CENPD-283-NP-RAI, rev.1
(NRC TAC No. M86126)

BWR ECCS Evaluation Model: Boiling Water Reactor ECCS Evaluation Model: Response to Request for Additional Information on Code Sensitivity for SVEA-96 Fuel

ABB Combustion Engineering Nuclear Operations

ABB

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Boiling Water Reactor ECCS Evaluation Model: Response to Request for Additional Information on Code Sensitivity for SVEA-96 Fuel

August 1995

ABB Combustion Engineering Nuclear Operations

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TABLES OF CONTENTS

A1 INTRODUCTION

This supplemental report contains responses to the NRC Request for Additional Information regarding Reference A1 which was transmitted to ABB by the NRC in Reference A2. They will be included in the approved version for Reference A1 as Appendix A.

The calculations presented in Reference A1 and this document used the NRC approved LOCA evaluation methods described in References A4 and A5, which has been designated "USA1".

A2 QUESTIONS AND RESPONSES

NRC Question A1

ABB/CE should define and justify" hydraulic compatibility" between SVEA-64 and -96 fuels.

ABB Response to Question A1

Reload fuel types are hydraulically compatible with the resident fuel in the core when:

(1) The pressure drop characteristics of the reload fuel types are similar enough to the resident fuel characteristics to assure that the thermal and mechanical performance of all of the assemblies in the mixed core are within acceptable limits, and

(2) Active flow and bypass flow fractions of the reload fuel are within the design range for the plant for operating conditions which span the power/flow domain.

The manner of demonstrating hydraulic compatibility is described in Section 5.3.3 of CENPD-300-P (Reference A3). This method will be used for each reload as a part of the core design effort.

Question A1 specifically requested that hydraulic compatibility of SVEA-64 and SVEA-96 fuels be justified. There are no current plans to load batches of SVEA-64 and SVEA-96 into the same core in the U.S. The demonstration of hydraulic compatibility is a process which involves the whole core, as well as the individual fuel bundles. Should SVEA-64 and SVEA-96 be loaded into the same core, the methods described in Section 5.3.3 of CENPD-300-P would be used to demonstrate hydraulic compatibility.

The core designs of SVEA-64 and SVEA-96 fuel used in the sample LOCA calculations presented in Reference A3 and A1 are similar designs as shown in the table below.

Fuel Type	Core Pressure Drop at Rated Conditions	Bypass Flow Fraction at Rated Conditions
SVEA-64	[Proprietary	Information]
SVEA-96	[Proprietary	Information]

Note that these characteristics can be modified by changing bypass flow hole sizes and lower tie plate flow hole sizes. These adjustments may be necessary to achieve hydraulic compatibility with different types of resident fuel on a plant specific basis.

NRC Question A2

The code qualification was performed with QUAD+/SVEA-64 fuel in RPB 90-94-P-A and RPB 90-93-P-A. Since the extension is sought with SVEA-96 fuel, ABB/CE should justify that other model qualifications and the experimental data used in the code qualification for its ECCS methodology remain applicable to SVEA-96.

ABB Response to Question A2

Licensing Topical Reports RPB 90-94-P-A and RPB 90-93-P-A (Reference A4 and A5) describe a significant amount of code qualification work. Table A2-1 summarizes the qualification cases and their applicability to SVEA-96 fuel. Much of this qualification (e.g. 'LTA integral tests and jet pump model against INEL 1/6 scale data) is independent of the fuel type. Where there is a fuel type dependence, a reference is given to the location of the performed qualification specifically for SVEA-96 fuel. The applicable general qualification is also referenced.

NRC Question A3

ABB/CE is required by the SER on UR 89-210 that ABB/CE demonstrate that the use of the XL-S96 CPR correlation with GOBLIN/DRAGON produces bounding or conservative predictions of CPR by presenting analysis specifically to address adequacy of implementation.

ABB Response to Question A3

Implementation of the XL-S96 boiling length critical power correlation in GOBLIN/DRAGON is described in Section 4.1 of CENPD-293-P (Reference A7). ABB has certified in Response B3 on CENPD-293-P that the formulation of the XL-S96 correlation is identical to that reviewed and approved in UR-89-210-P-A. Adequacy of implementation is addressed in Section 7.1 of CENPD-293-P.

The calculations presented in CENPD-283-P (Reference A1) used the "USA1" licensing methodology and the use the fuel specific CPR correlation for the SVEA-96 fuel design. The sample calculations and sensitivity studies presented in CENPD-283-P are independent of the specific CPR correlation used. [Proprietary Information]

NRC Question A4

The vendor is relying upon conclusions reached with SVEA-64 to conclude that the same conclusion would be reached for SVEA-96 with the ECCS methodology. ABB/CE should provide FULL range of calculational graphic results and compare between analyses for SVEA-64 and SVEA-96 (p.15).

ABB Response to Question A4

The full range of calculational results for the hot assembly response, discussed on page 15 of CENPD-283-P (Reference A1), are shown for a sample case with SVEA-96 fuel in Figures 5.16 through 5.21 of CENPD-283-P. Similar calculational results were presented for the QUAD+/SVEA-64 fuel design in Figures 3.16 through 3.20 and Figure 3.22 of RPB-90-94-P-A (Reference A4). Figures A4-1 through A4-6 present a direct comparison of the hot assembly response for SVEA-96 and SVEA-64 fuel. This direct comparison shows the small differences between the two calculated hot channel responses. The small differences in results are attributed to differences in flow geometry, fuel rod geometry, nodalization, and simulation assumptions (all discussed in detail in Reference A1). It is apparent that the differences in responses as a result of the change in fuel design and modeling assumptions are minimal.

NRC Question A5

The original topical report concluded that level tracking was important. In this topical report ABB/CE proposes to deactivate the level tracking in the upper plenum in an effort to reduce computer time. ABB/CE should demonstrate that conservatism is not compromised by eliminating this option. Thorough discussion of its impact upon PCTs should be included in the response.

ABB Response to Question A5

In the original Evaluation Methodology (Reference A4) the level tracking was used in three regions - upper plenum, lower plenum, and downcomer region. Licensing Topical Report CENPD-283-P (Reference A1) demonstrates that accurate results are obtainable without activation of the upper plenum level tracking model. ABB will have the option to perform LOCA analysis with or without the upper plenum two-phase level explicitly modeled.

The GOBLIN level tracking model is described in Section 3.3.2 of RPB 90-93-P-A (Reference A5). This model is used to determine energy partition when the two-phase level is near the elevation of a flow path, specifically influencing the fraction of liquid and vapor entering the flowpath. In the level tracking model, the two-phase level position is a primary variable, solved for in the solution matrix, replacing the mass flow rate. The model has been generally used in LOCA analysis for the upper plenum, lower plenum, and downcomer region. These regions typically have coarse nodalization, changing two-phase levels, and horizontal flow junctions.

