IMPROVED GUIDELINES FOR RELAP4/MOD6 REFLOOD CALCULATIONS

Tien-Hu Chen
Scientist
LOFT Test Support Branch
EG&G Idaho, Inc.
P. O. Box 1625
Idaho Falls, ID 83415
Member, ASME

C. D. Fletcher
Senior Engineer
Code Assessment Branch
EG&G Idaho, Inc.
P. O. Box 1625
Idaho Falls, ID 83415
Associate Member, ASME

DISCLAIMER

ABSTRACT

Computer simulations were performed for an extensive selection of forced- and gravity-feed reflood experiments. This effort was a portion of the assessment procedure for the RELAP4/MOD6 thermal hydraulic computer code. A common set of guidelines, based on recommendations from the code developers, was used in determining the model and user-selected input options for each calculation. The comparison of code-calculated and experimental data was then used to assess the capability of the RELAP4/MOD6 code to model the reflood phenomena. As a result of the assessment, the guidelines for determining the user-selected input options were improved.

INTRODUCTION

The RELAP4/MOD6[1] computer code was developed for the analysis of light water reactor (LWR) thermal-hydraulic behavior during the transient phase of a postulated loss-of-coolant accident (LOCA). Earlier versions of this code primarily had capability for analysis of blowdown and refill phenomena. With RELAP4/MOD6, the capability has been extended through the core reflood phase.

When the RELAP4/MOD6 code is used for reflood analysis, the user is required to specify input parameters for the reflood heat transfer and liquid entrainment models. Results of previous comparisons between code-calculated and experimental data have indicated no single selection of input parameters is adequate when modeling a spectrum of tests and test facilities. These comparisons have also revealed the importance of adequately calculating dispersed-flow heat transfer and liquid entrainment during reflood calculations. Code user's guidelines for the proper selection of input options were originally developed from data comparisons with full-length emergency core heat transfer (FLECHT) low flood rate (LFR) cosine forced-feed tests at Westinghouse. The RELAP4/MOD6 code assessment was performed using code reflood heat transfer inputs selected according to these forced-feed derived guidelines. This code assessment has shown that the present guidelines are deficient for adequately predicting dispersed-flow heat transfer during reflood in forced-feed tests with skewed axial power profiles or during reflood in gravity-feed experiments.

This paper presents the development of improved guidelines for the selection of heat transfer input options and a demonstration of that improvement.

DEVELOPMENT OF IMPROVED CODE USAGE GUIDELINES

The RELAP4/MOD6 reflood heat transfer package is designed specifically for modeling heat transfer from core rods during the reflood phase of a LOCA. For a dispersed flow regime, the rod heat flux is partitioned between the liquid and vapor phases by the following relationship:

$$q'' = \overbrace{h_1 \, (Z^M) \, (T_w - T_f)}^{\text{wall-to-vapor phase}} + \overbrace{(h_2 + h_3) \, (1 - Z^N) \, (T_w - T_{sat})}^{\text{wall-to-liquid phase}}$$

where

h_1	=	Dittus-Boelter heat transfer coefficient (forced convection)
h_2	=	Hsu heat transfer coefficient (transition boiling)
h_3	=	Bromley heat transfer coefficient (film boiling)
Z	=	Flow property (void fraction or quality)
T_w	=	Wall temperature
T_{sat}	=	Saturated liquid temperature
T_f	=	Vapor temperature (saturated or superheated)
q''	=	Wall-heat flux
M	=	Vapor weighting factor exponent
N	=	Liquid weighting factor exponent.

The option exists for selecting the intersection (i.e., the maximum) of h_2 and h_3, rather than the sum as shown above.

For dispersed-flow heat transfer, the guidelines developed from FLECHT cosine forced-feed reflood studies specify the use of a void fraction as the independent variable (Z) in the liquid and vapor weighting functions, and a liquid weighting factor exponent (N), which is selected as a function of test conditions. Also specified, is the use of the sum of transition (h_2) and film (h_3) boiling heat-transfer correlations. Results of previous code-data comparisons indicated that when poor comparisons were observed, code-calculated heat transfer was generally insufficient and no value of N provided adequate heat transfer calculation at all core elevations. The method used in this study was to try various combinations of code input options in modeling FLECHT cosine bundle test 4019, and, when a significant improvement in the comparison of code-calculated and experimental data was obtained, to apply that combination in modeling three other FLECHT cosine tests. Where results of these calculations were also improved, the input-option combination was then used in modeling FLECHT forced-feed skewed bundle test 11003 and FLECHT-SET gravity-feed test 2714 (for which code-calculated dispersed-flow heat transfer was significantly deficient).

Void-Fraction Weighting

The first set of input-option combinations that was investigated used void-fraction weighting and the intersection of the Hsu and Bromley correlations. Elevation-dependent and power-profile-dependent weighting factors were tried, but no generally improved cladding-temperature agreements were obtained. The results, however, reconfirmed the desirability of transferring a larger portion of the rod heat to the liquid than would be realized using the original guidelines. However, during the development of the original guidelines, larger values of N were rejected because peak cladding temperatures were underestimated. Therefore, no improvement in the guidelines was feasible as long as void-fraction weighting of dispersed-flow heat transfer was used.

Quality Weighting

The second set of input-option combinations that was investigated used quality weighting and the intersection of Hsu and Bromley correlations. Figure 1 shows the liquid weighting factor (LWF) versus quality (X) for various combinations of the independent variable, N, and critical quality, X_{crit}. Increasing LWF permits greater heat flux between the rod cladding and the liquid phase of the core dispersed flow. The quality and void fraction of the dispersed flow generally increases with core elevation.

The heat flux at any elevation is dependent in a complex way on the selection of entrainment and LWF options. Referring to Figure 1, one would expect the heat flux at any elevation to be greater if Curve 3 were used instead of Curve 2. However, this is not always true. As an example, let the quality at an elevation be 0.2, giving an LWF of 0.28, using Curve 2. If Curve 3 is used instead, the quality at that elevation will rise as a result of additional heat flux below that elevation; if the quality rises to a value greater than 0.4, the LWF is actually less than when using Curve 2. Such complications inhibit the orderly development of an improved selection process for code heat-transfer input options. Nevertheless, for FLECHT Test 4019, a weighting function for increased dispersed-flow heat transfer was desired. To this end, the expression $1 - (X/0.75)^{0.25}$ was used as an LWF, and results were compared against those using the original guidelines for FLECHT Test 4019. No significant improvement was evident, so another selection, $1 - X^{0.333}$, was similarly tried, this time with encouraging results. Generally improved cladding temperature comparisons were obtained using the revised input.

The $1 - X^{0.333}$ liquid weighting factor was further applied to three other FLECHT cosine tests (4831, 6638, 5239) with different test conditions. The revised-input calculation for Test 4831 provided an improved cladding temperature comparison. However, for the other tests this was not the case. Conditions for Tests 6638 and 5239 (at a pressure of 0.138 and 0.414 MPa, respectively, and flooding rates of 0.02 m/s) differ significantly from those of Tests 4019 and 4831 (at 0.276 MPa and 0.038 m/s). Thus, while the use of the 1 - $X^{0.333}$ weighting factor and the intersection of the Hsu and Bromley correlations provided improved results for 0.276 MPa, 0.038 m/s FLECHT cosine test conditions, improvement at other pressures and flooding rates was not obtained. Nevertheless, such a significant improvement was found in the calculation for Test 4019 that the revised-input was next used in modeling a FLECHT skewed-bundle test.

Poor cladding temperature comparisons were previously obtained in the guideline-input calculation for FLECHT skewed-bundle Test 11003. This was a 0.276 MPa forced-feed reflood test with a flooding rate of 0.038 m/s. In Figure 2, the cladding temperature results of the guideline-input calculation and the revised-input calculation are compared against the experimental data. A significant improvement in peak cladding temperature and quench time comparisons was obtained by using the 1 - $X^{0.333}$ weighting factor and the intersection of Hsu and Bromley correlations.

