Enclosure 1

Sensitivity Evaluation of the C-E ECCS Evaluation Model to Cladding Rupture Strain and Fuel Assembly Flow Blockage Models

I. INTRODUCTION AND SUMMARY

On November 9, 1979, a letter (Reference 1) was sent from NRC (Division of Operating Reactors) to all operating U.S. LWR's requesting verification of compliance with the ECCS Acceptance Criteria of 10CFR50.46, in light of recent questions regarding the conservatism of approved LWR vendor models for cladding rupture strain and fuel assembly flow blockage. This report provides the required verification for five PWR's designed by Combustion Engineering: ANO-2 (Arkansas Power and Light), Calvert Cliffs I and II (Baltimore Gas and Electric), Millstone Point 2 (Northeast Utilities), and St. Lucie I (Florida Power and Light).

The results of this study, presented in Section IV and summarized in Table 1, demonstrate that, even if the most adverse rupture conditions from the proposed NRC cladding deformation model (Reference 2) are postulated for the C-E operating plants listed above, the Acceptance Criteria of 10CFR50.46 continue to be met. The analysis supporting this conclusion was performed using the heat transfer portion of the C-E Alternate Flow Blockage/Heat Transfer Model.

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II. SELECTION OF REFERENCE PLANT

C-E has evaluated the effects of rupture strain and flow blockage in a two-step process. First, the proposed NRC strain and blockage model (Reference 2) has been reviewed and compared to the current C-E strain and blockage model. The results of this comparison are shown in Figures 1 through 3. From the figures, the current C-E model is observed to produce generally lower rupture strains and flow blockage percentages over the range of conditions encountered in C-E's operating plants than would be calculated by the NRC model under the same conditions.

Since the results of step one show that the model used in the current ECCS analyses for C-E's operating plants produced rupture strains and blockages that are lower than would be predicted by the NRC model, Reference 1 requires that additional analyses be performed to verify that all operating plants would continue to be in compliance with the Acceptance Criteria of 10CFR50.46 even if a more conservative strain and blockage model were used. Step two therefore involves a compilation of rupture-related parameters for the five C-E plants included in this evaluation and the selection of a limiting reference plant for these additional required calculations.

The significant information regarding cladding rupture, flow blockage, and steam cooling heat transfer for the limiting break in the current ECCS analysis for C-E operating plants is summarized in Table 2. Of the parameters listed, the following were deemed to have the greatest potential impact upon the sensitivity of calculated peak clad temperature to changes in rupture strain or steam cooling heat transfer:

1. Margin to 2200^{o}F above blockage: Sensitivity studies reported in Reference 3 indicate that, when the C-E alternate steam cooling heat transfer model is used in conjunction with high rupture strains and blockages, the maximum cladding temperature is calculated to occur above the blockage plane. Therefore, plants with less available margin at this location will be more sensitive to a decrease in steam cooling heat transfer coefficient. From Table 2, ANO-II and Millstone-II have the least available margin at this critical location.

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2. Effectiveness of steam cooling: In the C-E ECCS Evaluation Model, cooling of the hot rod at and above the blockage plane during late (<1.0 in/sec) reflood is accomplished by a combination of steam cooling and rod-to-rod radiation. The sensitivity of calculated clad temperatures to changes in steam cooling heat transfer coefficient is therefore strongly dependent upon the relative contribution of the steam cooling component to the total heat transfer coefficient at the critical location described above. From Table 2, Millstone-II is easily the most sensitive to steam cooling at this location.

3. Rupture time: In the C-E model, an increase in rupture strain also produces a corresponding increase in pre-rupture plastic strain, which has a two-fold effect upon the prediction of eventual clad rupture. First, by increasing the volume of the gap region, plastic strain results in clad rupture at a lower internal gas pressure. Second, by increasing the local gap width at the hot spot, plastic strain results in a temporary reduction in the local clad temperature (or at least the clad heating rate) causing the clad to reach the rupture temperature at a later time. For ruptures which occur during reflood, coolant conditions (pressure) outside the rod are essentially constant, so a delay in rupture has little effect upon the eventual rupture strain. For blowdown ruptures, however, the pressure outside the rod is decreasing at a much faster rate than the internal pressure, so a delay in the rupture time results in a significant increase in clad differential pressure at rupture, and therefore a decrease in rupture temperature. From Table 2, Millstone II, which currently ruptures during blowdown at a temperature which places it in the transition region between the α-phase peak and the $\alpha+\beta$-phase valley in the rupture strain vs. temperature curve (Figure 1), would be expected to experience the greatest increase in rupture strain and flow blockage by changing from the current C-E model to the NRC strain and blockage models.