Experience with the GOBLIN code has shown that the upper plenum level tracking provides an insignificant contribution to the simulation accuracy. Figure 3.10 of Reference A5 shows an example response of the upper plenum level during a LOCA event. The three static upper plenum nodes adequately simulate level changes that occur during the event. Hence, in LOCA analysis, it is sufficient to perform calculations without explicitly tracking the upper plenum level.

To further demonstrate that the effects of using the upper plenum level tracking model are minimal, the LOCA reactor system response described in Section 5.2 of Reference A1, was repeated using upper plenum two-phase level tracking as described in Section 6.1.2 of CENPD-283-P. Figures A5-1 through A5-5 show graphically the comparison results with the upper plenum level tracking turned on and off. It is apparent that there is very little difference in responses. The peak cladding temperature for both cases is shown in Figure A5-5. It can be seen that the PCT is unchanged when the upper plenum level is not explicitly modeled.

<u>NRC Question A6</u>

In the SVEA-64 design, the cruciform structure has a uniform geometry, while in the SVEA-96, the wings have considerably smaller flow cross section. In the core nodalization, ABB/CE proposes modeling the central box and wings as a single channel instead of separate channels. ABB/CE should justify treating the new cruciform as a single channel; in particular, explain how the smaller openings can be lumped with the large opening for two-phase modeling and reflood. The explanation should be quantitative and accompanied by graphic results which include pressure, flow rate, void fraction, relative velocities of two phases and fuel temperature profiles.

<u>ABB Response to Question A6</u>

Cross sections for SVEA-64 and SVEA-96 fuel assemblies are shown schematically in Figures 3.1 and 3.3 of CENPD-283-P (Reference A1). SVEA-64/QUAD+ has a single water channel with the four wings hydraulically coupled through the center of the watercross. SVEA-96 has four hydraulically independent wings and a central water box. [Proprietary Information]

In LOCA analysis, parallel channels having similar response characteristics are typically combined. For example, in modeling SVEA-96 fuel the four wings are identical, and hence are combined both for the vessel system response and hot channel response calculations. ABB will maintain the option to also combine the center water box and water wings in the LOCA analysis. Combining the center box with the water wings assumes that the flow response of the combined channel is not significantly different than the sum of the individual channel responses.

The validity of this assumption was demonstrated in Section 6.1.1 of CENPD-283-P (Reference A1) where the sample LOCA system response calculation was run with the watercross channels explicitly represented and key results compared to the combined simulation. Figures A6-1 through A6-4 show additional comparison results of the GOBLIN system response with and without explicit modeling of the water wings. The pressure, vessel mass inventory, core mass inventory, and core pressure drop are very similar.

Figures A6-5 through A6-11 show detailed results of a hot channel response with and without explicit modeling of the water wings. Figures A6-5 through A6-8 show the inlet flow rates of the fuel assembly, center box, water wings, and total watercross (center box plus water wings). Figure A6-9 shows the channel mass inventory and Figures A6-10 and A6-11 show the void fraction at the midplane for the active channel and watercross components. [Proprietary Information] The results of this delay in midplane dryout is seen in a lower final calculated peak cladding temperature for the case with the explicit center box and wings (see Figure A6-12). These additional hot channel calculations results further substantiate the assumption that the center box and water wings channels have similar response characteristics. Lumping the watercross channels in the system response produces a very similar system response. Furthermore, lumping the watercross channels in the hot channel response also produces very similar and slightly conservative results.

<u>NRC Question A7</u>

ABB/CE cannot apply to SVEA-96 the previous validation of CCFL correlation in GOBLIN/DRAGON for an 8x8 configuration due to geometric differences. Therefore, ABB should demonstrate the applicability of the CCFL correlation specifically to SVEA-96 fuel design in terms of reflood behavior (both from the top and the bottom of the core), including explanation and justification of values selected for K_1 and K_u for SVEA-96.

ABB Response to Question A7

The countercurrent flow limitation (CCFL) model used in GOBLIN/DRAGON is a form of the Wallis (Reference A8) correlation which is widely used to predict the limitation on the downward flow of water for a given steam upflow. The model is described in Section 3.3 of RPB 90-93-P-A (Reference A5). There are two correlating parameters K_1 and K_u in the CCFL model. For a wide range of flow geometries,

[Proprietary Information] (A7-1)

has been shown to fit the data well. The parameter K_u has both a geometry and a void fraction dependence. Two geometric parameters, the hydraulic diameter, D_h and the characteristic length D_L are used in the calculation of K_u, which is determined as a function of void fraction, α, as follows:

[Proprietary Information]

The above correlation is based upon extensive round tube and world data for other geometries (Reference A8 through A12 and Response to Question 8 of Reference A5). In the GOBLIN code it is an integral part of the drift flux formulation and evaluated at all flow paths. The correlation defines the upper limit of relative velocity between phases under countercurrent flow conditions. The correlation as implemented in GOBLIN has been successful in predicting the wide range of geometries including those present in the GOBLIN qualification test matrix (i.e., TLTA and FIX-II). Comparisons have also been made to other correlations applicable to BWRs available in the literature (see Section 6.1.3 of Reference A5).

Furthermore, the CCFL correlation has been compared to test data for the SVEA watercross fuel design and found to compare very well (see Response to Question 8 of Reference A5). Based on the proven robust characteristic of the general CCFL correlation in GOBLIN and the similarity of geometries, the correlation can predict CCFL performance for the SVEA-96 fuel design when the appropriate geometric parameters are provided.

The relative importance of CCFL on the overall LOCA response for SVEA-96 fuel was studied in Section 7.1 of CENPD-283-P (Reference A1). [Proprietary Information]

NRC Question A8

A key item in this report is validation of the convective spray HT coefficients, yet the argument for determination of convective heat transfer during spray cooling is lacking substance. ABB/CE should:

a. justify the conclusion that lowering the value for the central fuel rods always compensates conservatively for the overprediction of the energy transfer from the central bundle to the canister;

b. describe in detail how the data were transformed to be consistent with the improved radiation model;

c. ABB/CE's method to determine coefficients must be supported by experimental data applicable to this fuel as was done for the other fuel designs. Justify extending data obtained using 8x8, 64 fuel rod assembly test data to SVEA-96 with very different configuration.

ABB Response to Question A8

The development and justification of convective spray heat transfer coefficients for SVEA-96 fuel is summarized in Section 7.2 of Reference A1. Presented below is a more detailed discussion of the development of a mechanistic approach for conservatively determining fuel design specific convective spray heat transfer coefficients. The discussion includes validation of the approach against experimental measurements and the application of the approach for the SVEA-96 fuel design. Following the general discussion, items (a), (b), and (c) of the reviewer's question are specifically addressed.

