CENPD-133
Supplement 5

CEFLASH-4A

A FORTRAN77 DIGITAL COMPUTER PROGRAM FOR REACTOR BLOWDOWN ANALYSIS

TRANSIENT METHODS AND LOCA
NUCLEAR FUEL ENGINEERING

JUNE 1985

COMBUSTION ENGINEERING

Power Systems

LEGAL NOTICE

CENPD-133

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ABSTRACT

This report describes changes made to the CEFLASH-4A computer code. CEFLASH-4A is used by Combustion Engineering to analyze the thermal-hydraulic response of pressurized water reactors during the blowdown period of a loss-of-coolant accident. The changes are (1) implementation of an improved integration technique and automatic time step procedure and (2) enhancements to the leak flow model.

The improved integration technique is a fully implicit interative procedure which uses a predictor-corrector alogrithm. The improved integration technique and automatic time step procedure combine to significantly reduce code running time with no significant effect on the transient results.

The enhancements to the leak flow model include (1) an improved method of calculating stagnation pressure and enthalpy and (2) options which expand the versatility of the leak flow model.

TABLE OF CONTENTS

Section	Title	Page
1.0	INTRODUCTION	1
2.0	DESCRIPTION OF CODE MODIFICATIONS	
	2.1 Fully Implicit Iterative Integration Technique	2
	2.2 Modifications to the Leak Flow Model	4
	2.2.1 Calculation of Stagnation Pressure and Enthalpy	4
	2.2.2 Modifications to Increase Versatility	4
3.0	SENSITIVITY STUDIES	
	3.1 Fully Implicit Iterative Integration Technique	6
	3.2 Modifications to the Leak Flow Model	6
4.0	REFERENCES	25

LIST OF APPENDICES

Appendix	Title	Page
Appendix A	Description of CEFLASH-4A Input Changes	A-1
Appendix B	Homogeneous Equilibrium Critical Flow Tables	B-1

1.0 INTRODUCTION

The CEFLASH-4A code is a computer program which is used by Combustion Engineering (C-E) to analyze the thermal-hydraulic response of a pressurized water reactor (PWR) during the blowdown period of a loss-of-coolant accident (LOCA). A detailed description of CEFLASH-4A is presented in References 1 through 5.

This report describes two enhancements made to CEFLASH-4A. The first enhancement is the implementation of an improved integration technique for the solution of the mass, energy, and momentum conservation equations. The improved integration technique is more stable and accurate than the technique it replaces. To take advantage of this improved technique an automatic time step size selection procedure has been added to CEFLASH-4A. The procedure dynamically optimizes the time step based on the convergence characteristics of the solution. Implementation of the improved integration technique and the automatic time step calculation has reduced the execution time of CEFLASH-4A by approximately a factor of seven with a negligible effect upon the results of the transient calculations.

The second enhancement is to the leak flow model. This enhancement includes (1) an improved method of calculating the stagnation pressure and enthalpy used by the leak flow model to calculate critical flow out the break and (2) an expansion of the versatility of the leak flow model.

The version of CEFLASH-4A with the improvements described in this report is herein referred to as the current version of CEFLASH-4A. The version prior to this version is referred to as the previous version.

Section 2.0 of this report describes each improvement in detail. Section 3.0 presents the results of sensitivity studies which were performed using the current version of CEFLASH-4A. Appendix A presents a description of the input changes for the current version of CEFLASH-4A. Appendix B presents the Homogeneous Equilibrium Critical Flow Tables that have been added to CEFLASH-4A.

2.0 DESCRIPTION OF CODE MODIFICATIONS

2.1 FULLY IMPLICIT ITERATIVE INTEGRATION TECHNIQUE

The improved CEFLASH-4A integration technique applies standard two-step, predictor-corrector methods to the FLASH-4 implicit integration technique (Reference 7). This procedure results in a fully implicit iterative (FII) technique for solution of the one dimensional conservation equations of mass, energy, and momentum for the node-flowpath network used in CEFLASH-4A to model a PWR. The FII procedure applies the technique described in References 6 and 10. Convergence of the procedure is coupled to the time step size. The time step size is adjusted to obtain convergence without iteration beyond the first correction on the prediction.

The FII procedure in CEFLASH-4A uses the FLASH-4 (Reference 7) integration technique to perform the first integration of the conservation equations (the prediction of the solution). It then uses a modified version of the FLASH-4 integration technique using the predicted solution to correct the solution. The second integration is fully implicit in the sense that it directly depends on the value of the solution at the new time step.

Predictor-corrector integration techniques in general have better stability and a higher order of accuracy than one step procedures such as the FLASH-4 integration procedure which was used in the previous version of CEFLASH-4A. Accordingly, the current version of CEFLASH-4A can use much larger time steps than the previous version without decreasing the stability of the solution or increasing the discretization errors that accumulate due to temporal differencing. In order to maintain the stability and accuracy of the solution when using large time steps, the degree of implicitness of the solution was improved by the linearization of those major variables which were previously assumed constant during each time step in the FLASH-4 integration algorithm.

To take advantage of the ability to use large time steps, an automatic time step selection procedure which dynamically optimizes the time step size for accuracy, efficiency, and stability based on the convergence characteristics of the solution has been added to CEFLASH-4A. The automatic time step

technique is based on the degree of convergence which has been achieved during the integration of the conservation equations. The technique calculates the magnitude of the difference between the predicted and corrected values of the solution for the three primary variables: nodal mass, nodal energy, and junction mass flow rate. If the magnitude of these differences is less than internally specified values, then a slightly larger time step, up to an input specified maximum time step, is used for the next time step. If the difference is greater than the specified values, then the magnitude of the next time step is reduced. The internally specified values have been chosen such that the results obtained using the current version differ negligibly from those obtained using the previous version.

In addition, a test which detects significant changes in nodal pressure has been incorporated into the calculational logic. If the change in pressure for any node during the predictor or corrector calculations is larger than internally specified values, the size of the time step is automatically reduced and the calculations for that time step are restarted.

Since the FII procedure has only been applied to the conservation of mass, energy, and momentum equations, the time step size for other equations (e.g., heat conduction, reactor kinectics) has been retained at the shorter values used in the previous version by dividing each time step into smaller steps for these calculations. These parallel time step sizes are chosen to ensure that the accuracy and stability of these calculations is maintained.

2.2 MODIFICATIONS TO THE LEAK FLOW MODEL

2.2.1 Calculation of Stagnation Pressure and Enthalpy

The CEFLASH-4A leak flow model is described in Section III.B.4 of Reference 1 and Section II.B.3 of Reference 5. The model calculates the critical flow in a leak path as a function of the leak path stagnation pressure and enthalpy. In the previous version of CEFLASH-4A the leak path stagnation pressure and enthalpy were approximated by the leak node pressure (adjusted to the elevation of the leak path) and enthalpy. The nodal pressure and enthalpy are static properties, however, and as such, do not reflect the dynamic effects included in stagnation properties.

In the current version of CEFLASH-4A the stagnation pressure, P_{stag}, and enthalpy, h_{stag}, are calculated and used to determine the leak flow rate. By definition

$$P_{stag} = P + (\rho)(V^2)/(2g_c) \qquad (2\text{-}1)$$

and

$$h_{stag} = h + (\rho)(V^2)/(2g_c J) \qquad (2\text{-}2)$$

The leak node pressure is directly calculated to be P_{stag} by, first, modifying the momentum pressure drop in the inlet path to the leak node to be that associated with ideal nozzle flow (which is the basis of the Moody model, Reference 8) and then adding the velocity head term of Equation 2-1. The stagnation enthalpy is directly calculated from the leak node enthalpy by means of Equation 2-2. In applying Equations 2-1 and 2-2, the velocity, V, and density, ρ, are those of the inlet path to the leak node.

2.2.2 Modifications to Increase Versatility

Several improvements were made to the CEFLASH-4A leak flow model to expand its range of applicability and to allow more flexibility in modeling critical flow. Each improvement has been added as a user option. They are as follows:

(1) Homogeneous Equilibrium Critical Flow Model

The homogeneous equilibrium critical flow model has been added to CEFLASH-4A. The other critical flow models in CEFLASH-4A are Henry-Fauske, Henry-Fauske/Moody and Moody. The homogeneous equilibrium critical flow tables used in CEFLASH-4A are presented in Appendix B.

(2) Choice of Critical Flow Model

The critical flow model for each leak path can be independently specified for both subcooled and two-phase flow. Previously, only one critical flow model, applicable to all leak paths and for both subcooled and two-phase flow, could be specified. The quality for switching from the critical flow model used for subcooled flow to that used for two-phase flow is specified by input.

(3) Discharge Coefficient Versus Leak Path Quality

Each leak path discharge coefficient can be independently specified as a function of quality. Previously, a discharge coefficient could only be specified for subcooled, saturated and two-phase flow conditions.

3.0 SENSITIVITY STUDIES

3.1 FULLY IMPLICIT INTERATIVE INTERGRATION TECHNIQUE

This section presents the results of a sensitivity study which demonstrates the effect of the FII integration technique on the transient results of a large break LOCA. The sensitivity study was performed for a 1.0 double ended guillotine break in the reactor coolant pump discharge leg of a typical C-E PWR. Two CEFLASH-4A cases were run: (1) a case using the current version of CEFLASH-4A with the FII integration technique and (2) a case using the presently NRC approved version of CEFLASH-4A, i.e., with the previous CEFLASH-4A integration technique. The code inputs in both cases were identical except for those required for the FII integration technique, for example, inputs for the automatic time step calculation.

The results of the two CEFLASH-4A cases are compared in Table 3-1 and Figure 3-1 through Figure 3-17. The comparisons demonstrate that the FII integration technique produces no significant change in the blowdown transient results calculated by CEFLASH-4A. The peak cladding temperature for the transient, which occurs during reflood at approximately 250 seconds, would differ by less than 20°F between the two cases.

3.2 MODIFICATIONS TO THE LEAK FLOW MODEL

The sensitivity of the transient results of a large break LOCA to the modifications made to the leak flow model is presented in Reference 9. In Reference 9, the sensitivity is presented in conjunction with the sensitivity to a change in the nodalization of the broken leg.