The next use of the revised input was in modeling the FLECHT-SET 2714B gravity-feed reflood test. Test 2714B was a 0.138 MPa test with an emergency core cooling (ECC) injection rate that was varied to effect a constant downcomer static head. Figure 3 shows cladding temperature comparisons of the experimental data, the guideline-input calculation, and the revised-input calculation at the 1.92 m elevation. The results show a significant improvement in the peak cladding temperature prediction, although the improvement was not significant for temperature calculations at low core elevations. Quench-time prediction was poor at all core elevations.

In summary, a revision of the original guidelines, including the use of quality weighting, an N value of 1/3, and the intersection of Hsu and Bromley correlations, has been developed to describe reflood dispersed-flow heat transfer. This development encompassed many cosine-bundle forced-feed comparisons, a skewed-bundle forced-feed comparison, and a gravity-feed comparison, and gave generally improved predictive capability. However, before the improvements were recommended for use, additional checkout was required. The remainder of this paper presents a description of that effort.

EVALUATION OF IMPROVED CODE GUIDELINES FOR REFLOOD ANALYSIS

The evaluation of improved code guidelines was planned with two objectives. The first objective was to provide a set of experiments similar to the previously analyzed tests, but with each of the selections differing in some significant control parameter or boundary condition, therefore providing an evaluation of the guideline versatility. The second objective was to assess the improvement in code-data agreement, for the given range of experiments, attainable through improved guidelines for heat transfer code input.

Experiment Selection

The forced-feed reflood tests which were available consisted of the Westinghouse FLECHT LFR cosine- and skewed-bundle tests, and the Idaho National Engineering Laboratory (INEL) Semiscale MOD-1 test series. The following tests were selected for code-data comparison because their conditions differed significantly from those of previously analyzed tests: FLECHT LFR Cosine-Bundle Test 2414, FLECHT LFR Skewed-Bundle Test 13404, FLECHT LFR Skewed-Bundle Test 13609, and Semiscale Mod-1 Test S-03-A.

The gravity-feed reflood test series which were available were the Westinghouse FLECHT-SET Phase B and INEL Semiscale MOD-1 test series. The tests selected for code-data comparison were FLECHT-SET Test 2213, and Semiscale MOD-1 Test S-03-8.

Test Facility Description

The test facilities used to obtain the experimental data for the selected forced-feed reflood tests are the Westinghouse FLECHT and INEL Semiscale MOD-1, forced-feed, test facilities. A detailed description of the FLECHT Facility is given in References 2 and 3, and that of the Semiscale facility is given in Reference 4. The test facilities where the experimental data were obtained for the selected gravity-feed reflood tests are the Westinghouse FLECHT-SET and INEL Semiscale MOD-1, gravity-feed, test facilities. Their detailed description can be found in References 5 and 6, respectively.

Measurement Accuracy

An extensive measurement accuracy analysis was performed for both FLECHT and Semiscale forced-feed reflood tests. The results are reported in detail in Appendix B of References 2, 3, and 4. The pertinent instrumentation errors were extracted from those sources and are summarized in Table I.

A measurement accuracy analysis for the selected FLECHT-SET and Semiscale gravity-feed reflood tests has also been performed. The detailed results are presented in References 5 and 6. Table II shows full-scale values and the corresponding absolute transducer errors for gravity-feed data presented in this paper. The errors were used in developing experimental data bands against which code-calculated data are compared.

TABLE I

EXPERIMENTAL MEASUREMENT ERROR FOR FORCED-FEED REFLOOD TEST

Measurement	Test 2414	Tests 13404 and 13609	Test S-03-A
Clad Temperature (K)	± 5.3	± 3.2	± 3.9
Fluid Temperature (K)	± 5.3	± 3.2	± 2.8
System Pressure (kPa)	± 4.3	± 2.7	± 6.9
Differential Pressure (kPa)	± 1.8	± 0.7	± 7.6
Bundle Power (kW)	± 8.1 (by zone)	± 3.1 (by zone)	± 3.2 (total bundle)
Mass Flow Rate (g/s)	±30.3	±30.3	±94.3

TABLE II

EXPERIMENTAL MEASUREMENT ERROR FOR GRAVITY-FEED TEST DATA

	FLECHT-SET Test 2213B			Semiscale S-03-8		
Location	Full Scale Error	Full Scale Value	Absolute Error	Full Scale Error	Full Scale Value	Absolute Error
Rod Clad	±0.75%	1533 K	±11.5 K	—	—	± 4 K
Test Section	±0.75%	68.9 kPa	± 0.517 kPa	±3%	103.4 kPa	± 3.102 Pa
Broken Loop Orifice	±0.75%	34.5 kPa	± 0.259 kPa	±3%	34.5 kPa	± 1.034 Pa
Intact Loop Orifice	±0.75%	34.5 kPa	± 0.259 kPa	±3%	34.5 kPa	± 1.034 Pa
Upper Plenum Extension	±0.75%	1380 kPa	±10.3 kPa	±1%	1.72 MPa	±17.2 kPa

RELAP4/MOD6 MODEL DESCRIPTION

The RELAP4/MOD6 Model Nodalization, code-input options, and the boundary conditions used to predict the selected forced- and gravity-feed reflood tests are discussed in the following sections.

Nodalization

The computer input nodalizations for the forced-feed FLECHT cosine-bundle Test 2414, and FLECHT skewed-bundle Tests 13404 and 13609 are shown in Figure 4. The nodalization for Semiscale Test S-03-A is shown in Figure 5. Average power rods were modeled. Volumes, areas, and lengths were obtained from the respective data reports (2, 3, 8).

The computer input nodalizations for FLECHT-SET Test 2213B and Semiscale Test S-03-8 are shown in Figures 6 and 7. For FLECHT-SET Test 2213B, which used a peaked radial power profile, an average-power rod was modeled. Semiscale Test S-03-8 used a uniform radial power profile. The FLECHT-SET 2213B model included heat slabs on cold leg piping volumes where electrical strip heaters were used during the test. Volumes, areas, and lengths were obtained from the respective data reports (5, 6) and system descriptions (4, 9).

Code input options were selected according to the original and revised user guidelines. Results of these selections are shown in Table III for time-step, moving-mesh, reflood heat transfer, and Steen-Wallis implicit type entrainment input.

TABLE III

ORIGINAL AND REVISED USER INPUT OPTIONS

	FLECHT-SET 2213B	Semiscale S-03-8	FLECHT 2414	FLECHT 13404	FLECHT 13609	FLECHT S-03-A
Time Steps						
Fixed Time Step(s) (First 0.2 s)	0.01	0.01	0.01	0.01	0.01	0.01
Code Selected Range(s) (After 0.2 s)	0.2-0.001	0.05-0.0001	0.2-0.001	0.2-0.001	0.2-0.001	0.2-0.001
Moving Mesh						
DZF-Fine Mesh Size (cm)	0.762	0.635	0.762	1.089	1.089	0.635
DZM-Medium Mesh Size (cm)	3.048	2.540	3.048	4.354	4.254	2.54
SMINUP-Min. Extent Upper Med. Mesh (cm)	18.288	15.24	18.288	26.126	26.126	15.24
SMINLO-Min. Extent Lower Med Mesh (cm)	18.288	15.24	18.288	26.126	26.126	15.24
SMINF-Min. Extent Fine Mesh (cm)	18.288	15.24	18.288	26.126	26.126	15.24
Reflood Heat Transfer						
Hsu Correlation Calculated by HSUA Subroutine, Energy Partitioning Coefficient Internally Calculated, Multiplier on Bromley Correlation	1.0	1.0	1.0	1.0	1.0	1.0
Bromley and Hsu Correlations Added[a], Void Fraction Independent Variable in Weighting Functions[b], Dryout Void Fraction	1.0	1.0	1.0	1.0	1.0	1.0