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Based upon the above comparison of important rupture-related parameters, Millstone-II is clearly the most limiting of the five C-E plants with respect to sensitivity to rupture strain and flow blockage, and has therefore been selected as the reference plant for the calculations described in the following sections. A discussion of the applicability of the results of these calculations to other C-E operating plants is given in Section V of this report. The ECCS analysis using the current approved C-E ECCS Evaluation Model, which demonstrates compliance with the Acceptance Criteria of 10CFR50.46 for the current operating cycle at Millstone-II, is documented in Reference 4.

III. METHOD OF ANALYSIS

The calculation described in the following sections was performed using the approved C-E ECCS Evaluation Model (References 5 through 8) and the C-E alternate model for steam cooling heat transfer at and above the blockage plane (Reference 3). The rupture strain was simply assumed to be the maximum value obtained in the NRC Staff Analysis reported in Reference 2. In this calculation, the assumed rupture strain was converted to a corresponding reduction in coolant channel area (percent blockage) using the conversion technique of the C-E Alternate Model described in Reference 3. Figure 4 compares this conversion technique to that proposed by the NRC Staff, and shows that the two techniques produce essentially identical results over most of the range of interest for C-E operating plants. At very high rupture strains (>70%), the C-E technique actually produces higher blockages than the NRC model, so use of the maximum NRC strain and the C-E strain/blockage conversion introduces additional conservatism into the C-E vs. NRC model comparison described above.

The calculation described above was performed for the limiting break (0.8 x double-ended guillotine at the pump discharge) in the current Millstone-II ECCS analysis documented in Reference 4. The remaining breaks in the Millstone-II large break spectrum exhibited similar rupture characteristics, but lower peak clad temperatures. The computer programs and version identification numbers used in this analysis are as follows:

PROGRAM	VERSION I.D.	PURPOSE
CEFLASH-4A	76041	Calculate blowdown hydraulics
STRIKIN-II	79254	Calculate hot rod clad temperatures
VIEWFACTØR	77061*	Calculate view factors for rod-to-rod radiation
HCROSS	79074*	Calculate flow diversion and recovery at and above blockage
PARCH	79003*	Calculate steam cooling heat transfer coefficients

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* These codes or code versions are components of the C-E alternate flow blockage and steam cooling heat transfer model.

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IV. ANALYSIS RESULTS

Table 1 summarizes the results of the LOCA calculation described in the previous section, and compares these results to the corresponding results from the analysis, with the current C-E blockage and heat transfer model, documented in Reference 4. Even assuming as a conservative upper bound the maximum strain of the NRC model (80%) and the blockage as calculated with the C-E Alternate Model (87%), the reference plant continues to conform to the Acceptance Criteria of 10CFR50.46. In fact, when compared with the Reference 4 analysis, the combination of improved heat transfer model and higher strain and blockage actually resulted in a decrease in the calculated peak clad temperature of 75°F.

Conformance with the individual ECCS Acceptance Criteria is summarized as follows:

Maximum Cladding Temperature: Using the C-E alternate flow blockage and steam cooling model, and assuming an upper limit of the NRC rupture strain curve, the maximum cladding temperature calculated for the limiting break at the reference plant is 2006°F, which is well below the criteria limit of 2200°F. The hot spot clad temperature transient for this case is shown in Figure 5.

Maximum Local Oxidation: Using the C-E alternate blockage and heat transfer model and an upper limit of the NRC rupture strain curve, the maximum local oxidation is 5.8%. The 10CFR50.46 criterion limit is 17%.

Maximum Hydrogen Generation (Core-Wide Oxidation): In the current ECCS analysis for the reference plant, reported in Reference 4, the maximum core-wide oxidation was <0.609%. In the C-E model, core-wide oxidation is influenced by rupture strain and flow blockage through the contribution of inside oxidation at the rupture location. Since the local oxidation at the rupture location for the calculation in Table 1 is under 2%, as compared to ~16% in the Reference 4 calculation, the core-wide oxidation in this case would be well below the criteria limit of 1.0%.

Coolable Geometry and Long-Term Cooling: Conformance to ECCS Acceptance Criteria regarding Coolable Geometry and Long-Term Cooling remains as summarized in Reference 4.