Table 3-1

Comparison of Important Blowdown Transient Results

Parameter	Current Version (FII Integration)	Previous Version (FLASH-4 Integration)
Time of Annulus Downflow (TAD), sec.	22.4	22.5
Fuel Average Temperature of Hot Node at TAD, °F	1192	1186
Clad Temperature of Hot Node at TAD, °F	1139	1140
Integrated Leak Flow at TAD, lbm	4.599×10^5	4.593×10^5
Integrated Leak Energy at TAD, BTU	2.757×10^8	2.758×10^8
Safety Injection Tank Gas Pressure at TAD, psia	289	290
Safety Injection Tank Liquid Volume at TAD, ft^3	1140	1141

FIGURE 3-1

CORE POWER

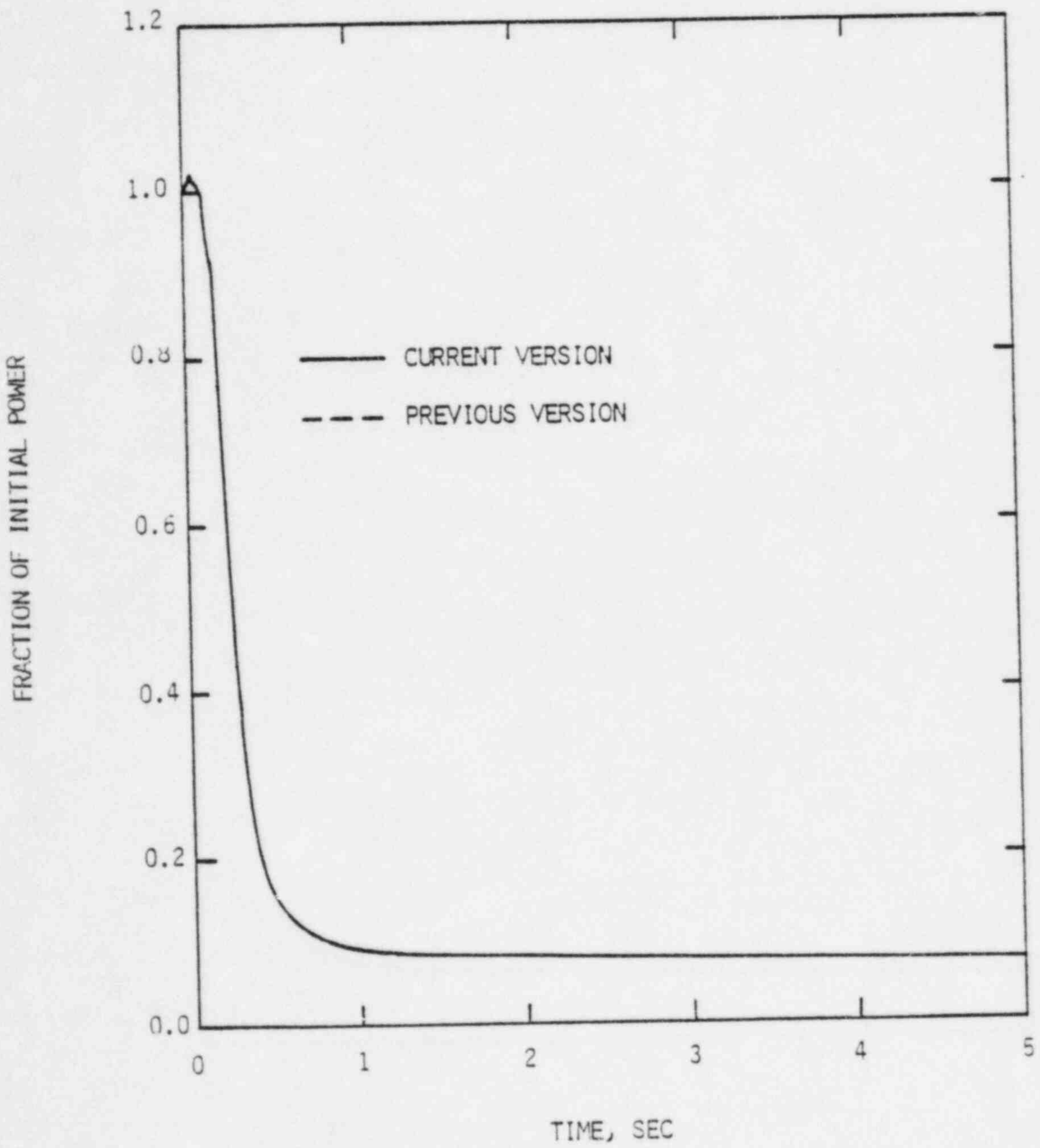


FIGURE 3-2

PRESSURE IN CENTER OF HOT ASSEMBLY

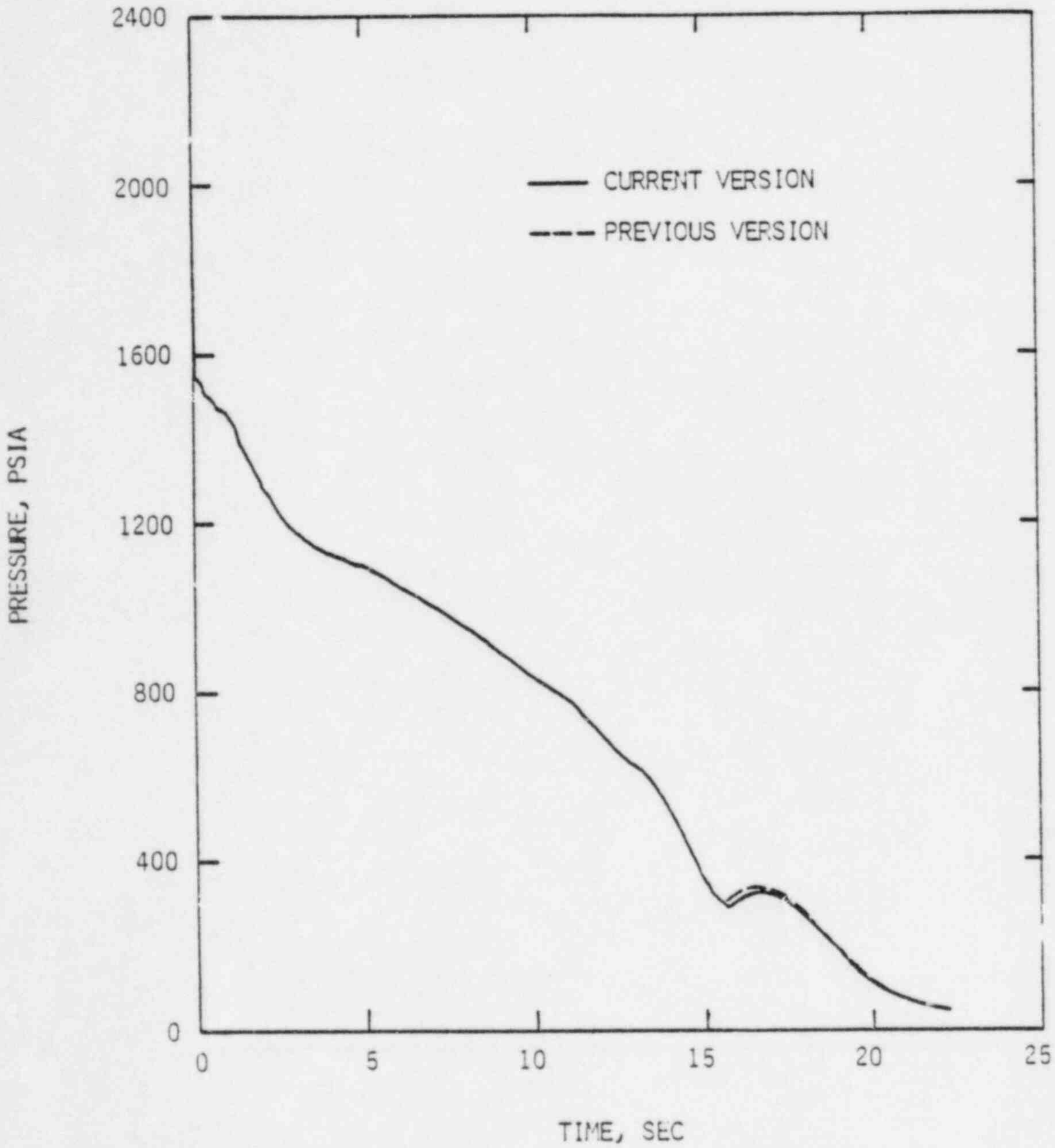


FIGURE 3-3

LEAK FLOW, REACTOR VESSEL SIDE

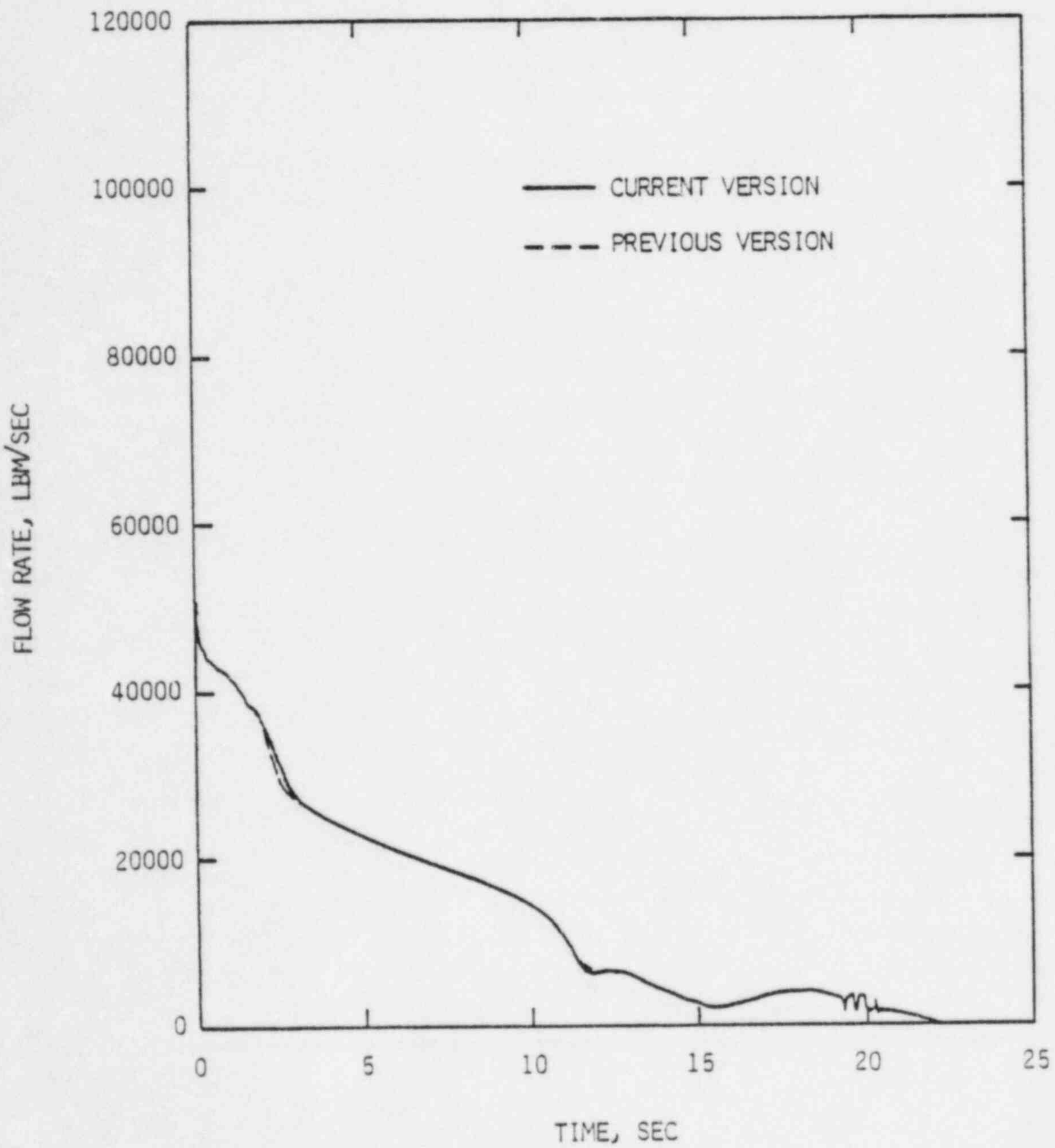


FIGURE 3-4

LEAK FLOW, REACTOR COOLANT PUMP SIDE