TABLE III (Cont'd)

	FLECHT-SET 2213B	Semiscale S-03-8	FLECHT 2414	FLECHT 13404	FLECHT 13609	FLECHT S-03-A
Reflood Heat Transfer (Cont'd)						
Quality Times Mass Flux Used to Calculate Reynolds Number for Superheated Vapor, Exponent in Vapor Weighting Factor (M)	1.0	1.0	1.0	1.0	1.0	1.0
Exponent in Liquid Weighting Factor (N)[c]	51.0	61	23	16	58	44
Entrainment (Steen-Wallis Implicit Type)						
HCl (Curve Shaping Factor)	$1x10^{6}$	$1x10^{6}$	$1x10^{6}$	$1x10^{6}$	$1x10^{6}$	$1x10^{6}$
HC2 (Entrainment Onset Factor)	$3x10^{-6}$	$3x10^{-6}$	$3x10^{-6}$	$3x10^{-6}$	$3x10^{-6}$	$3x10^{-6}$
EN2 (Maximum Entrainment Fraction)	0.89	0.855	0.67	0.64	0.81	0.725

The revised user input options are the same as the original one except:

a. Use the intersection of Bromley and Hsu correlations
b. Use quality as the independent variable in weighting functions
c. Use constant value of 0.333 as the exponent in liquid weighting factor

Boundary Conditions

The following boundary conditions for each calculation were taken directly from the experimental results: heater power, heater initial axial clad temperature profile, fluid initial temperature and phase, system pressure profile, and ECC injection rate and temperature.

COMPARISONS OF THE REVISED AND ORIGINAL GUIDELINE PREDICTIONS WITH THE EXPERIMENT DATA

In this section, results of the revised and original guideline predictions are compared with experiment data. Experiment data bands were constructed using the envelope of the test data at the appropriate elevation and the instrumentation errors listed in Tables I and II.

Forced-Feed Experiments

At the midplane for Test 2414 (see Figure 8), the revised guidelines underestimate maximum temperature by about the same amount as the original guideline overestimated it (60 K), but turnaround and quench-time comparisons are improved. High in the core (see Figure 9), the revised-guideline temperature history lies within the data band, an evident improvement.

Even more significant are the effects of using revised guidelines for the skewed bundle test (Test 13404), as shown in Figures 10 through 12. The core-liquid-mass inventory agreement (Figure 10) is better, particularly in the period just prior to hot-spot quench (400 to 500 s). Below the hot spot (Figure 11), the cladding temperature history is much improved by the new guidelines. Maximum temperature is underestimated by about 30 K; turnaround time shows no appreciable error; and quench time is closely predicted. At the hot spot (3.05 m core height, Figure 12), quench and turnaround times are both well predicted and the maximum calculated temperature is within the data band. The original guideline calculation overpredicted maximum temperature by more than 300 K and substantially overpredicted turnaround and quench times.

Code-data comparisons for the reduced-pressure skewed-bundle test (FLECHT Test 13609), showed similar advantages of using the revised guidelines.

The Semiscale Mod-1 Test S-03-A code-data comparisons also show improvement with the use of the revised guidelines, although this improvement is but slight for core fluid inventory. For clad temperatures near the core midplane (Figures 13 and 14) the change is also relatively small. However, at 0.174 m, the new guidelines provide a match of experimental quench time, and at 0.99 m, calculated maximum cladding temperature is decreased from near the top of the data band to the middle of it.

Gravity Feed Experiments

The effect of the guideline change is more emphatic for the Semiscale gravity-feed experiment, Test S-03-8, than for the forced-feed test S-03-A. Except for the initial core liquid inventory rise in the period 0-30 second, the calculated data fall within the experimental data band. At a core height of 0.73 m, maximum cladding temperature is in the middle of the data band and both turnaround and quench times are well matched (Figure 15). The major improvement is in quench time, where the calculation error has been improved from 65% to approximately 15% of the measured values.

Application of the guideline change to the gravity-feed FLECHT-SET Test 2213 analysis showed no significant change in results.

CONCLUSIONS

Comparisons of the revised and original guideline calculations with experimental data indicate that the revised guidelines provide a significant improvement in cladding temperature prediction at all elevations for the FLECHT Skewed Bundle Tests 13404 and 13609, and Semiscale Gravity-Feed Test S-03-8. For FLECHT Test 2414 and Semiscale Forced-Feed S-03-A, improvement was noticed at some core elevations but not at others. For FLECHT-SET Test 2213B, calculations using the original and revised guideline inputs showed little difference.

While the use of the revised guidelines does not provide adequate cladding temperature predictions at all elevations for all experiments, a significant improvement over the use of the original guidelines has been obtained for a variety of reflood calculations. The use of the revised guidelines is therefore recommended. An advantage of the revised guidelines is that reflood heat transfer input options are no longer a function of test conditions, thus facilitating the use of the RELAP4/MOD6 computer code.

To restate the recommended options in describing dispersed flow reflood heat transfer: (1) use quality-weighting; (2) use an N value of 1/3; and (3) use the intersection of Hsu and Bromley correlations.

ACKNOWLEDGEMENTS

The authors express their sincere appreciation to Messrs. W. S. Haigh and G. E. Wilson for their valuable advice and comments, which made this work possible. Acknowledgement is also due to the LOFT Test Support Branch and Code Assessment Branch of EG&G Idaho, Inc., for their encouragement and assistance in publishing the results. This work was supported as part of the Nuclear Regulatory Commission (NRC) sponsored research efforts in pressurized water reactor safety.

REFERENCES

1. S. R. Fischer, et al., "RELAP4/MOD6 - A Computer Program for Transient Thermal-Hydraulic Analysis of Nuclear Reactors and Related Systems - User's Manual," CDAP-TR-003, January 1978. See Configuration Control No. 00010006 for the code and No. H0021IB for the associated steam tables. The computer code and the document are available from the Argonne Code Center.

2. E. R. Rosal, et al., "FLECHT Low Flooding Rate Cosine Test Series Data Report," WCAP-8651, December 1975.

3. E. R. Rosal, et al., "FLECHT Low Flooding Rate Skewed Test Series Data Report," WCAP-9108, May 1977.

4. E. M. Feldman, "Semiscale Mod-1 Program and System Description for the Reflood Heat Transfer Tests (Test Series 3)," ANCR-NUREG-1305, May 1976.

5. J. P. Waring, et al., "PWR FLECHT-SET Phase B1 Data Report," WCAP-8431, December 1974.

6. H. S. Crapo. et al., "Experimental Data Report For Semiscale Mod-1 Tests S-03-5, S-03-6, S-03-7, and S-03-8," ANCR-NUREG-1308, June 1976.

7. J. P. Waring and L. E. Hochreither, "PWR FLECHT-SET Evaluation Report," WCAP-8583, August 1975.

8. H. S. Crapo, et al., "Experiment Data Report for Semiscale Mod-1 Tests S-03-A, B, C and D (Reflood Heat Transfer Tests)," ANCR-NUREG-1307, May 1976.

