time, s	1643/45	1631/42
	Unruptured, °F/Time, s	1931/135	1856/136

Figure 1. CORE REFLOODING RATE VS TIME COMPARISON.
15.5 kW/ft at the 2-Foot Elevation

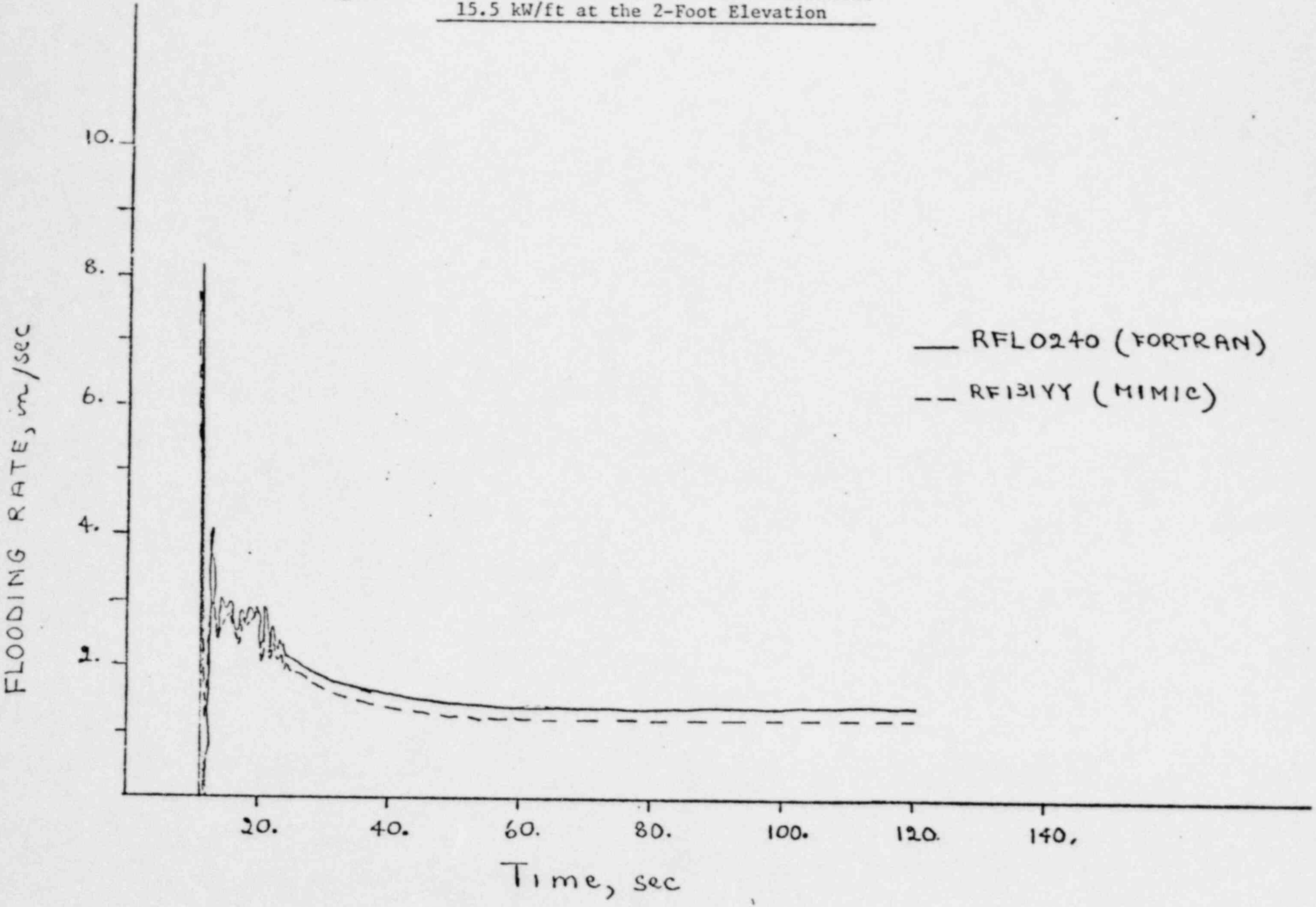