Background

The total heat transfer from a fuel rod, q''_{tot}, is composed of a radiative component to other surfaces, q''_{rad}, and a surface to coolant component, q''_{co}:

$$q''_{tot} = q''_{rad} + q''_{co} \qquad \text{(A8-1)}$$

The radiative heat transfer for surface "k" is calculated by (Reference A5, Equation 4.5-25),

$$q''_{rad} = \sum_{i=1}^{N} GBF_{ki} \; (\sigma T_k^4 - \sigma T_i^4) \qquad \text{(A8-2)}$$

where σ is the Stefan-Boltzmann constant, T_k is the temperature for surface "k", "i" are the other surfaces in view of rod "k", and GBF_{ki} is the gray body factor based on the surface view factor between surface "i" and "k" and radiative conditions of the surfaces (see in Reference A5, Section 4.5 for additional details).

The surface to coolant heat transfer is calculated by (Reference A5, Equation 4.1-28),

$$q''_{co} = h_{co} (T_{surf} - T_{co})$$

where h_{co} is the heat transfer coefficient and T_{surf} and T_{co} are the rod surface and coolant temperatures, respectively. For the spray cooling h_{co} is referred to as the convective spray heat transfer coefficient.

The radiative heat transfer depends on global geometric parameters of the fuel assembly, such as the rod arrangement and location of the unheated channel surfaces.

The surface to coolant heat transfer depends on local geometric parameters of the fuel assembly, such as the subchannel geometry next to the rod and rod diameter.

Fuel assembly spray cooling tests measure the fuel rod surface temperature and total heat transfer from the rod. The convective spray heat transfer is deduced from the total heat transfer and calculation of the radiative heat transfer component. Generally, a constant spray heat transfer coefficient is used for each type of rod with a similar local subchannel geometry (e.g., side, corner and interior rods). The spray heat transfer coefficients calculated from test data are not strictly independent of the rod surface temperature. Hence, when a constant set of values are used in analysis applications the set is chosen to yield conservative results in the intended range of application.

Fuel bundle tests without spray flow (radiation only tests) have been used to qualify the radiative heat transfer models. A consistent radiative model is used in the derivation and application of the spray heat transfer coefficients.

SVEA-96 convective spray heat transfer coefficients

[Proprietary Information]

ABB Response to Question A8, Item a

[Proprietary Information]

The convective heat transfer coefficients for spray cooling specified in 10CFR50 Appendix K were based on an evaluation of the BWR FLECHT test data for 7x7 fuel. In this evaluation the convective heat flux of a rod was determined as the difference of the total heat flux and the radiative heat flux. The total heat flux was determined from the rate of change of measured temperature, the heat capacity of the rod and the measured electric power generation. The radiative heat flux was determined from the measured temperatures of all rods and the channel wall using a radiation model with isotropic reflection. [Proprietary Information]

ABB Response to Question A8, Item b

[Proprietary Information]

ABB Response to Question A8, Item c

[Proprietary Information]

NRC Question A9

Mixed core effects should be investigated further to support ABB/CE's position regarding the transition cores by presenting mixed core analysis results with transition from QUAD+/SVEA64 fuel to SVEA-96 fuel. The watercross for each fuel design should be explicitly modeled in the nodalization. Provide plots from core void fraction, pressure, flow, and flow velocities.

ABB Response to Question A9

Reload cores of mixed fuel designs are designed to be hydraulically compatible (See Response A1 of this document). Cores designed to be hydraulically compatible are generically demonstrated in Reference A5, to yield a LOCA reactor system response that is insignificantly altered relative to that of a full core of one fuel design. A full core of one fuel design is used in the LOCA evaluation for that specific fuel design. Hence, the industry accepted process of performing LOCA evaluations for a specific fuel design based on a full core of that fuel design is also valid for mixed core applications.

To further demonstrate that the discussion presented and conclusions drawn in the response to Question 5 of RPB-90-94-P-A are valid in general, the results for a full core of SVEA-96 were compared to the previous system responses in Section 8 of Reference A1. Additional comparative results are shown in Figures A9-1 through A9-8 which correspond to Figures 5-1 through 5-8 on pages 18 through 25 of the Addendum to RPB 90-94-P-A. The core compositions in the four cases presented in Figures A9-1 through A9-8 are:

Core Description	8x8R	QUAD+	SVEA-96
Full Core 8x8R	764	–	–
Mixed Core	260	504	–
Full Core QUAD+	–	764	–
Fuel Core SVEA-96	–	–	764

For the Mixed Core case, as applicable, both QUAD+ and 8x8R channel results are shown in the figure. There are insignificant differences between the system responses of the four cores presented.

As discussed in Response 5 of RPB-90-94-P-A small differences in the responses are attributed to differences in fuel component designs. As noted in Response A1 of this document, the SVEA-96 core used as an example was not specifically designed to be hydraulically comparable with the previous example cores (i.e., QUAD+ and 8x8). Hence, in some instances in Figures A9-1 through A9-8, the SVEA-96 results deviated slightly more than those observed for the other cores configurations. However, the overall system responses are very similar.

The results presented here further substantiate the general conclusion that the core average system response is relatively independent of local differences in fuel assembly design.

A3 REFERENCES

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A2. NRC Facsimile Transmissions from R. Frahm (NRC) to D. Ebeling-Koning (ABB), March 20, 1995 (original) and March 28, 1995 (revision 1).

A3. Reference Safety Report for Boiling Water Reactor Reload Fuel, ABB Report CENPD-300-P (proprietary), CENPD-300-NP (nonproprietary), November 1994.

A4 Boiling Water Reactor Emergency Core Cooling System Evaluation Model: Code Sensitivity, ABB Report RPB-90-94-P-A (proprietary), RPB-90-92-NP-A (nonproprietary), October 1991.

A5. Boiling Water Reactor Emergency Core Cooling System Evaluation Model: Code Description and Qualification, ABB Report RPB-90-93-P-A (proprietary), RPB-90-91-NP-A (nonproprietary), October 1991.

A6. Fuel Assembly Mechanical Design Methodology for Boiling Water Reactors, ABB Report CENPD-287-P (proprietary), CENPD-287-NP (nonproprietary), June 1994.

A7. Boiling Water Reactor Emergency Core Cooling System Evaluation Model: Supplement 1 to Code Description and Qualification, CENPD-293-P (proprietary), CENPD-293-NP (nonproprietary), August 1994.

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A8. Graham B. Wallis, One-dimensional Two-phase Flow, McGraw-Hill Book Co., 1969, p 339.

A9. K. H. Sun "Flooding Correlations for BWR Bundle Upper Tieplates and Bottom Side-Entry Orifices," Multiphase Transport: Fundamentals, Reactor Safety, Applications; Hemisphere Publishing, 1979 pg. 1615-1635.