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V. APPLICABILITY OF REFERENCE PLANT RESULTS TO OTHER C-E PLANTS

Section II of this report describes the rationale employed to ensure that the reference plant for this calculation would provide a conservative representation of the effect of increased rupture strain and flow blockage upon LOCA consequences for all of the C-E plants included in the analysis. Section IV describes the results of a sensitivity study which shows that, even assuming conservative upper limits for rupture strain and flow blockage, the reference plant continues to meet the Acceptance Criteria of 10CFR50.46. To verify that this conclusion also holds for the other four C-E plants listed in Table 2, we have compared the steam cooling heat transfer coefficients at the peak temperature location for Case 2 in Table 1 (80% strain, 87% blockage) to those calculated for the corresponding location in the current LOCA analyses for these plants (References 9-12). In the current C-E steam cooling model, a minimum heat transfer coefficient, representative of cooling by natural convection and rod-to-steam radiation with no forced convection contribution, is often used instead of the more detailed calculation described in Reference 5. This simplified heat transfer model was used in the LOCA analyses for all of the plants included in this analysis except the reference plant. Therefore, a detailed steam cooling heat transfer calculation accounting for forced convection will produce higher heat transfer coefficients, even with very high blockages. In Case 2 of Table 1, the hot spot steam cooling heat transfer coefficient calculated for the reference plant, even with 87% blockage, was 20-30% higher than this minimum coefficient. We estimate that a similar calculation for the other C-E plants included in this study would produce an equivalent increase. Reanalysis of these plants using the C-E alternate steam cooling model and up to 87% flow blockage would therefore result in higher heat transfer coefficients and lower clad temperatures than those reported in References 9-12. All of these plants therefore continue to conform to the Acceptance Criteria of 10CFR50.46.

VI. CONCLUSIONS

C-E has evaluated the sensitivity of LOCA consequences for five of its operating plants, Calvert Cliffs I and II, Millstone II, St. Lucie I, and ANO-II, to differences in cladding rupture strain and fuel assembly flow blockage models. The results of this study demonstrate that, even assuming an upper limit of the proposed NRC rupture strain curve, the calculated peak cladding temperature and local oxidation for the five plants listed above remain well below the 10CFR50.46 Acceptance Criteria limits of 2200°F and 17%.

VII. REFERENCES

1. Letter, dated November 9, 1979, D. G. Eisenhut of USNRC to Operating Light Water Reactors.

2. NUREG 0630 (Draft), "Cladding Swelling and Rupture Models for LOCA Analysis", D. Powers and R. Meyer, November 8, 1979.

3. LD-78-069, Enclosure 1-P, "C-E ECCS Evaluation Model Flow Blockage Analysis", September, 1978 (Proprietary).

4. Docket No. 50-336, Millstone-II FSAR.

5. "Calculative Methods for the C-E Large Break LOCA Evaluation Model", CENPD-132, August 1974 (Proprietary).

   "Updated Calculative Methods for the C-E Large Break LOCA Evaluation Model", CENPD-132, Supplement 1, February 1975 (Proprietary).

   "Calculational Methods for the C-E Large Break LOCA Evaluation Model", CENPD-132, Supplement 2, July 1975 (Proprietary).

6. "CEFLASH-4A, A FORTRAN-IV Digital Computer Program for Reactor Blowdown Analysis", CENPD-133, April 1974 (Proprietary).

   "CEFLASH-4A, A FORTRAN-IV Digital Computer Program for Reactor Blowdown Analysis (Modification)", CENPD-133, Supplement 2, December 1974 (Proprietary).

7. "PARCH, A FORTRAN-IV Digital Program to Evaluate Pool Boiling, Axial Rod and Coolant Heatup", CENPD-138, August, 1974 (Proprietary).

8. "STRIKIN-II, A Cylindrical Geometry Fuel Rod Heat Transfer Program", CENPD-135, August 1974 (Proprietary).

   "STRIKIN-II, A Cylindrical Geometry Fuel Rod Heat Transfer Program (Modification)", CENPD-135, Supplement 2, February 1975 (Proprietary).

   "STRIKIN-II, A Cylindrical Geometry Fuel Rod Heat Transfer Program", CENPD-135, Supplement 4, August 1976 (Proprietary).

   "STRIKIN-II, A Cylindrical Geometry Fuel Rod Heat Transfer Program", CENPD-135, Supplement 5, April 1977 (Proprietary).