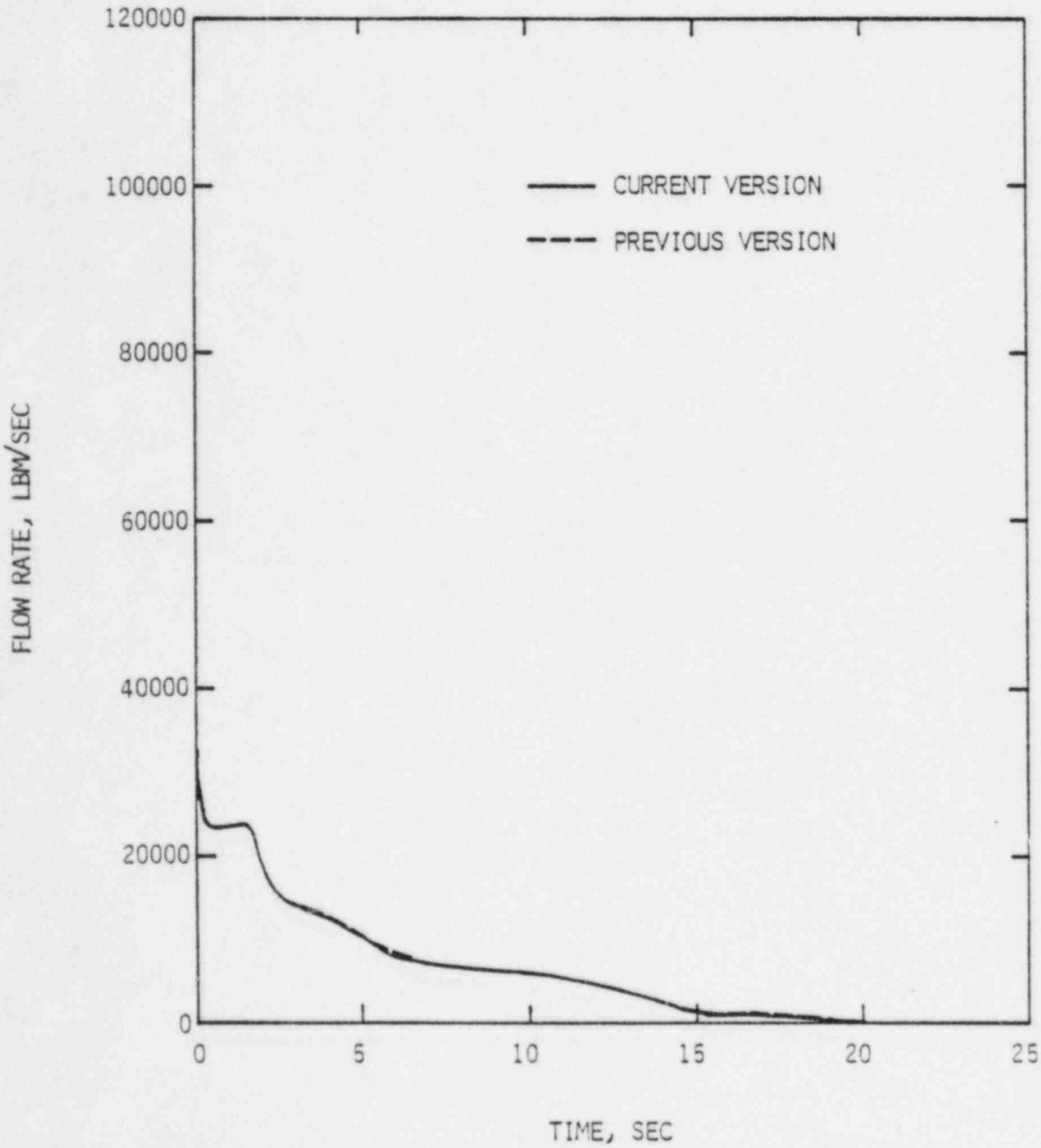


FIGURE 3-5

HOT ASSEMBLY FLOW BELOW HOT SPOT

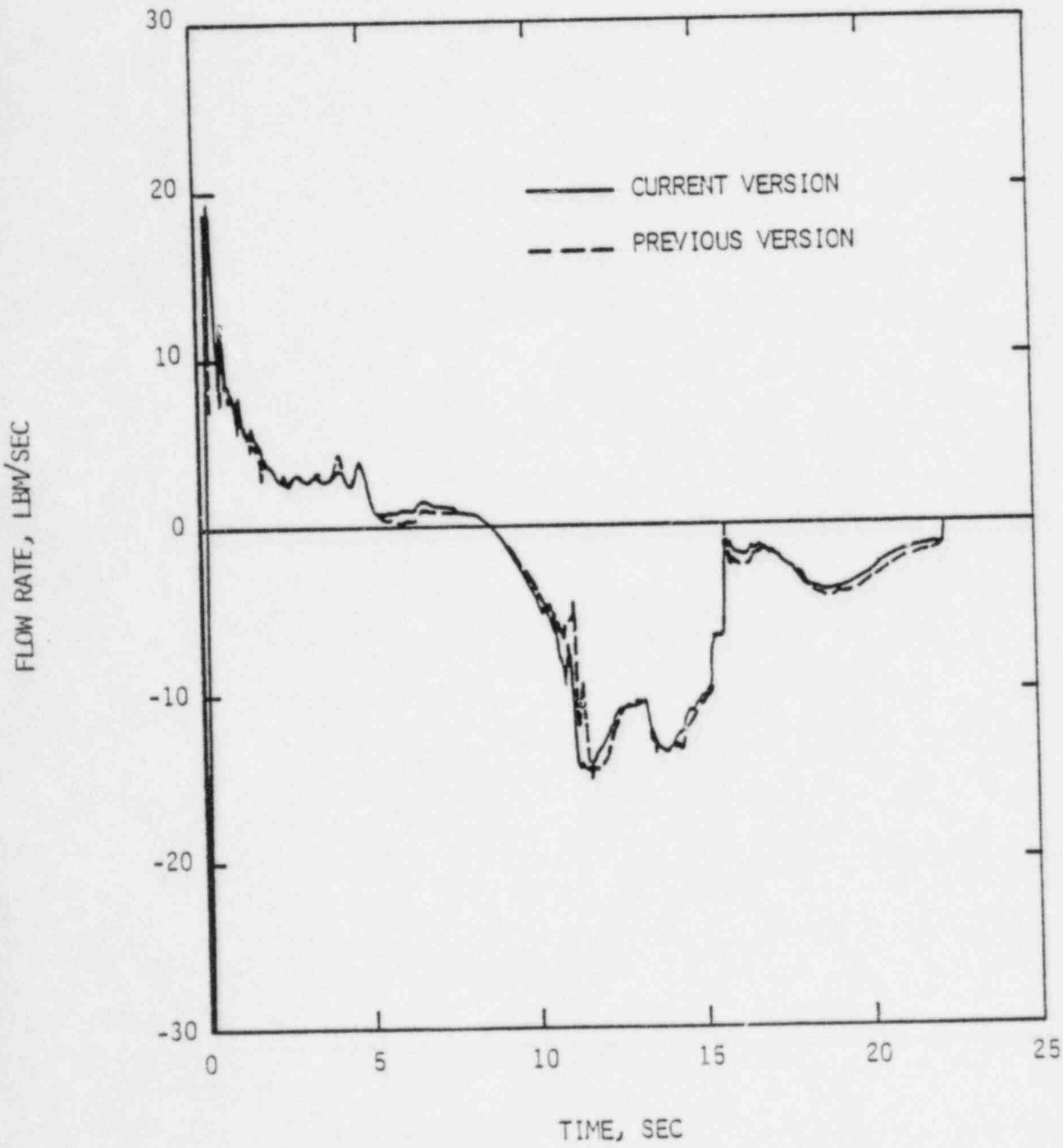


FIGURE 3-6

HOT ASSEMBLY FLOW ABOVE HOT SPOT

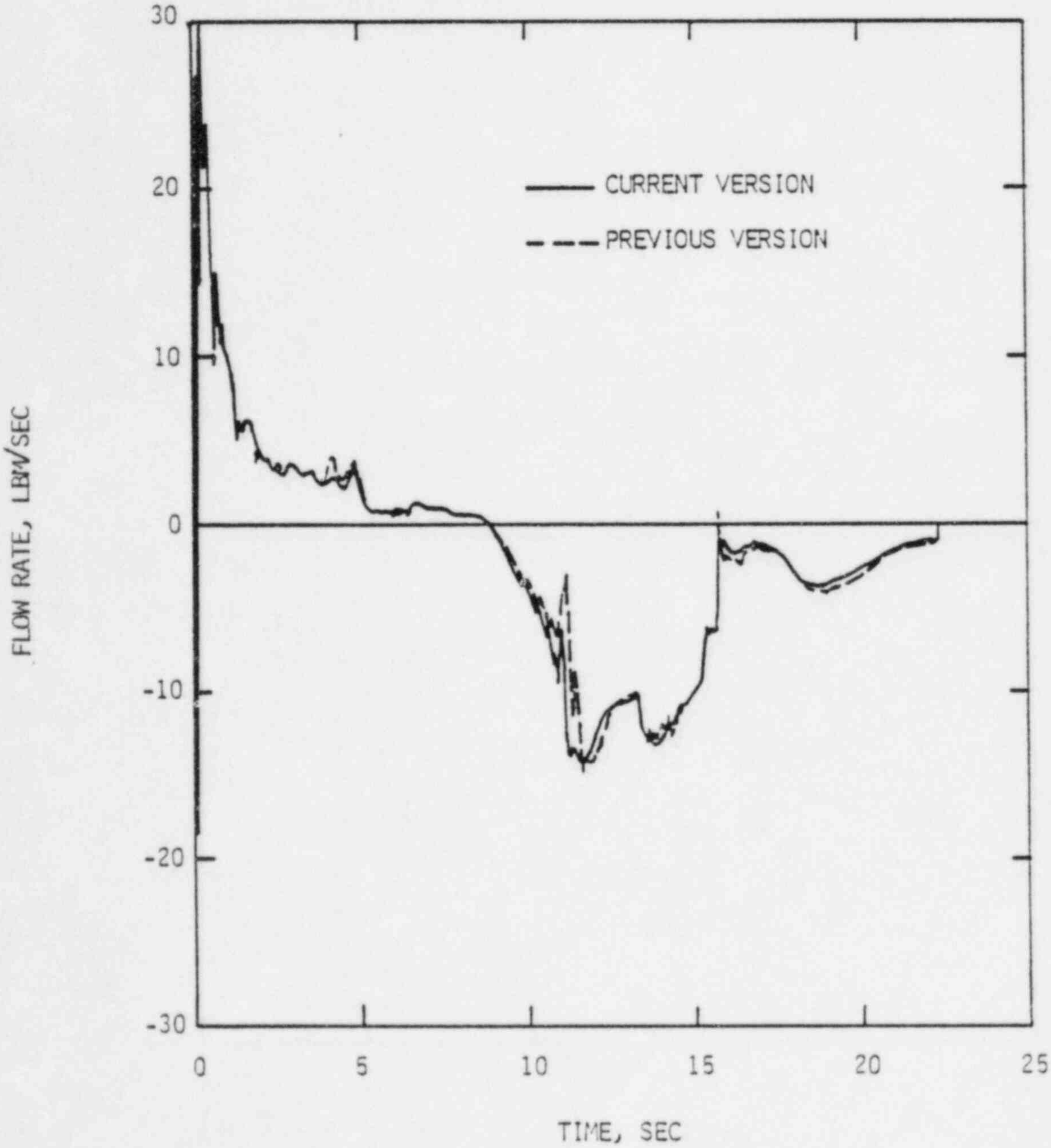


FIGURE 3-7

QUALITY IN HOT ASSEMBLY NODE BELOW HOT SPOT

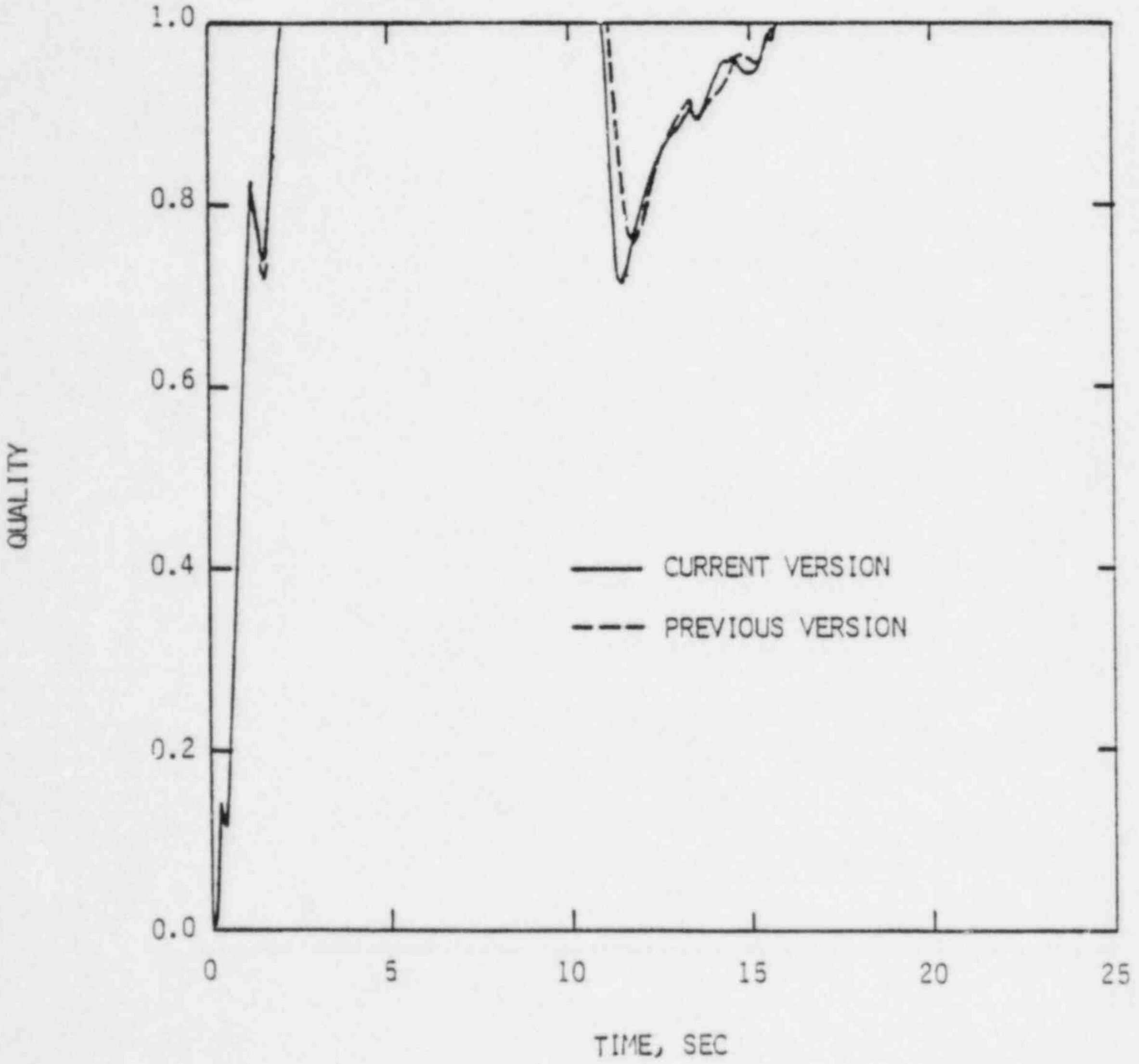


FIGURE 3-8

QUALITY IN HOT ASSEMBLY NODE AT HOT SPOT

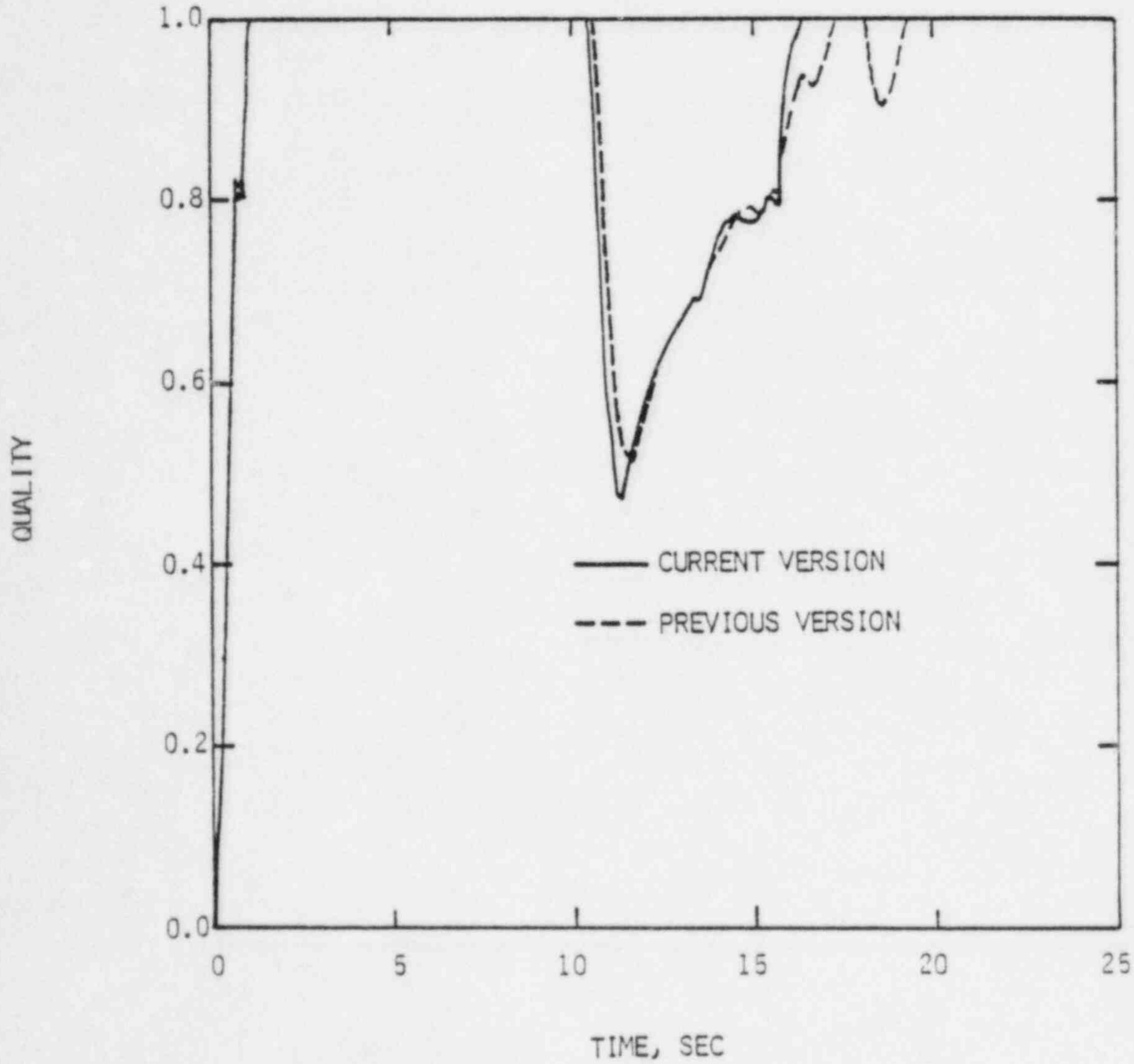


FIGURE 3-9

QUALITY IN HOT ASSEMBLY NODE ABOVE HOT SPOT

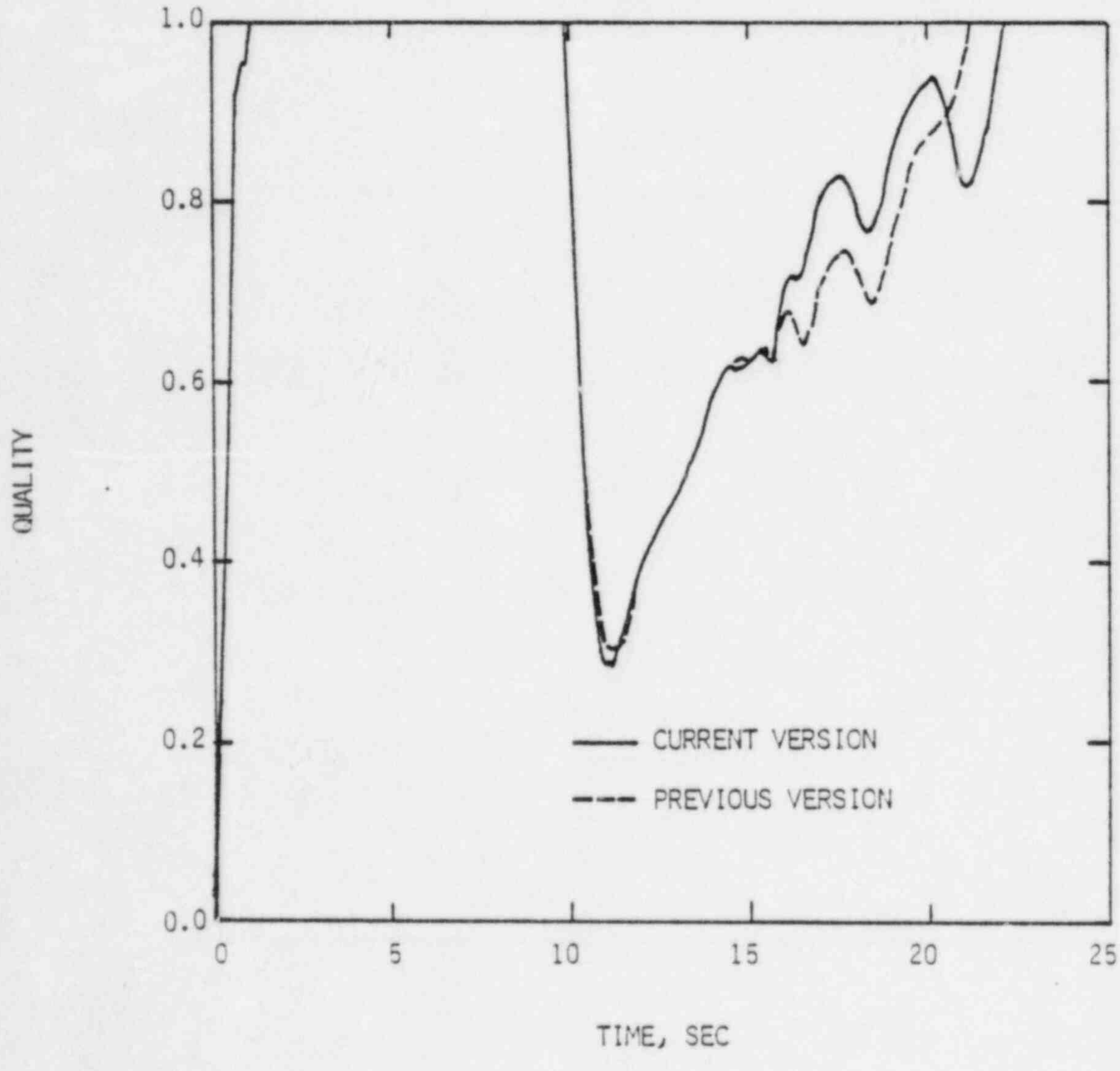


FIGURE 3-10

MID-ANNULUS FLOW RATE

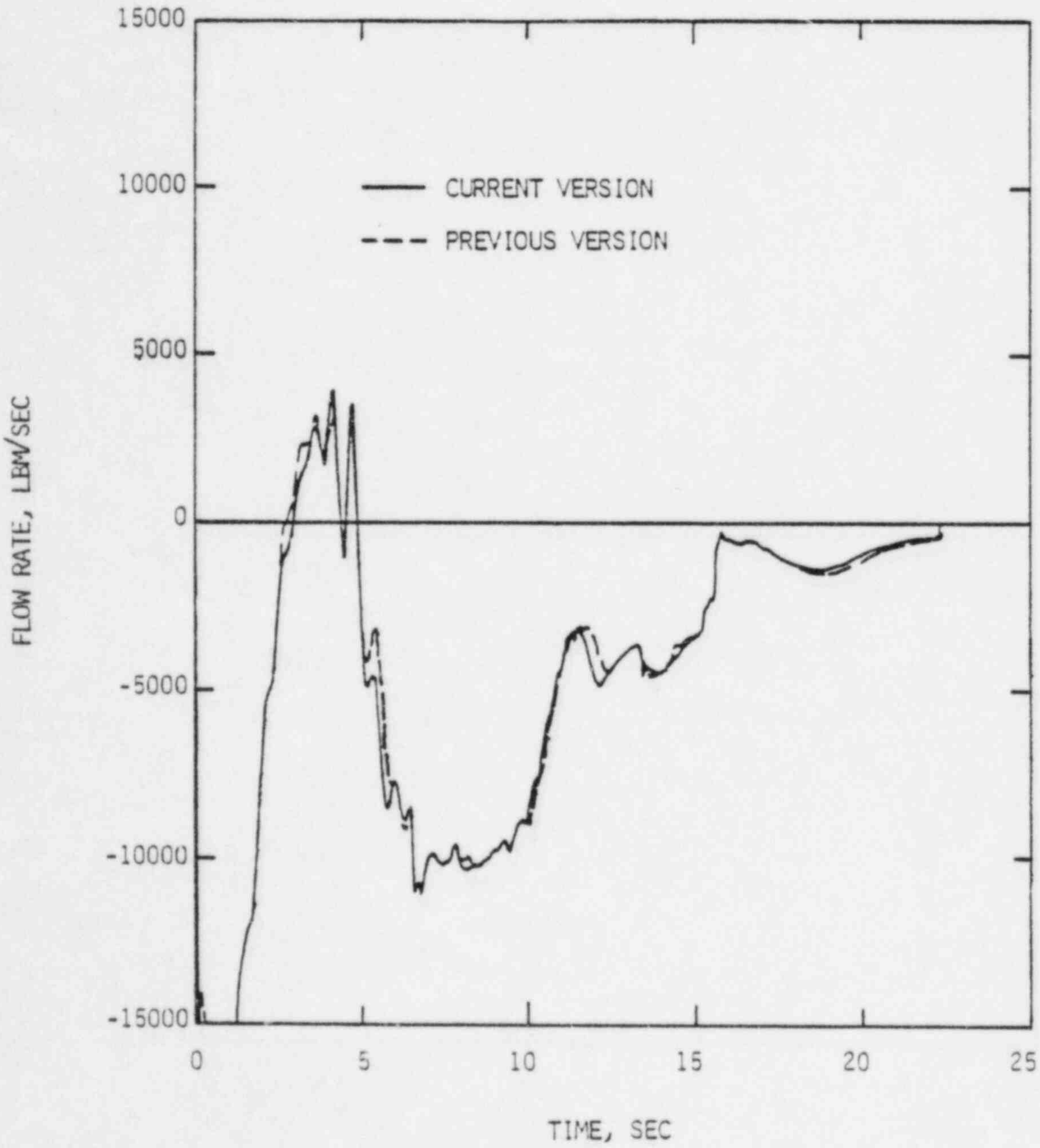


FIGURE 3-11

CORE INLET FLOW RATE

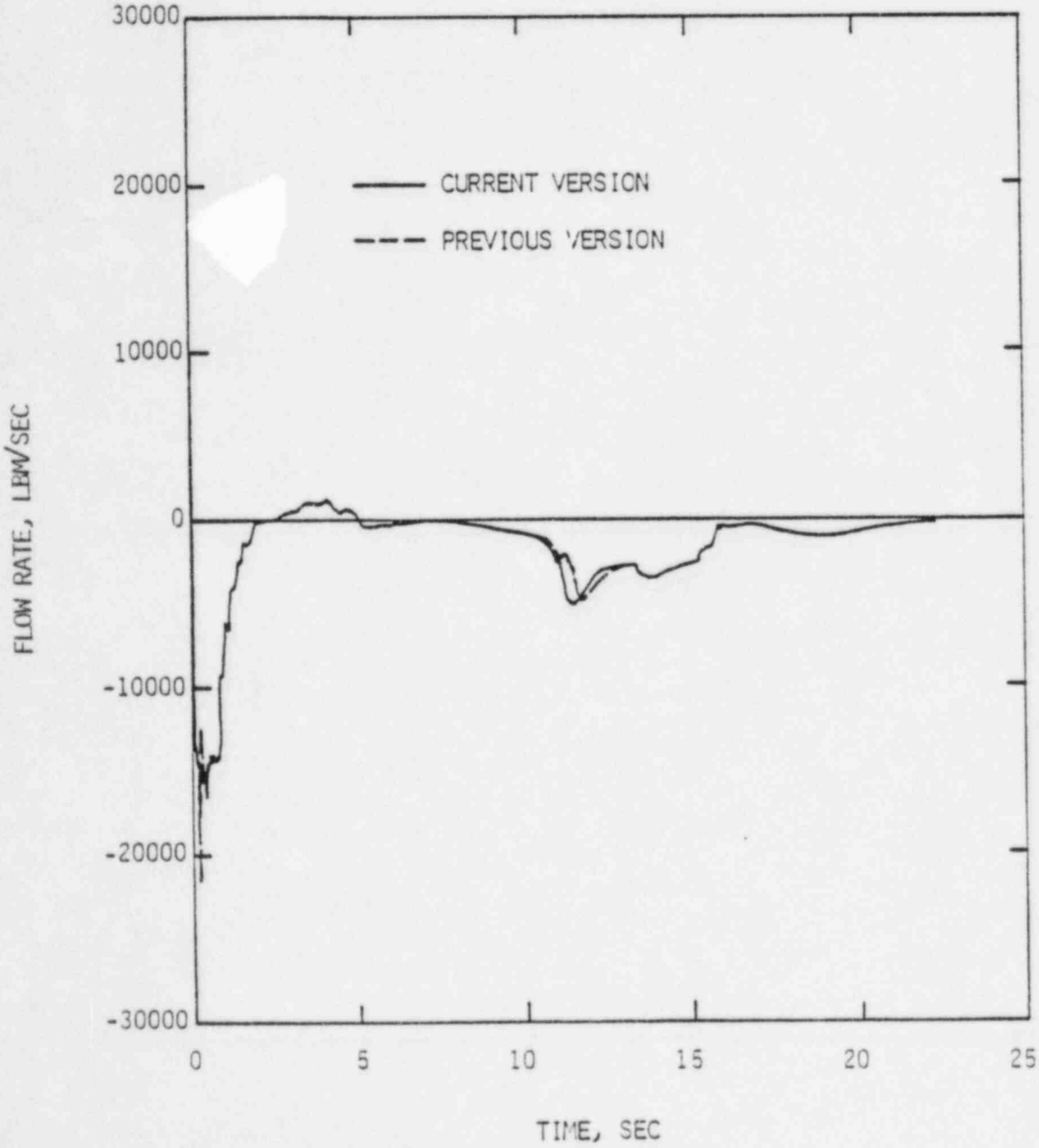


FIGURE 3-12

CORE EXIT FLOW RATE

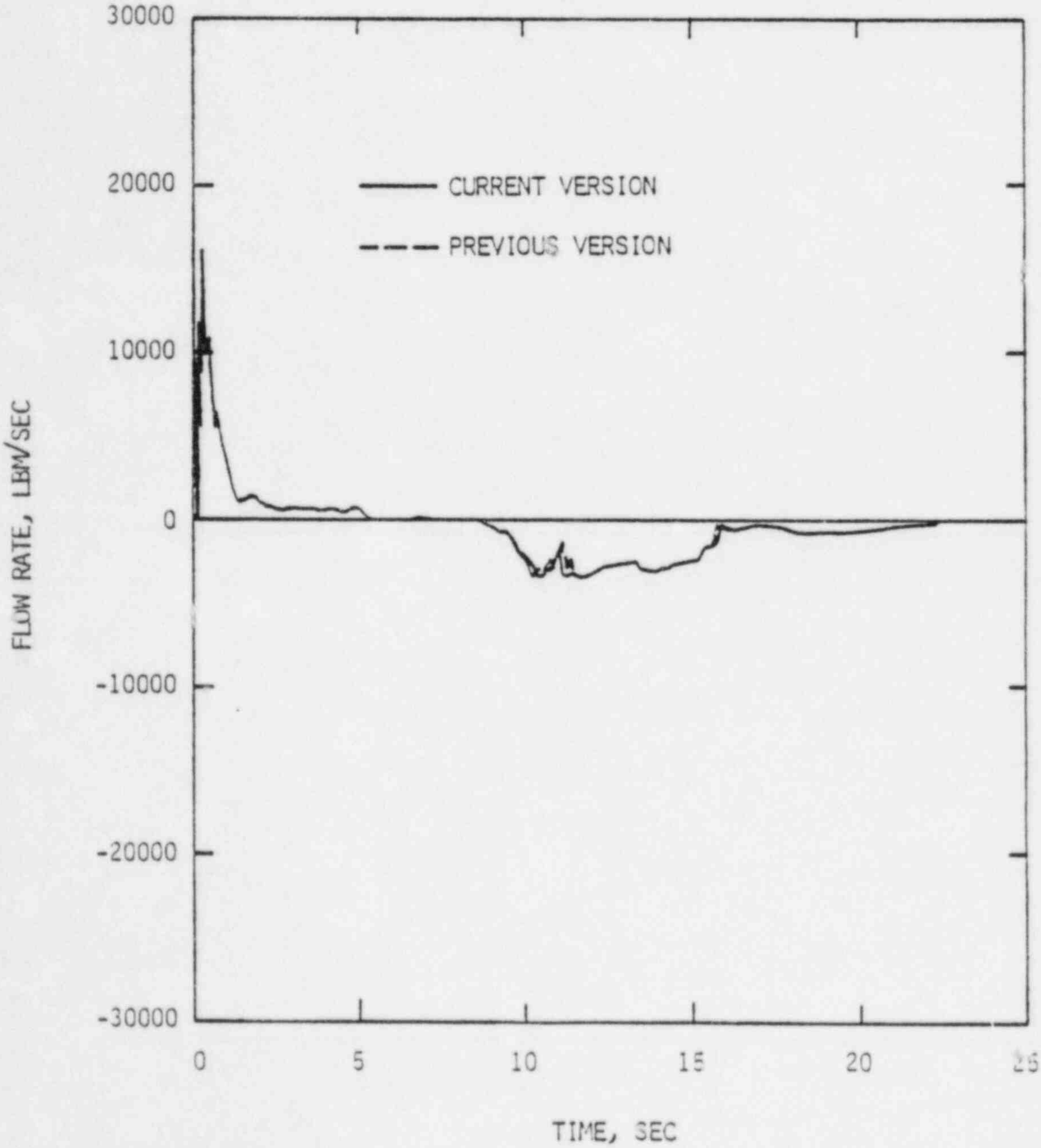


FIGURE 3-13

QUALITY BELOW CORE

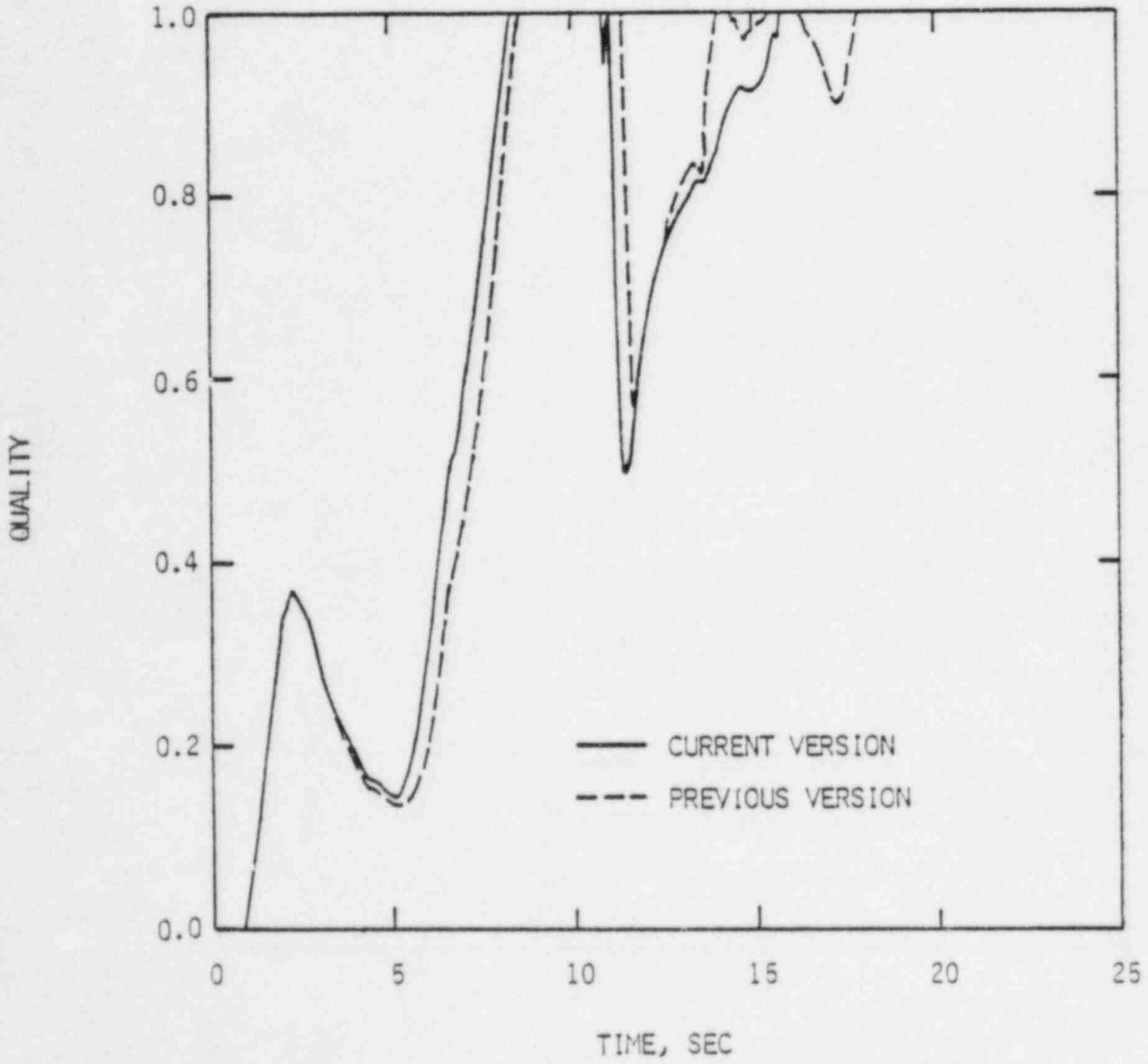


