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ENCLOSURES:
Additional Information Concerning Loss-of-Coolant Analyses dtd 1-3-74 for H. B. Robinson Unit #2

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Regulatory Docket File

CP&L
Carolina Power & Light Company

January 2, 1974

File: NG-3514 Serial: NG-74-6

Mr. Robert J. Schemel, Chief
Operating Reactors Branch #1
Directorate of Licensing
Office of Regulation
U. S. Atomic Energy Commission
Washington, D. C. 20545

50-261

Dear Mr. Schemel:

H. B. ROBINSON UNIT NO. 2
LICENSE DPR-23
ADDITIONAL INFORMATION - EFFECT OF AXIAL FLUX SHAPE ON LOCA

In your letter of November 15, 1973, you requested additional information for H. B. Robinson Unit No. 2 regarding the effect of axial flux shape on analyses of the consequences of a loss-of-coolant accident. The information submitted as an attachment to this letter supplements and completes the information on this subject previously submitted in our letter of October 1, 1973, and should provide a satisfactory resolution of your questions.

Yours very truly,

E. E. Utley
Vice-President
Bulk Power Supply

DBW:mvp
Attachment

cc: Messrs. N. B. Bessac
T. E. Bowman
B. J. Furr
B. Howell
D. V. Menscer
D. B. Waters

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H. B. ROBINSON UNIT NO. 2
LICENSE DPR-23
ADDITIONAL INFORMATION CONCERNING LOSS-OF-COOLANT ANALYSES
JANUARY 3, 1974

Question 1

We requested a description of axial flux shape. Your response (Table 1) provided only the peak linear heat rate (LHR) and its location. This is necessary, but not sufficient to characterize axial flux shape. Supplement the material with the actual flux shapes used in the analysis. We understand that the shape is not usually an input to LOCTA, but we require the shape for our independent confirmation.

Answer 1

The distribution of the axial flux for the hot rod analyzed in the LOCTA code is of minor importance relative to the elevation and magnitude of the peak itself. The calculations performed in this study were intended to define the upper bound for peak local rod power as a function of axial position in the core. Thus, the requirement was to select a method of inputting the power distribution such that the peak clad temperature calculated conservatively represented that for a general axial flux shape.

The actual flux shapes used in the LOCTA code calculations considering peak local power at the three specified elevations are as follows:

For the cases where the peak power occurred at the 6 foot and 8 foot elevations, a chopped cosine axial power distribution was used. This is the standard flux shape used in LOCA analyses for symmetric power (peak at 6 foot elevation) and was applied, in this study, to the case with peak power at the 8 foot elevation. This provided additional conservatism for the 8 foot case for the following reason. The clad temperature during blowdown as calculated in the LOCTA code is not dependent on the axial location of the peak power per se, (for a variation in elevation of 2 feet as studied here) but is influenced considerably by the way core quality (calculated in SATAN) is used in LOCTA. SATAN calculates core quality in the upper and lower halves of the core and the higher of the two is used in calculating the hot spot rod heat transfer coefficient, during blowdown, in the LOCTA code. To maximize the peak clad temperatures (as affected by the use of SATAN quality) during blowdown, the peak power was located in the fourth axial length step (of 7) for the 6 foot and 8 foot peaks. However, during reflood, the proper heat transfer coefficient derived from the FLECHT correlation for the 6 foot and 8 foot elevations was used.

The peak power was varied parametrically to determine that peak power value which would result in limiting temperatures for collapsed (1800^{o}F) and non-collapsed (2300^{o}F) fuel. Since previous sensitivity studies using the LOCTA code have clearly shown that the peak clad temperature during blowdown depends almost entirely on the peak local power, these results are completely applicable.