Figure 2. CORE REFLOODING RATE VS. TIME COMPARISON
18.0 Kw/ft at 6 ft. Elevation

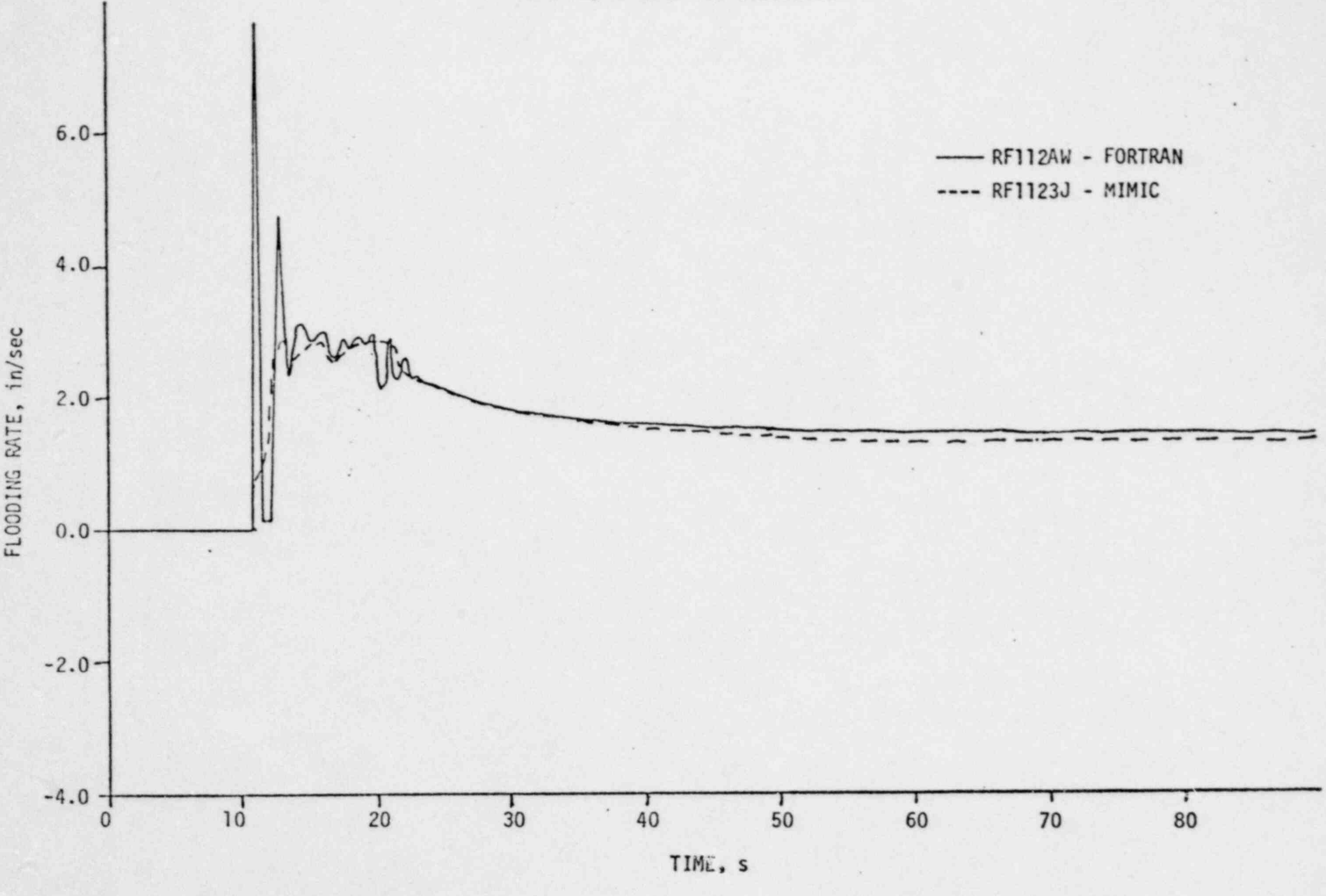


Figure 3. Flooding Rate Vs Time REFLOD3 VSN 1.0
16.0 kW/ft at 10 Ft Elevation - 177-FA
LL Plant