FIGURE 3-14

QUALITY ABOVE CORE

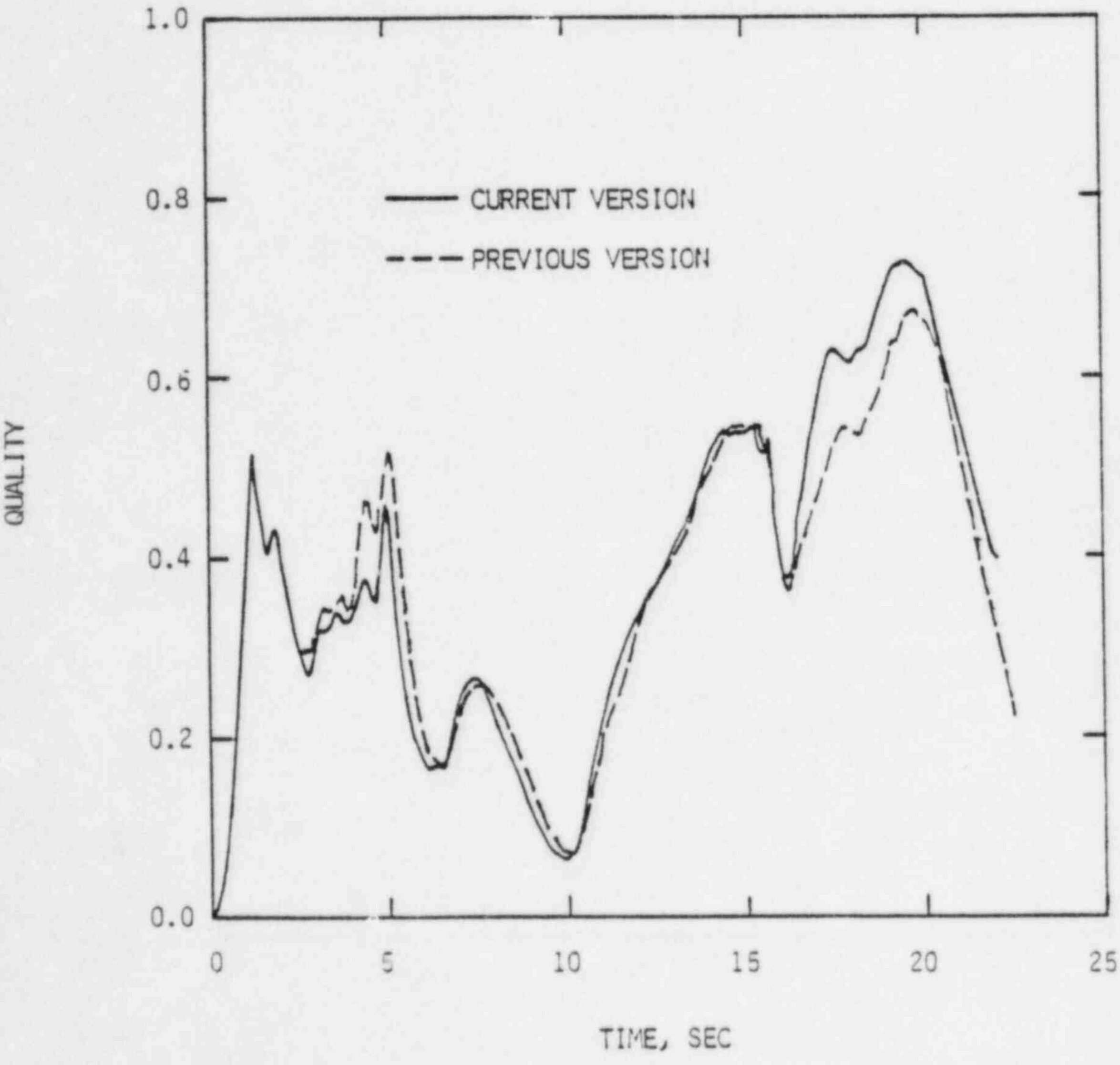


FIGURE 3-15

CORE PRESSURE DROP

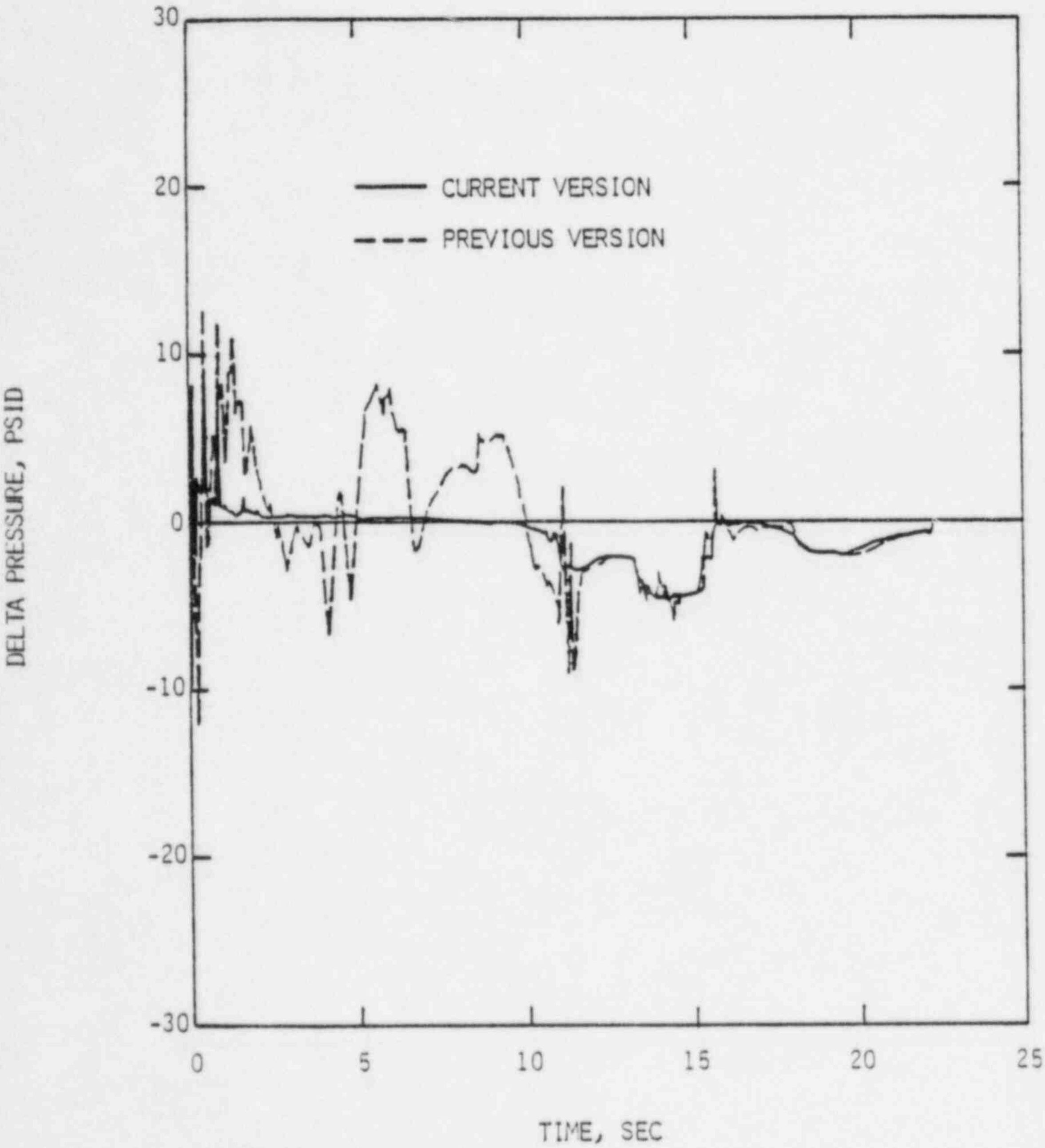


FIGURE 3-16

FUEL AVERAGE TEMPERATURE OF HOT SPOT OF HOT ASSEMBLY

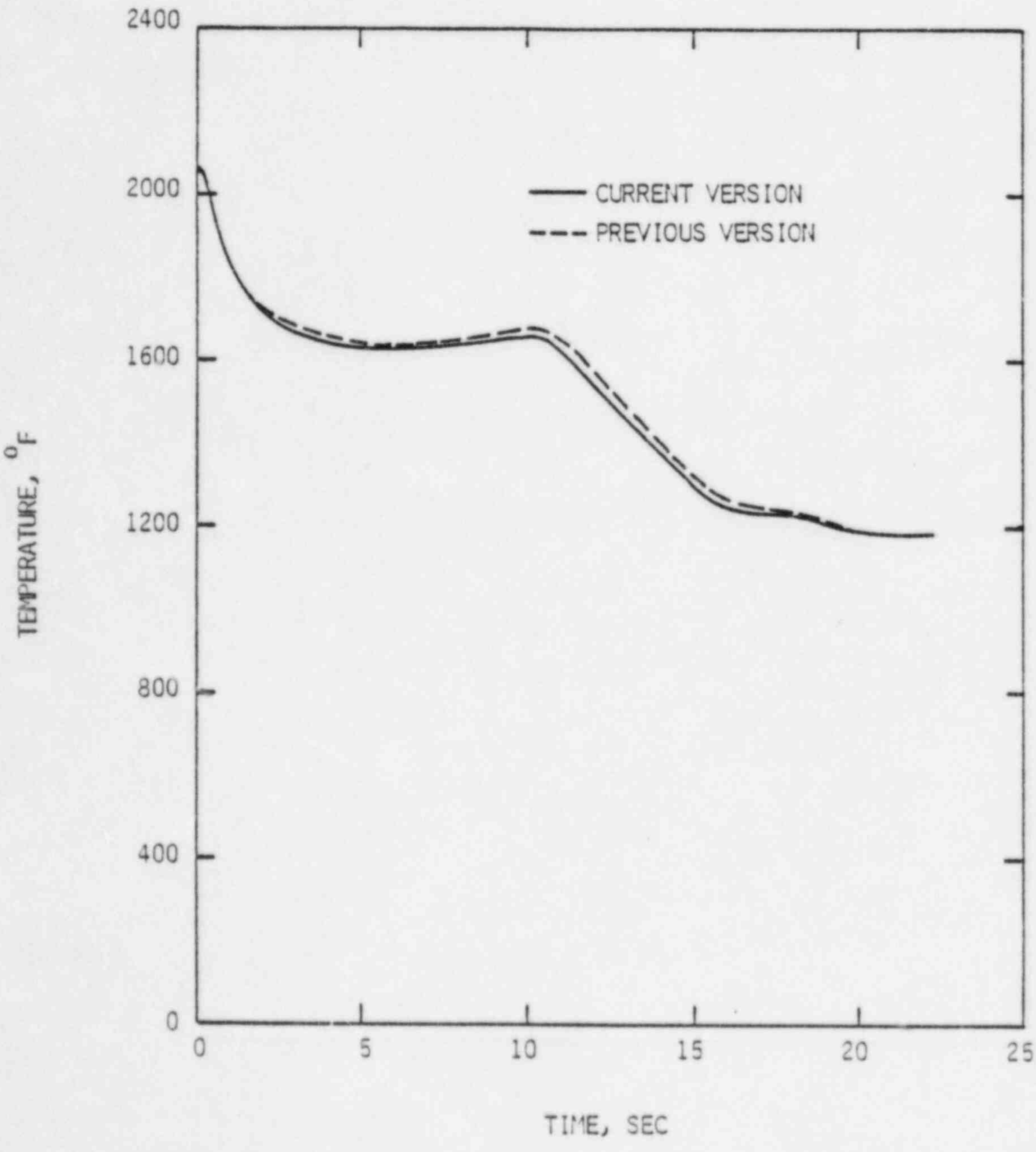
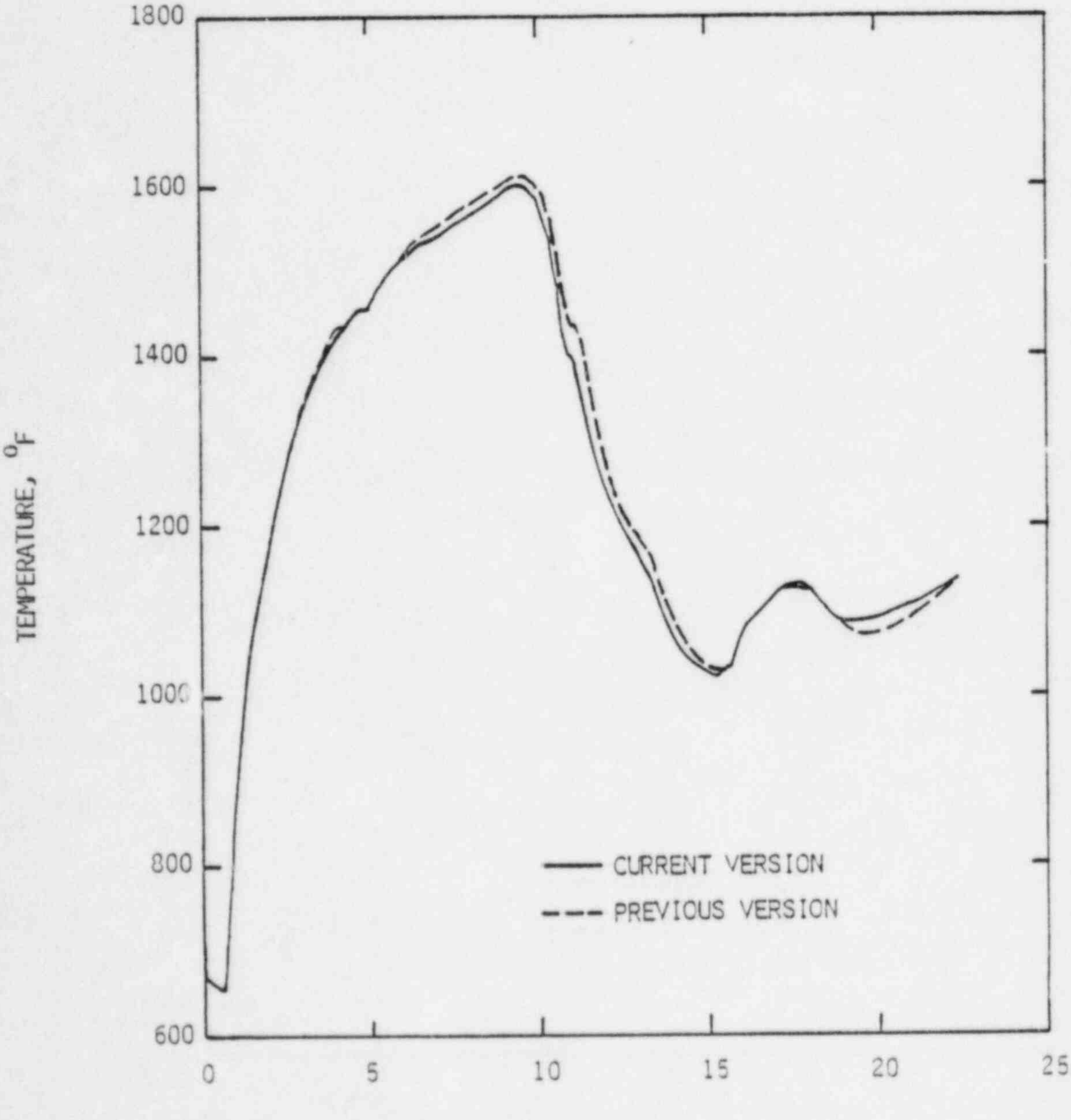


FIGURE 3-17

CLAD TEMPERATURE OF HOT SPOT OF HOT ASSEMBLY



4.0 REFERENCES

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4. LD-76-026, Letter from A. E. Scherer (C-E) to D. F. Ross (NRC), March 4, 1976.

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8. "Maximum Flow Rate of a Single Component, Two-Phase Mixture", F. J. Moody, Journal of Heat Transfer, Transactions of the ASME, February 1965.

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APPENDIX A

Description of CEFLASH-4A Input Changes