A10. General Electric Company Analytical Models for Loss of Coolant Analysis in Accordance with 10CFR50, Appendix K, NEDO-20566, 1976.

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A13. J. S. Chiou and L. E. Hochreiter. COBRA/TF Analysis of SVEA Spray Cooling Experiments," 1989 National Heat Transfer Conference, HTD-Vol. 106, page 69-80.

A14. R. Pettersson, "GÖTA Data Analysis, SKI Project B 39/77. Final Report" , ABB Atom Report RCC 79-107, 1979.

TABLE A2-1

LOCA METHODS QUALIFICATION MATRIX

Code Model/ Qualification Test	Applicability	Reference General Qualification	Reference for SVEA-96 Qualification
Drift Flux	fuel type independent; uses fuel specific geometric information	Reference A5, Sect. 6.1.1	-
Level Swell	fuel type independent	Reference A5, Sect. 6.1.2	-
Countercurrent Flow Limitation	fuel type dependent; uses fuel specific geometric information	Reference A5, Sect. 6.1.3 and response to Question 8	This document response to Question A7
Fuel Bundle Pressure Drop	fuel type dependent; included in fuel design mechanical design evaluation	Reference A5, Sect. 6.1.4; Reference A3, Sect. 5.3.3	Reference A3, Sect. 5.3.3
Jet Pump	fuel type independent	Reference A5, Sect. 6.1.5	-
CHF Correlation	fuel type dependent; uses fuel specific correlation	Reference A5, Sect. 6.1.6	Reference A7, Sect. 7.1
Post-Dryout Heat Transfer	fuel type independent	Reference A5, Sect. 6.1.7	-
Reactor Power Generation Model	fuel type independent	Reference A5, Sect. 6.1.8	-

TABLE A2-1 (CONTINUED)

LOCA METHODS QUALIFICATION MATRIX

Fuel Rod Conduction Model	fuel type independent; uses fuel specific geometric information	Reference A5, Sect. 6.1.9; Reference A7, Sect. 7.3	-
Cladding Strain and Rupture Model	fuel type independent; uses fuel specific geometric information	Reference A7, Sect. 7.2	-
Radiation Heat Transfer Model	fuel type independent; uses fuel specific geometric information	Reference A5, Sect. 6.1.11	-
Spray Cooling and Channel Wetting	fuel type dependent; uses fuel specific values	Reference A5, Sect. 6.1.11	Reference A1, Sect. 7.2
Integral System Qualification	fuel type independent; uses test fuel specific geometric information	Reference A5, Sect. 6.2 and 6.3; Reference A7, Sect. 7.4	-

Figures A4-1 through A9-8 deleted

[Proprietary Information]