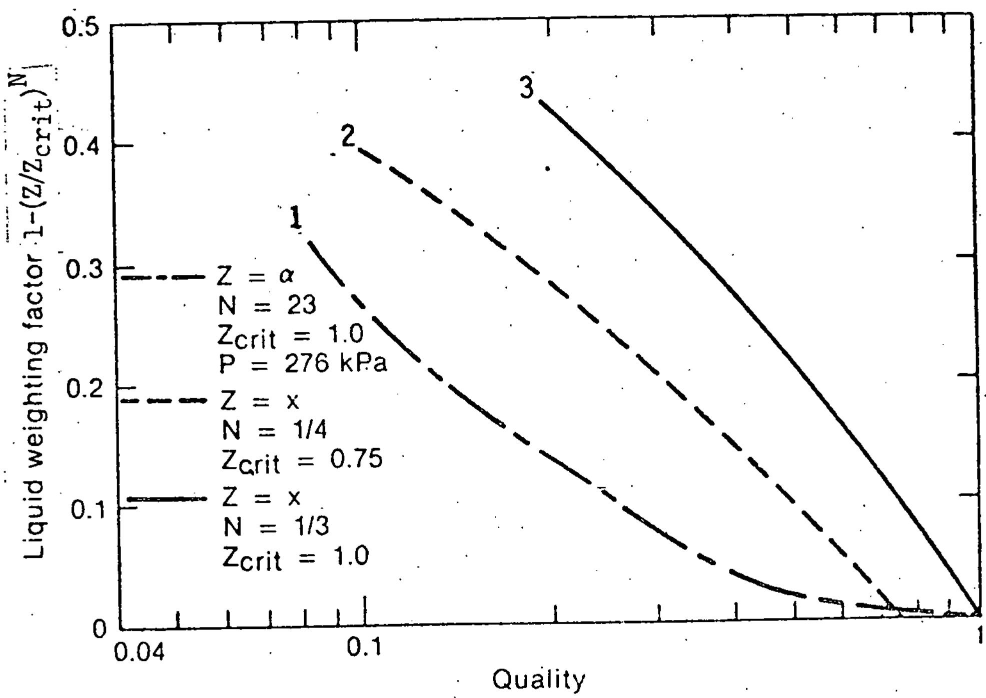
9. W. F. Cleary, et al., "FLECHT-SET Phase B System Design Description," WCAP-8410, UC-78a, no date.

FIGURES

13. Effect of guideline change on cladding temperature just below midplane, Semiscale MOD-1 Test S-03-A.

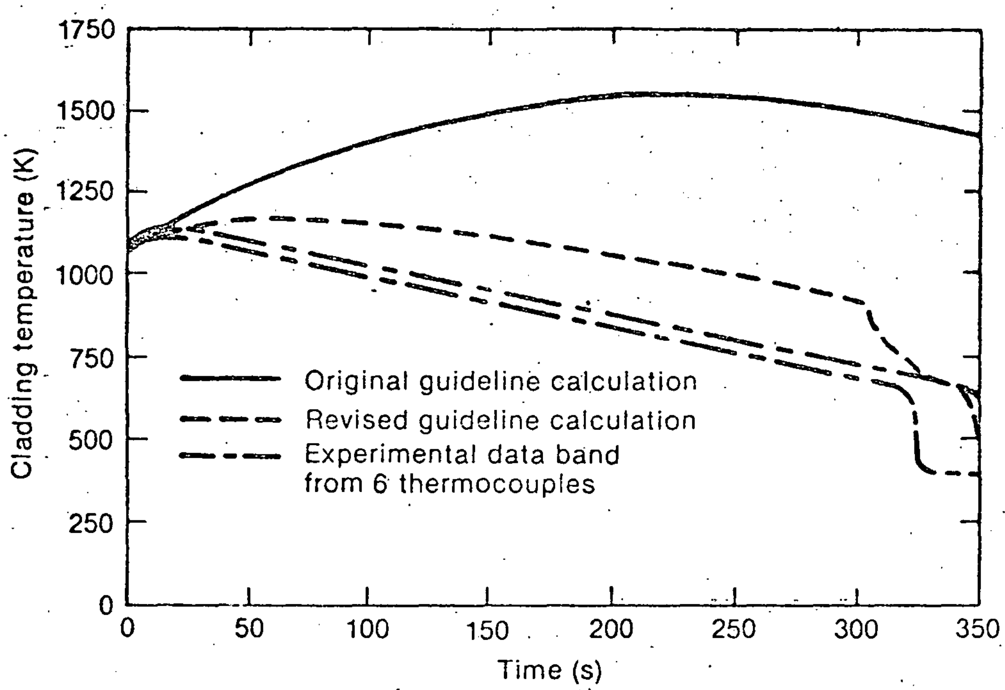
14. Effect of guideline change on cladding temperature near midplane, Semiscale MOD-1 Test S-03-A.

15. Effect of guideline on cladding temperature just below midplane, Semiscale MOD-1 Test S-03-8.



0.5
0.4
0.3
0.2
0.1
0
0.04
0.1
1
Quality
Liquid weighting factor $1-(Z/Z_{crit})^N$
1
2
3
$Z = \alpha$
$N = 23$
$Z_{crit} = 1.0$
$P = 276$ kPa
$Z = x$
$N = 1/4$
$Z_{crit} = 0.75$
$Z = x$
$N = 1/3$
$Z_{crit} = 1.0$

Fig. 1



1750
1500
1250
1000
750
500
250
0
Cladding temperature (K)
0
50
100
150
200
250
300
350
Time (s)
Original guideline calculation
Revised guideline calculation
Experimental data band
from 6 thermocouples

Figure 2

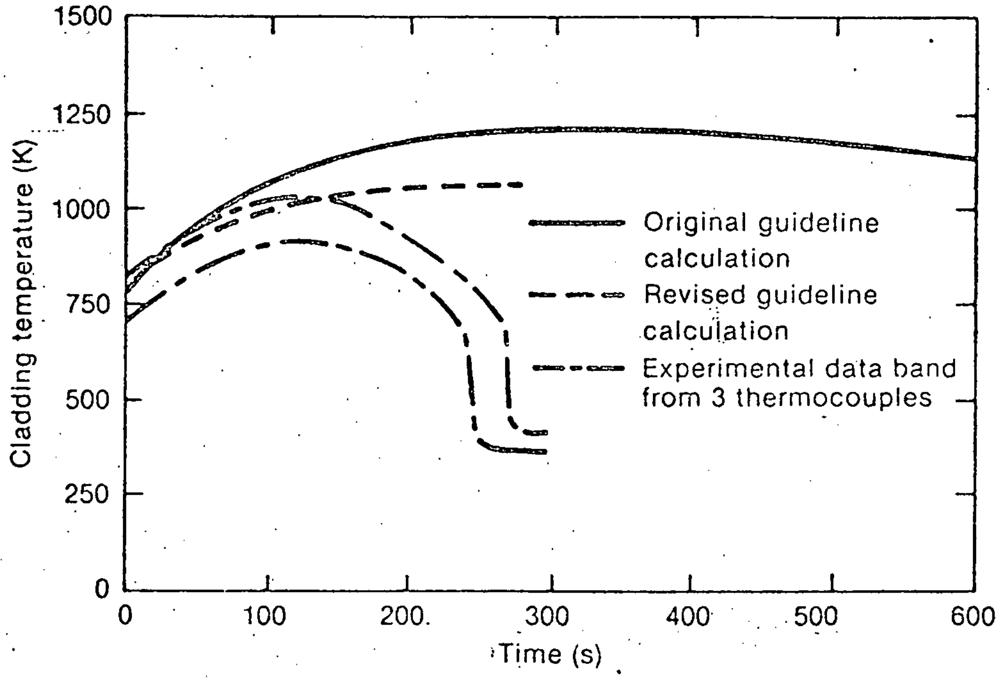
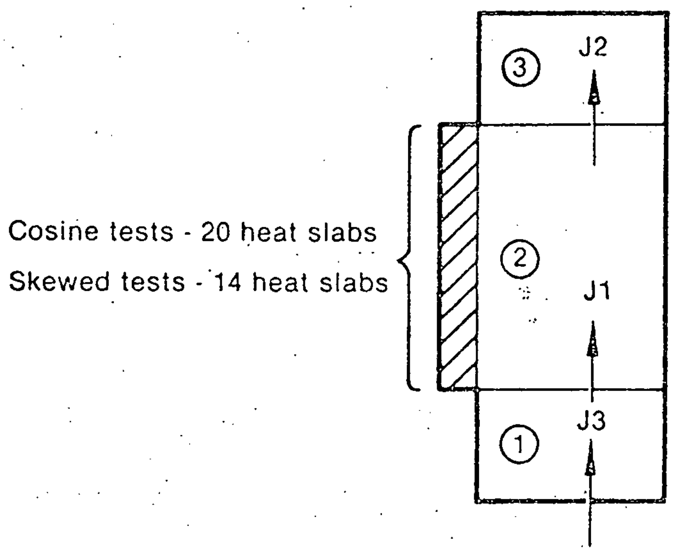