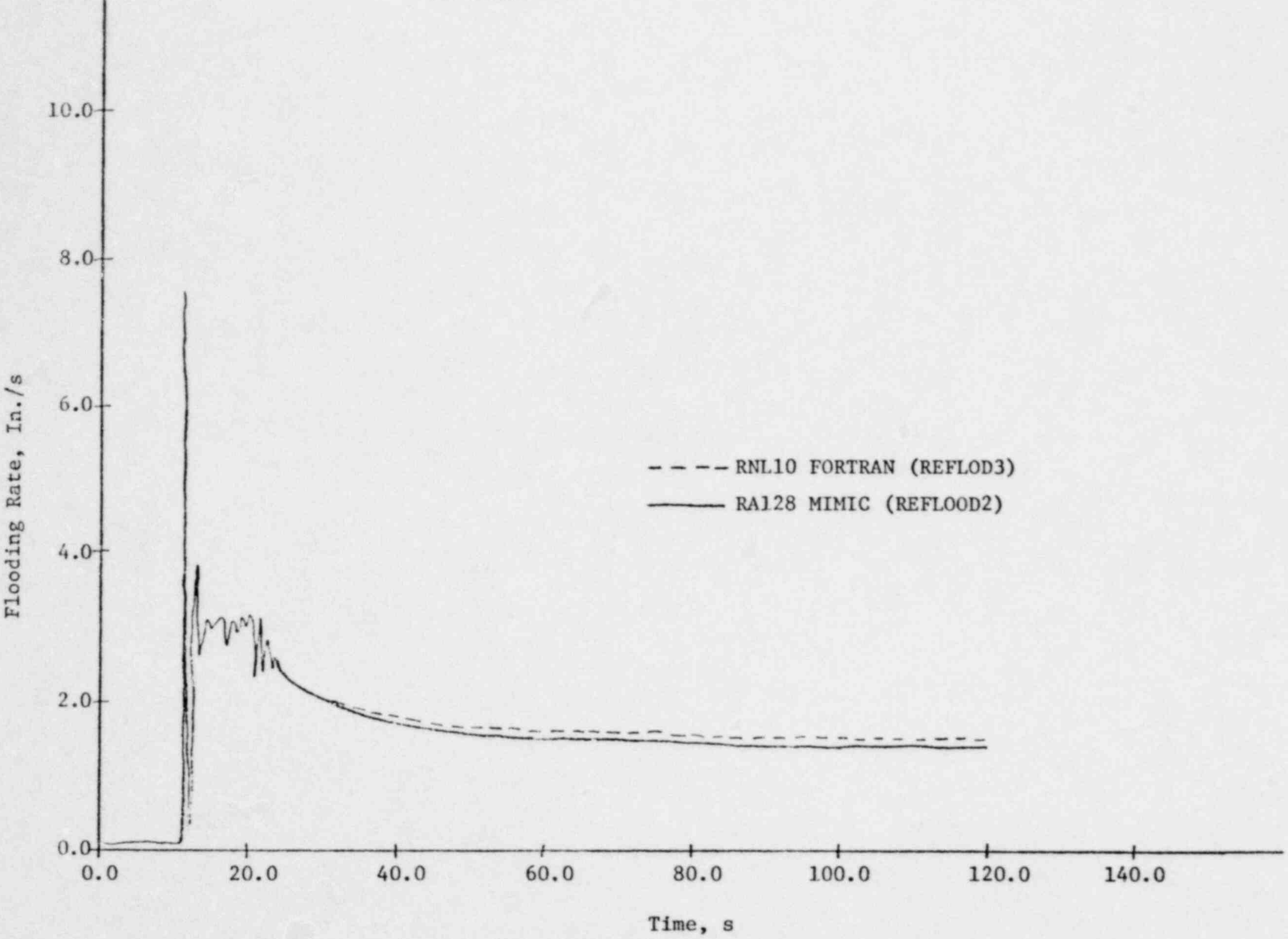


Figure 4. Peak Unruptured Node Clad Temperature 15.5 kW/ft at 2 Ft Elevation - 177 LL Plants