9. Docket No. 50-368, ANO-II FSAR.

10. Docket No. 50-317, Calvert Cliffs I FSAR.

11. Docket No. 50-318, Calvert Cliffs II FSAR.

12. Docket No. 50-335, St. Lucie I FSAR.

TABLE 1

Comparison of ECCS Analysis Results Using
Current C-E and Maximum Value of Proposed NRC Rupture Strain and Flow Blockage Models
Reference Plant: Millstone II

Parameter	Calculation Results	
1. Case Number	1	2
2. Rupture Strain Model	Current C-E Model	NRC Maximum Value
3. Heat Transfer Model	Current C-E Model	C-E Alternate Model
4. Peak Cladding Temperature and Location	$2081^{o}F$, Above Blockage	$2006^{o}F$, Above Blockage
5. Peak Local Oxidation and Location	<16%, At Blockage	5.8%, Above Blockage
6. Local Oxidation at Rupture Location	<16%	1.6%
7. Rupture Strain	30%	80%
8. Flow Blockage	19%	87%

TABLE 2

Clad Rupture Information for C-E NSSS's

PARAMETER	PLANT				
	Calvert Cliffs I	Calvert Cliffs II	Millstone Point II	St. Lucie I	ANO II
Current Cycle	4	2	3	3	1
Peak LHGR (Kw/FT)	14.2	15.5	15.6	14.68	14.5
Rupture Time	Reflood	Blowdown	Blowdown	Reflood	Reflood
Hoop Stress at Rupture	7.37 KPSI	4.31 KPSI	6.72 KPSI	6.46 KPSI	7.22 KPSI
Heating Rate at Rupture	4.7°C/sec	10.3°C/sec	8.3°C/sec	2.5°C/sec	3.3°C/sec
C-E Model ε_r	30%	35%	30%	31%	30%
NRC Composite Model ε_r*	75%	37%	80%	74%	79%
C-E Model Blockage	19%	22%	19%	20%	19%
NRC Model Blockage*	75%	35%	75%	74%	75%
Margin to 2200°F (PCT Location)	420°F	77°F	119°F	214°F	122°F
Margin to 2200°F (Above Blockage)	420°F	209°F	119°F	252°F	122°F
Effectiveness of Steam Cooling ($H_{Stm. Cool}/H_{Rad. + Stm. Cool}$)	0.42	0.40	0.59	0.45	0.39