1500
1250
1000
750
500
250
0
Cladding temperature (K)
0
100
200.
300
400
500
600
Time (s)
Original guideline calculation
Revised guideline calculation
Experimental data band from 3 thermocouples

Fig. 3



Volumes:

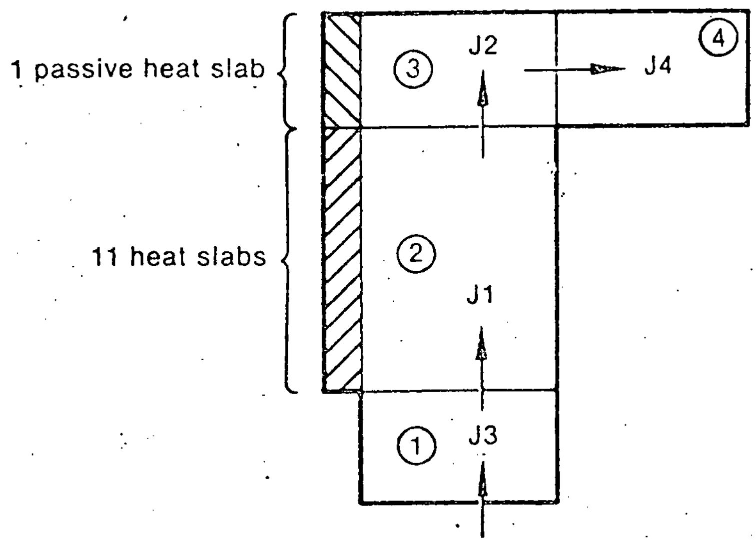
1 - Manifold (normal volume)
2 - Bundle test section (normal volume)
3 - Upper plenum (normal volume-Semiscale)

Junctions:

J1 - Test section inlet (normal junction)
J2 - Test section outlet (normal junction)
J3 - Emergency core coolant injection (fill junction)

Fig. 4

Figure 5



Volumes:

1 - Manifold (normal volume)

2 - Bundle test section (normal volume)

3 - Upper plenum (normal volume-Semiscale)

4 - Separation chamber (time dependent volume)

Junctions:

J1 - Test section inlet (normal junction)

J2 - Test section outlet (normal junction)

J3 - Emergency core coolant injection (fill junction)

J4 - Upper plenum outlet (normal junction)

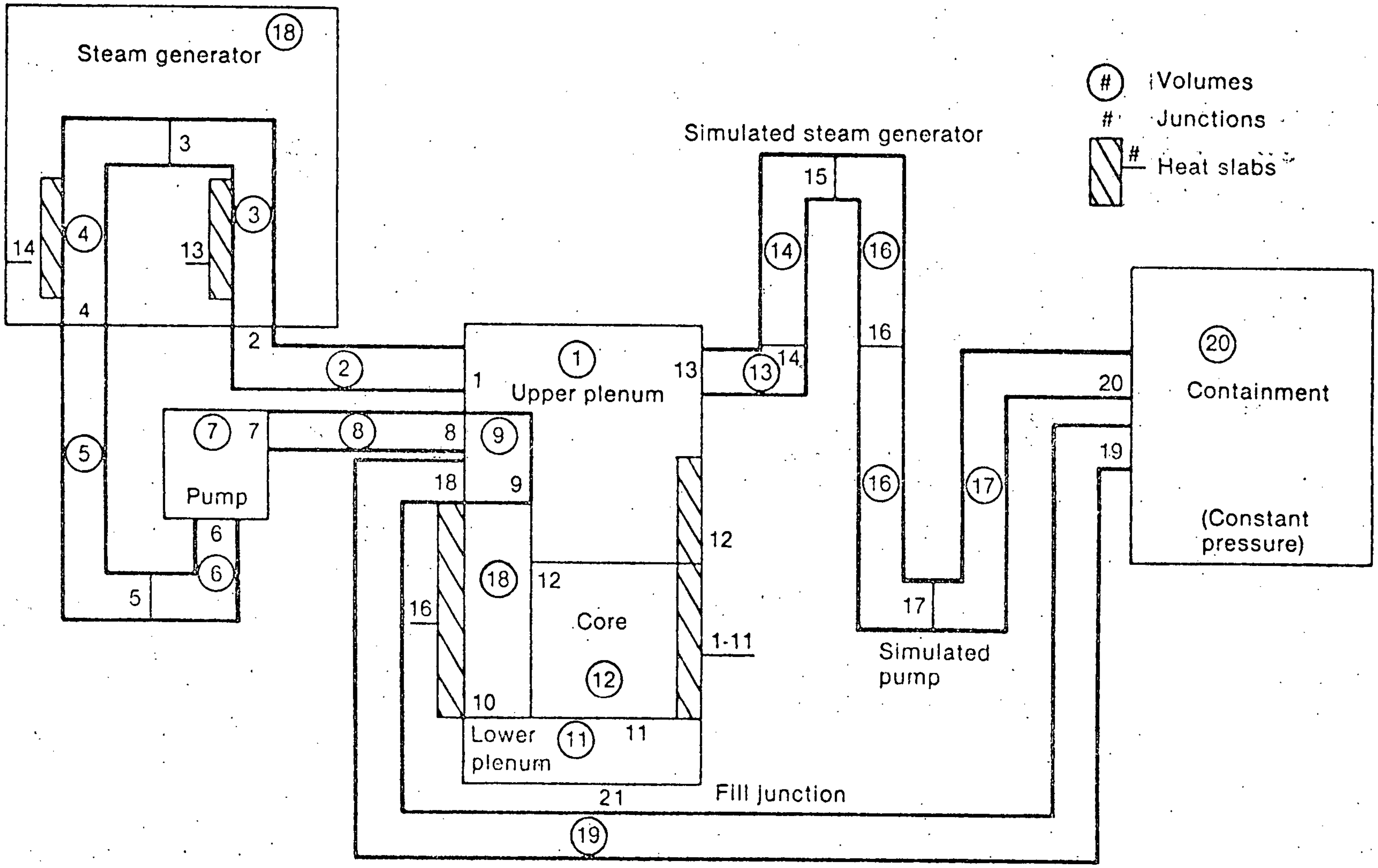

Steam generator
18
3
4
14
13
2
1
Upper plenum
13
14
15
Simulated steam generator
16
17
20
Containment
19
(Constant pressure)
7
8
9
Pump
6
5
18
12
Core
1-11
16
10
11
Lower plenum
21
Fill junction
Simulated pump
Volumes
Junctions
Heat slabs