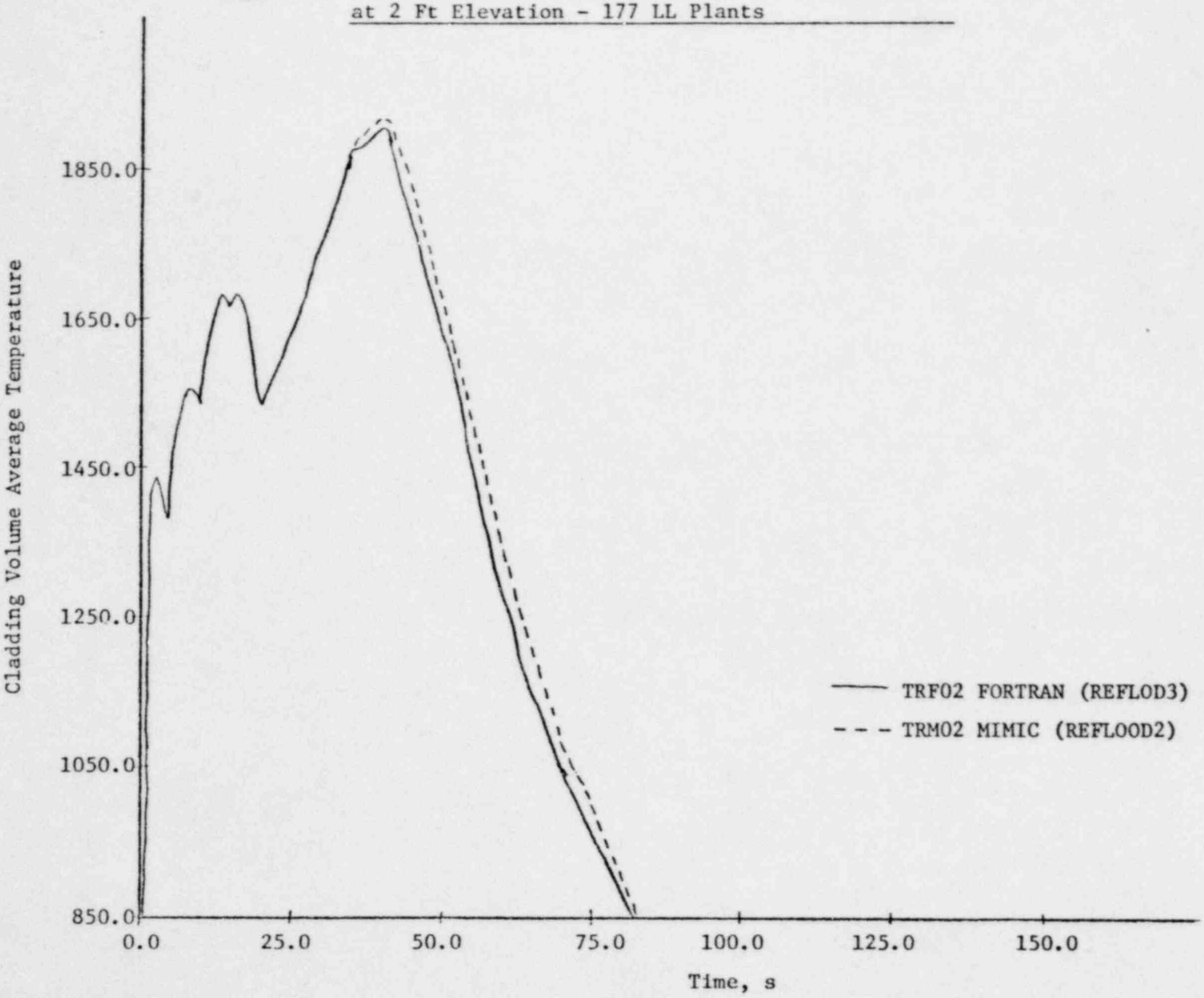


Figure 5. Ruptured Node Clad Temperature 15.5 kW/ft at 2 Ft Elevation