* Estimated

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FIGURE 1

COMPARISON OF C-E AND

PROPOSED NRC (COMPOSITE) STRAIN CURVES

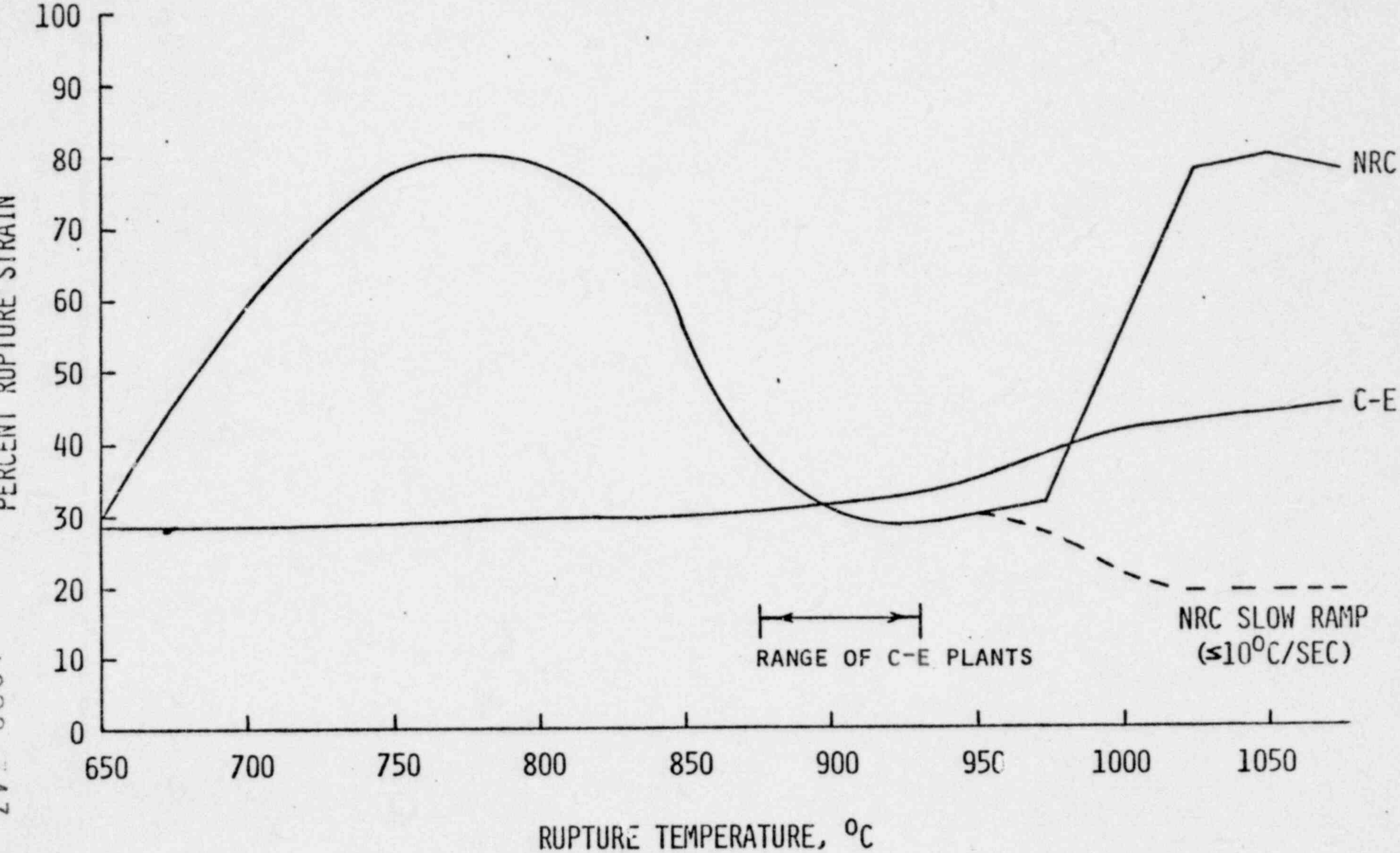

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FIGURE 2