Fig. 6

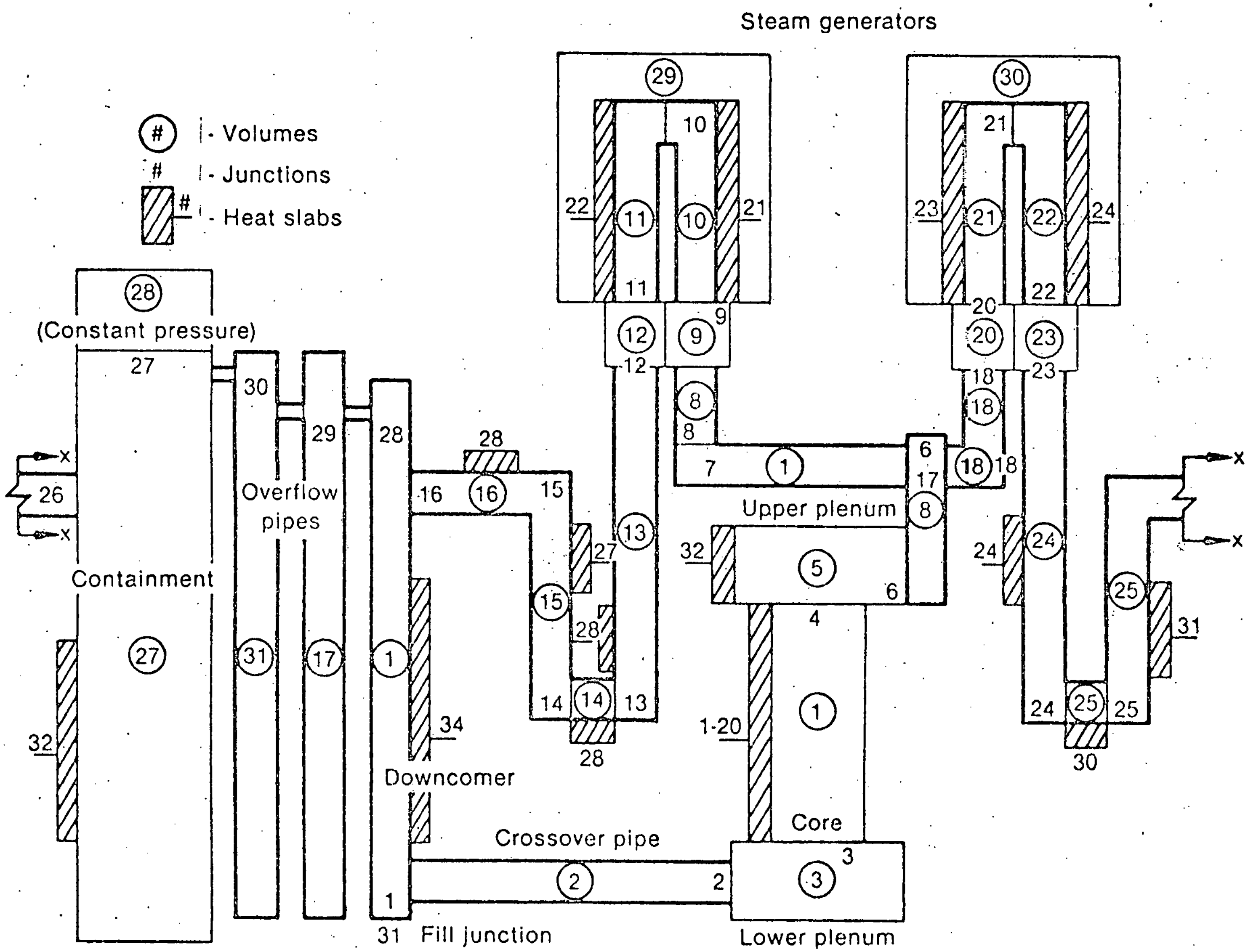

Steam generators
Volumes
Junctions
Heat slabs
(Constant pressure)
Containment
Overflow pipes
Downcomer
Upper plenum
Core
Crossover pipe
Fill junction
Lower plenum

Fig. 7

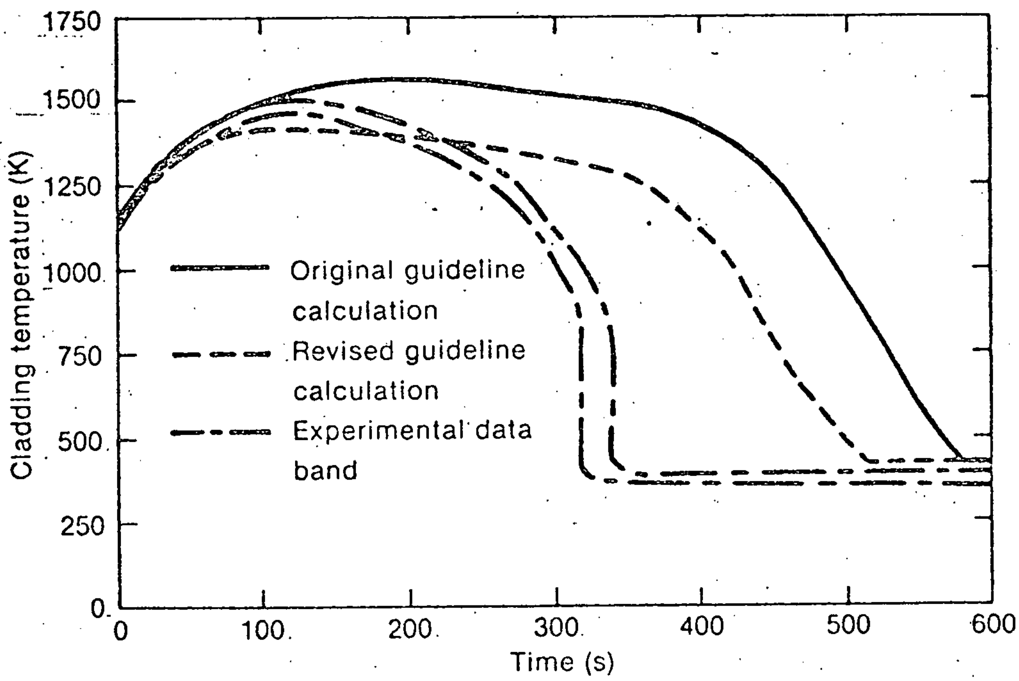
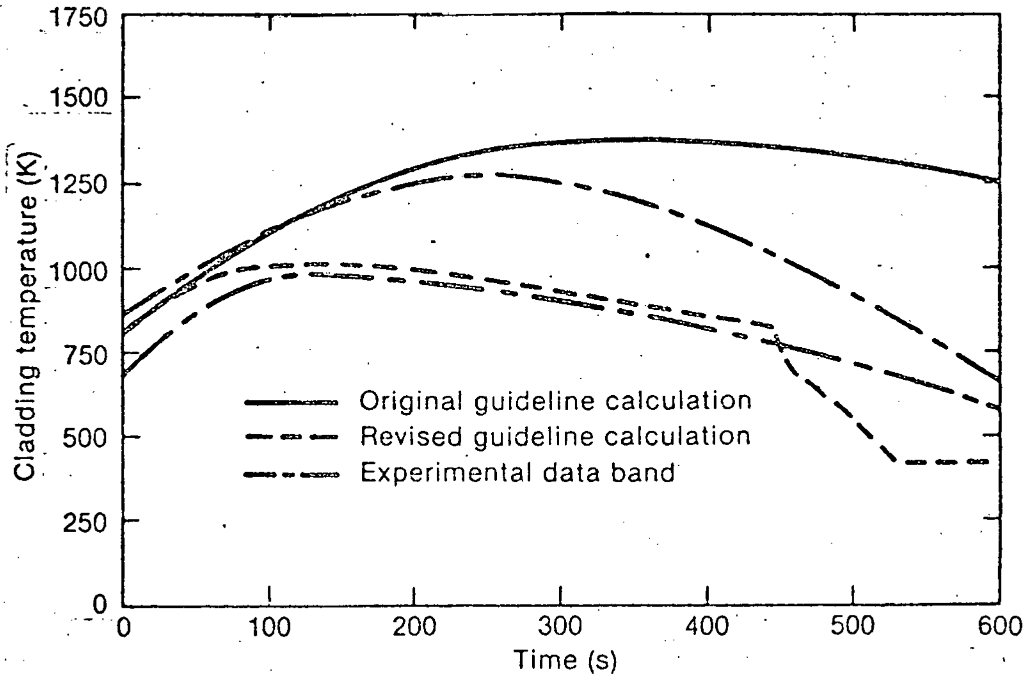
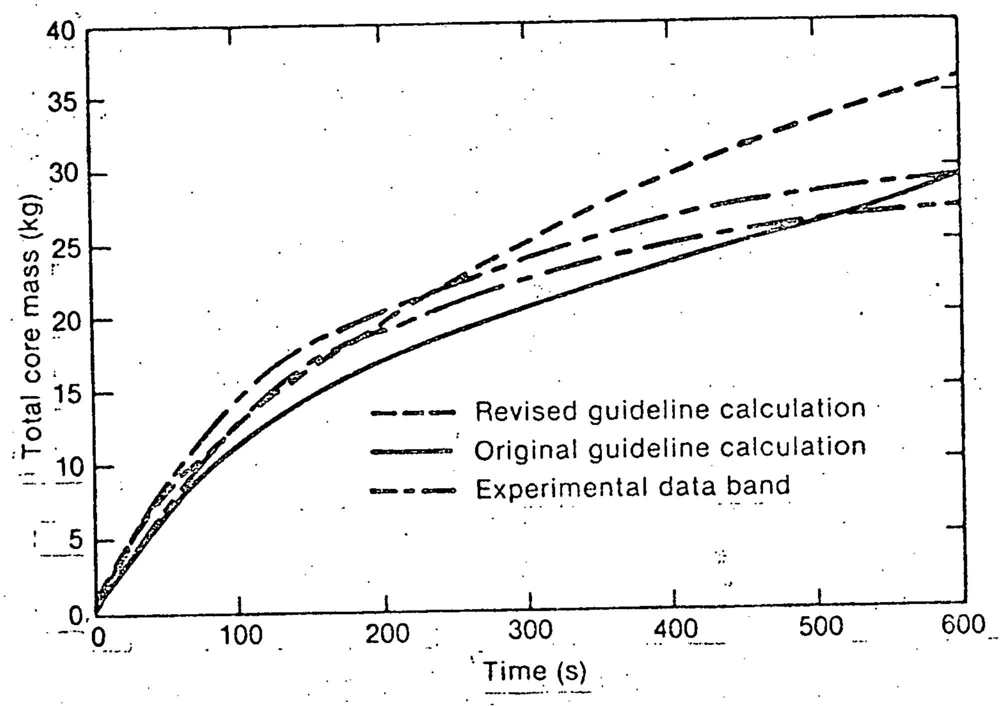