Maximum Execution Time

Card Series 1021-1030

1021, F1

F1	CPSMAX	Maximum execution time (sec)

Note:

The recommended value for CPSMAX is at least 50 seconds less than the time on the job card.

Edit and Punch Information

Card Series 2001-2200

2001, F1, F2, I3, I4

F1	EOI	End of interval (sec)
F2	DTPRINT	Edit interval (sec)
I3	NTIMEN	Number of edits per punch for enthalpy, pressure, and normalized flow rate for interval
I4	NTIMPOW	Number of edits per punch for the normalized power for the interval

Minimum and Maximum Time Step Information

Card Series 2201-2400

2201, F1, F2

F1	DELTMIN	Minimum time step for interval (sec)
F2	DELTMAX	Maximum time step for interval (sec)

Note:

The number of subintervals in Card Series 2001-2200 and 2201-2400 must coincide.

Initial Time Step and Absolute Minimum Time Step

Card Series 2401-2500

2401, F1, F2

F1	DELTONE	Initial time step (sec)
F2	DTABSMI	Absolute minimum time step (sec)

Note:

DTABSMI is used to put an absolute minimum on the time step. Execution will terminate whenever the calculated time step is less than or equal to DTABSMI.

Leak Flow Paths (Types 7, 13, 14, 15 and 16)

Card Series 4201 - 4288

42NN, I1, I2, I3, F4, F5, I6, I7, I8, I9

I1	NTYPE	Type (7, 13, 14, 15, 16)
I2	NUP	From node
I3	NDOWN	To node
F4	TA	Area (ft^2)
F5	QSCTP	Value of quality for switching from sub-cooled critical flow table to two-phase critical flow table $X \leq$ QSCTP use subcooled $X >$ QSCTP use two-phase
I6	ILKSC	Option for subcooled critical flow table = 1 H-F = 2 H-F/M = 3 MOODY = 4 HEM
I7	ILKTP	Option for two-phase critical flow table = 1 H-F = 2 H-F/M = 3 MOODY = 4 HEM
I8	NLKA	Feed path for guillotine or slot break (0 for type 7)
I9	NLKB	Second feed path for slot break (0 for types 7, 13 and 15)

Notes:

(1) Type 7 is regular leak path as in earlier code versions. Types 13 and 15 have one feed path (guillotine model) and types 14 and 16 have two feed paths (slot model).

(2) The maximum number of leak flow paths is eight.

Discharge Coefficient versus Quality Table

Card Series 4311 - 4390

4311 - 4320	Leak path #1
4321 - 4330	Leak path #2
4331 - 4340	Leak path #3
etc.	etc.

4311, $F1_1$, $F2_1$,....,$F1_n$, $F2_n$ $(2 \leq n \leq 15)$

F1	DCQ	Discharge coefficient
F2	DCQ	Quality

Notes:

(1) One table is necessary for each leak path.

(2) A negative value of quality may be calculated by the code. This quality is only used in the interpolation for the discharge coefficient.