COMPARISON OF C-E AND
PROPOSED NRC BLOCKAGE CURVES

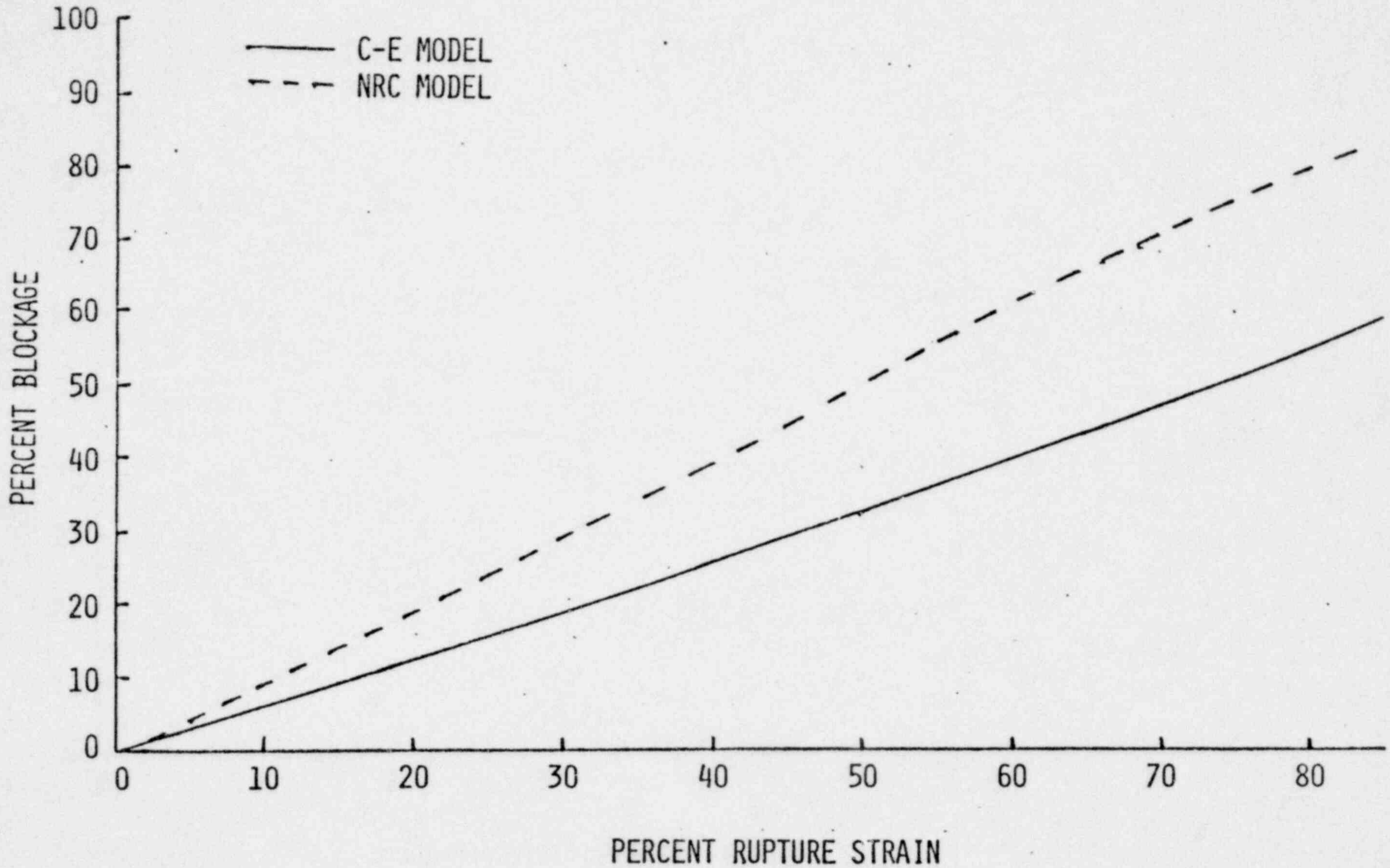

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FIGURE 3

COMPARISON OF C-E AND

PROPOSED NRC (COMPOSITE) BLOCKAGE CURVES