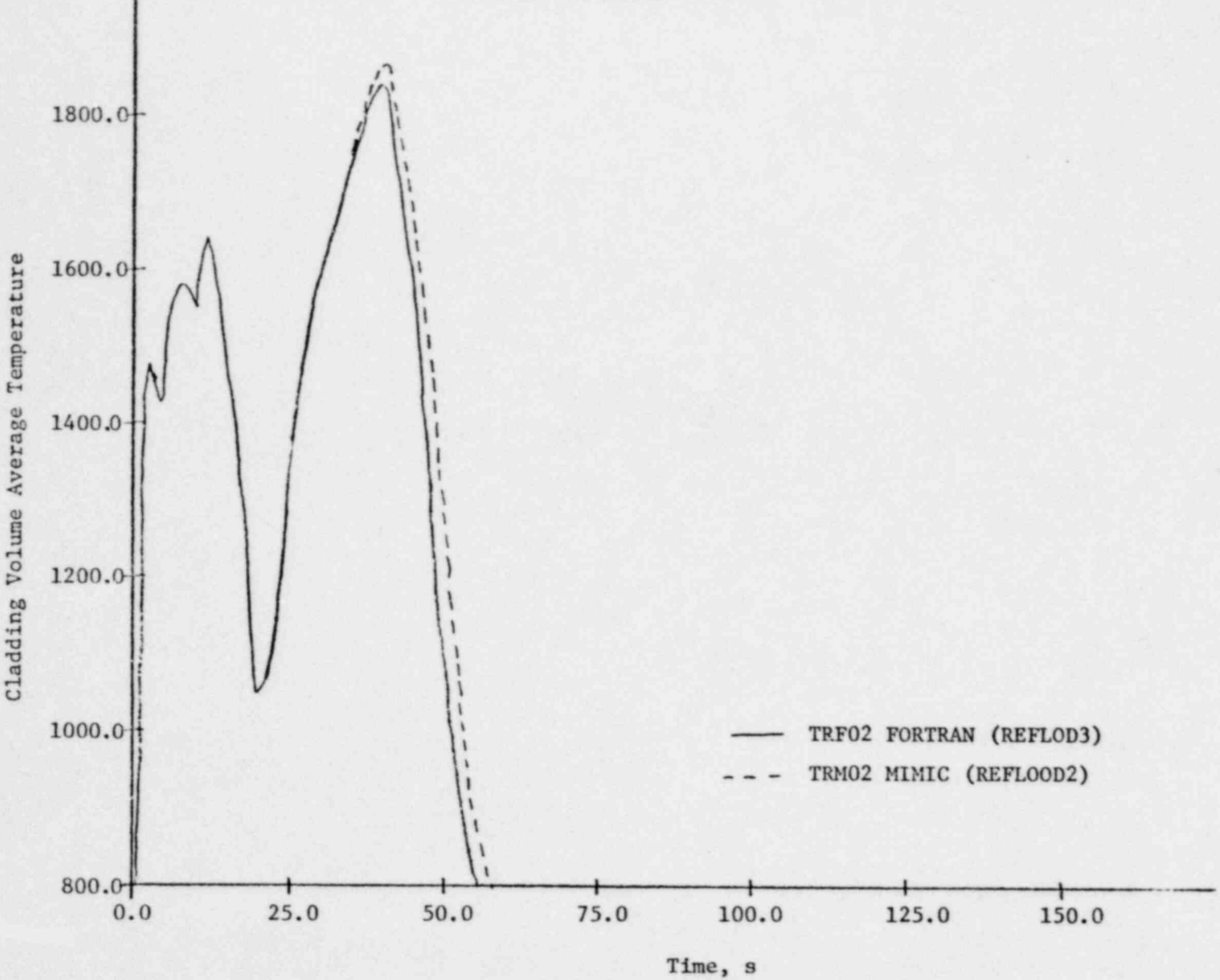


Figure 6.
Unruptured Node Cladding Temperature Vs Time
Comparison, 18.0 Kw/ft at 6-Ft Elevation