In the LOCTA calculations for the peak power at the 10 foot elevation, the rod was divided into 7 equal length axial increments (as done for 6' and 8' runs). The lower 5 increments had a uniform power which was the hot rod average (KW/FT) and in the 6th increment the power was varied parametrically to determine the limiting values. Power in the 7th length step was merely adjusted to preserve total rod power. Again, the distribution of the flux in the lower 5 axial increments will have very little effect on the peak clad temperature calculated in length step 6 (10' elevation). In this set of calculations, however, since the peak power was in length step number 6, fluid quality in the top half of the core (from SATAN) was considered in the hot spot thermal transient calculation which resulted in a clad temperature benefit (compared to a calculation with peak power at the core midplane) during the negative flow period of blowdown. Also in this case the rod heat transfer coefficients during reflood were calculated for the 10' elevation using the FLECHT correlation.

With the exception of the axial power shape and use of core quality mentioned above, the LOCTA code calculations were made in the same manner typically used for Interim Acceptance Criteria analyses (for example, DNB assumed at 0.1 second, hot channel flow multiplier is 0.8).

Note that the peak power defined by this analysis includes the fuel densification spike penalty as calculated using an early Westinghouse fuel densification model. The current fuel densification model (as described in WCAP-8218) will reduce this spike, thus improving the clad temperature ECCS limits. It is also expected that significant potential benefit exists in consideration of radiation from the cladding at the relatively short (approximately 3 inches) high power rod spike to adjacent rods. An additional area of conservatism lies in not accounting for axial heat conduction from the power spike region.

Question 2

Describe how the core reflooding rate (Figure 1) is modified for use as input to the computation of FLECHT heat transfer coefficients; include the actual values used in each case.

Answer 2

The core flooding rate shown in Figure 1 of the previous submittal is not actually modified for use as input to the computation of FLECHT heat transfer coefficients for all of the power shapes analyzed. This flooding rate is calculated using the carryover fraction specified in the Interim Acceptance Criteria for W reactors. This carryover fraction is conservatively high and tends to yield lower core flooding rates.

The flooding rate presented in Figure 1 is used directly in the calculation of the heat transfer coefficient. However, in order to apply the FLECHT correlation to a varying flooding rate, the history of the reflood transient must be considered. This is accomplished by using a pseudo time in the FLECHT correlation which is calculated as the integral of the reflood water that entered the core up to some time (t) divided by the actual flooding rate at time (t). That pseudo time is used as the time argument in the FLECHT correlation.

Question 4 and 5

The FLECHT correlation is keyed to a symmetric flux shape with a flux peak at 6 ft., the initial cladding temperature at 6 ft., the heat generation rate at the 6 ft. level, the time to quench the 6 ft. elevation, and the integral of heat release up to the point in question. All of these factors vary when the axial shape is non-symmetric. Describe, in detail, the mathematical treatment that is applied to FLECHT data to generate heat transfer coefficients at any elevation.

It appears in the response to Question 5 that the heat transfer coefficients at the upper elevations were taken directly from symmetric shape data. In order to clarify this matter, provide the input data, and suitable justification, for each of the three curves on Figure 2.

Answer 4 and 5

In order to calculate heat transfer coefficients at the peak power level for skewed axial power distributions, the revised FLECHT heat transfer coefficient correlation of WCAP-7931 was used. As input to this correlation, the local flooding rate, rod power, clad temperature, quench front pressure, injection water subcooling and the core level of interest are input as usual. This method yields conservative results when compared to the best estimate calculation described below.

It appears that the heat transfer at a skewed power peak location can be calculated using the six-foot FLECHT data (or coorelation which W has revised) with an adjustment in the time scale due to the power shape. The basic hypothesis employed is that for a given reflood rate the fluid conditions during reflood are primarily dependent upon the power (heat release rate) below the quench front; and the distance the peak power location is from the quench front.