1750
1500
1250
1000
750
500
250
0
Cladding temperature (K)
0
100
200
300
400
500
600
Time (s)
Original guideline calculation
Revised guideline calculation
Experimental data band

Fig. 8



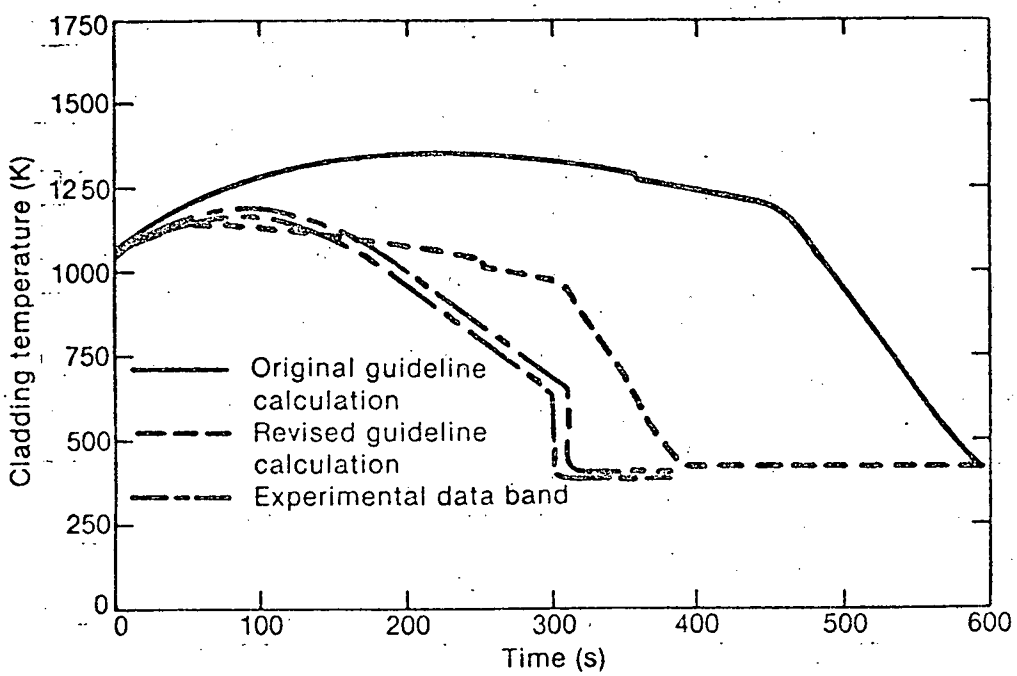
Cladding temperature (K)
1750
1500
1250
1000
750
500
250
0
0
100
200
300
400
500
600
Time (s)
Original guideline calculation
Revised guideline calculation
Experimental data band

Fig. 9



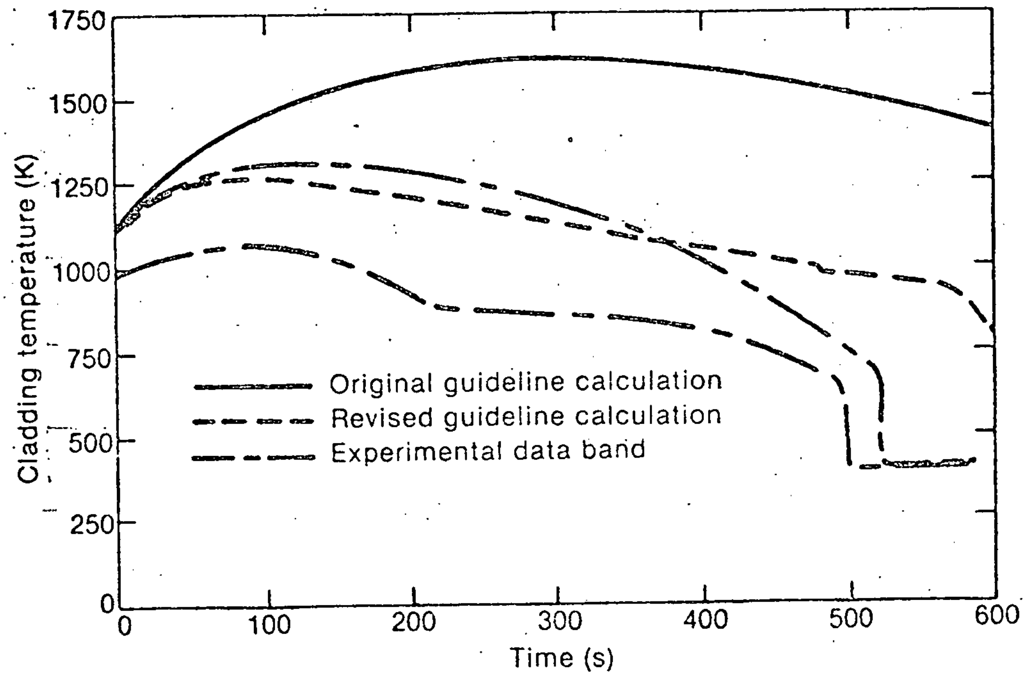
Total core mass (kg)
0
5
10
15
20
25
30
35
40
0
100
200
300
400
500
600
Time (s)
Revised guideline calculation
Original guideline calculation
Experimental data band

Fig. 10



1750
1500
1250
1000
750
500
250
0
Cladding temperature (K)
0
100
200
300
400
500
600
Time (s)
Original guideline calculation
Revised guideline calculation
Experimental data band