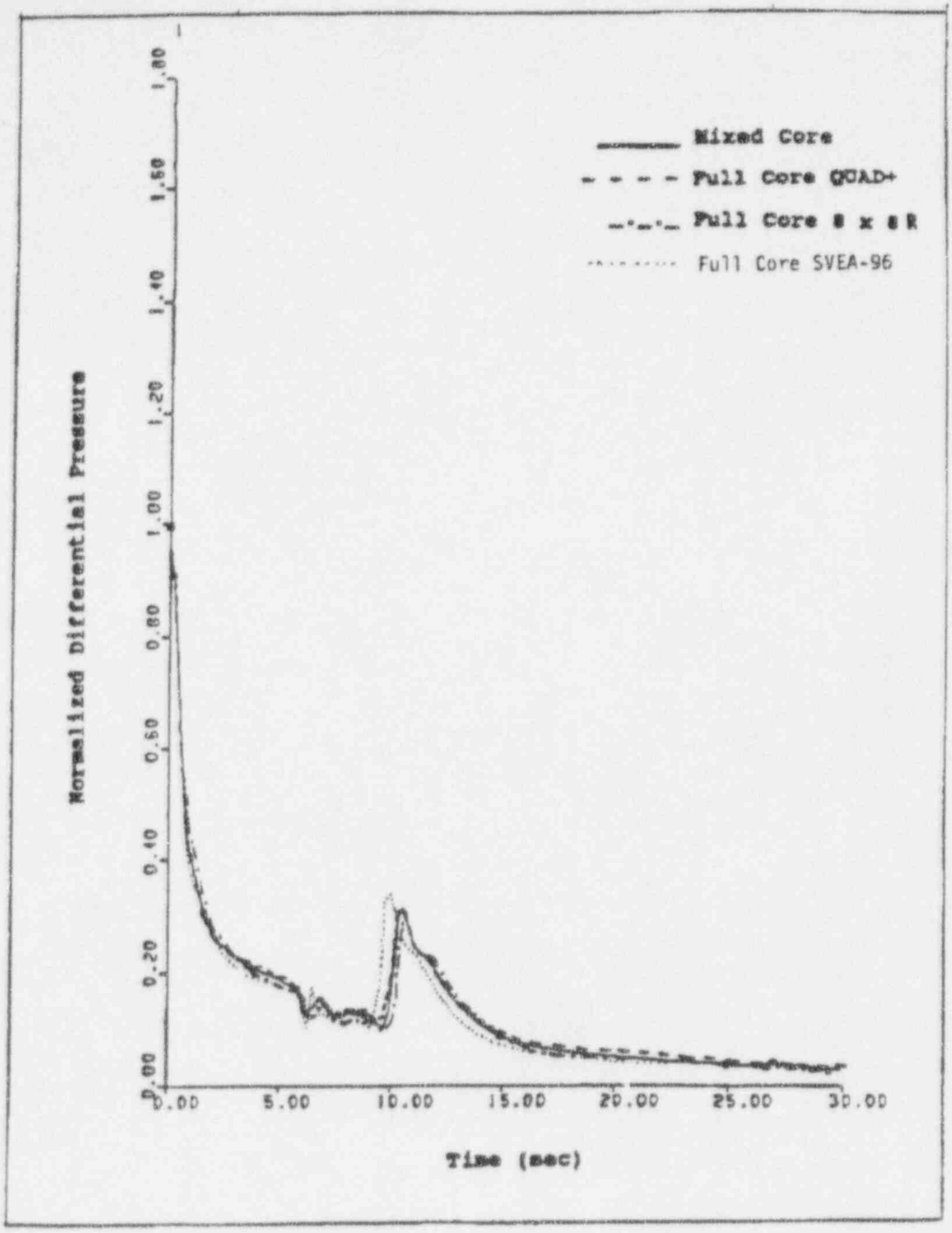

Figure A9-1 Normalized Assembly Differential Pressure versus Time

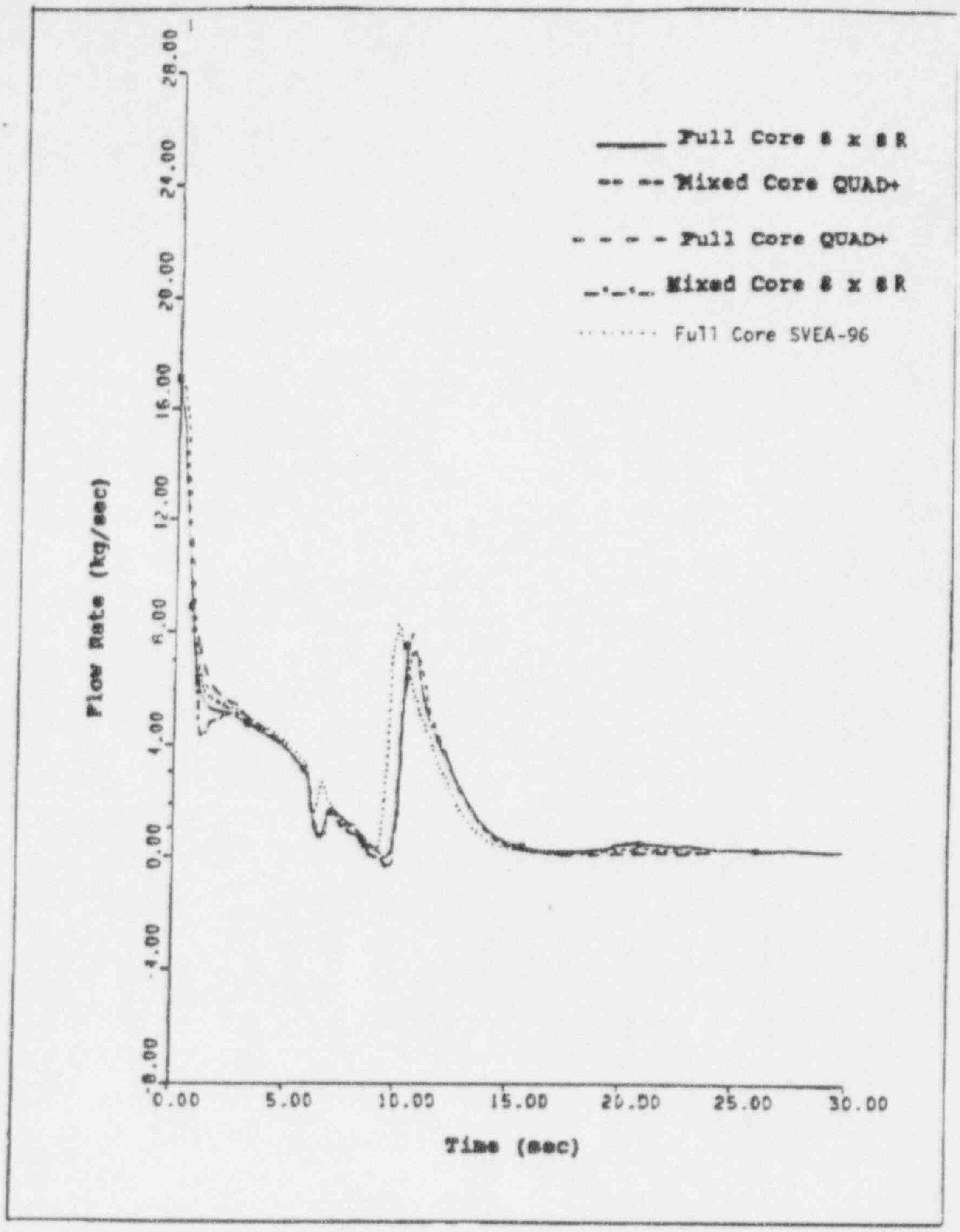

Figure A9-2 Side Entry Orifice Flow per Assembly versus Time