The method consists of first constructing a quench front curve for the skewed power shape and a corresponding cosine FLECHT power shape in which the total integrated power up to the six-foot elevation is the same as the integrated power up to the peak location for the skewed shape. This quench curve is a plot of quench front elevation versus time. The skewed bundle peak location quench time can then be calculated using the FLECHT quench correlation with the appropriate power peak calculated to preserve the total skewed profile power up to the peak. Comparisons made using FLECHT data for cosine power shapes of varying peak power levels verify that, for elevations below the peak power elevation, quench time is a function of integrated power beneath the quench front and not the quench front elevation (within the range of FLECHT conditions). It follows that the calculated quench time for the equivalent FLECHT cosine power shape is the same quench time for the skewed power shape. This fixes one point on the quench curve for the skewed power shape. The second point of the quench curve is the point where "cold filling" of the core ends and reflooding dominated by high steam generation and entrainment begins. This point we will call the entrainment threshold.

Since the early stages of reflood have a high flooding velocity (6-10"/sec) the exact location of the entrainment threshold for both the skewed and cosine power shape will have a very small effect on the calculated heat transfer behavior at the peak power location. Further, because of the high flooding rate the difference between the entrainment threshold time for any skewed power distribution and a cosine power distribution is not large. Therefore, for the purposes of this study, the FLECHT entrainment threshold was used, along with the calculated flooding rate to find the location of the entrainment threshold as shown in Figure 4-1. By connecting points A-B, and A-B' the quench curves for the skewed power shape and the 6-foot FLECHT run which has the same integrated power up to the six foot elevation, can be drawn.

In order to calculate the heat transfer at the peak elevation for the skewed power shape, it is necessary to match up the skewed power quench curve and compare locations and times to the 6-foot FLECHT quench curve. Since the two normalized quench times are equal, the 6-foot FLECHT power peak is adjusted to preserve the same total power below 6' and below the peak location of the skewed power profile. That is

$$q''_{max} \cdot \int_0^6 \cos \frac{\pi Z}{L}\, dZ = \int_0^{Z_{peak}} q''(Z)\, dZ$$

and the value of q''_{max} is determined.

At any given time, the heat transfer coefficient for the skewed power distribution is equal to the heat transfer coefficient for the cosine power case at an equivalent time for which the integrated power beneath the quench front for the cosine and skewed power shapes is equal.