Appendix B

Homogeneous Equilibrium Critical Flow Tables

HOMOGENEOUS EQUILIBRIUM CRITICAL FLOW TABLES

STAGNATION PRESSURE 10.0 PSIA

STAGNATION ENTHALPY BTU/LB	FLOW RATE LB/SEC-FT2
127.971	1723.749
137.983	1501.987
148.006	1181.103
158.038	607.653
161.261	151.564
167.154	123.084
180.903	99.308
210.365	77.371
220.186	72.932
259.470	60.844
357.678	46.069
455.887	38.620
554.096	33.919
652.305	30.605
848.722	26.134
1143.348	22.040

STAGNATION ENTHALPY BTU/LB	THROAT PRESSURE PSIA
127.971	4.743
137.983	5.995
148.006	7.515
158.038	9.340
1143.348	6.943

STAGNATION PRESSURE 50.0 PSIA

STAGNATION ENTHALPY BTU/LB	FLOW RATE LB/SEC-FT2
208.502	3702.818
218.633	3316.603
228.787	2812.067
238.966	2097.026
249.174	655.801
250.212	571.607
255.755	501.807
268.690	423.603
305.645	325.329
342.600	276.601
434.988	213.904
527.376	181.015
619.765	159.842
712.153	144.728
896.929	124.116
1174.093	105.033

STAGNATION ENTHALPY BTU/LB	THROAT PRESSURE PSIA
208.502	24.957
250.212	46.403
259.451	41.407
342.600	33.248
1174.093	28.844

HOMOGENEOUS EQUILIBRIUM CRITICAL FLOW TABLES

STAGNATION PRESSURE 100.0 PSIA

STAGNATION ENTHALPY BTU/LB	FLOW RATE LB/SEC-FT2	STAGNATION ENTHALPY BTU/LB	THROAT PRESSURE PSIA
208.608	6410.551	290.420	89.624
239.066	5603.165	298.539	90.503
269.775	4188.359	307.425	82.876
280.078	3436.425	387.401	67.329
290.420	2333.636	1187.166	57.647
298.539	989.455		
303.870	897.414		
316.311	776.931		
351.856	612.185		
387.401	526.359		
476.264	412.361		
565.127	351.062		
653.990	311.089		
742.852	282.328		
920.578	242.815		
1187.166	205.965		

STAGNATION PRESSURE 200.0 PSIA

STAGNATION ENTHALPY BTU/LB	FLOW RATE LB/SEC-FT2	STAGNATION ENTHALPY BTU/LB	THROAT PRESSURE PSIA
208.820	9790.478	353.581	180.702
269.959	8408.490	355.506	175.406
311.391	6528.570	363.934	164.681
332.377	4911.990	439.789	136.489
342.949	3688.190	1198.334	115.377
355.506	1685.384		
360.563	1573.526		
372.363	1402.104		
406.076	1140.016		
439.789	994.153		
524.072	792.037		
608.354	679.714		
692.637	605.195		
776.920	550.991		
945.485	475.771		
1198.334	404.896		

HOMOGENEOUS EQUILIBRIUM CRITICAL FLOW TABLES

STAGNATION PRESSURE 400.0 PSIA

STAGNATION ENTHALPY BTU/LB	FLOW RATE LB/SEC-FT2	STAGNATION ENTHALPY BTU/LB	THROAT PRESSURE PSIA
209.243	14329.500	419.039	361.388
280.617	13053.378	424.168	337.392
322.169	11708.312	431.972	323.863
375.266	8740.656	502.210	276.702
407.962	5252.213	1204.591	231.530
424.168	2818.495		
428.850	2694.821		
439.776	2476.103		
470.993	2092.076		
502.210	1858.251		
580.252	1514.386		
658.295	1314.225		
736.337	1178.118		
814.379	1077.547		
970.464	935.914		
1204.591	800.417		

STAGNATION PRESSURE 600.0 PSIA

STAGNATION ENTHALPY BTU/LB	FLOW RATE LB/SEC-FT2	STAGNATION ENTHALPY BTU/LB	THROAT PRESSURE PSIA
209.667	17741.706	464.481	528.647
280.977	16614.918	471.697	492.631
332.970	15146.714	479.017	478.077
386.291	12671.931	544.893	417.923
430.322	9252.981	1203.657	348.679
471.697	3768.992		
476.089	3644.763		
486.336	3408.740		
515.615	2955.504		
544.893	2660.682		
618.089	2206.239		
691.285	1931.696		
764.481	1741.217		
837.677	1598.627		
984.069	1395.333		
1203.657	1198.326		

HOMOGENEOUS EQUILIBRIUM CRITICAL FLOW TABLES

STAGNATION PRESSURE 800.0 PSIA

STAGNATION ENTHALPY BTU/LB	FLOW RATE LB/SEC-FT2
210.092	20594.724
312.367	18821.594
354.379	17497.953
419.311	14261.115
464.479	10498.470
509.812	4606.210
513.949	4485.509
523.603	4245.774
551.186	3754.471
578.769	3417.408
647.727	2876.148
716.684	2538.149
785.642	2299.316
854.599	2118.374
992.514	1857.431
1199.387	1601.483

STAGNATION ENTHALPY BTU/LB	THROAT PRESSURE PSIA
487.879	678.173
509.812	643.036
516.707	628.302
578.769	559.344
1199.387	466.866

STAGNATION PRESSURE 1000.0 PSIA

STAGNATION ENTHALPY BTU/LB	FLOW RATE LB/SEC-FT2
210.517	23097.034
333.572	20846.147
397.548	18460.429
464.487	14298.541
511.794	9246.175
542.551	5360.902
546.453	5245.680
555.559	5009.688
581.574	4501.097
607.589	4136.186
672.628	3528.065
737.666	3136.416
802.705	2854.799
867.743	2638.963
997.821	2324.198
1192.936	2011.759

STAGNATION ENTHALPY BTU/LB	THROAT PRESSURE PSIA
536.693	809.840
542.551	789.565
549.055	775.094
607.589	700.640
1192.936	586.163

HOMOGENEOUS EQUILIBRIUM CRITICAL FLOW TABLES

STAGNATION PRESSURE 1200.0 PSIA

STAGNATION ENTHALPY BTU/LB	FLOW RATE LB/SEC-FT2	STAGNATION ENTHALPY BTU/LB	THROAT PRESSURE PSIA
221.027	25242.265	549.106	1038.770
344.373	22876.679	571.853	932.808
408.632	20471.967	577.983	918.803
476.035	16443.740	633.149	841.493
523.846	11929.063	1184.813	706.699
571.853	6049.910		
575.531	5941.258		
584.112	5713.592		
608.631	5202.613		
633.149	4821.498		
694.445	4164.140		
755.741	3728.105		
817.037	3409.157		
878.333	3161.884		
1000.925	2797.197		
1184.813	2430.801		

STAGNATION PRESSURE 1400.0 PSIA

STAGNATION ENTHALPY BTU/LB	FLOW RATE LB/SEC-FT2	STAGNATION ENTHALPY BTU/LB	THROAT PRESSURE PSIA
221.445	27311.296	574.999	1217.119
344.664	25003.606	598.830	1072.961
408.811	22735.452	604.594	1059.817
499.447	17359.113	656.477	981.714
548.677	12551.506	1175.307	828.583
598.830	6683.373		
602.288	6581.961		
610.359	6365.663		
633.418	5863.515		
656.477	5475.952		
714.125	4785.446		
771.773	4314.086		
829.420	3963.346		
887.068	3688.239		
1002.364	3277.791		
1175.307	2860.220		

HOMOGENEOUS EQUILIBRIUM CRITICAL FLOW TABLES

STAGNATION PRESSURE 1600.0 PSIA

STAGNATION ENTHALPY BTU/LB	FLOW RATE LB/SEC-FT2
221.864	29233.452
344.957	26962.526
408.994	24792.356
523.368	17972.269
574.355	12764.986
624.202	7267.662
627.444	7173.923
635.009	6971.114
656.622	6486.550
678.235	6100.921
732.268	5392.319
786.300	4894.736
840.333	4518.003
894.366	4218.939
1002.431	3767.341
1164.530	3301.789

STAGNATION ENTHALPY BTU/LB	THROAT PRESSURE PSIA
602.067	1351.223
624.202	1210.452
629.605	1198.185
678.235	1121.109
1164.530	951.904

STAGNATION PRESSURE 1800.0 PSIA

STAGNATION ENTHALPY BTU/LB	FLOW RATE LB/SEC-FT2
222.283	31036.024
345.253	28787.661
409.181	26690.691
523.157	20329.763
601.123	12579.661
648.490	7806.833
651.513	7721.073
658.567	7533.320
678.720	7073.416
698.874	6697.106
749.258	5984.809
799.642	5470.366
850.027	5073.868
900.411	4755.142
1001.179	4267.663
1152.332	3757.933

STAGNATION ENTHALPY BTU/LB	THROAT PRESSURE PSIA
630.734	1422.959
648.490	1345.381
653.528	1334.041
698.874	1259.537
1152.332	1076.741

HOMOGENEOUS EQUILIBRIUM CRITICAL FLOW TABLES

STAGNATION PRESSURE 2000.0 PSIA

STAGNATION ENTHALPY BTU/LB	FLOW RATE LB/SEC-FT2
222.702	32738.621
409.372	28462.117
476.028	25375.026
547.557	20586.680
629.345	11965.993
672.111	8303.237
674.909	8225.728
681.436	8054.323
700.085	7625.125
718.734	7264.862
765.356	6563.014
811.979	6041.578
858.601	5632.181
905.224	5298.682
998.468	4781.528
1138.336	4232.297

STAGNATION ENTHALPY BTU/LB	THROAT PRESSURE PSIA
661.733	1509.782
672.111	1477.914
676.774	1467.597
718.734	1396.955
1138.336	1203.341

STAGNATION PRESSURE 2200.0 PSIA

STAGNATION ENTHALPY BTU/LB	FLOW RATE LB/SEC-FT2
223.122	34356.401
409.567	30129.087
499.111	25858.071
572.671	20603.366
659.615	10853.927
695.462	8757.282
698.022	8688.324
703.996	8534.483
721.064	8141.535
738.132	7803.729
780.802	7126.689
823.471	6608.961
866.141	6194.457
908.811	5851.924
994.150	5312.658
1122.159	4729.915

STAGNATION ENTHALPY BTU/LB	THROAT PRESSURE PSIA
659.615	1839.125
695.462	1608.183
699.729	1599.026
738.132	1533.568
1122.159	1332.213

HOMOGENEOUS EQUILIBRIUM CRITICAL FLOW TABLES

STAGNATION PRESSURE 2400.0 PSIA

STAGNATION ENTHALPY BTU/LB	FLOW RATE LB/SEC-FT2
223.543	35900.708
409.766	31708.018
522.627	26153.428
598.675	20376.647
657.717	14164.294
718.953	9077.240
721.261	9020.882
726.648	8893.668
742.039	8559.883
757.431	8263.459
795.909	7645.704
834.387	7154.315
872.866	6750.324
911.344	6409.971
988.300	5863.158
1103.735	5258.487

STAGNATION ENTHALPY BTU/LB	THROAT PRESSURE PSIA
693.052	1834.514
718.953	1720.205
722.800	1713.230
757.431	1659.926
1103.735	1464.788

STAGNATION PRESSURE 2600.0 PSIA

STAGNATION ENTHALPY BTU/LB	FLOW RATE LB/SEC-FT2
223.964	37380.620
409.968	33211.573
546.656	26262.830
625.813	19894.616
690.036	12766.026
744.475	9408.918
746.500	9361.852
751.226	9254.915
764.729	8969.763
778.232	8711.047
811.988	8155.796
845.745	7699.268
879.502	7314.587
913.259	6984.249
980.772	6442.139
1082.043	5827.278

STAGNATION ENTHALPY BTU/LB	THROAT PRESSURE PSIA
733.410	1866.413
744.475	1842.720
747.850	1837.008
778.232	1791.561
1082.043	1601.543

HOMOGENEOUS EQUILIBRIUM CRITICAL FLOW TABLES

STAGNATION PRESSURE 2800.0 PSIA

STAGNATION ENTHALPY BTU/LB	FLOW RATE LB/SEC-FT2
224.385	38803.523
410.174	34649.523
571.299	26184.228
654.440	19137.051
727.621	11214.605
770.686	9700.237
772.396	9662.595
776.389	9576.551
787.794	9343.572
799.200	9127.767
827.715	8650.638
856.230	8244.436
884.745	7892.751
913.260	7584.103
970.289	7064.777
1055.834	6457.390

STAGNATION ENTHALPY BTU/LB	THROAT PRESSURE PSIA
727.621	2108.890
770.686	1962.770
773.537	1958.214
799.200	1921.627
1055.834	1744.450

STAGNATION PRESSURE 3000.0 PSIA

STAGNATION ENTHALPY BTU/LB	FLOW RATE LB/SEC-FT2
225.000	40000.000
421.150	35641.943
583.644	26886.759
668.593	19712.347
745.797	11705.472
801.845	9874.755
803.155	9848.202
806.213	9787.116
814.950	9619.000
823.687	9459.719
845.529	9095.344
867.371	8771.859
889.213	8481.964
911.055	8220.082
954.740	7763.885
1020.266	7206.021

STAGNATION ENTHALPY BTU/LB	THROAT PRESSURE PSIA
745.797	2247.868
801.845	2075.315
804.029	2072.253
823.687	2046.246
1020.266	1896.673

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