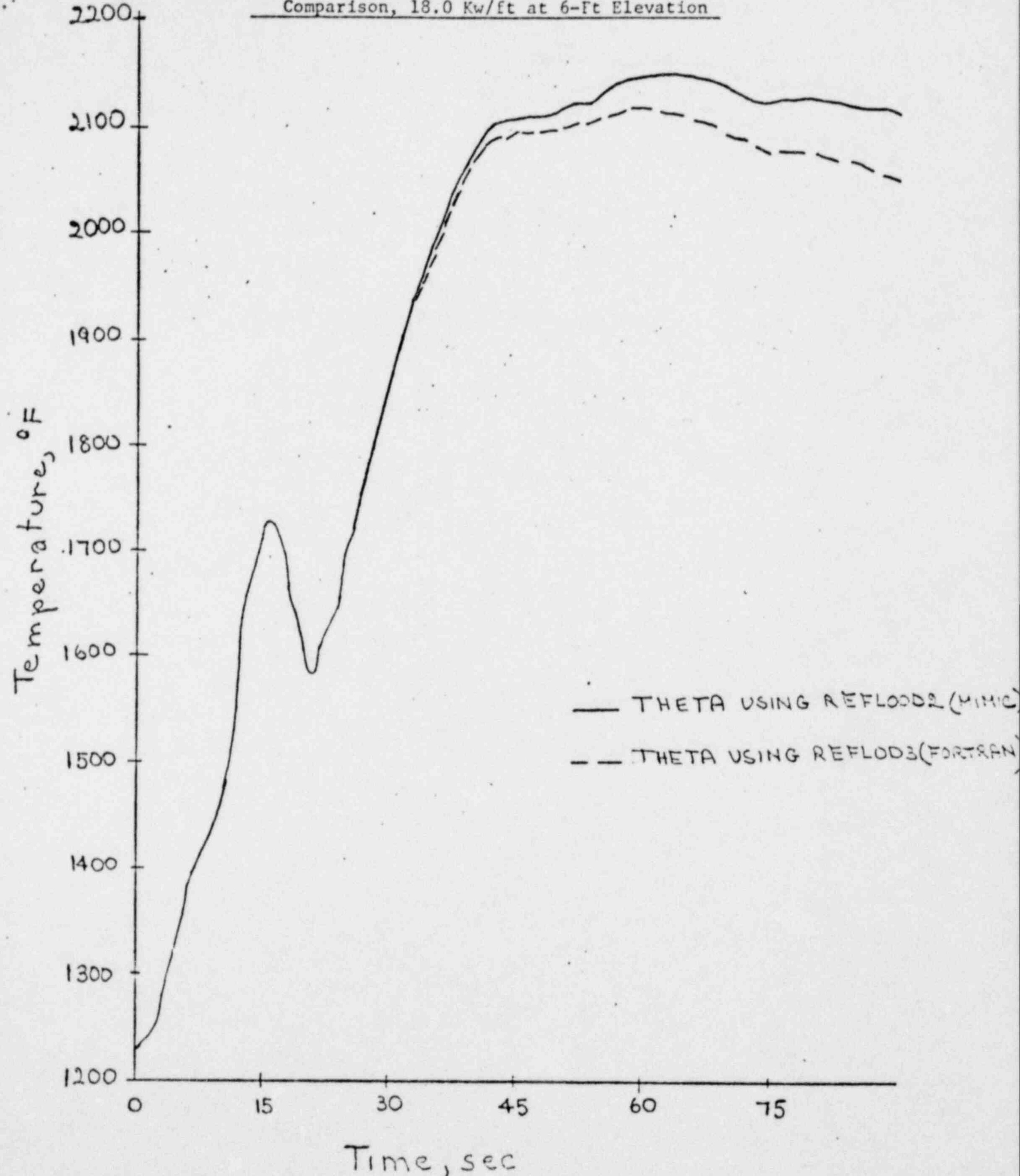


Figure 7.
Ruptured Node Cladding Temperature Vs Time
Comparison, 18.0 Kw/ft at 6-Ft Elevation