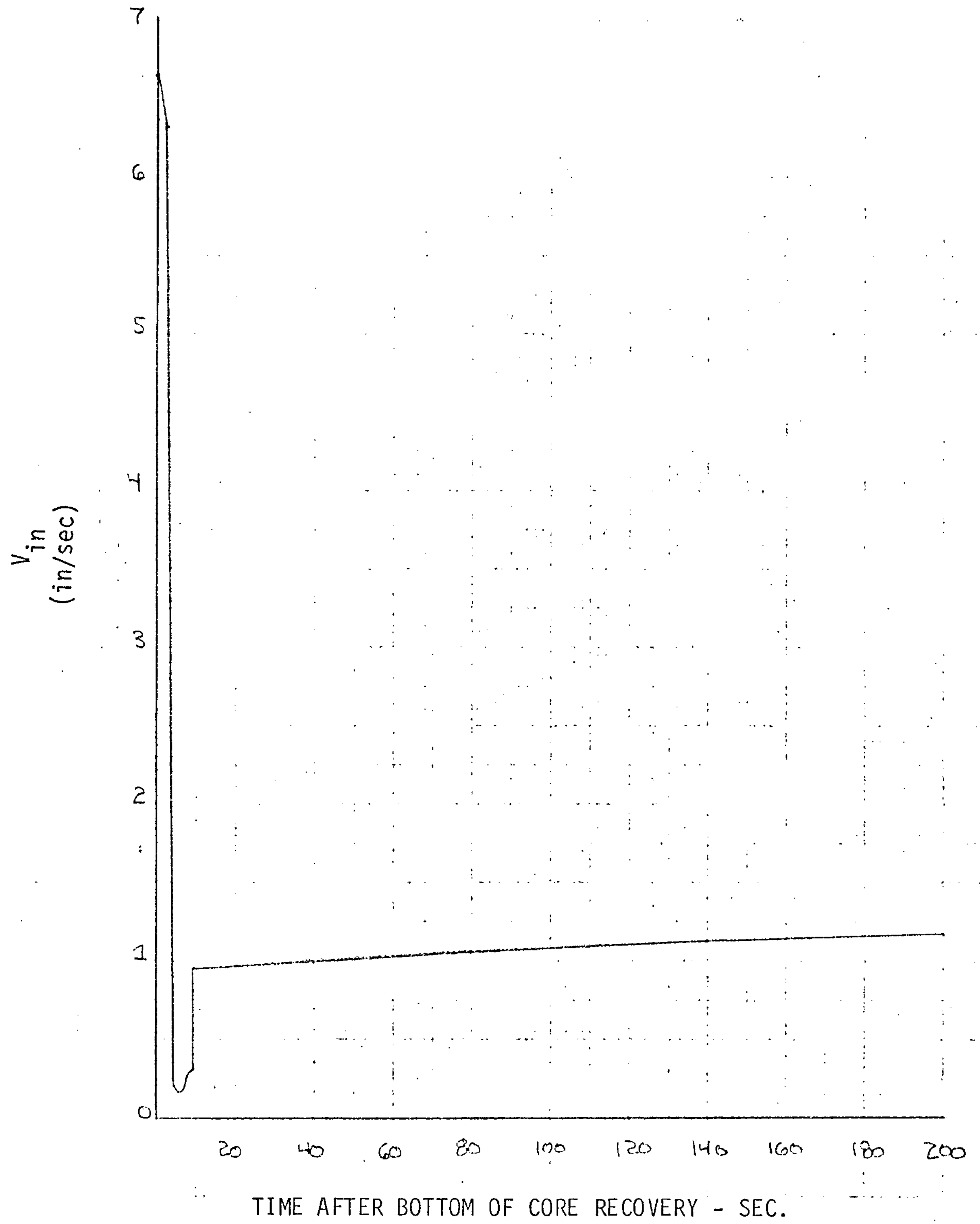
This procedure of relating the skewed profile curve to the FLECHT 6-foot quench curve allows the use of the 6-foot FLECHT correlation or data at different elevations.

The above procedure was used to calculate the expected heat transfer coefficient at 8 and 10 feet using arbitrary axial power shapes given in Figure 4-2. The heat transfer coefficients calculated in the above fashion are shown in Figures 4-3 and 4-4 along with the heat transfer coefficients found using the FLECHT correlation (WCAP-7931) at 8 and 10' feet respectively.

As expected the calculated FLECHT heat transfer coefficient (WCAP-7931) are significantly lower than those predicted using the method described above. The fluid conditions at 8 and 10 feet for the symmetrical power shape are different than those one would expect for a skewed power shape with the peak at 8 or 10 feet. With a symmetrical power shape, the two-phase mixture passes through the high power, high temperature zone before reaching the 8 and 10 foot elevations which can cause the steam to become heated above the rod temperature at the upper elevations, resulting in negative or very low heat transfer coefficients for some period of time as observed in FLECHT tests. Since the high temperature, high power zone is at the skewed location for the method described above, the vapor can never be heated above the local rod temperature such that the vapor-droplet mixture will always provide an efficient cooling medium for the skewed power case.

Therefore, use of the FLECHT correlation (WCAP-7931) does provide a conservative calculation of the expected heat transfer at upper elevations for skewed power shapes.