Fig. 11



1750
1500
1250
1000
750
500
250
0
Cladding temperature (K)
0
100
200
300
400
500
600
Time (s)
Original guideline calculation
Revised guideline calculation
Experimental data band

Fig. 12

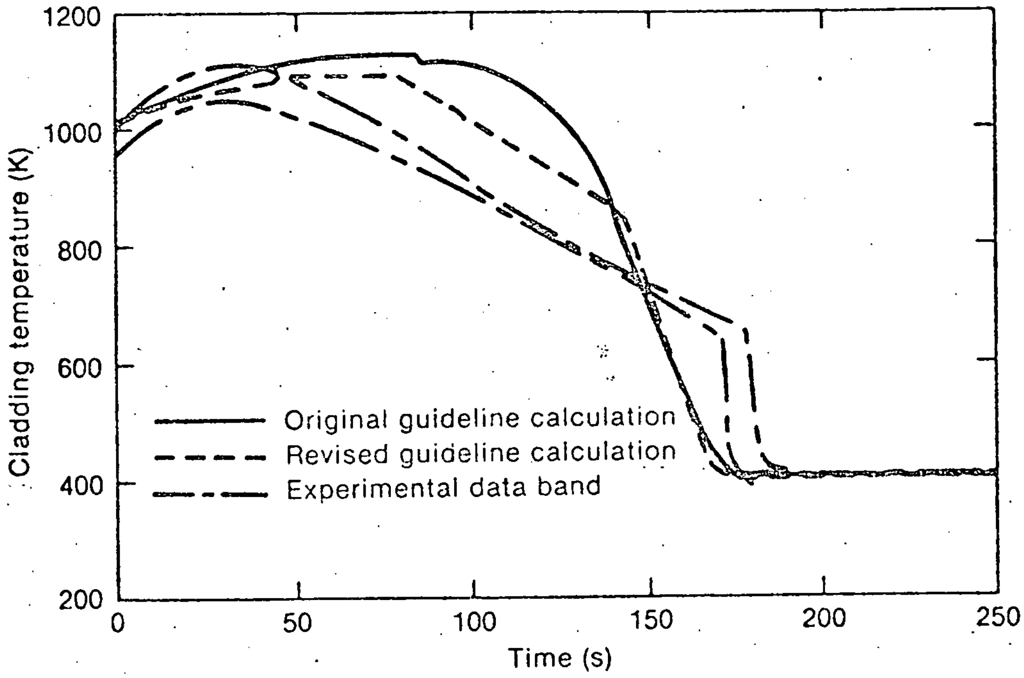

1200
1000
800
600
400
200
Cladding temperature (K)
0
50
100
150
200
250
Time (s)
Original guideline calculation
Revised guideline calculation
Experimental data band

Fig. 13

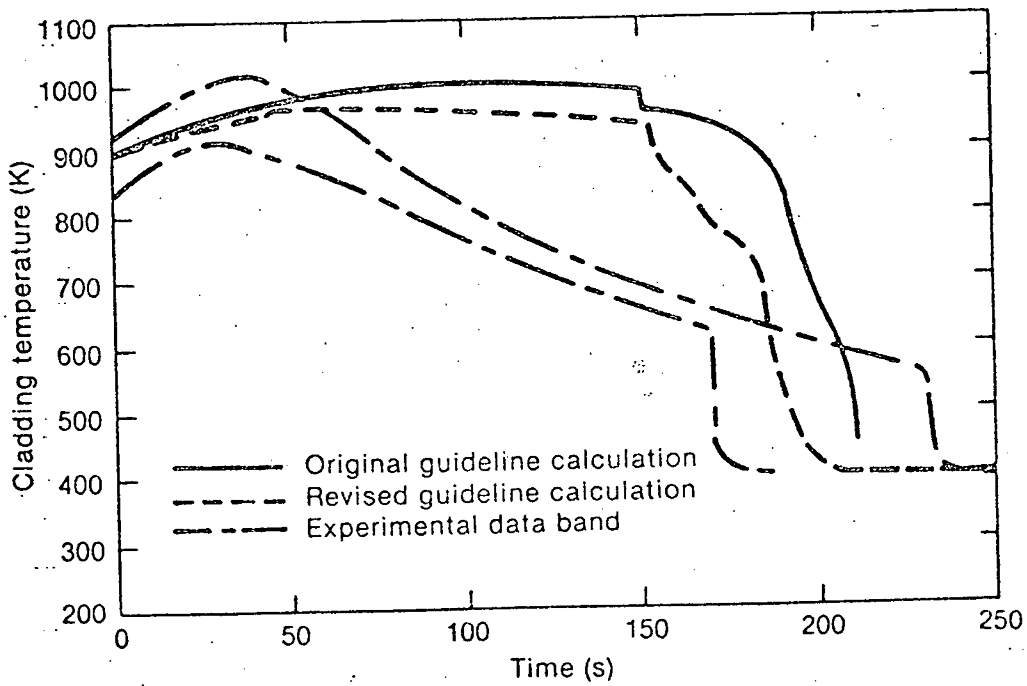
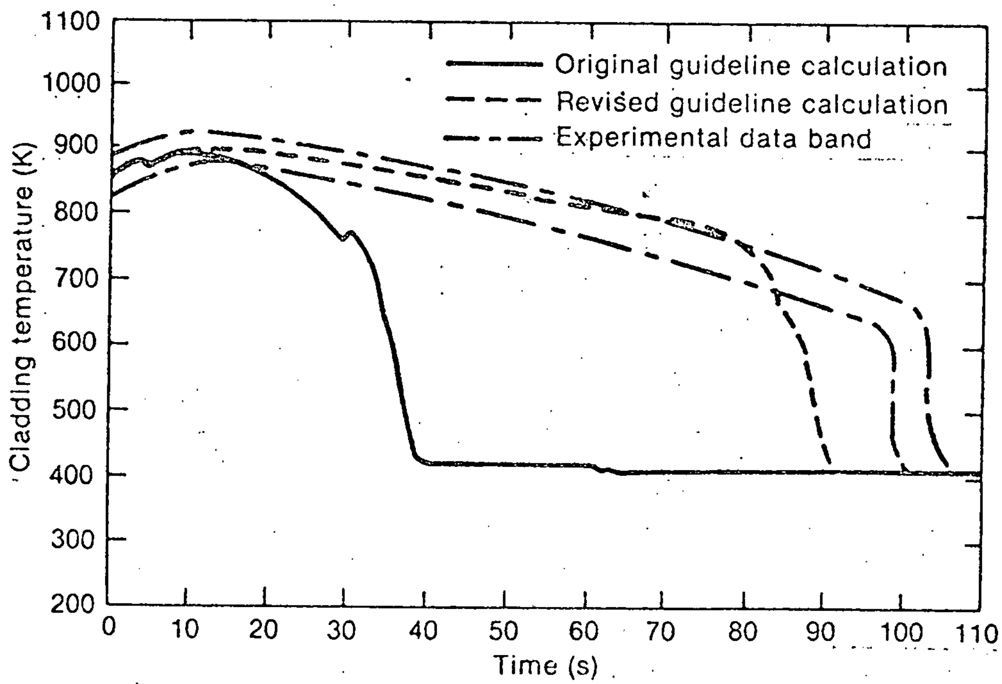

1100
1000
900
800
700
600
500
400
300
200
Cladding temperature (K)
0
50
100
150
200
250
Time (s)
Original guideline calculation
Revised guideline calculation
Experimental data band

Fig. 14



Original guideline calculation
Revised guideline calculation
Experimental data band
Cladding temperature (K)
1100
1000
900
800
700
600
500
400
300
200
0
10
20
30
40
50
60
70
80
90
100
110
Time (s)

Fig. 15