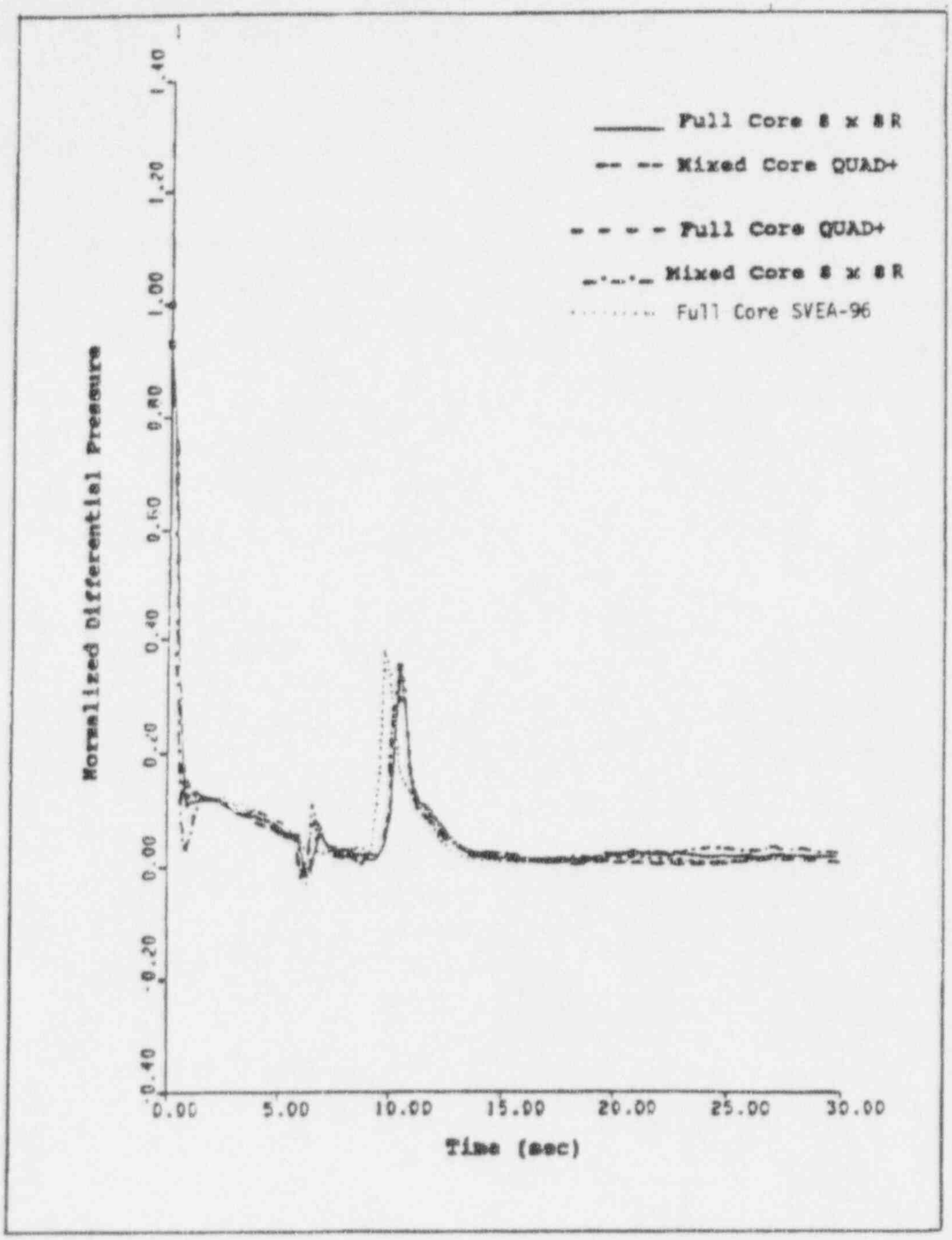

Figure A9-3 Normalized Side Entry Orifice Differential Pressure versus Time

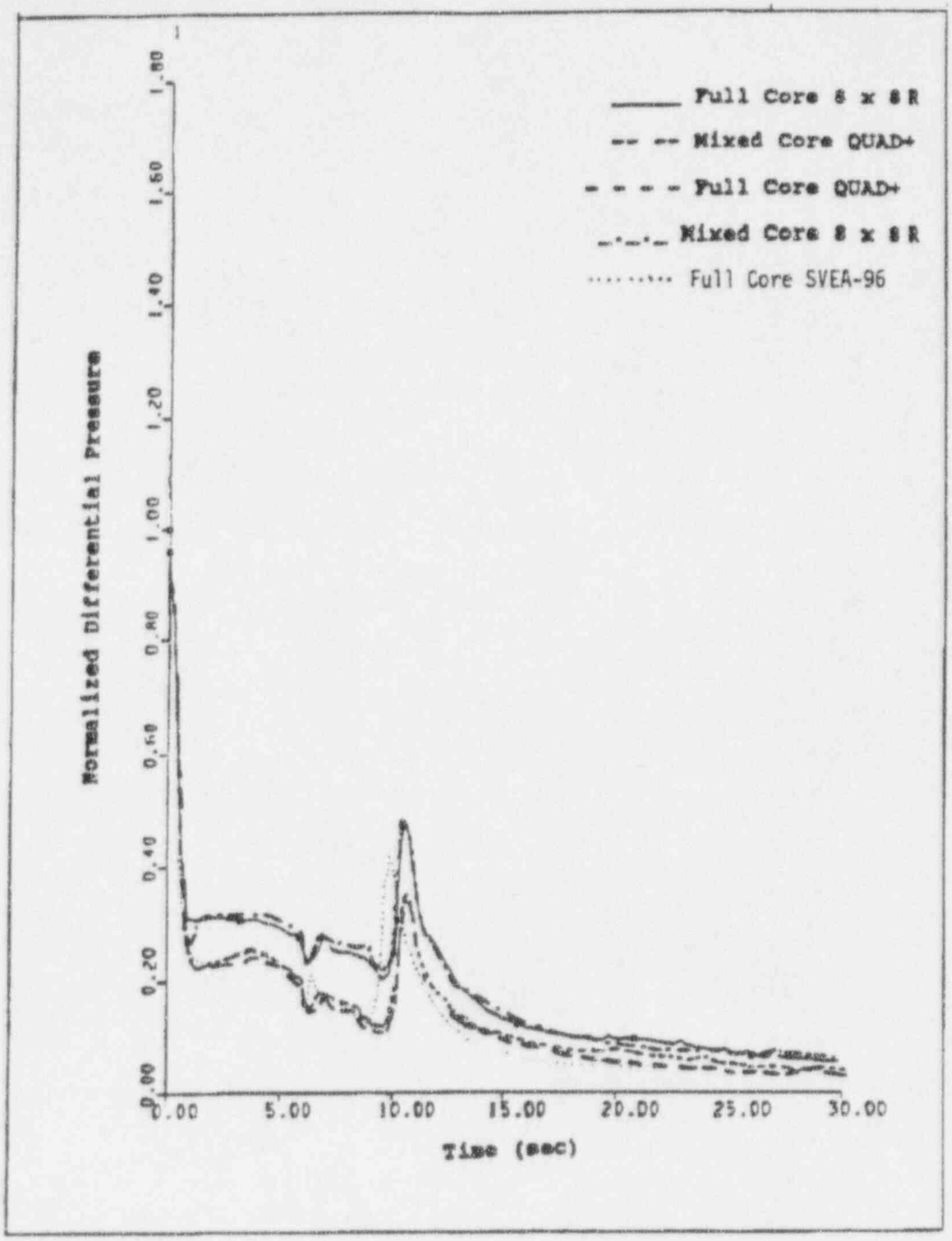

Figure A9-4 Normalized Lower Tie Plate Differential Pressure versus Time