FIGURE 2-1
FLOODING RATE VS. TIME
FOR CPL DECL-G



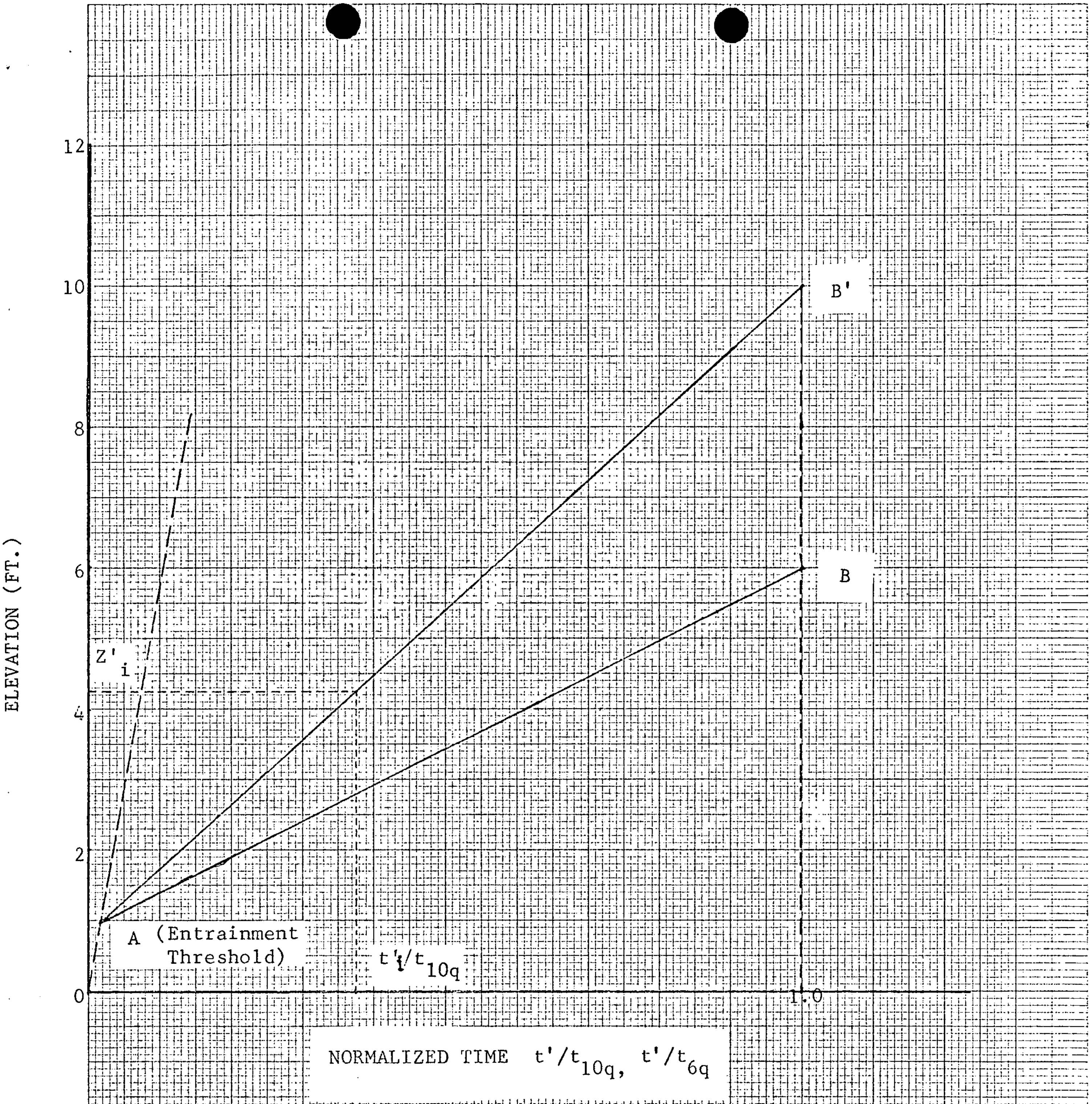
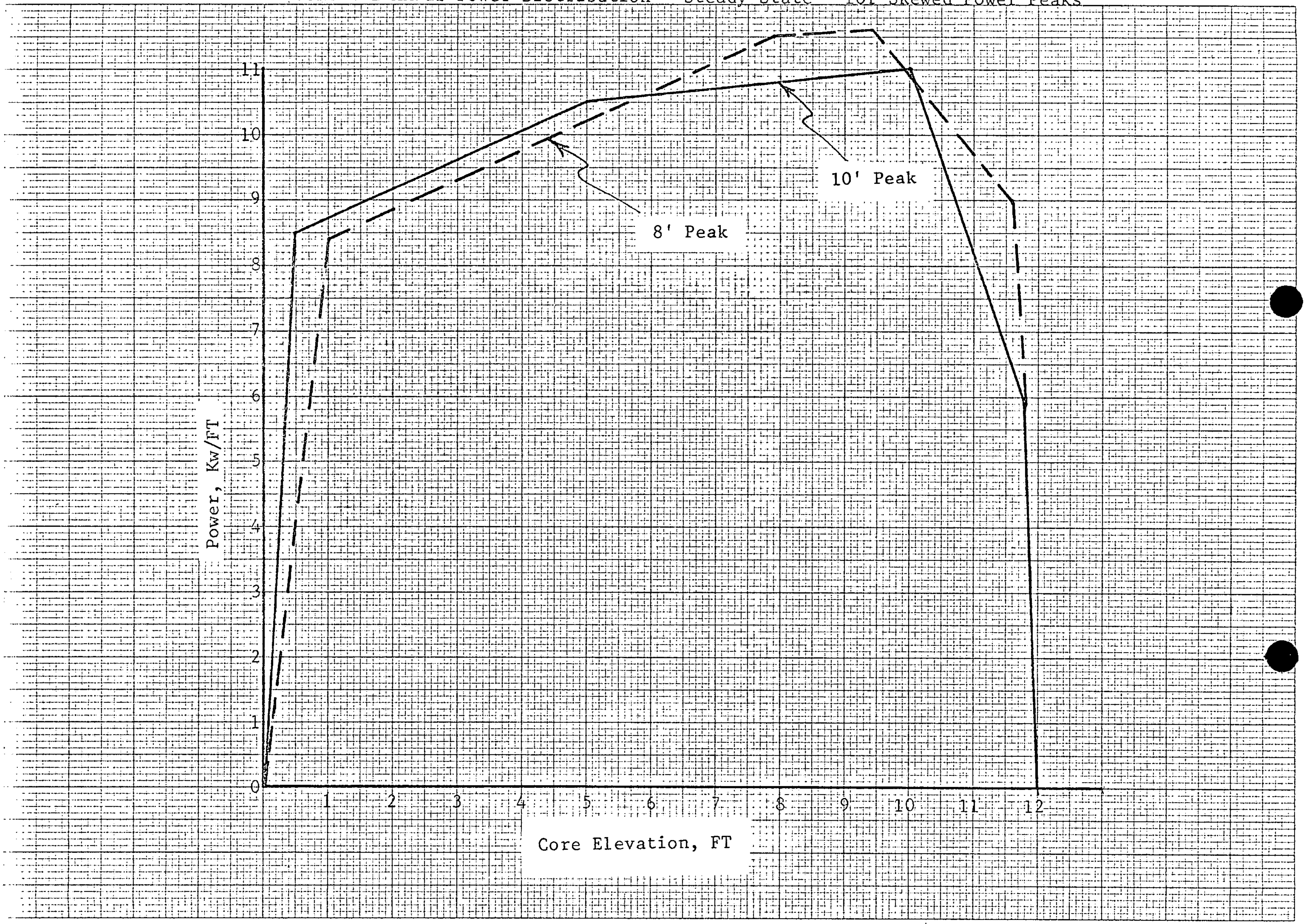