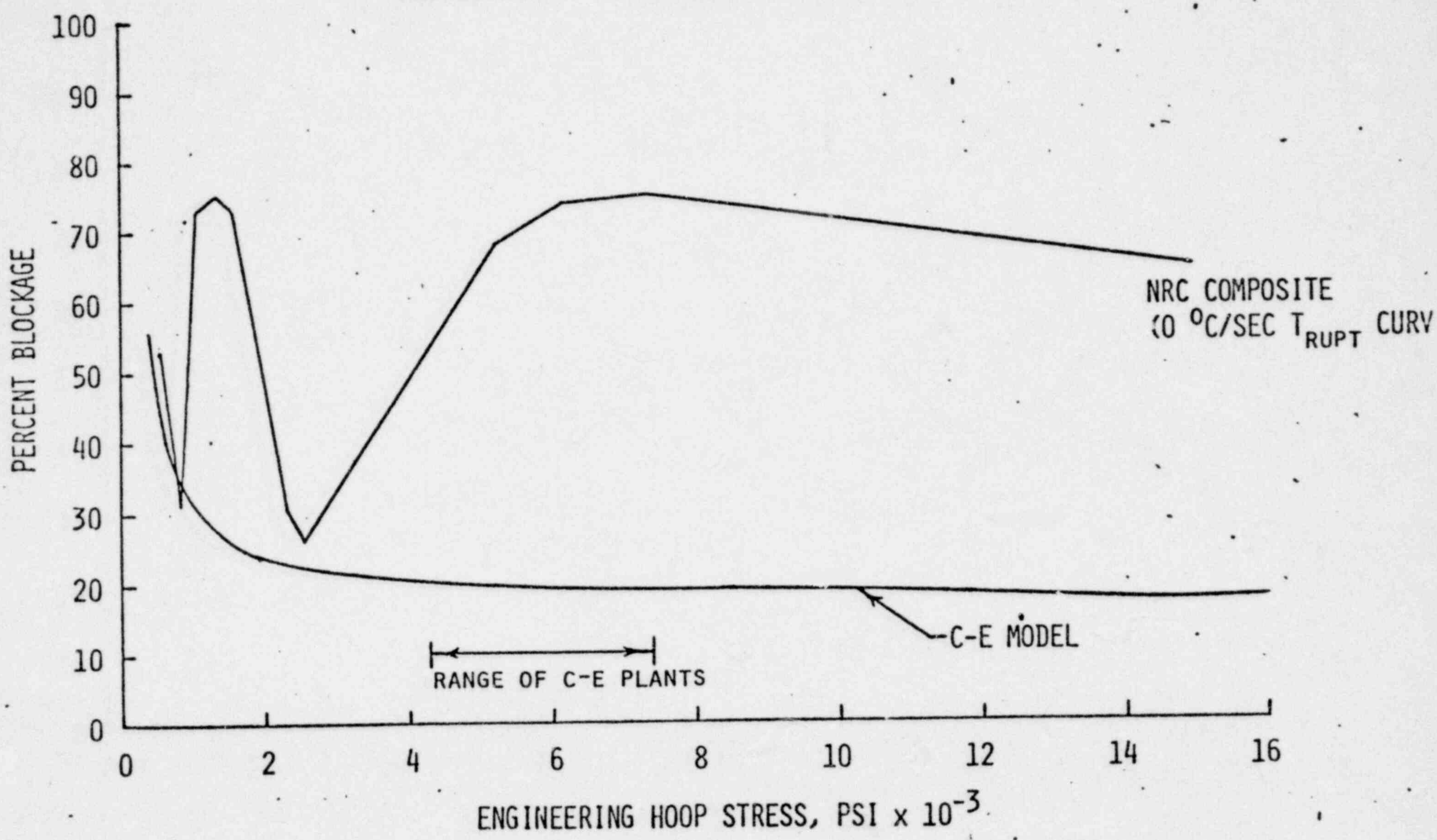

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FIGURE 4

COMPARISON OF C-E ALTERNATE AND PROPOSED NRC BLOCKAGE CURVES

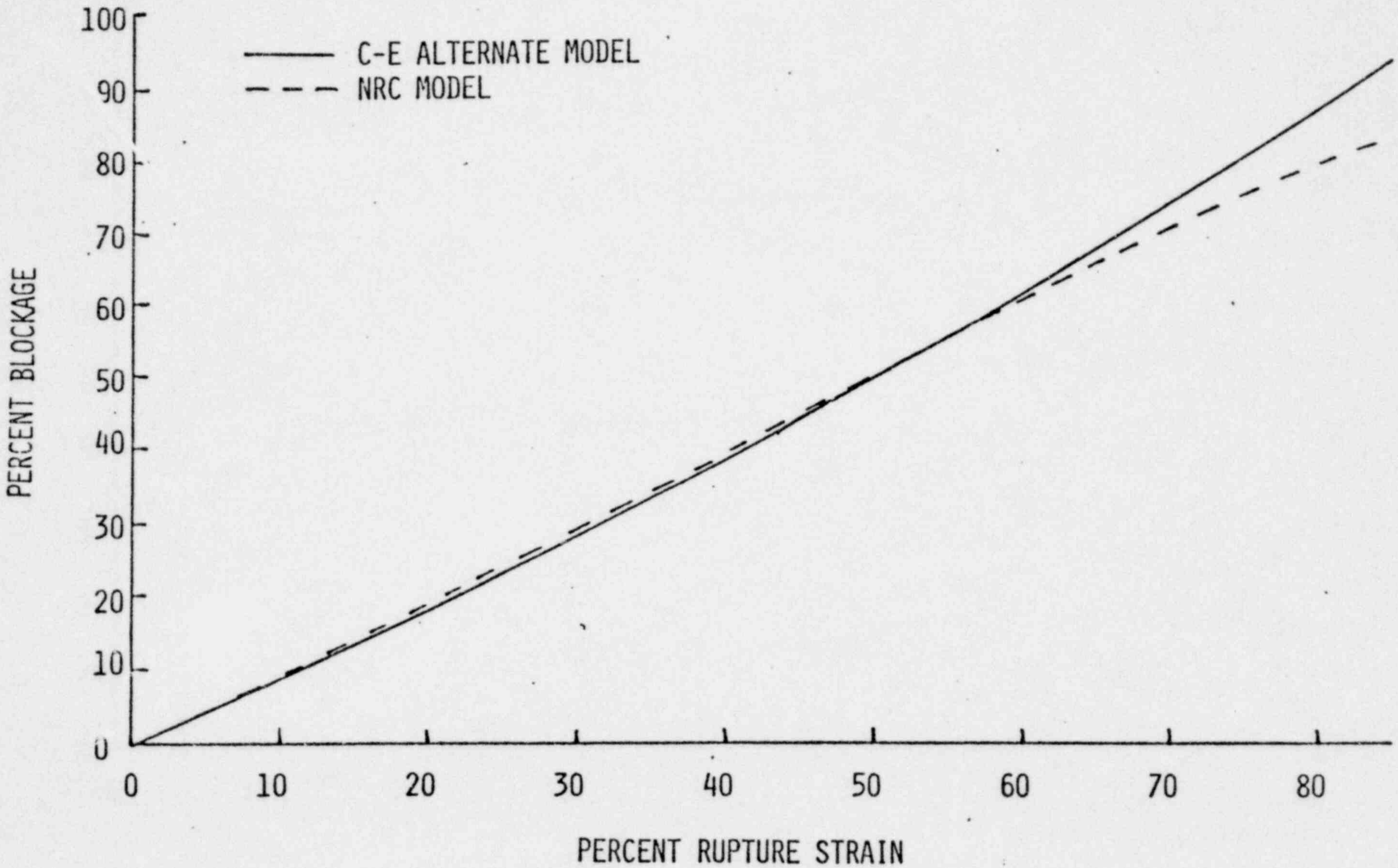

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