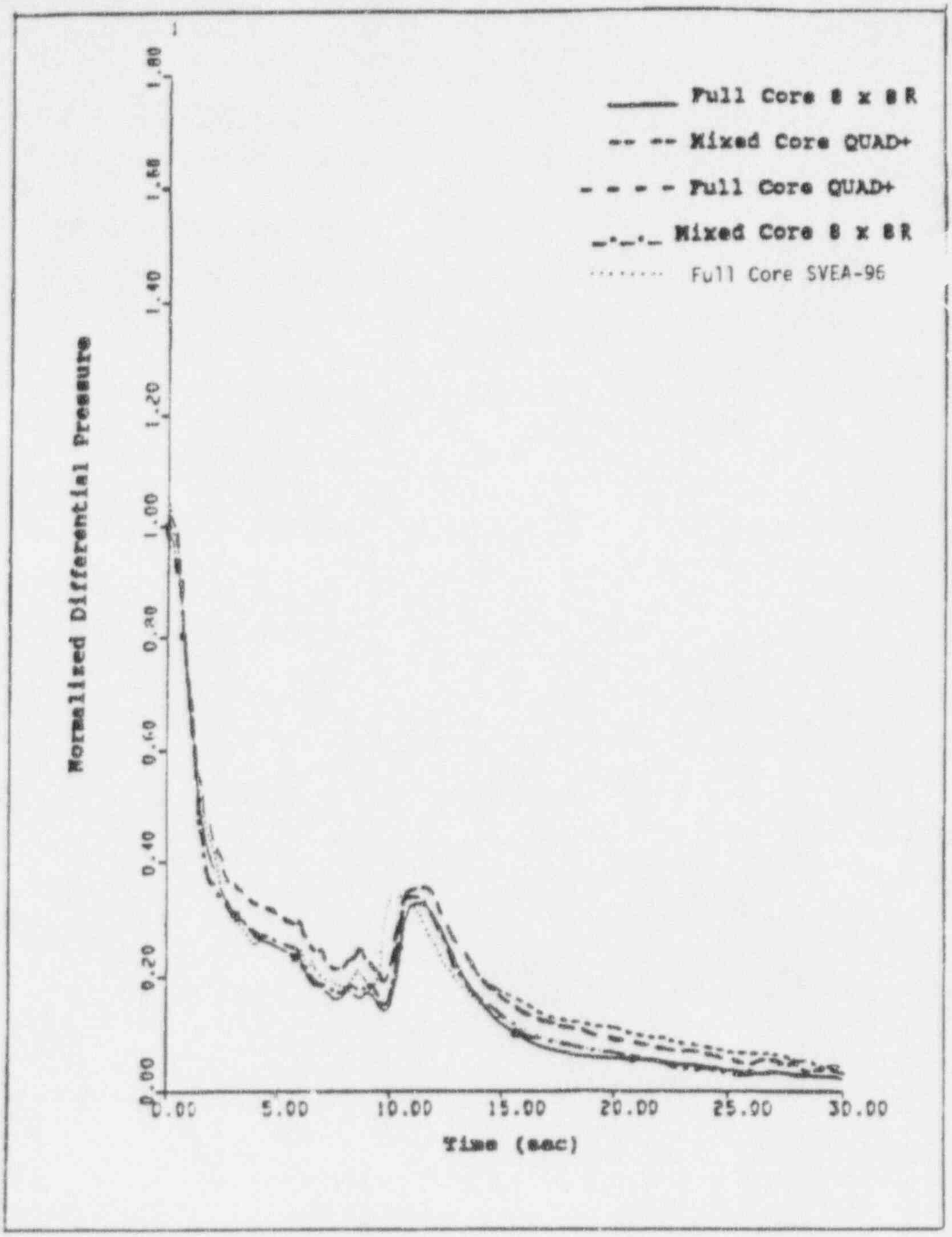

Figure A9-5 Normalized Heated Length Differential Pressure versus Time

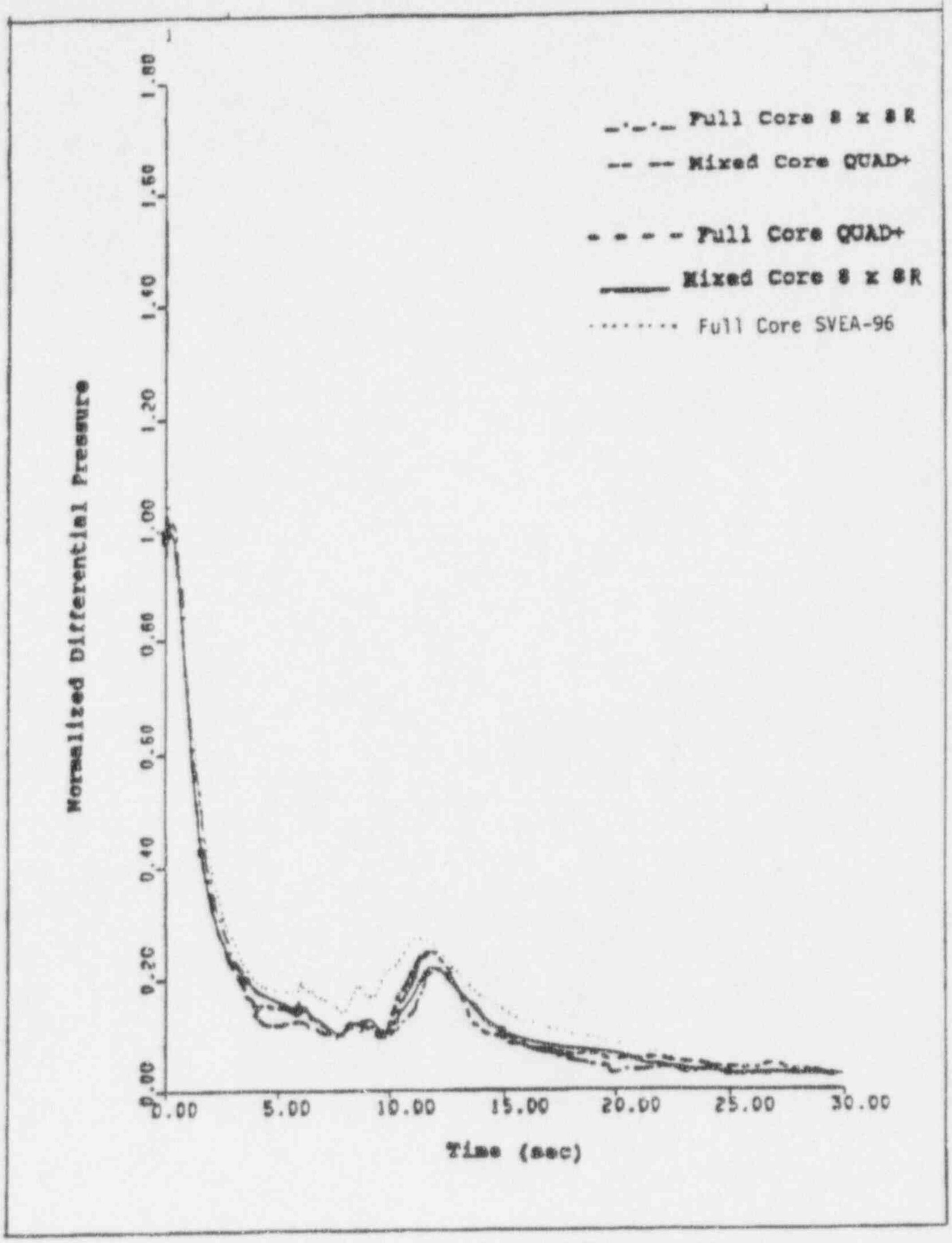

Figure A9-6 Normalized Upper Tie Plate Differential Pressure versus Time