Figure 4-1. Schematical Diagram of Quench Front Curves of a FLECHT Test and a Skewed Power Case

FIGURE 4-2 Axial Power Distribution - Steady State - for Skewed Power Peaks



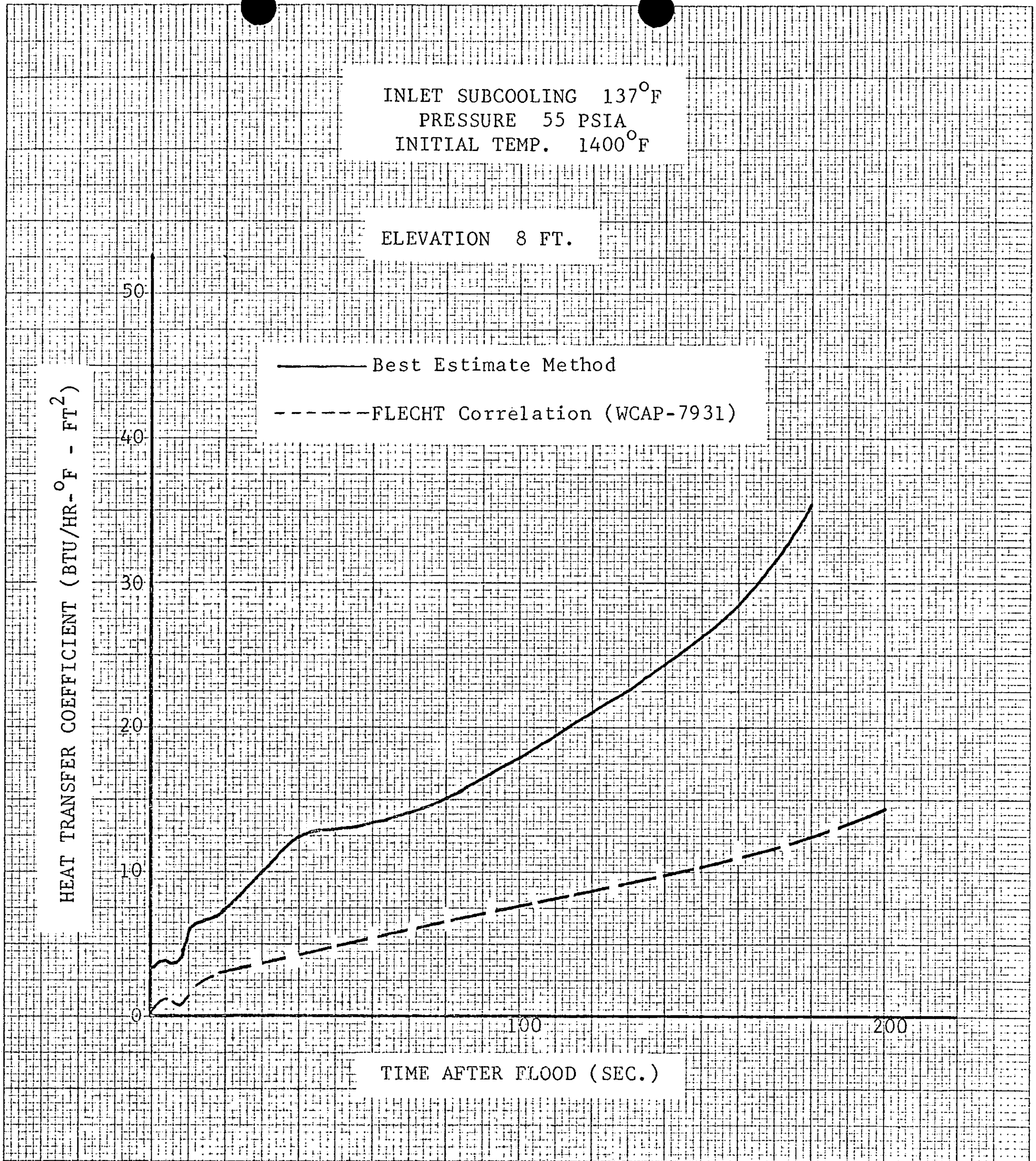


Figure 4-3 Comparison of Heat Transfer Coefficient Calculated with Best Estimate Techniques and FLECHT Correlation