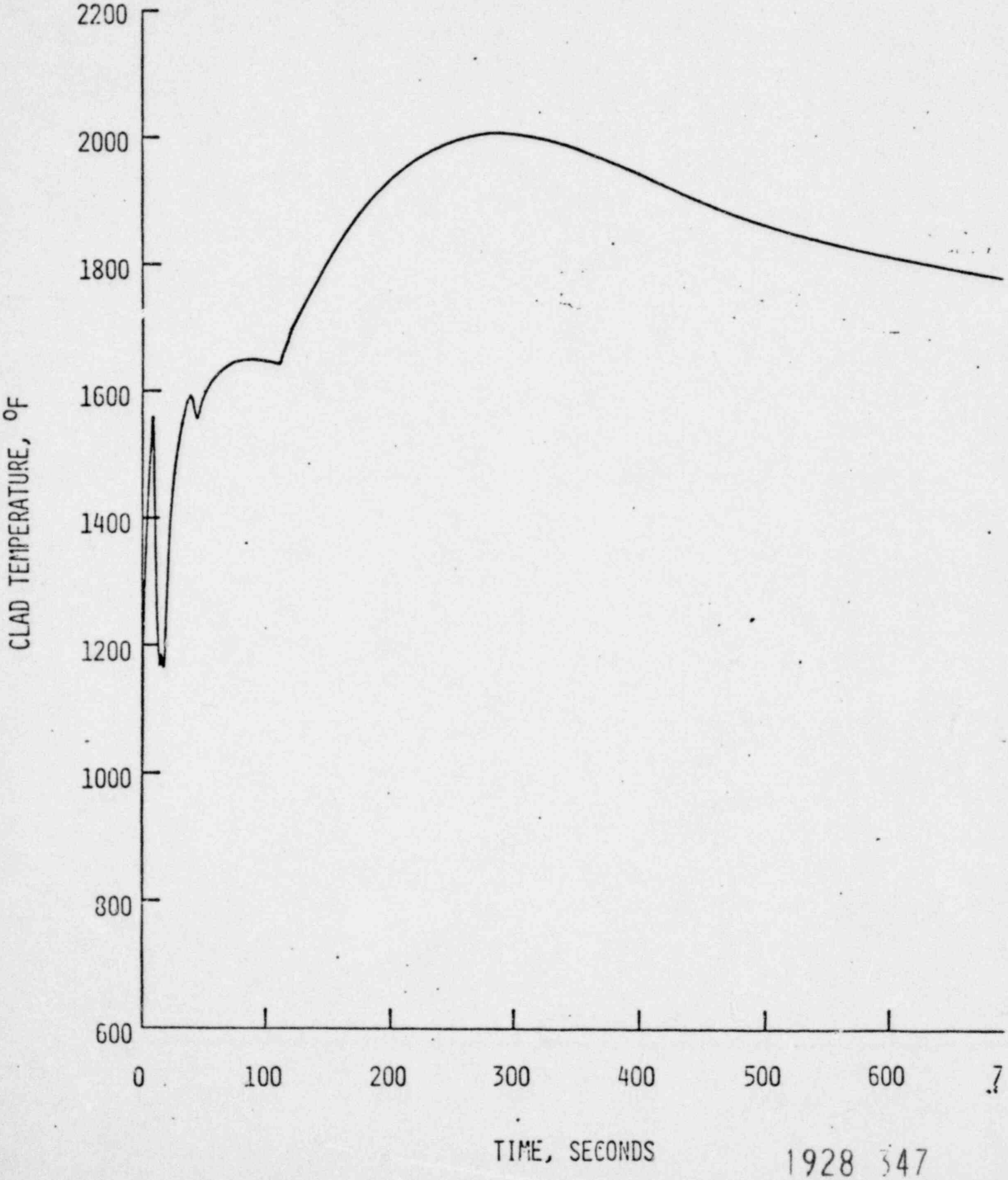
FIGURE 5

PEAK CLAD TEMPERATURE AT THE HOT SPOT
ASSUMING 80% STRAIN AND 87% BLOCKAGE
FOR THE REFERENCE PLANT (MILLSTONE - II)



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