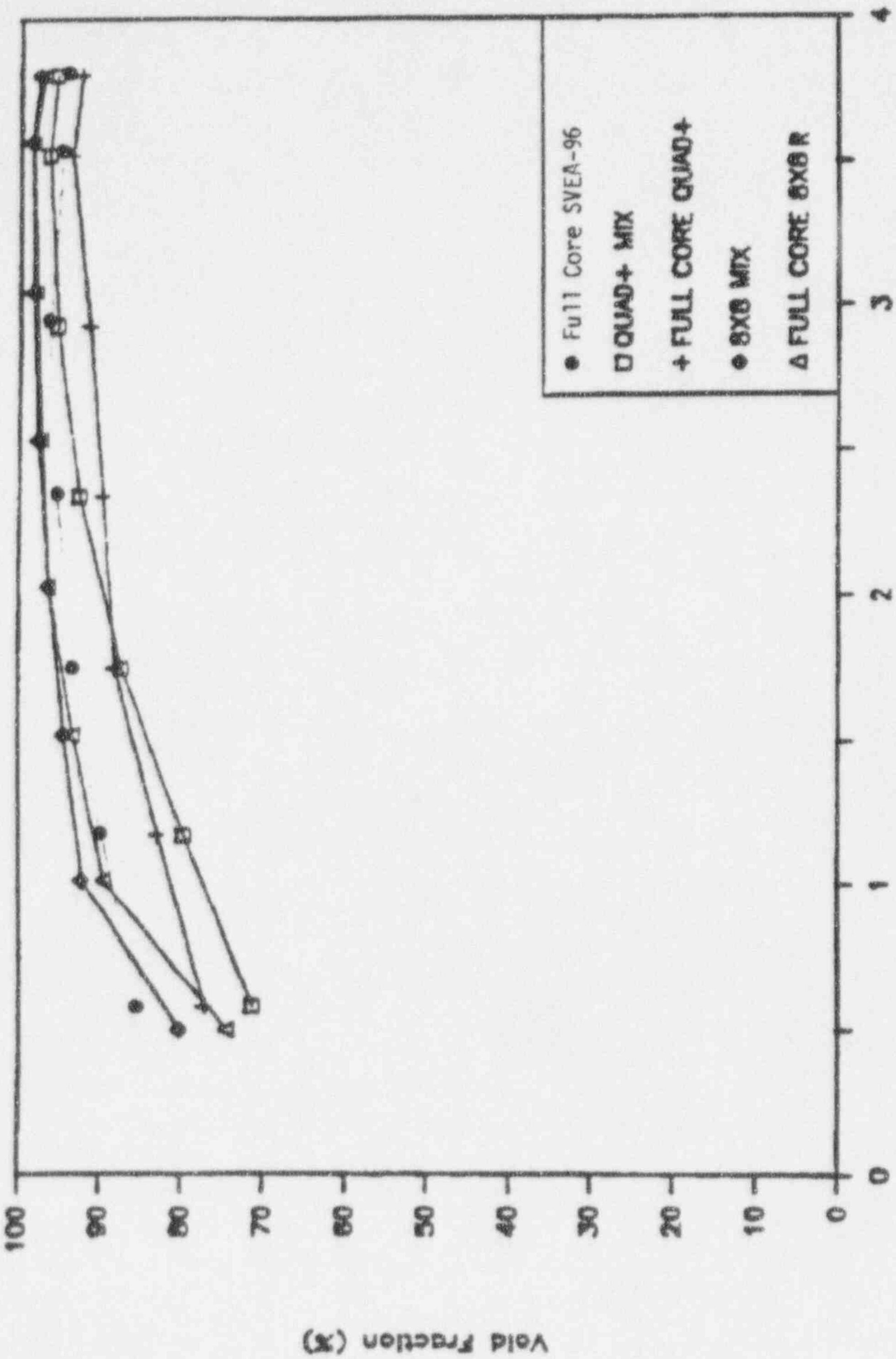

Figure A9-7 Core Void Fraction at 20 Seconds versus Core Elevation

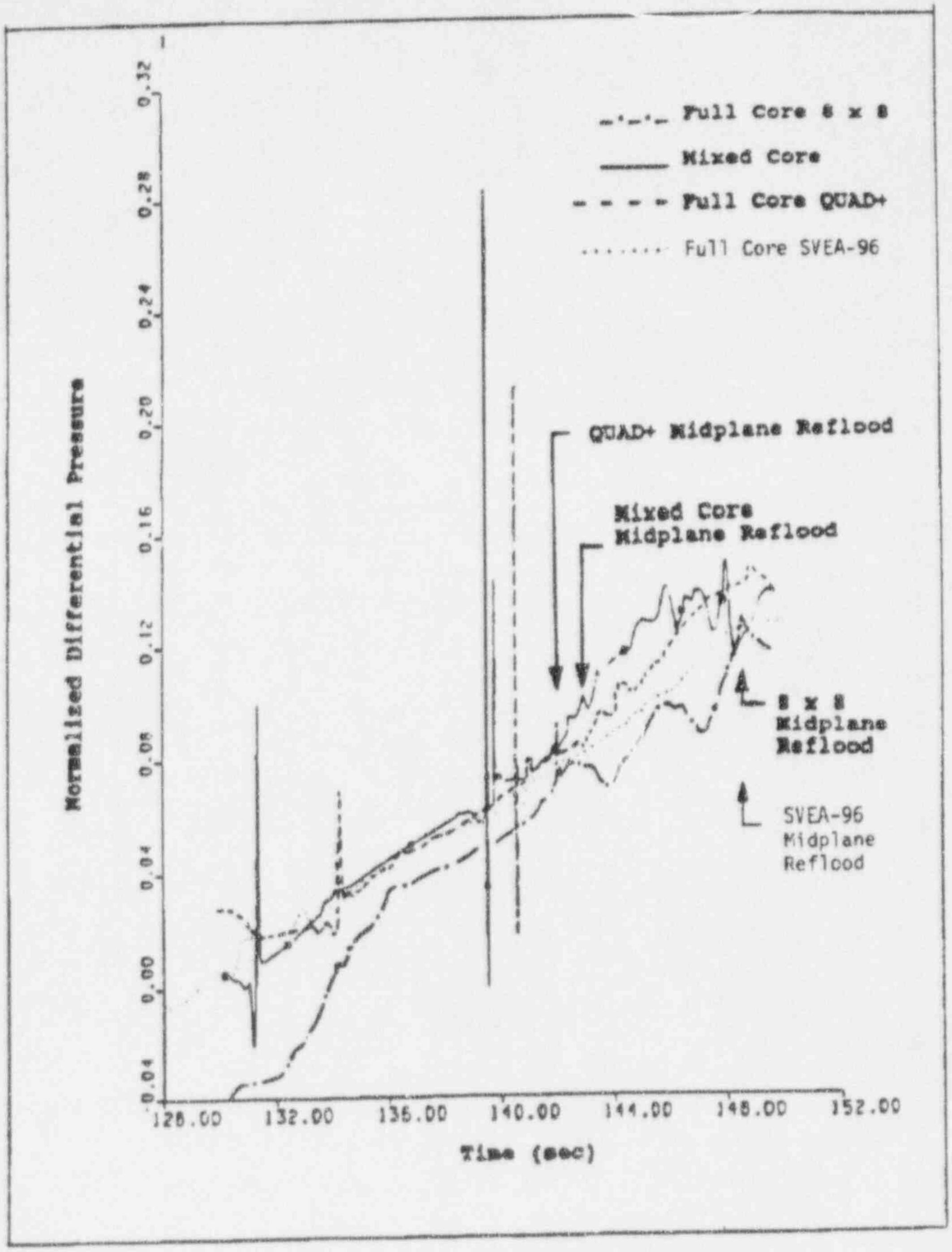

Figure A9-8 Normalized Assembly Differential Pressure versus Time