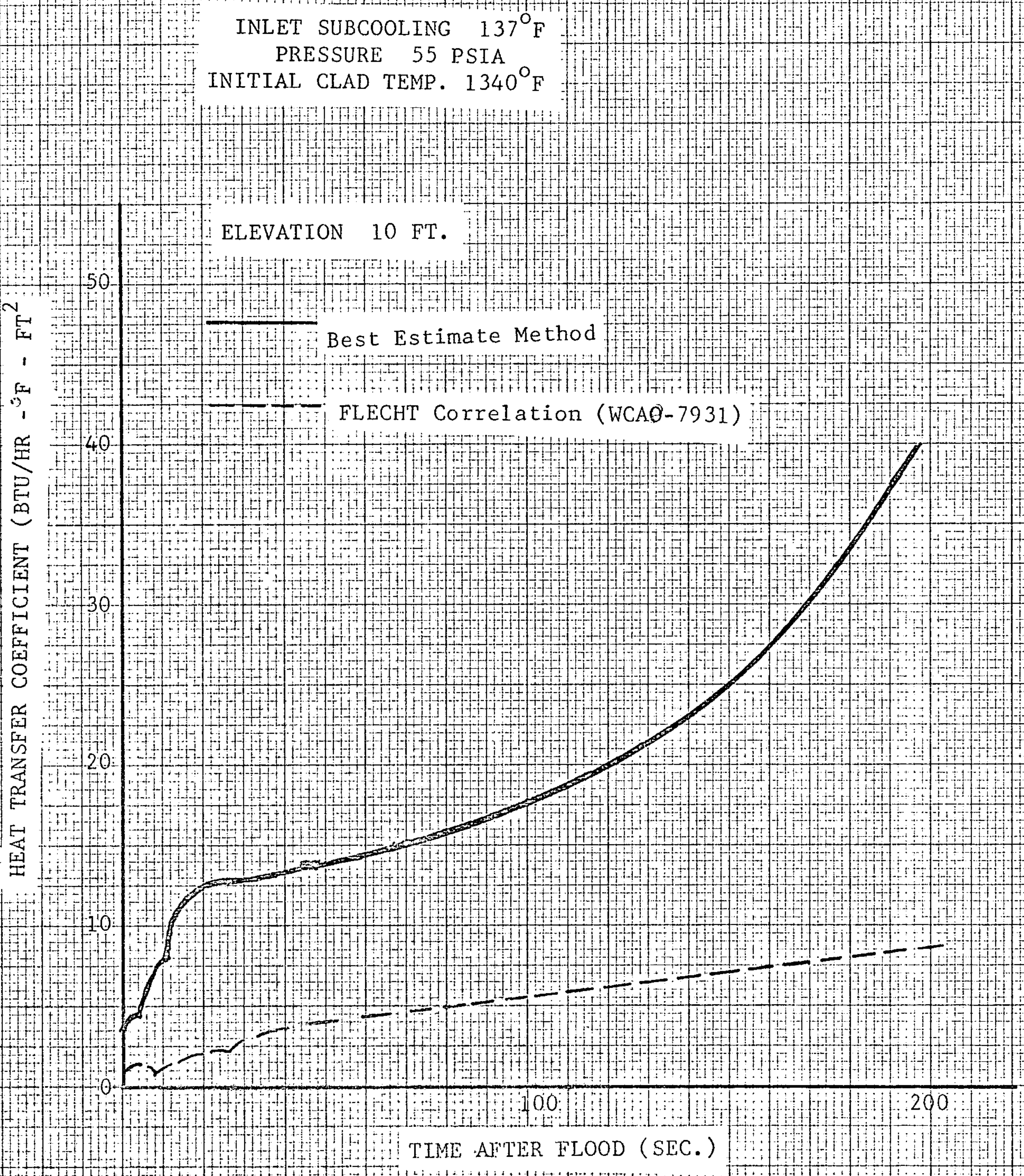


Figure 4-4. Comparison of Heat Transfer Coefficient Calculated with the Best Estimate Technique and the FLECHT Correlation.