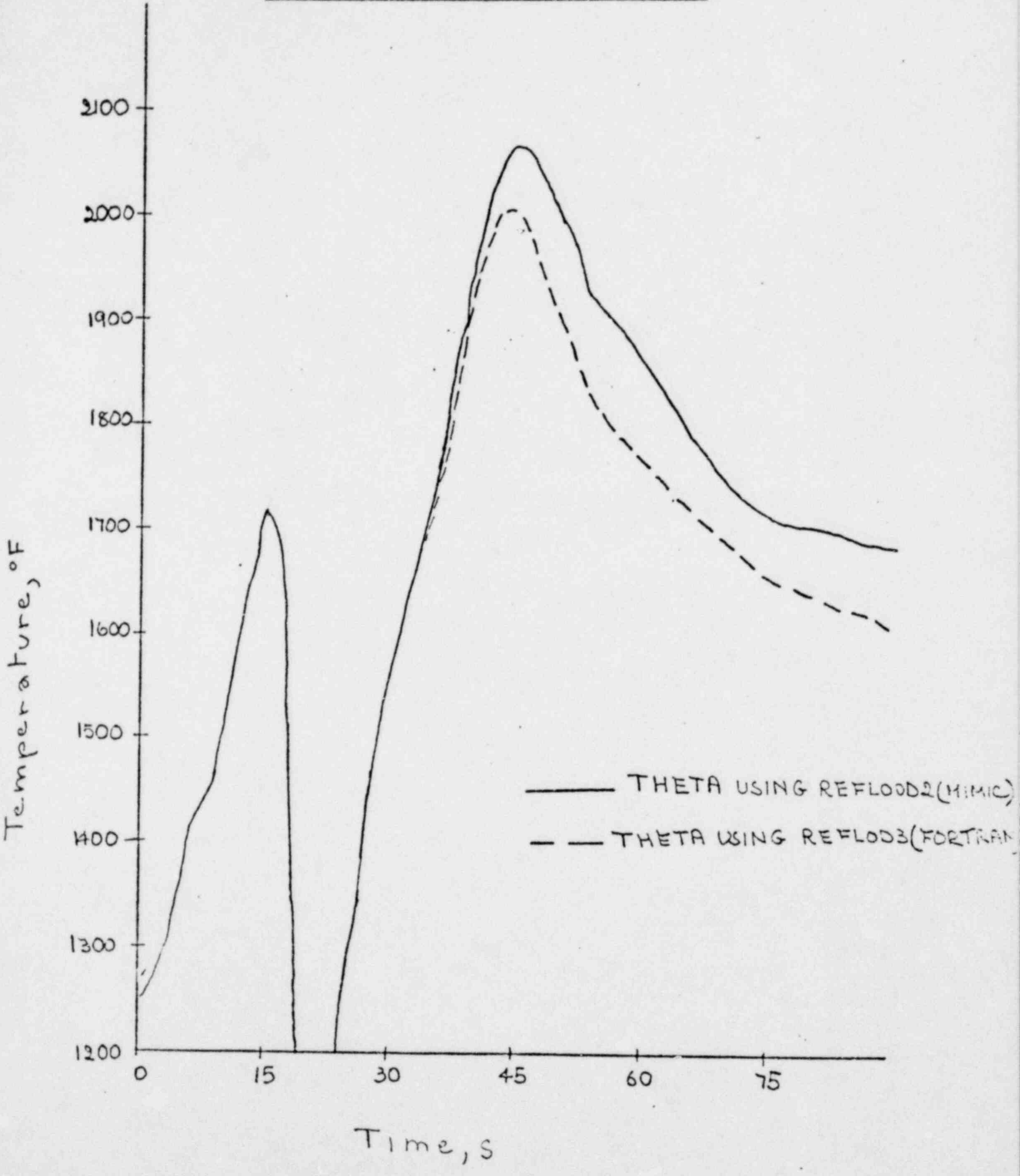


Figure 8. Peak Unruptured Node Cladding Temperature 16.0 kW/ft at 10 Ft Elevation - 177 LL Plant

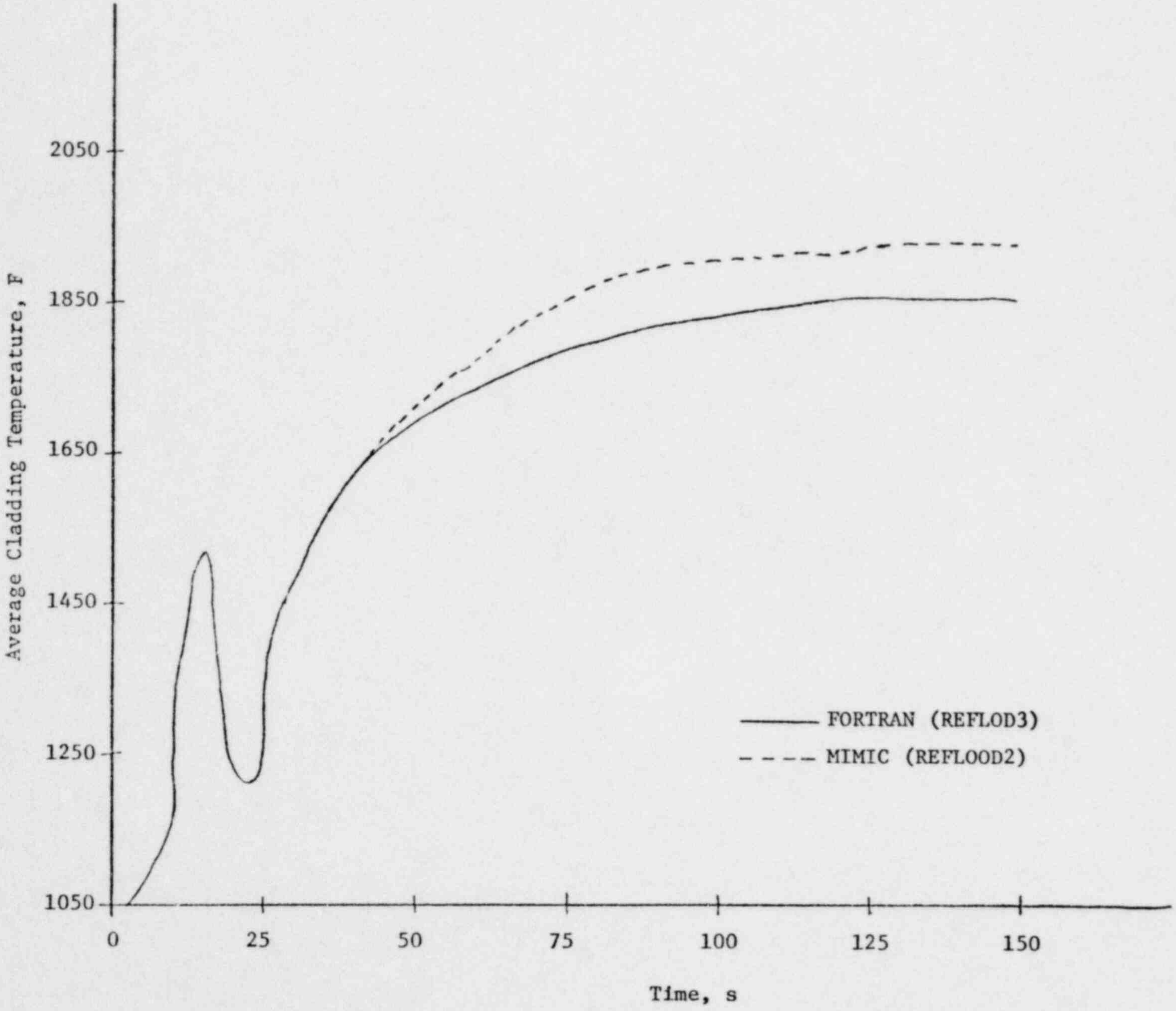


Figure 9. Ruptured Node Cladding Temperature 16.0 kW/ft at 10 Ft Elevation - 177 LL Plant